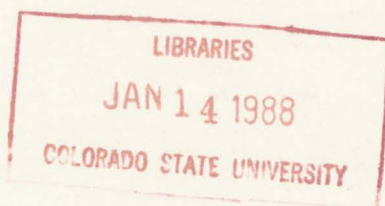# OPERATION OF A CEILOMETER DURING THE FIRE MARINE STRATOCUMULUS EXPERIMENT

by

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FIRE VOLUME 3

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OPERATION OF A CEILOMETER DURING
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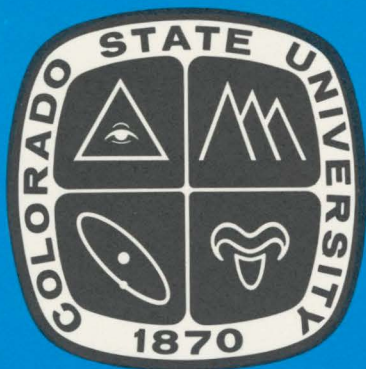WAYNE H. SCHUBERT, STEPHEN K. COX,

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ABSTRACT

We present an analysis of the cloud base height data obtained by the Vaisala CT 12K ceilometer during the marine boundary layer experiment on San Nicholas Island in the summer of 1987.

1. Introduction

During the FIRE Marine Stratocumulus Experiment (29 June – 19 July 1987) the Department of Atmospheric Science, Colorado State University, deployed a laser ceilometer on the northwest tip of San Nicolas Island. The goal of our effort was to document the time evolution of the stratocumulus cloud base. The ceilometer was set up at a location 14 m above mean sea level near site A in Fig. 1. The instrument was about 20 m west of NOAA's steerable dual-channel microwave radiometer (Hogg et al., 1983), which provides a record of the vertically integrated water vapor and liquid water in the column, and about 40 m north of Pennsylvania State University's acoustic sounder, which provides a record from which cloud top can be extracted. This group of three instruments thus provides a detailed record of cloud base, cloud top and cloud liquid water content.

In section 2 of this report we present a brief technical description of the ceilometer instrument. In section 3, we describe the procedure used by the ceilometer software to process the raw data. Graphs of unfiltered and filtered cloud base height are presented in section 4.

2. Technical description of the ceilometer

The operation of the Vaisala CT 12K ceilometer is based on the measurement of the time needed for a short pulse of light to travel from the transmitter to a backscattering cloud base and then back to the receiver of the ceilometer. The relation connecting the backscattering height h and the time delay t is $h = ct/2$. Since

the speed of light $c = 2.9979 \times 10^8$ ms^{-1}, a reflection from 3657 m (12,000 ft, hence the name 12K) will be detected after $t = 24.4$ μs. The Vaisala ceilometer digitally samples the return signal every 100 ns from 100 ns to 25,400 ns, providing a spatial resolution of 15 m from 15 m to 3657 m above the surface.

A block diagram of the ceilometer (adapted from Vaisala, Inc., 1986) is shown in Fig. 2. A measurement cycle begins when the microprocessor signals the laser control circuitry to issue a laser trigger pulse. This laser trigger pulse is sent from the laser control circuitry to the laser transmitter board where it fires the thyristors (semiconductor power control switches) of the laser circuit. The ultrafast thyristors force a current pulse through a GaAs diode laser, which then emits a short, high intensity pulse of 904 nm (infrared) radiation. The transmitter lens, situated a focal length away from the laser diode, then collimates the radiation into a parallel beam. A portion of the backscattered radiation enters the receiver lens and is focused onto a silicon avalanche photodiode sensor. A receiver filter with a bandwidth of 50 nm centered around 904 nm is used to block out most of the background radiation noise.

At the same time the laser control ciruitry issues the laser trigger pulse, the data acquisition circuitry is initiated. An A-to-D converter samples the received and amplified backscatter signal, digitizes it, and inputs it into the first location of the sample buffer memory. This all occurs within 100 ns. Exactly 100 ns after taking the first sample, the A-to-D converter takes

the second sample, which represents backscatter from a height 15 m above the first sample. The digitized second sample is stored in the second location of the sample buffer memory. In this way samples are taken every 100 ns for 25.2 μs, which provides 253 useful samples stored in consecutive locations of the sample buffer memory. These samples represent the backscatter signal of one laser pulse from 253 heights at 15 m intervals, resulting in a backscatter profile ranging from 0 to 3780 m. Because the laser pulse has a duration of about 150 ns, the digitized backscatter signal represents an average backscatter over 25 m at 15 m height intervals.

Since the amount of backscatter power within the field of view of the receiver decreases with the square of the height and is further attenuated by backscattering matter, the signal received from more than about 300 m is completely buried in noise. To overcome this, the laser is pulsed many times. Before the second pulse is transmitted, the data from the first pulse are transferred from the sample buffer memory to consecutive locations in the sample summing memory. Then the backscatter signal from the second pulse is digitized exactly the same as that of the first pulse, and the values in the sample buffer memory are added to the sample summing memory. The operation proceeds in this fashion until the end of a preset time interval. The 253 locations of the sample summing memory now contain the sums of thousands of samples arranged by height. If the number of pulses has been 10,000 for example, the useful signal is 10,000 times stronger while normal random (white) noise is only 100 times stronger, according to the laws of probability. The improvement in signal-to-noise ratio is thus $10,000/100 = 100$.

Before the next acquisition cycle begins, the processor checks the average laser power measured by the laser power monitor during the previous cycle. Based on the laser power measured, a new pulse repetition frequency is calculated to keep the average laser power as close as possible to the maximum permissible eye-safe value. Average laser power is thus controlled automatically by adjusting the pulse repetition rate.

3. Procedure for processing data

Once the acquisition and summation of the backscattered power samples is completed, the data are transferred from sample summing memory to processor controlled data memory. These raw values of backscattered power are then processed in the following manner.

(1) Values below a specified noise level are extracted from the signal.

(2) Values of noise filtered, backscattered power (P_{refl}) are height normalized.

(3) Adjustment is made for the energy of the transmitted pulse (E_{pulse}).

(4) Data is adjusted by a constant factor which accounts for optical, electrical and software design factors within the instrument.

(5) Values are scaled by an appropriate factor so that they will fit into the format of the displayed data message (i.e., range from $0 \ldots 99$).

Processing steps (2)-(5) are summarized in the following equation:

$$\text{DDD} = C \times \frac{P_{refl}}{E_{pulse}} \times \frac{h^2}{A} \qquad (1)$$

where

DDD $\equiv$ processed data value which appears in the output data message described in the Appendix A

C $\equiv$ a constant factor which accounts for instrument and software design as well as scaling (discussed in steps 4 and 5)

P_{refl} $\equiv$ noise filtered, backscattered power

E_{pulse} $\equiv$ energy of transmitted pulse (pulse peak power times its duration)

h $\equiv$ height (m)

A $\equiv$ area of receiver aperture (m^2)

The processed data are then analyzed to detect cloud layers (i.e., bases and thicknesses) using a specified cloud detection limit.

A standard message containing the processed data is output through the RS-232C interface on the CT 12K. The format of this data message, along with examples, is given in the Appendix A. The data message is output every 30 seconds at a 300 baud transmission rate. The time required for message transmission is 17.43 seconds. These data messages were received by an IBM PC XT computer through its serial port, and were logged to files on the PC's hard disk using the PROCOMM v2.3 communication package. A summary of the data files saved along with their dates and times is shown in Table 1. Due to the enormous quantity of data we wanted to save along with the limited storage capacity of the hard disk (20 megabytes), it was necessary to periodically save the files to

a magnetic tape and then delete them from the hard disk to free up space for additional data. Files were saved to magnetic tapes using the SY-TOS tape backup system. Unfortunately, the PC could not save incoming data during the execution of the backup procedure. This fact is reflected in the short data gaps in Table 1.

The ceilometer data listed in Table 1 can be obtained from the FIRE Central Archive. Alternately, a subset of this data, which contains unfiltered cloud bases and thicknesses, is available through NCAR's computer network. Additional information for obtaining the ceilometer data is contained in Appendix B.

4. Unfiltered and filtered data

Consider the following symmetric, nonrecursive digital filter which operates on the equally spaced cloud base data h_n to produce the filtered data $\bar{h}_n$:

$$\bar{h}_n = \sum_{k=-5}^{5} c_k h_{n-k}. \qquad (2)$$

The coefficients c_k are defined by

$$[-1, -5, -5, 20, 70, 98, 70, 20, -5, -5, -1]/256.$$

If the h_n have the pure oscillatory form $e^{2\pi i f n}$ with frequency f, it is easily shown that the $\bar{h}_n$ have the form $H(f)h_n$ where the transfer function $H(f)$ is given by

$$
\begin{aligned}
H(f) = [98 &+ 140\cos(2\pi f) + 40\cos(4\pi f) \\
&- 10\cos(6\pi f) - 10\cos(8\pi f) \qquad (3) \\
&- 2\cos(10\pi f)]/256
\end{aligned}
$$

which is plotted in Fig. 3. This figure shows that the response for periods longer than 4 minutes is greater than 90%, whereas the response for periods shorter than 2 minutes is less than 10%. A detailed discussion of this filter is given by Hamming (1983, pages 143–144).

Fig. 4 shows the unfiltered and filtered cloud bases for the time period over which the data was saved (cf. Table 1); the temporal resolution of the data presented here is 30 s. In these figures only the lowest cloud base was plotted, although reports of multiple cloud layers in the data were rare. In addition, clear sky is denoted in these figures by a point at 960 m. Fig. 5 shows a selected 4 hour period of the data in which the time scale of the graph has been expanded. With this perspective some interesting shorter time scale oscillations (e.g., on the order of 10 minutes) can now be seen in the data.

REFERENCES

Hamming, R. W., 1983: *Digital Filters*, Second Edition. Prentice-Hall, Englewood Cliffs, New Jersey, 257 pp.

Hogg, D. C., F. O. Guiraud, J. B. Snider, M. T. Decker and E. R. Westwater, 1983: A steerable dual-channel microwave radiometer for measurement of water vapor and liquid in the troposphere. *J. Climate Appl. Meteor.*, **22**, 789–806.

Vaisala, Inc., 1986: Ceilometer CT 12K Technical Manual, 400 pages.

TABLE 1. Ceilometer data files

| File | Start | | End | |
Name	Julian Date	Time (GMT)	Julian Date	Time (GMT)
CEIL.J1A	182	15:00:00	182	15:54:00
CEIL.J1B	182	17:05:00	183	15:38:00
CEIL.J2A	183	17:23:00	184	04:10:00
CEIL.J2B	184	04:20:00	184	17:42:00
CEIL.J3A	184	18:35:00	185	01:38:30
CEIL.J3B*	185	02:03:00	186	16:00:00
CEIL.J5A	186	16:10:00	186	23:56:30
CEIL.J5B	187	00:16:00	187	18:11:00
CEIL.J6A	187	18:14:00	188	17:01:30
CEIL.J7A	188	17:04:00	189	16:58:30
CEIL.J8A	189	17:03:00	190	16:59:00
CEIL.J9A	190	17:56:00	191	22:49:00
CEIL.10A	191	22:52:00	192	17:16:30
CEIL.11A	192	17:37:00	193	21:39:00
CEIL.12A	193	22:16:00	195	14:01:00
CEIL.14A	195	14:03:00	196	03:16:30
CEIL.14B	196	04:19:00	196	16:31:00
CEIL.15A	196	17:34:00	197	17:55:00
CEIL.16A	197	17:58:00	199	14:06:00
CEIL.18A	199	14:09:00	200	00:07:30
CEIL.18B	200	01:14:00	200	20:22:00

* file lost, perhaps due to a power interrupt
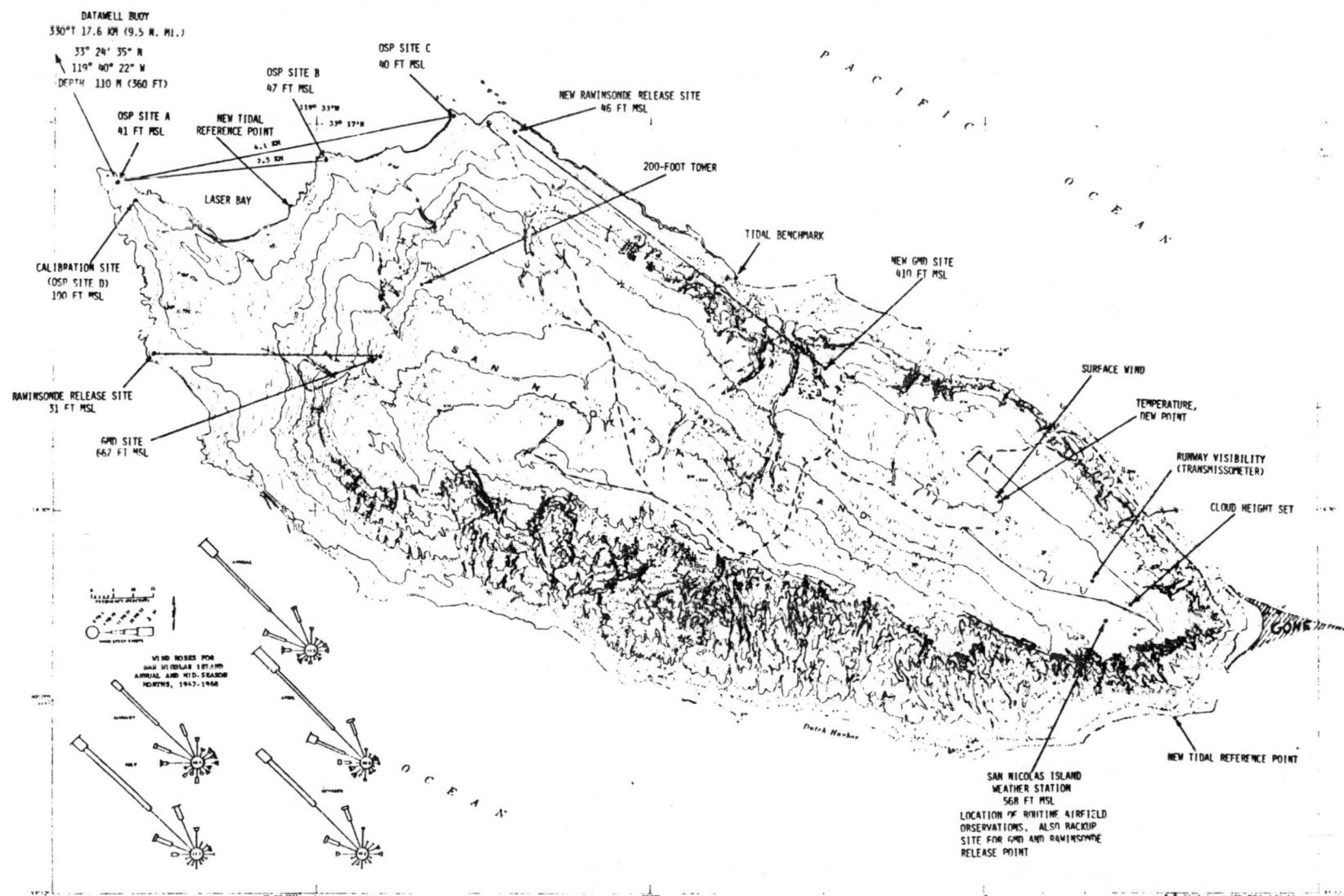
Figure 1. Map of San Nicolas Island, California. The island is approximately 16 km long and 5 km wide. The ceilometer was deployed at site A on the west side of Laser Bay.
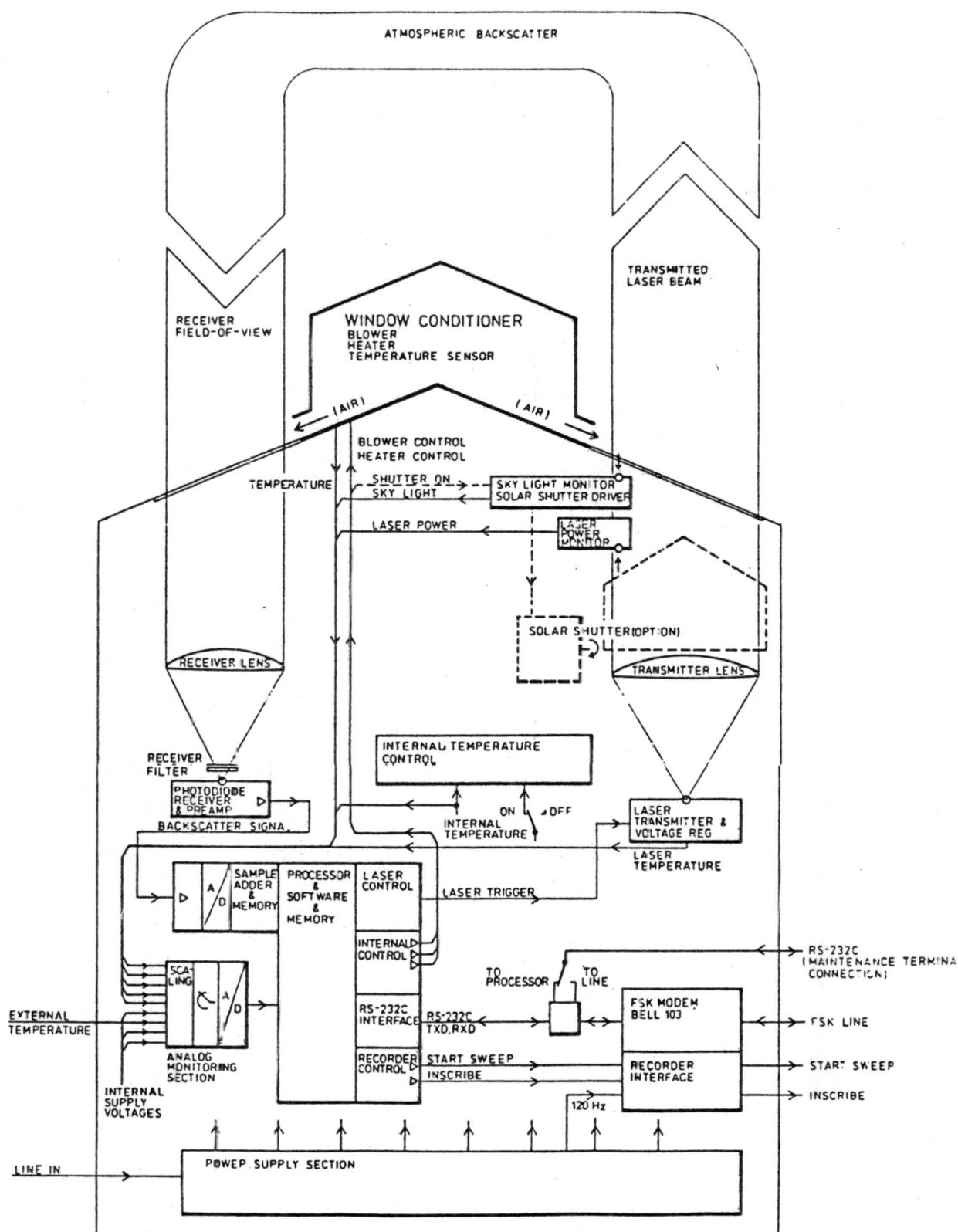
Figure 2. Block diagram of Vaisala CT 12K ceilometer. Pulses of laser light emerge from the transmitter side (i.e., the right side) of the instrument and are backscattered into the receiver side (i.e., the left side). The processing of the received signals is described in the text.
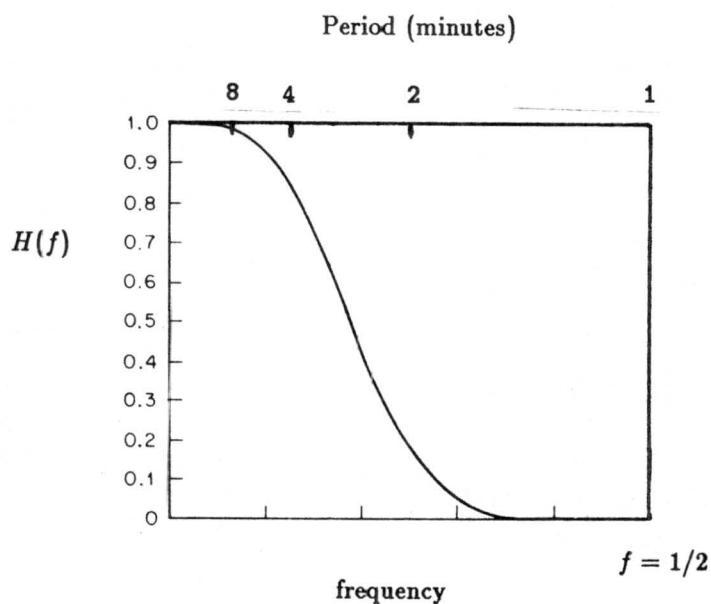
Figure 3. Response curve for the monotone filter described by (2). The response curve $H(f)$ is mathematically expressed by (3), where f is the frequency. The frequency $f = 1/2$ corresponds to one-half of a cycle per observation interval; i.e., $f = 1/2$ is the Nyquist frequency. For the 30 second observation interval of the ceilometer, $f = 1/2$ corresponds to a period of 1 minute.

Figure 4. The following pages show the unfiltered (top) and filtered (bottom) cloud base height for 1 July (Julian Day 182) through 19 July (Julian Day 200) 1987. Note all times are Greenwich Mean Time (GMT), which is seven hours later than Pacific Daylight Time (PDT).

JULY, 1
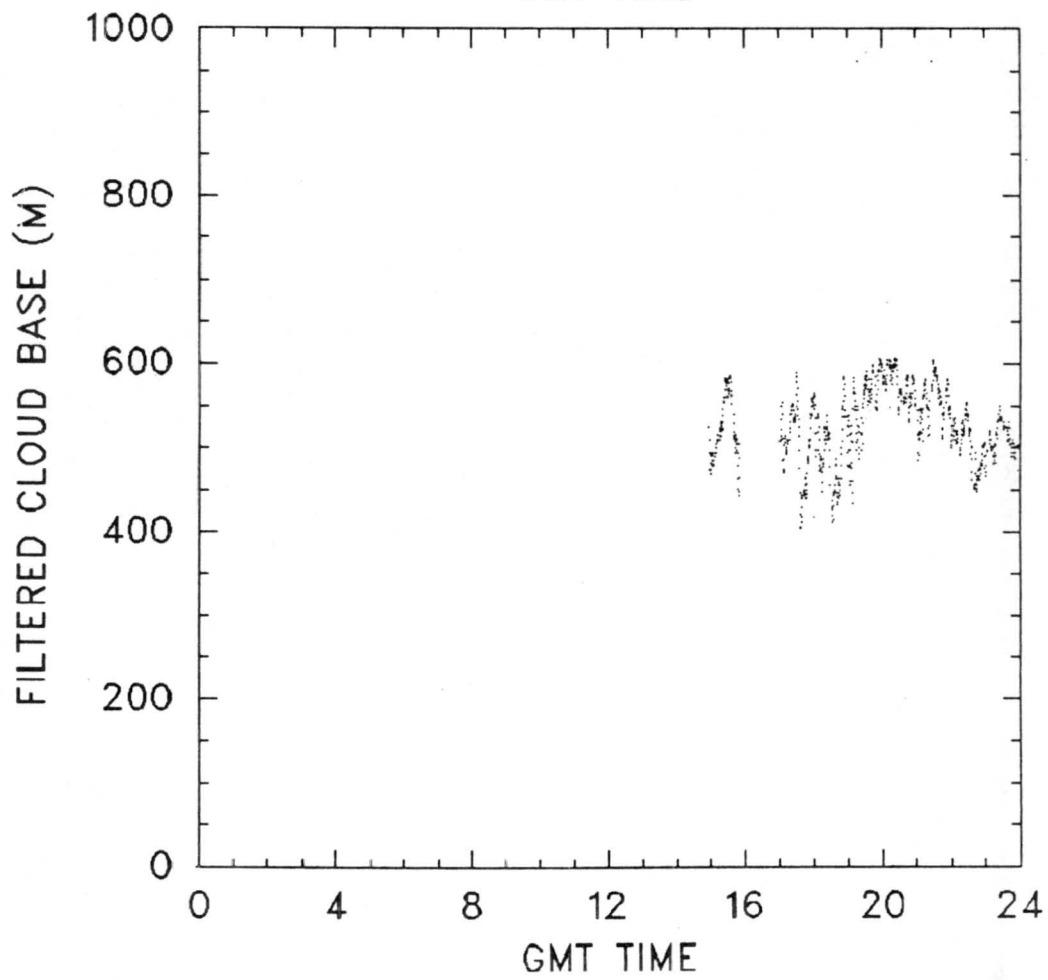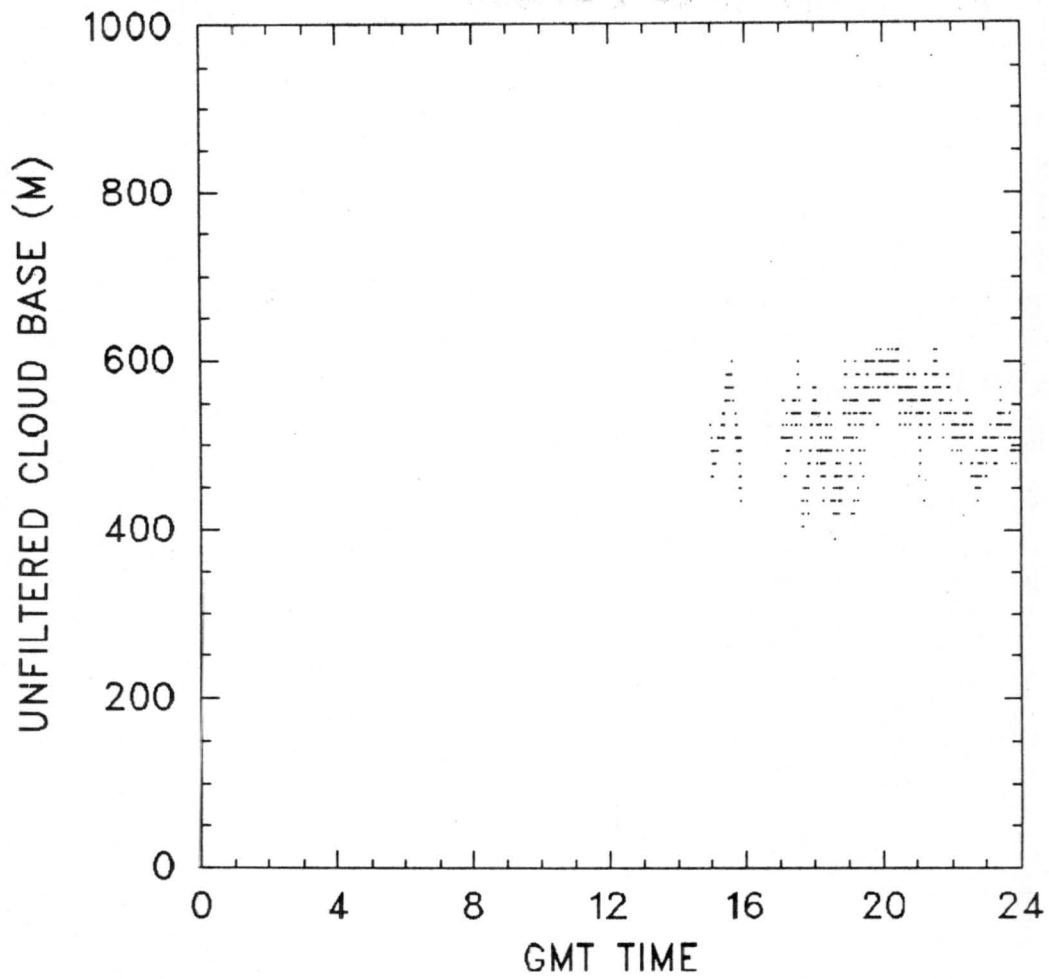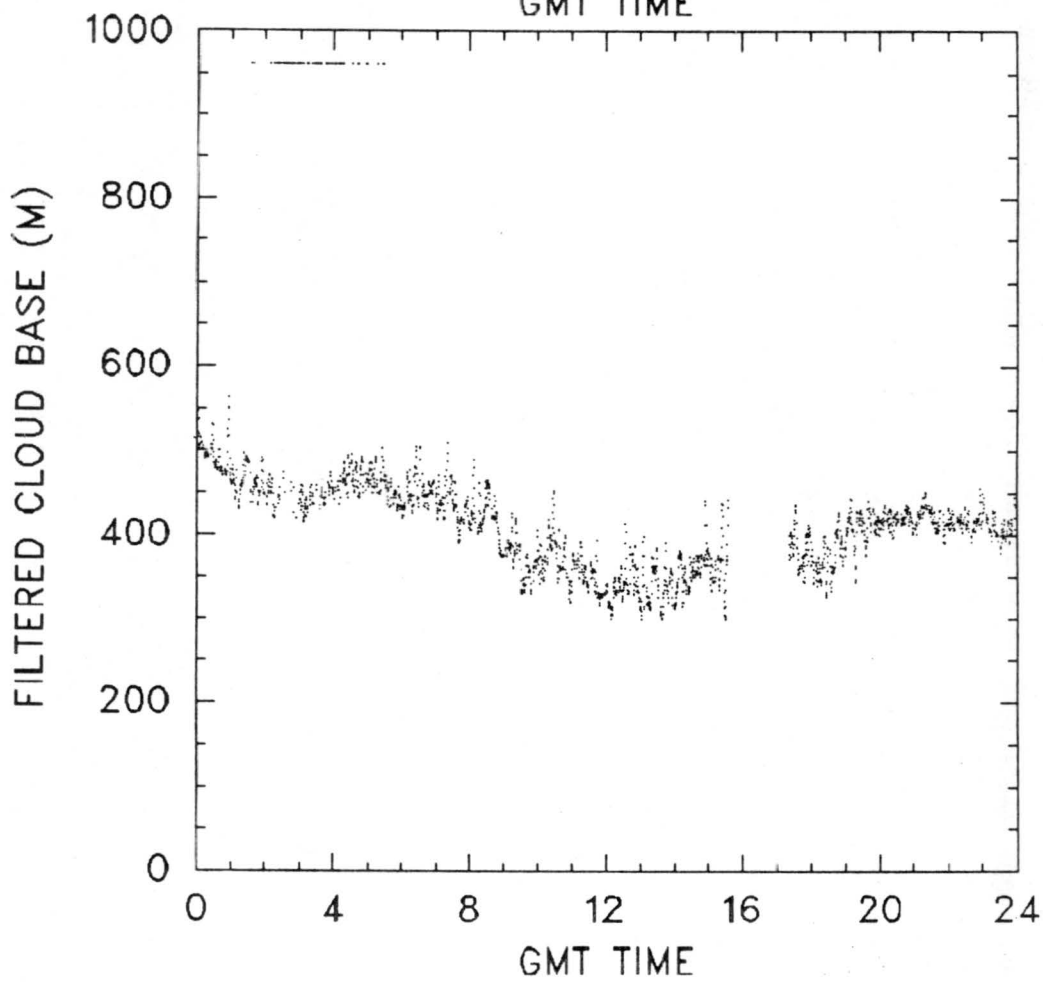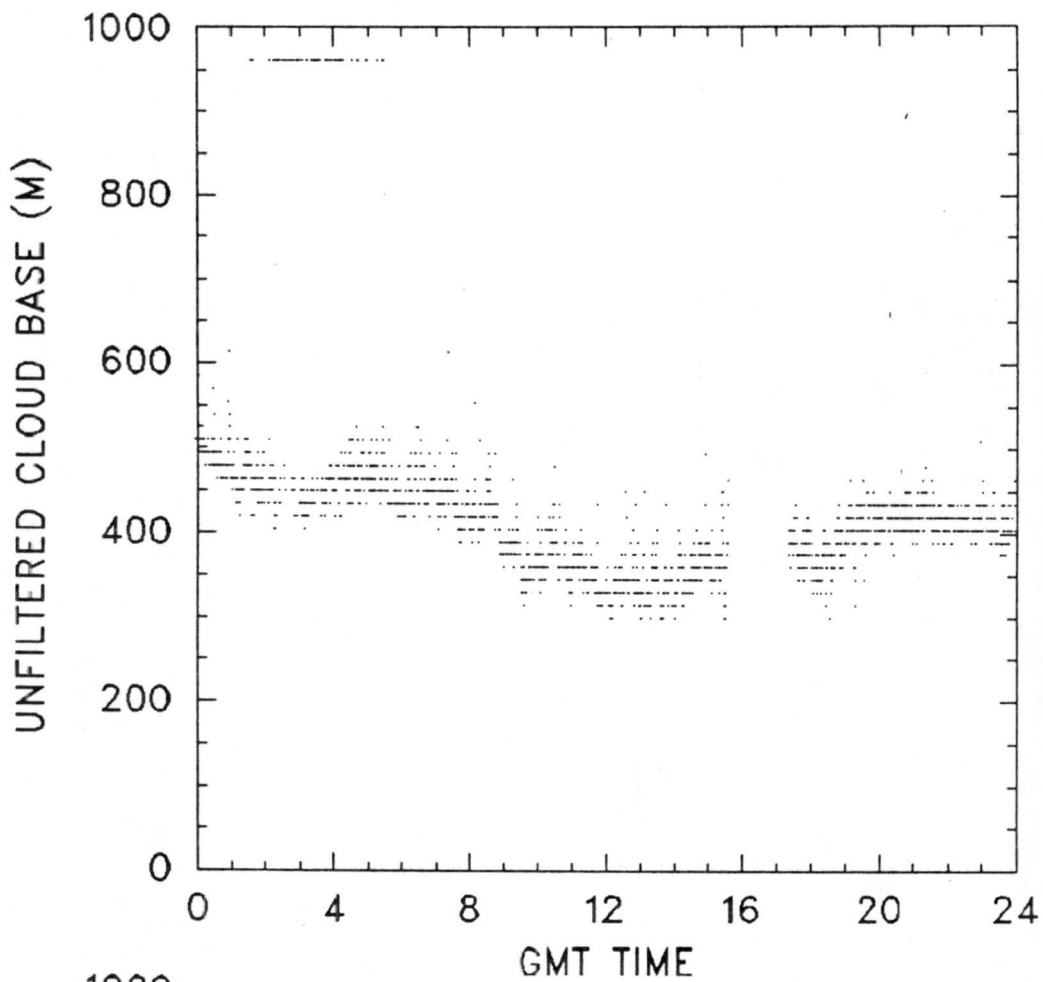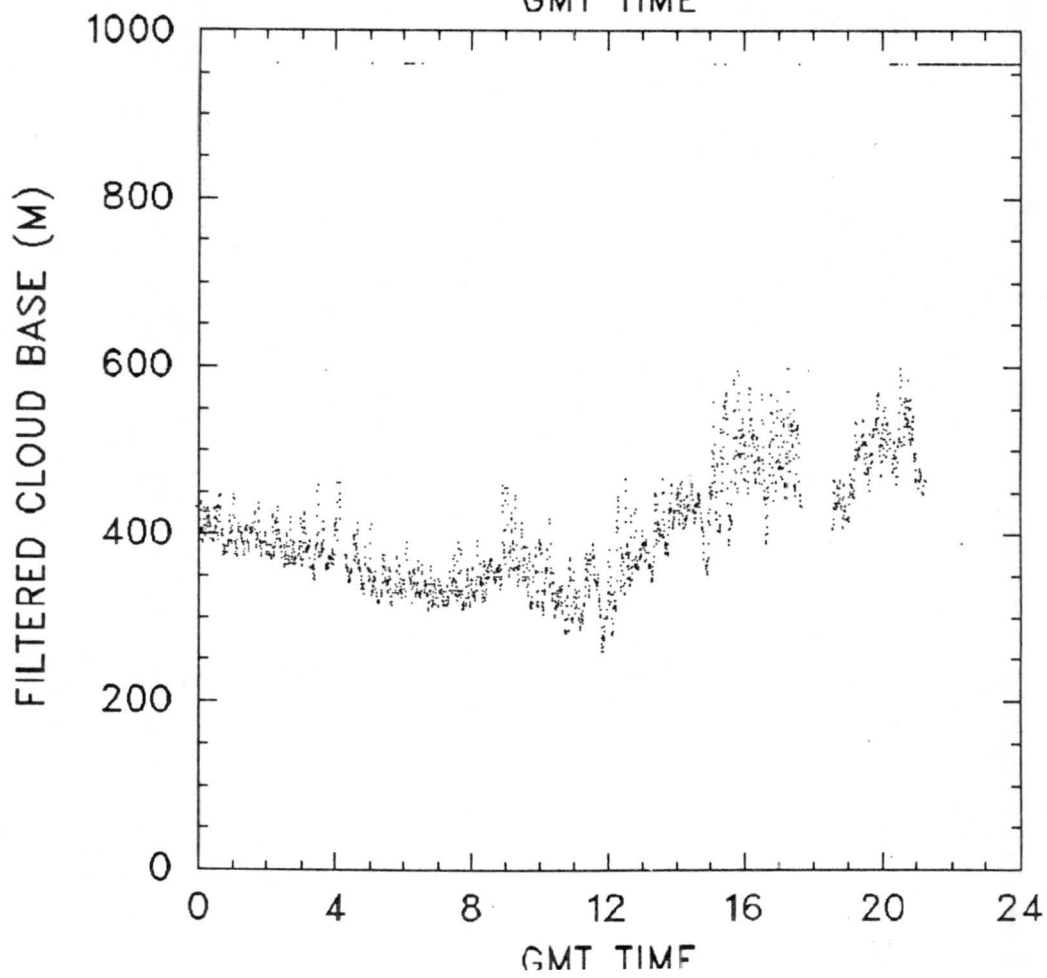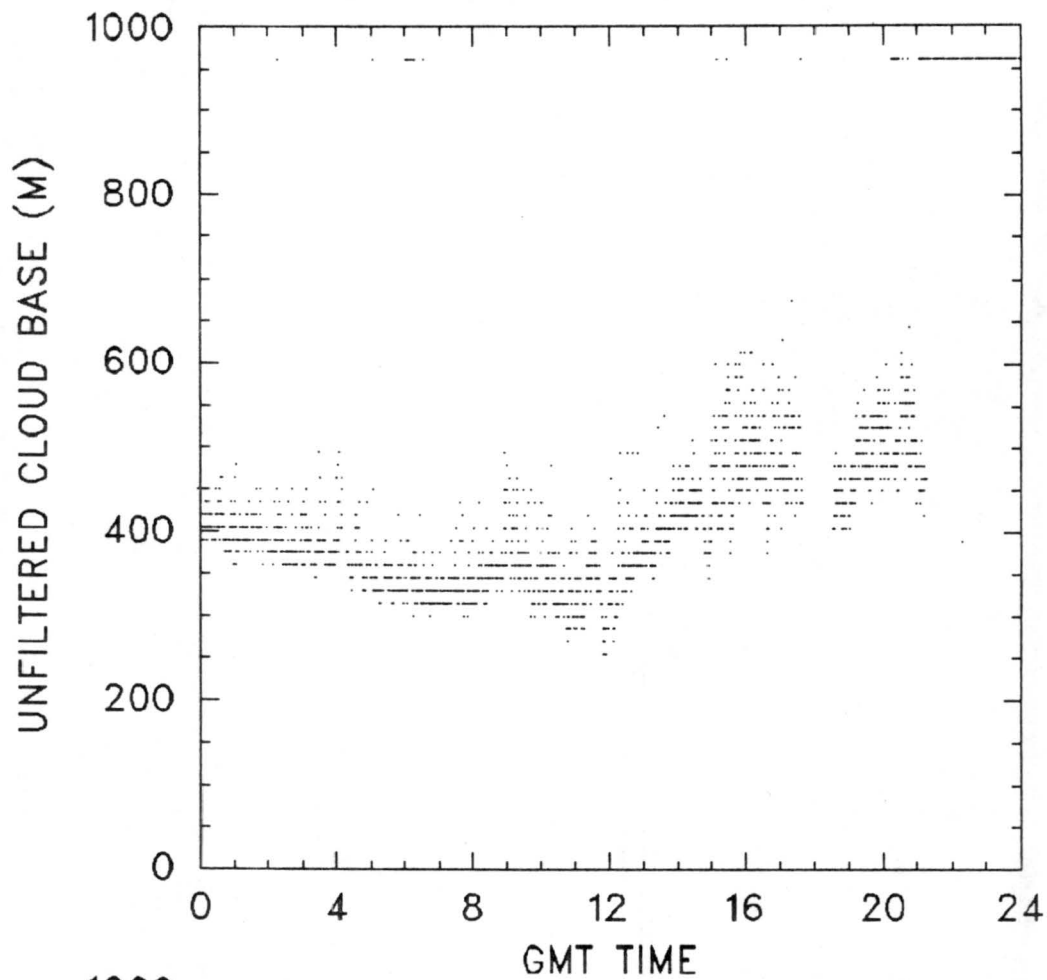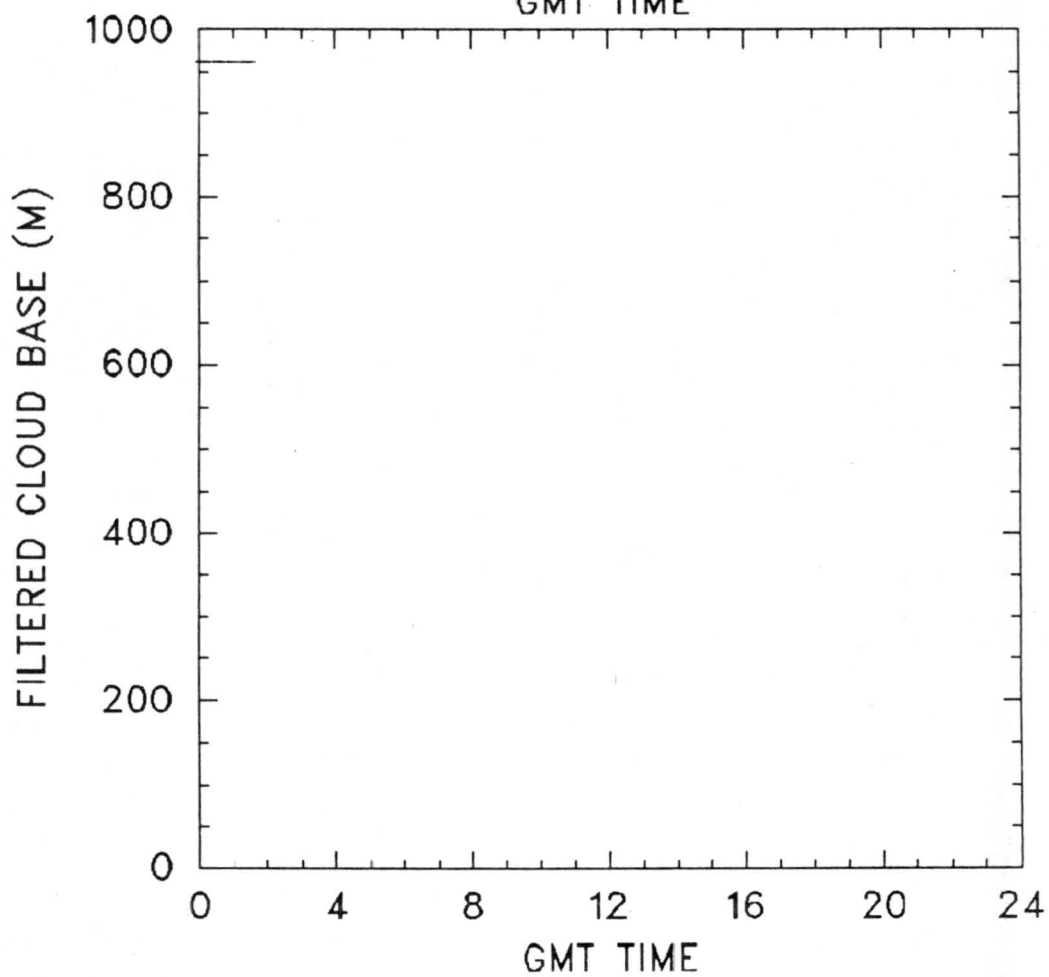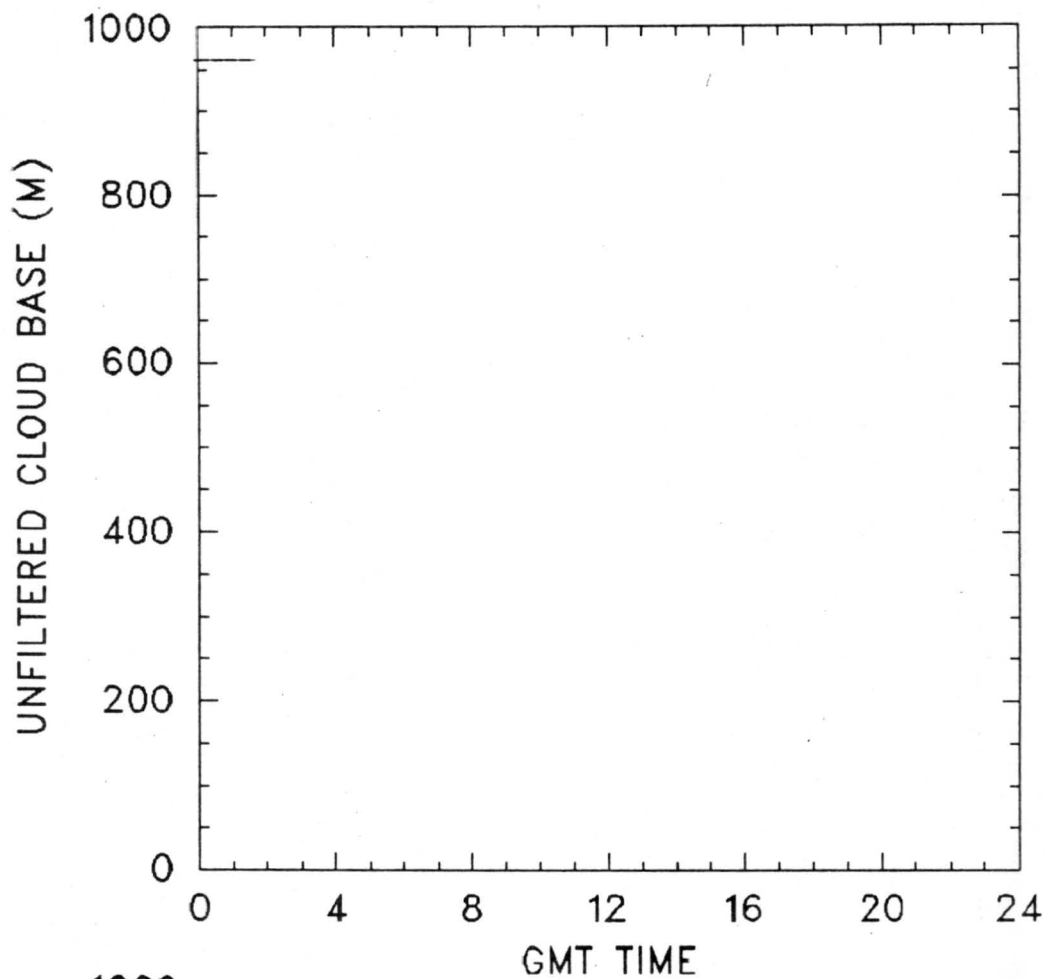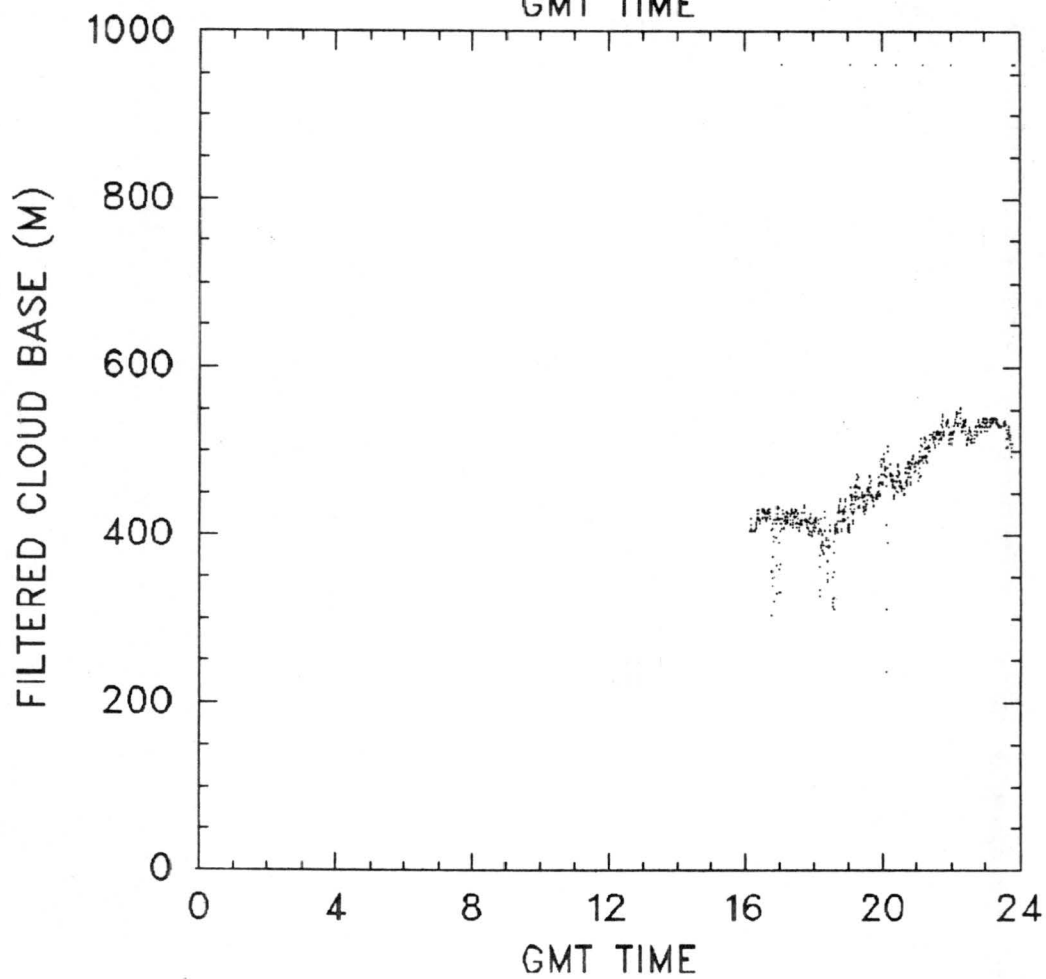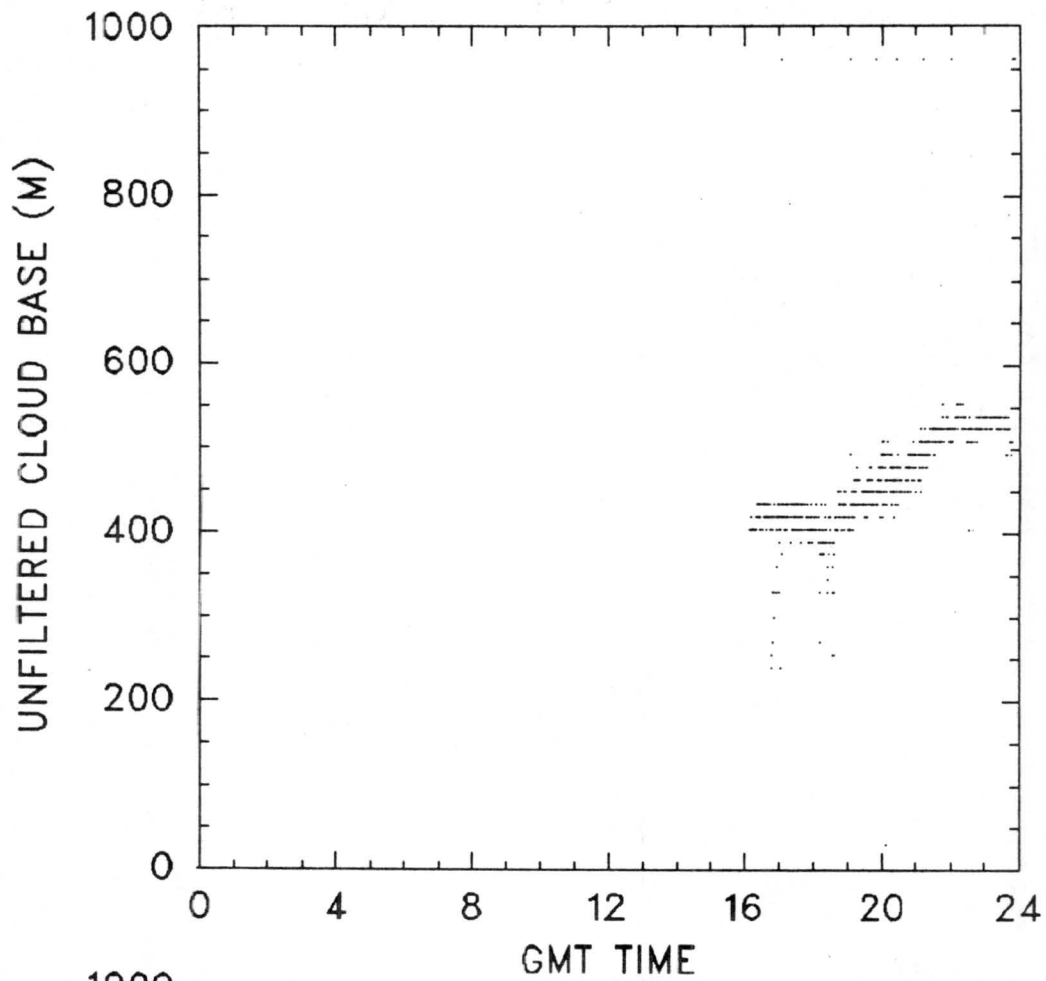
JULY, 2

JULY, 3

JULY, 4

JULY, 5

JULY, 6

JULY, 7

JULY, 8

JULY, 9
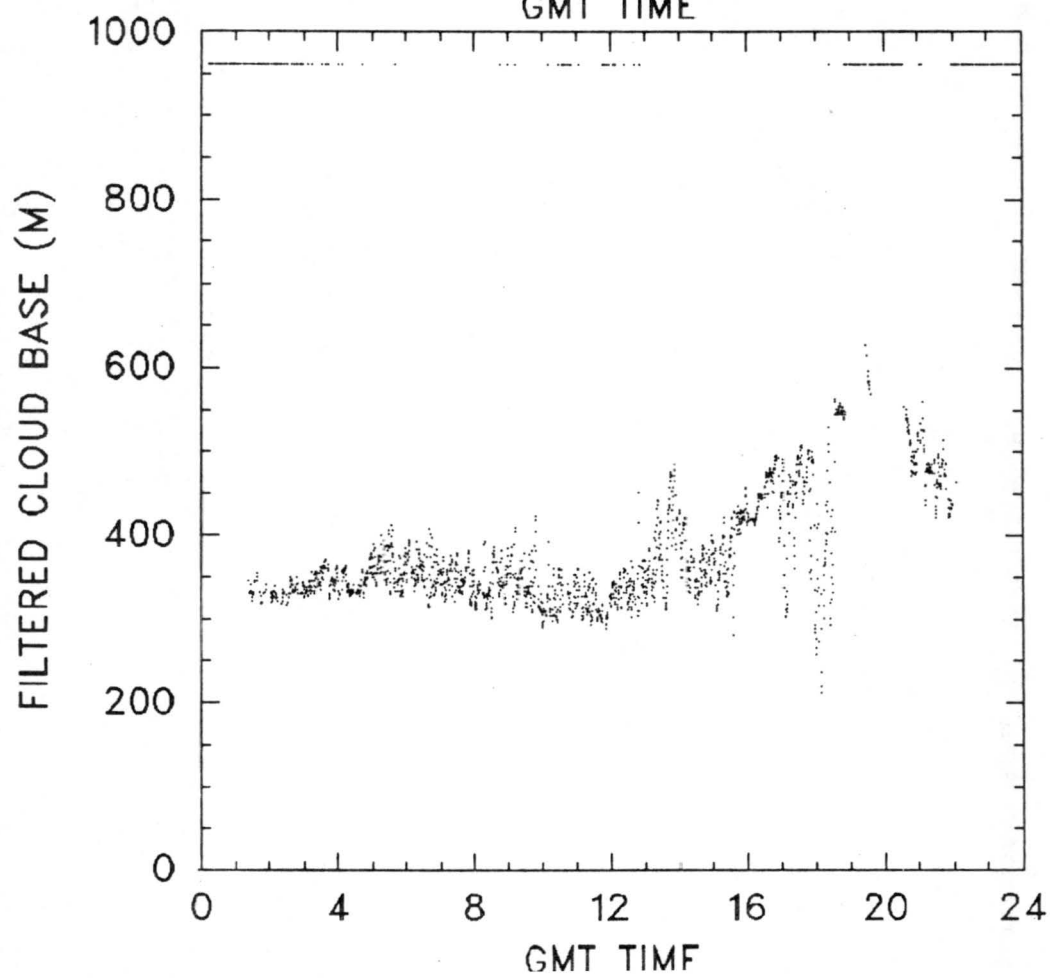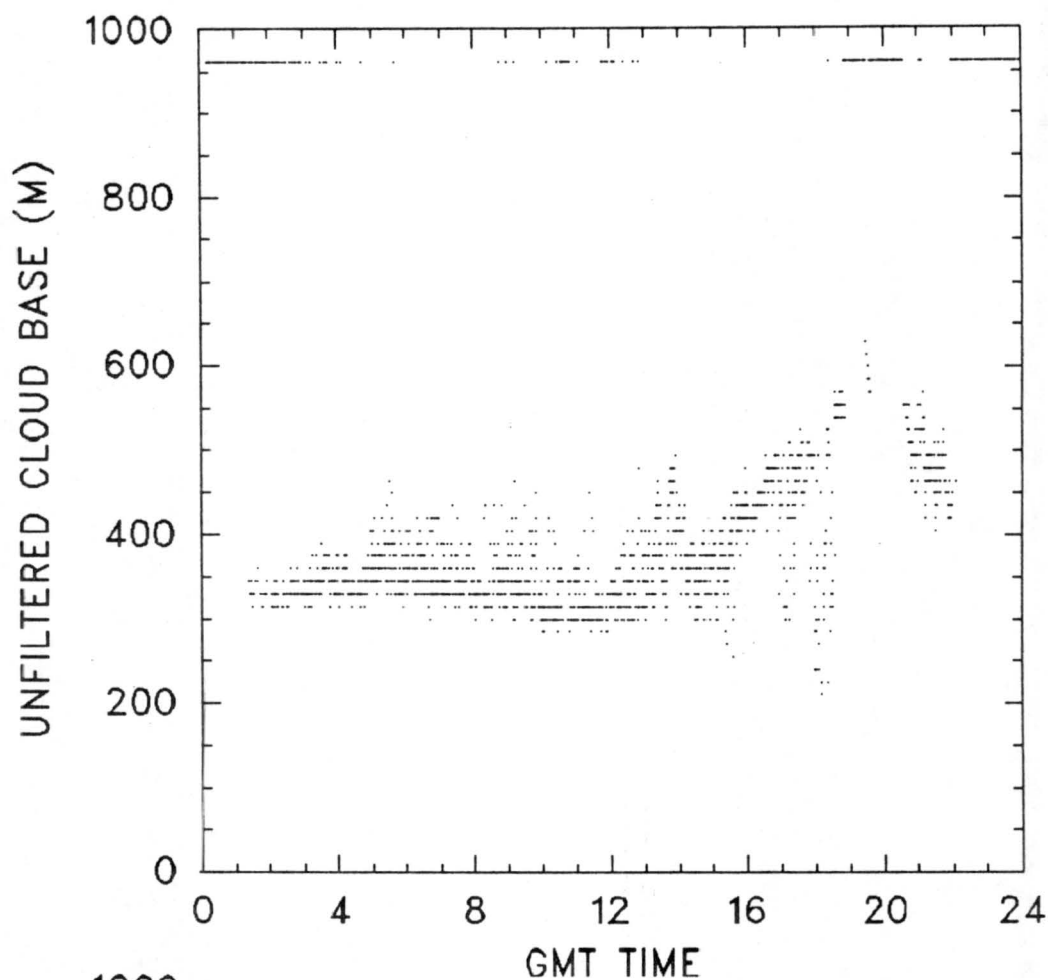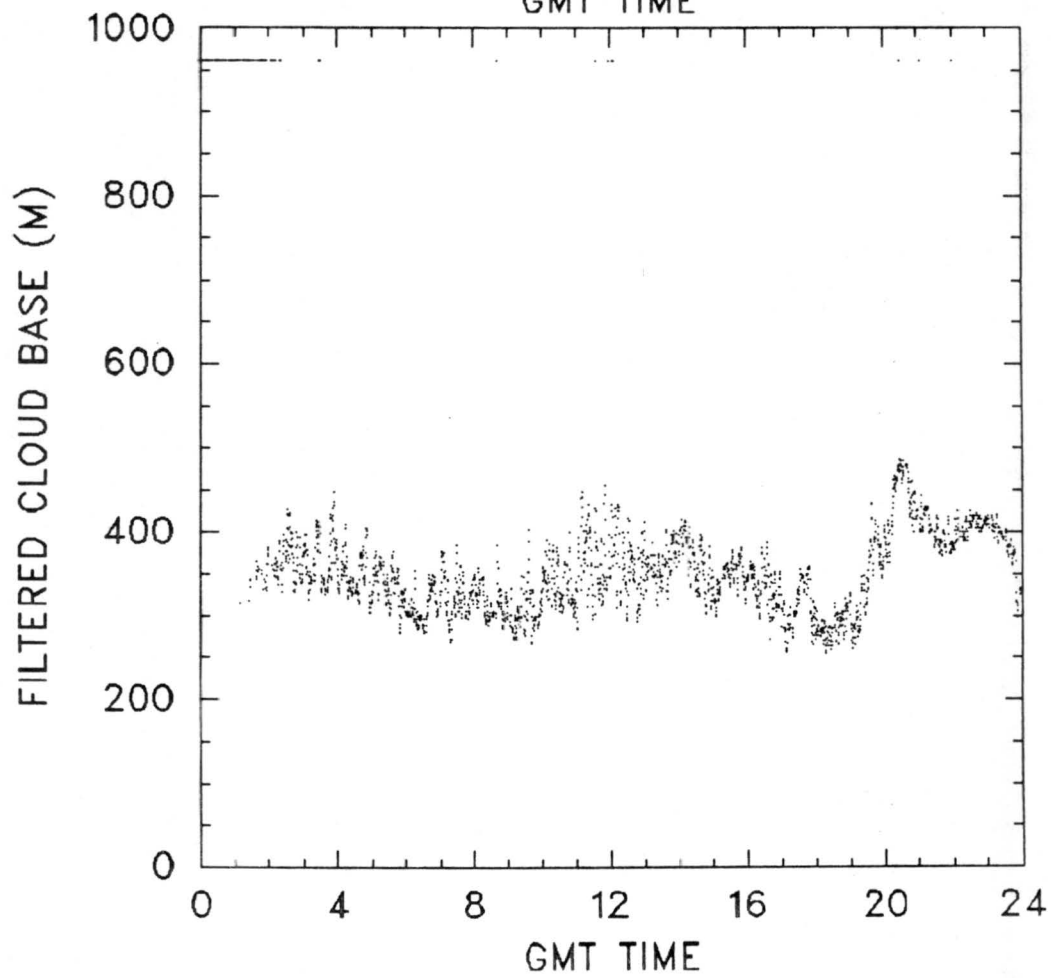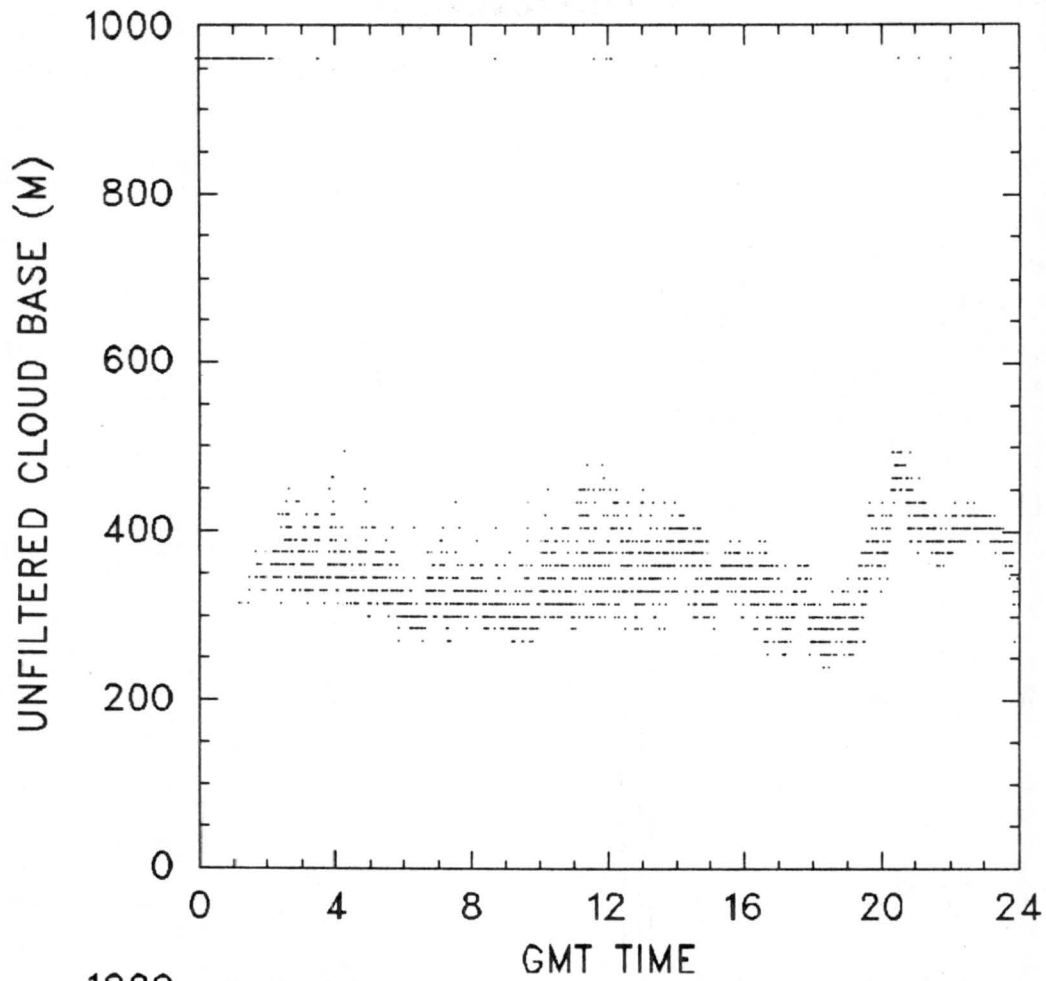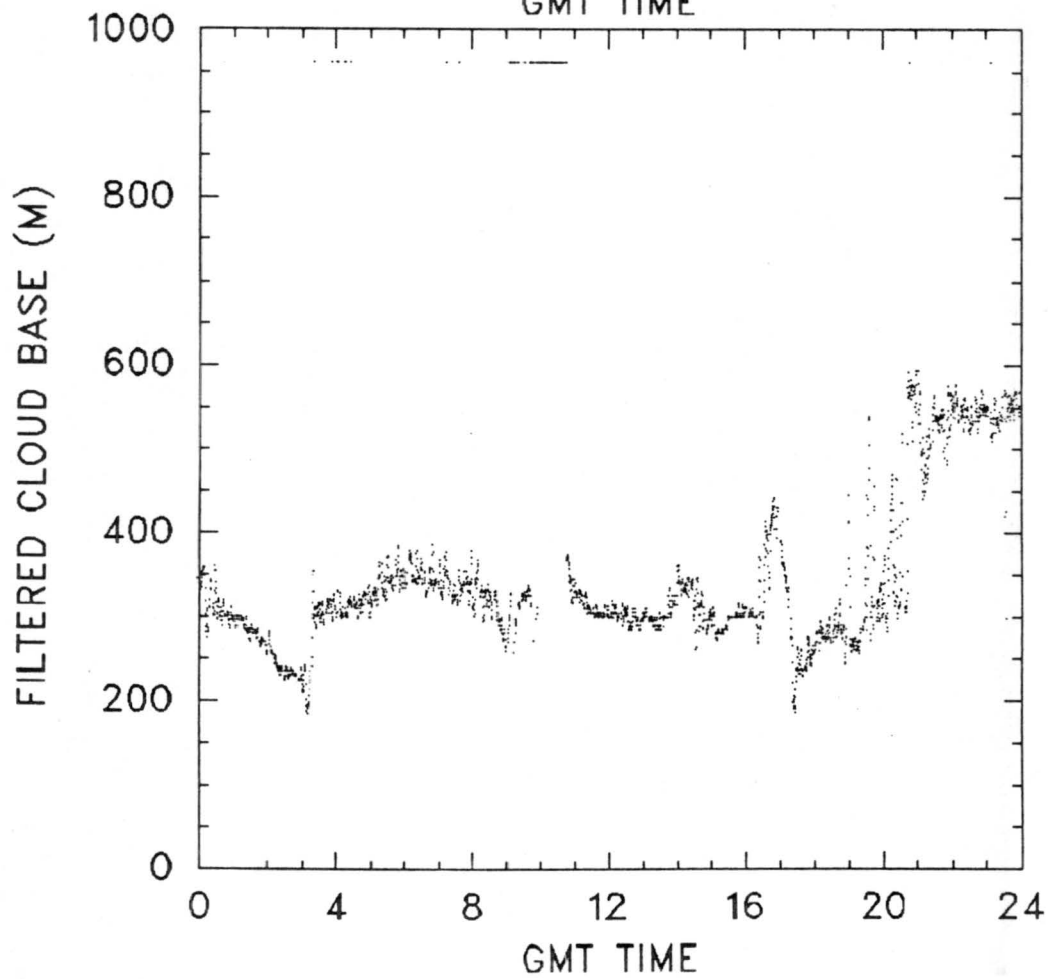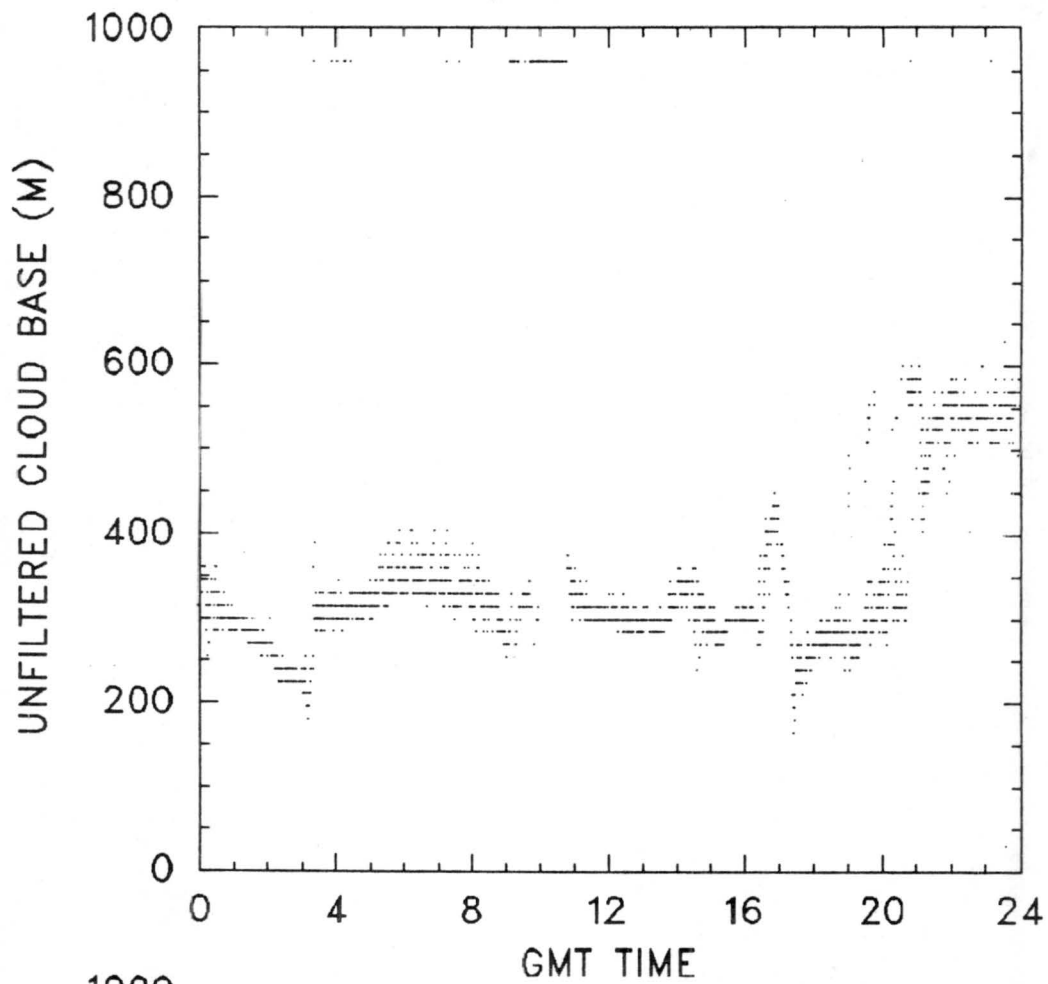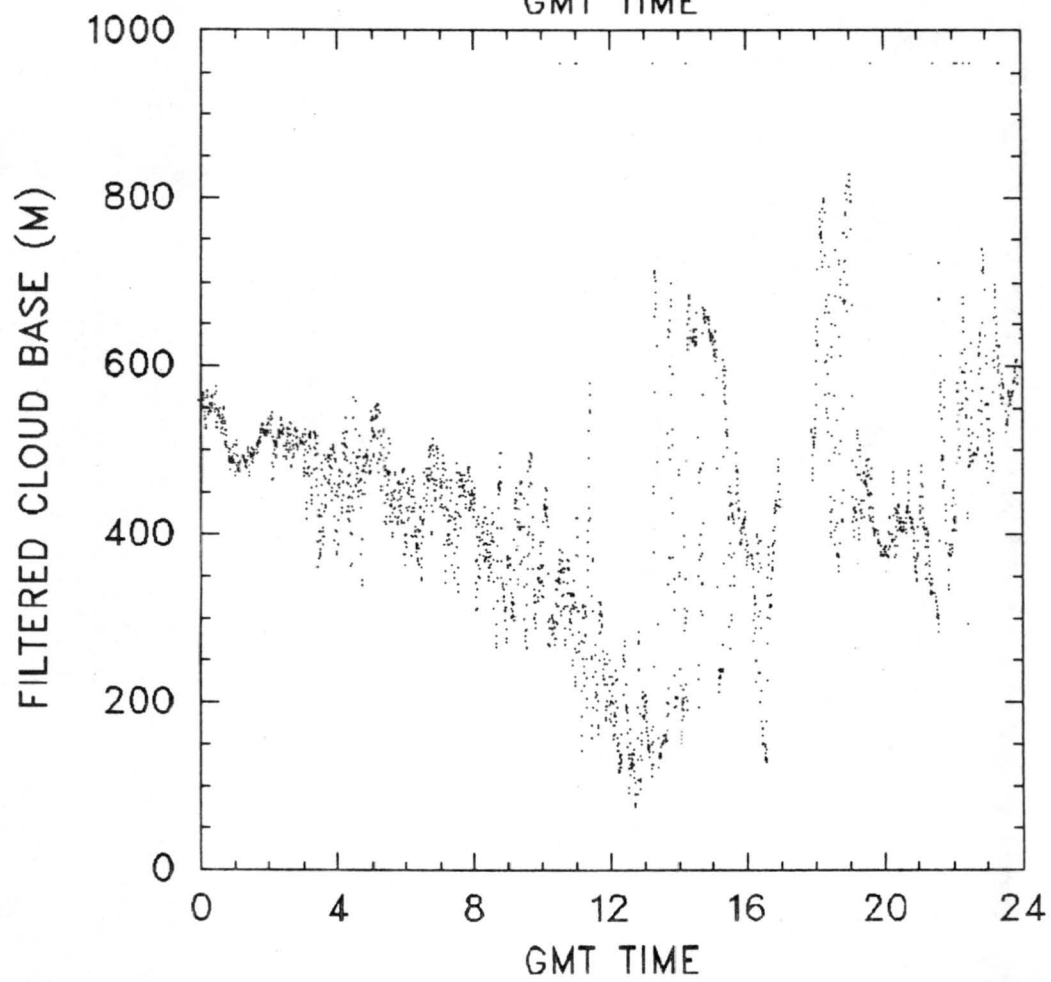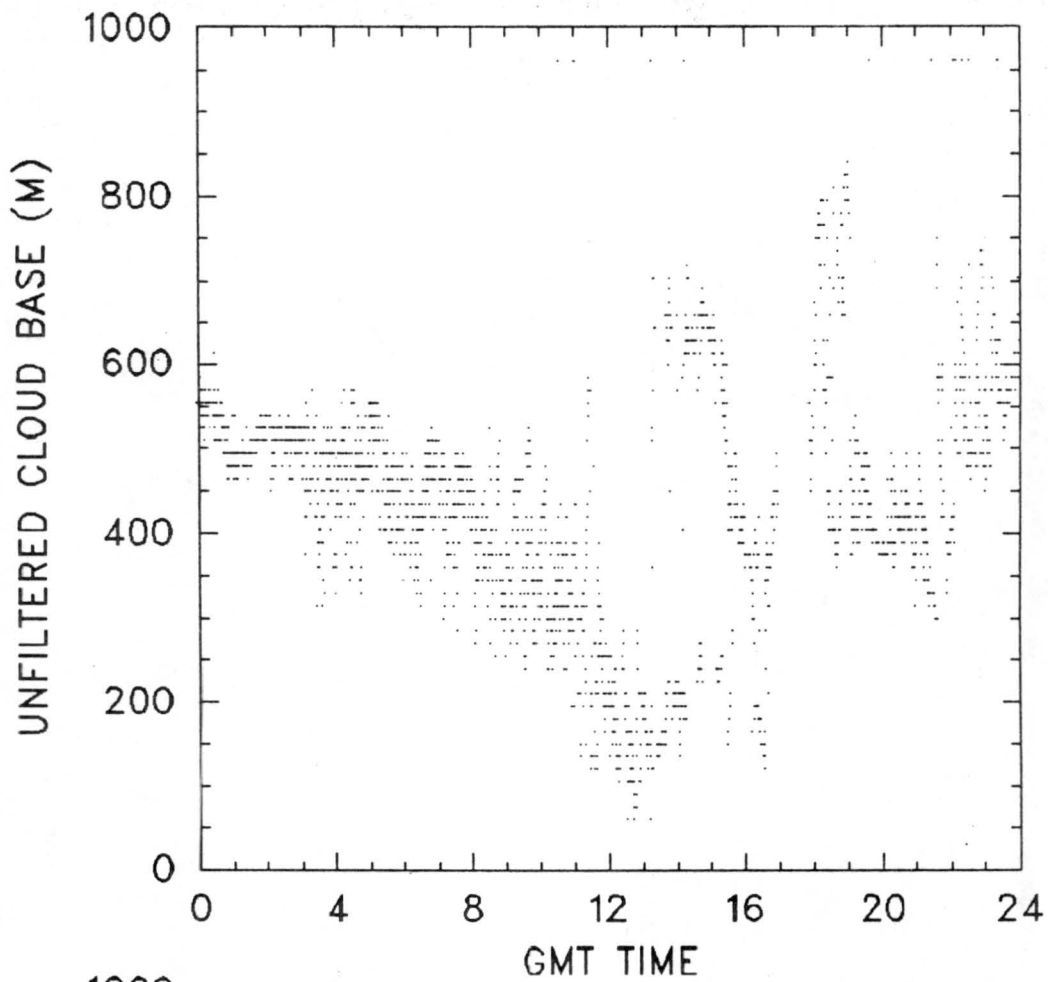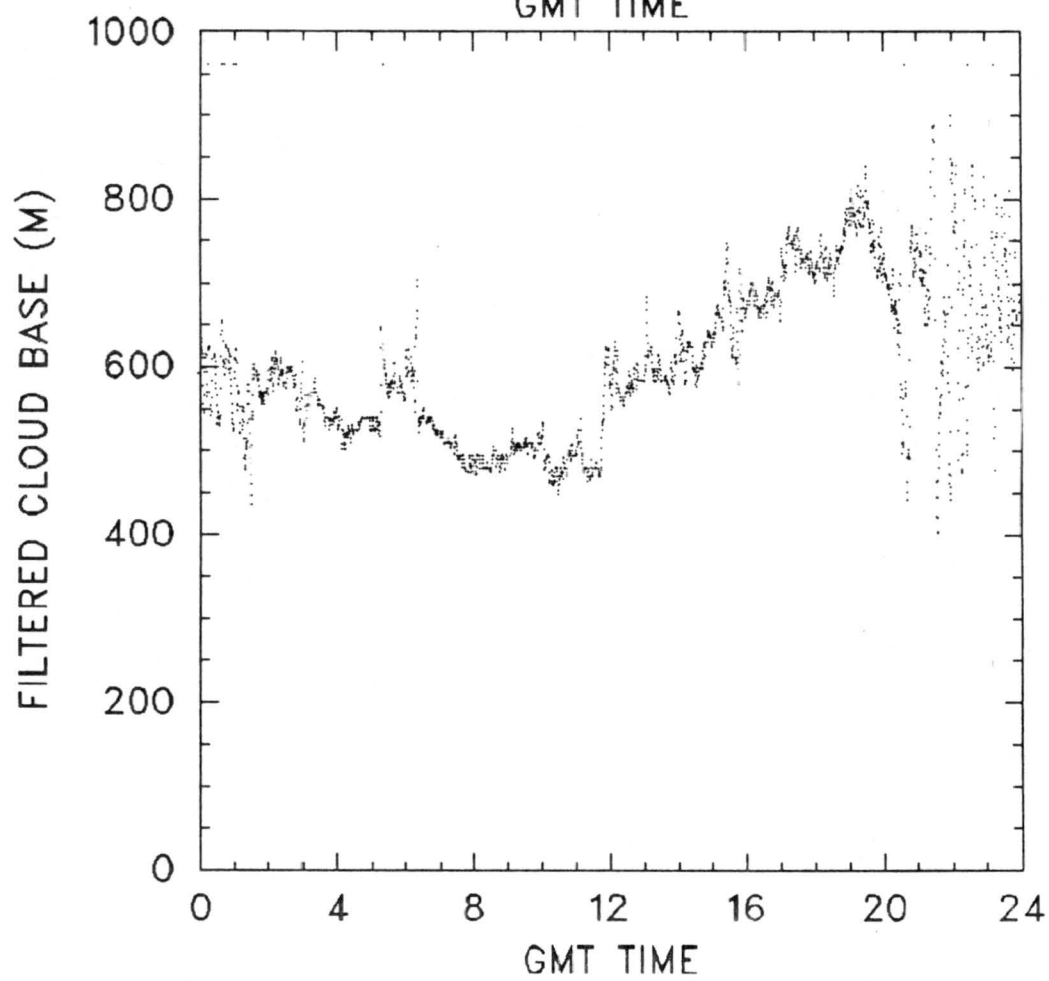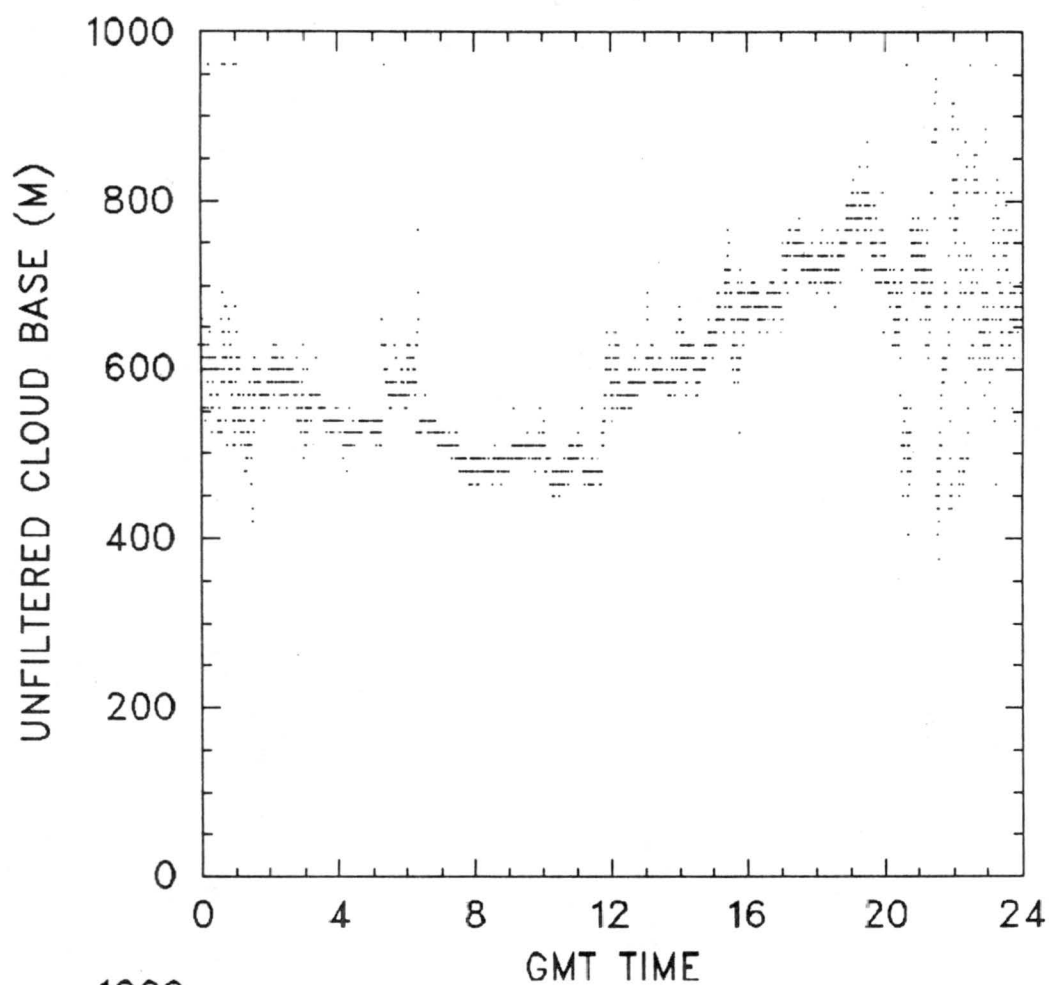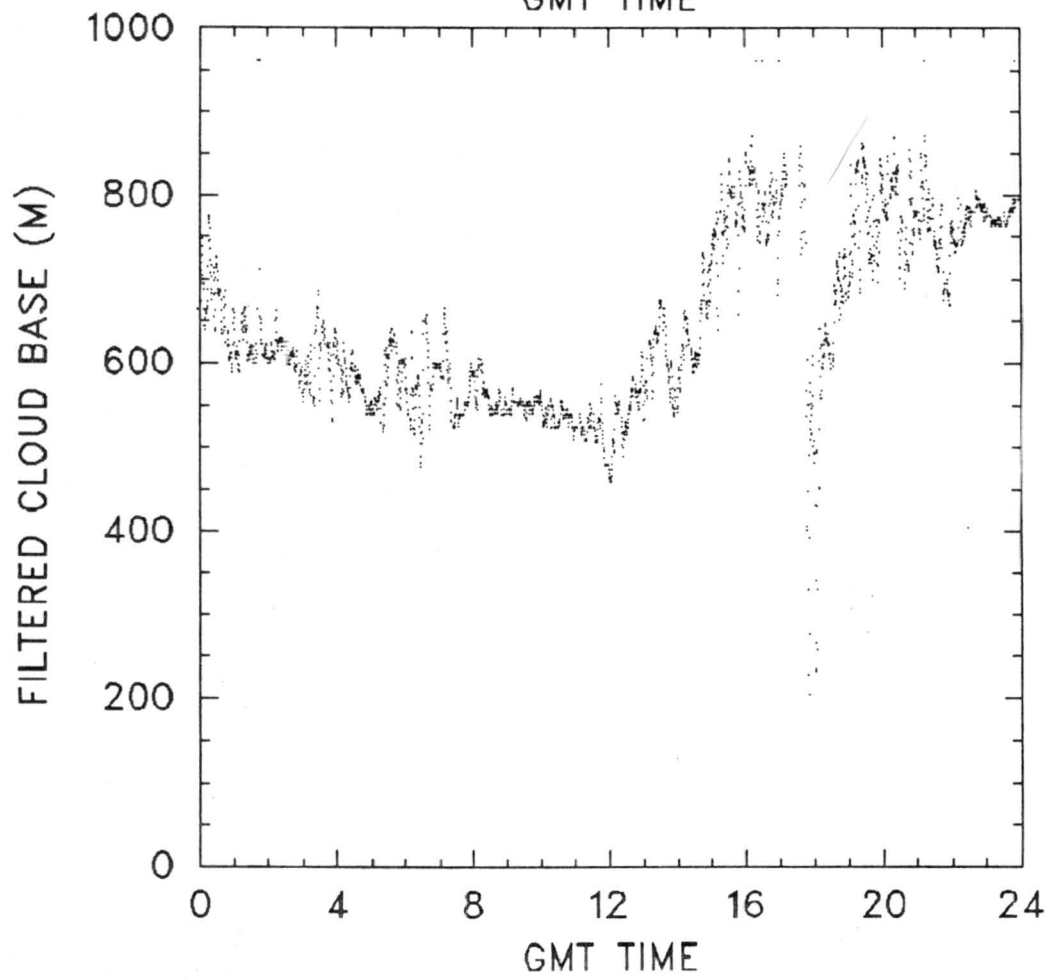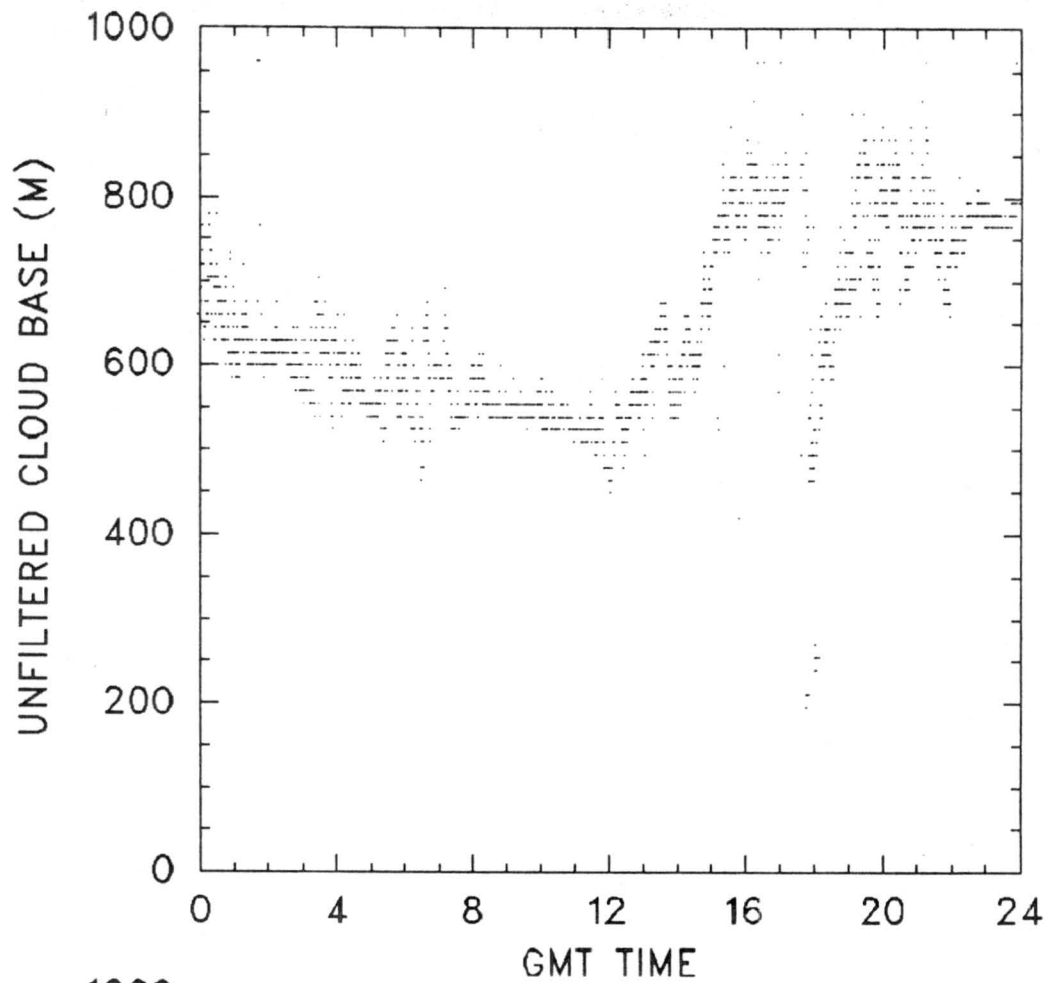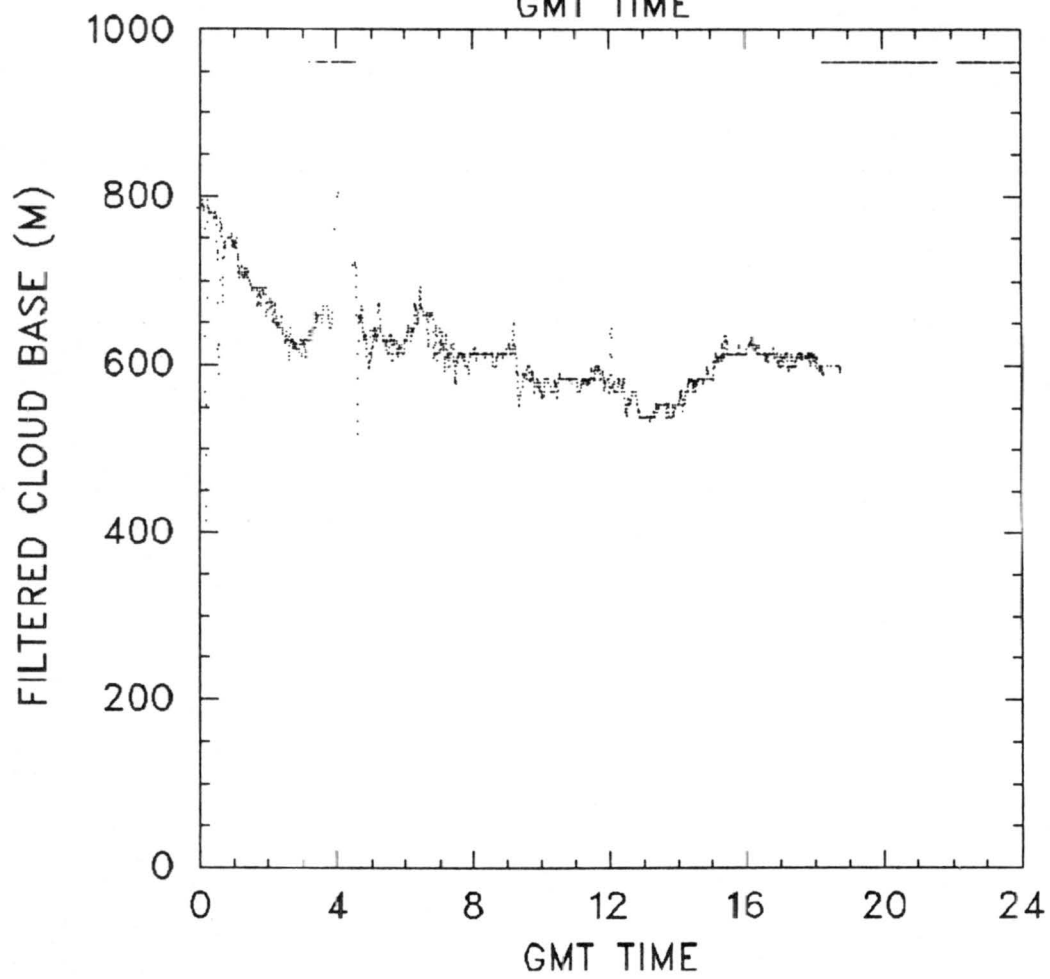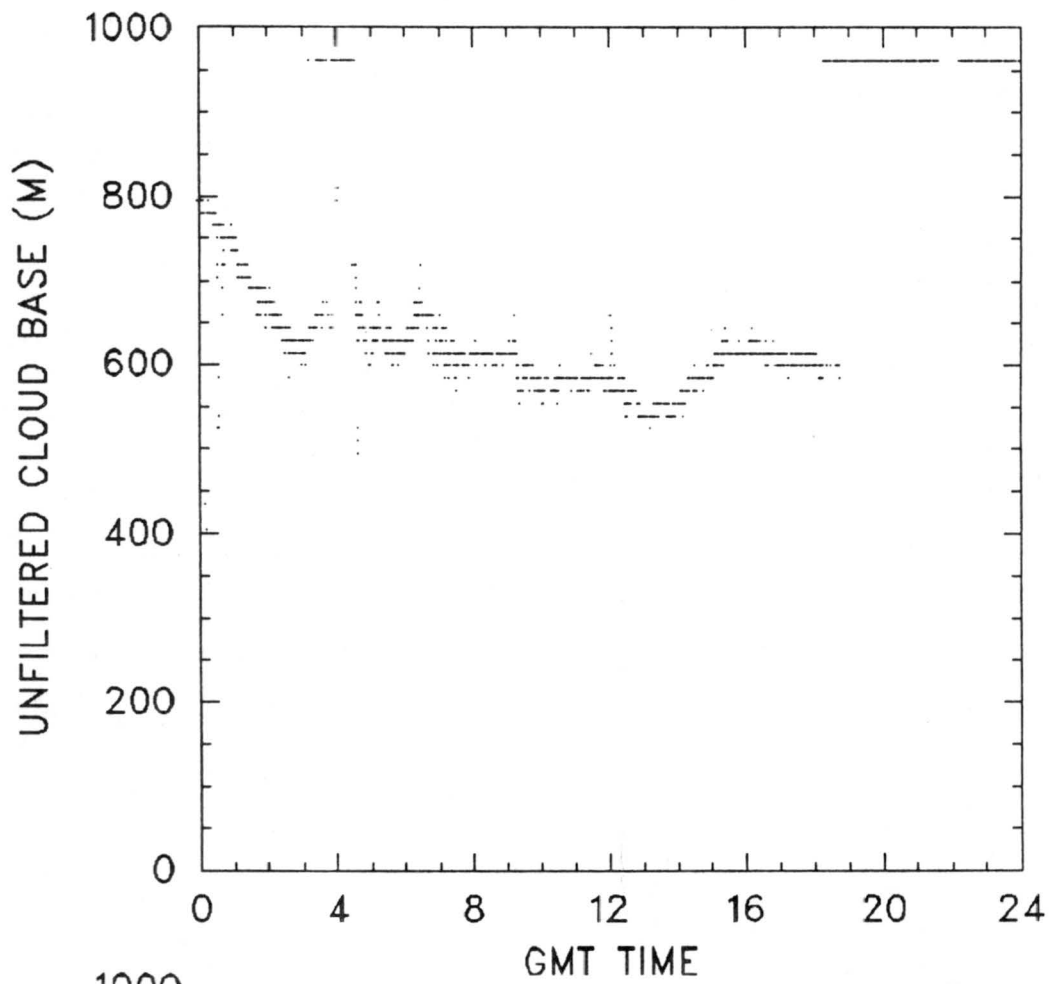
JULY,10
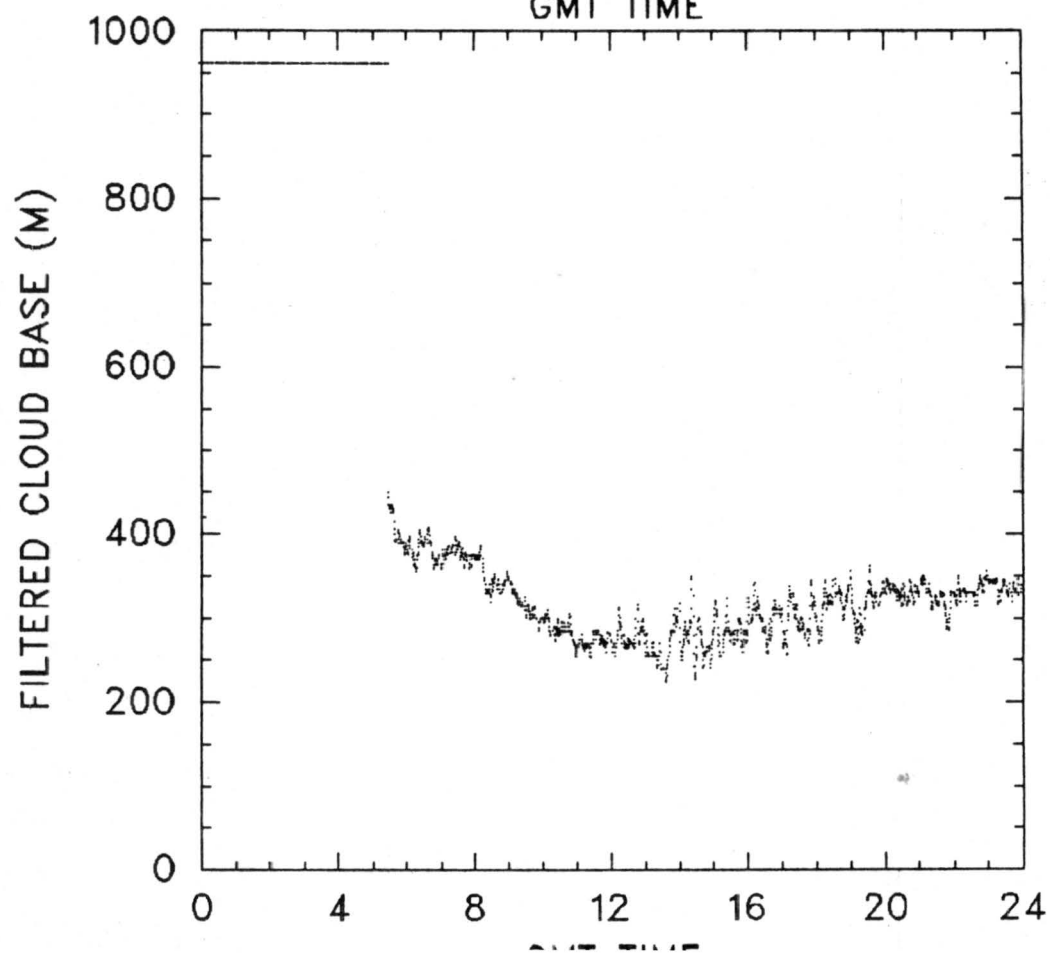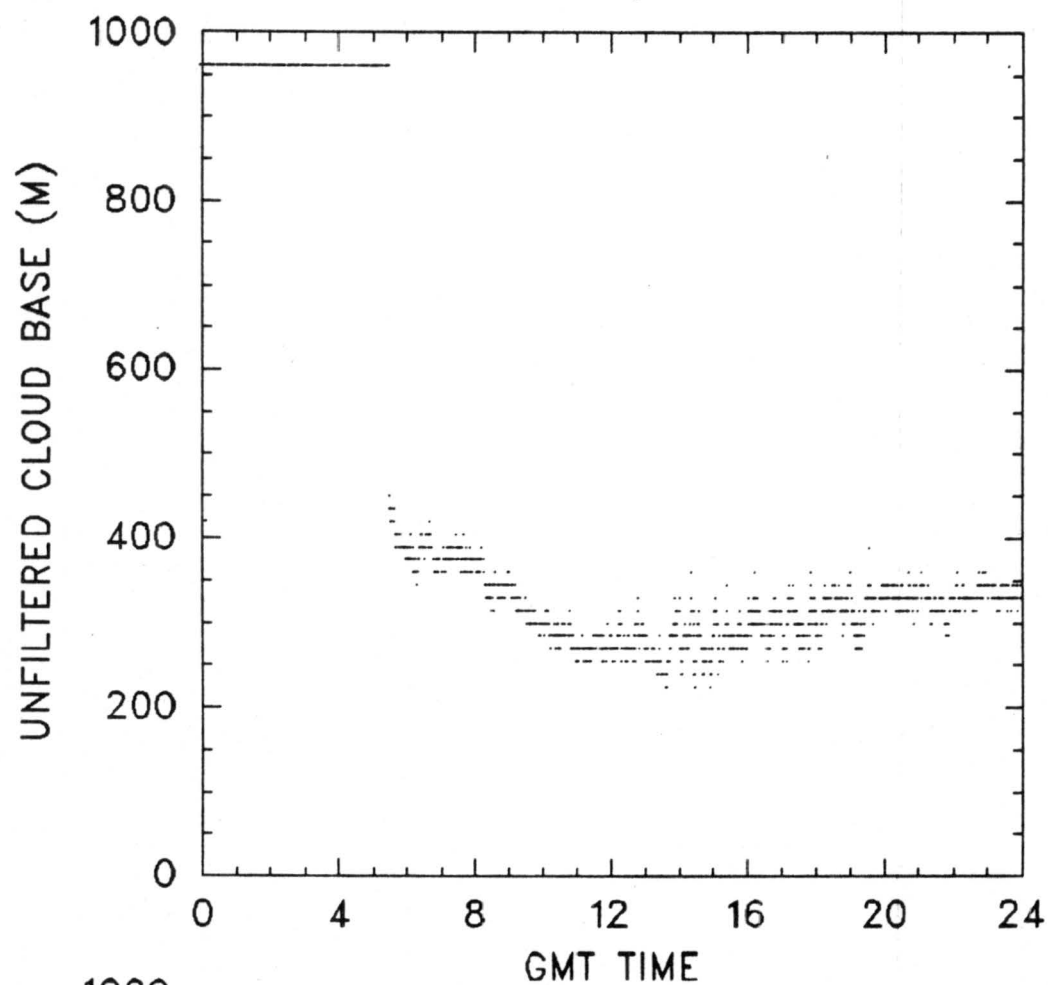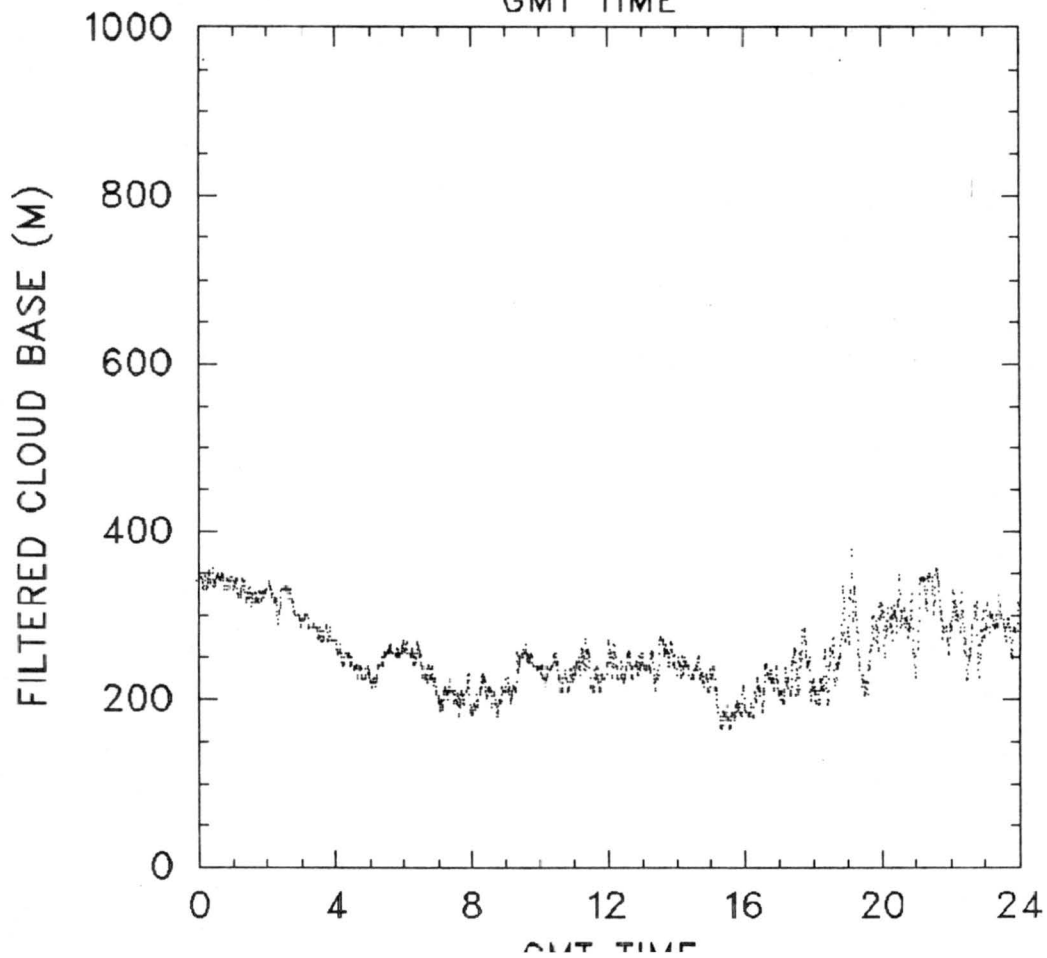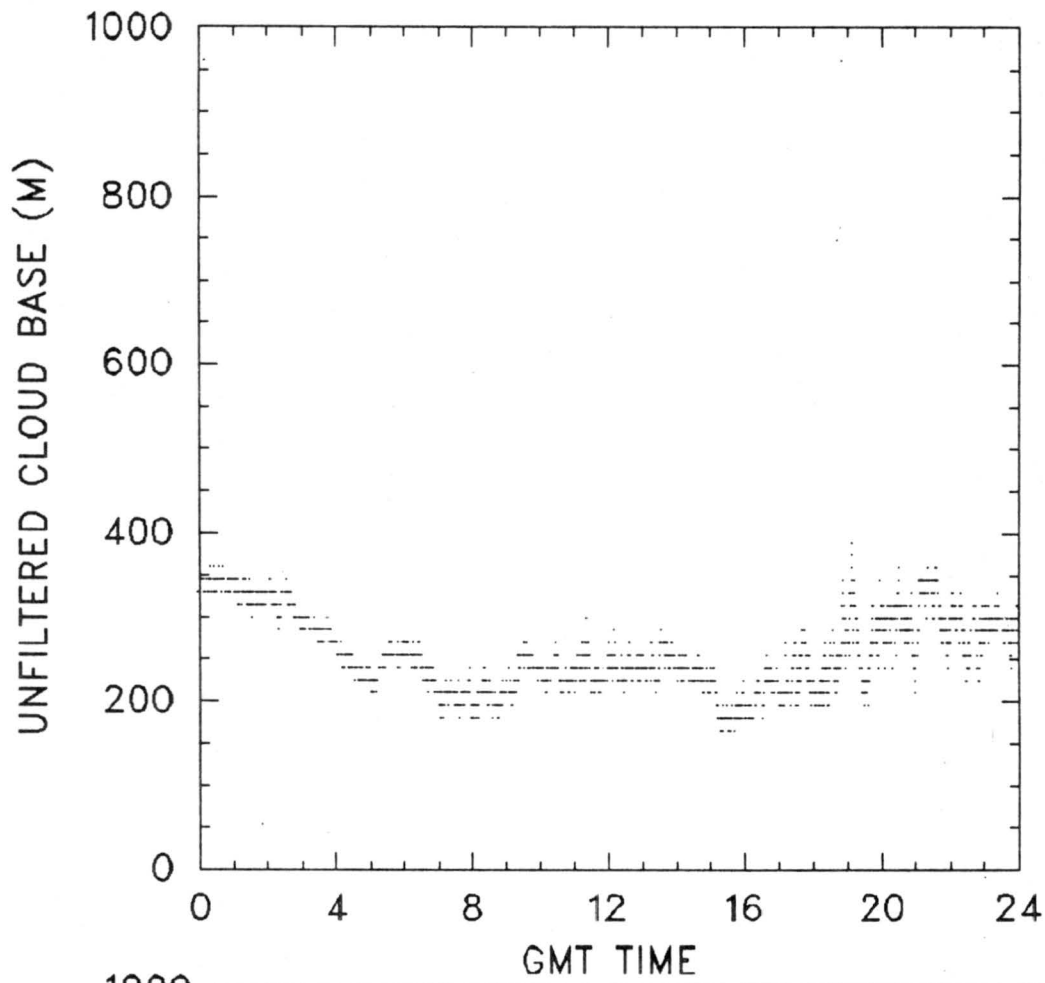
JULY,11
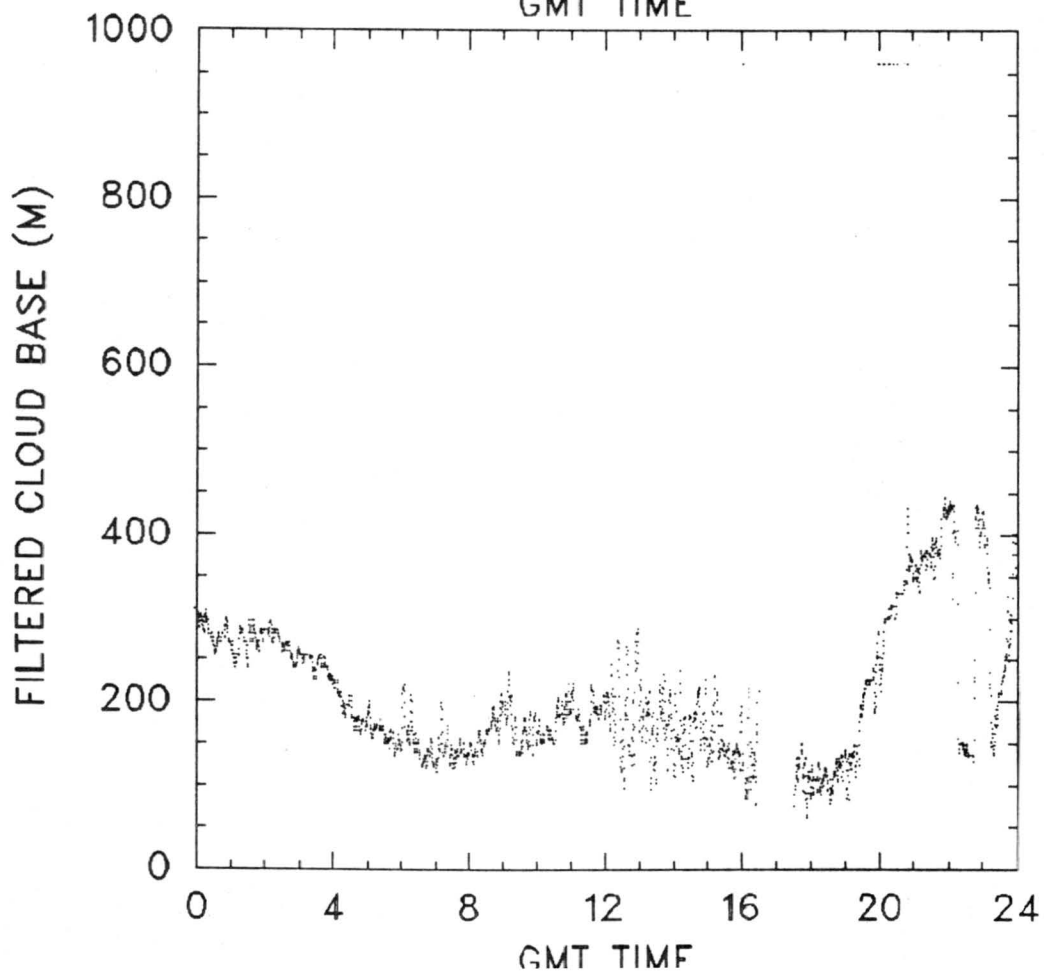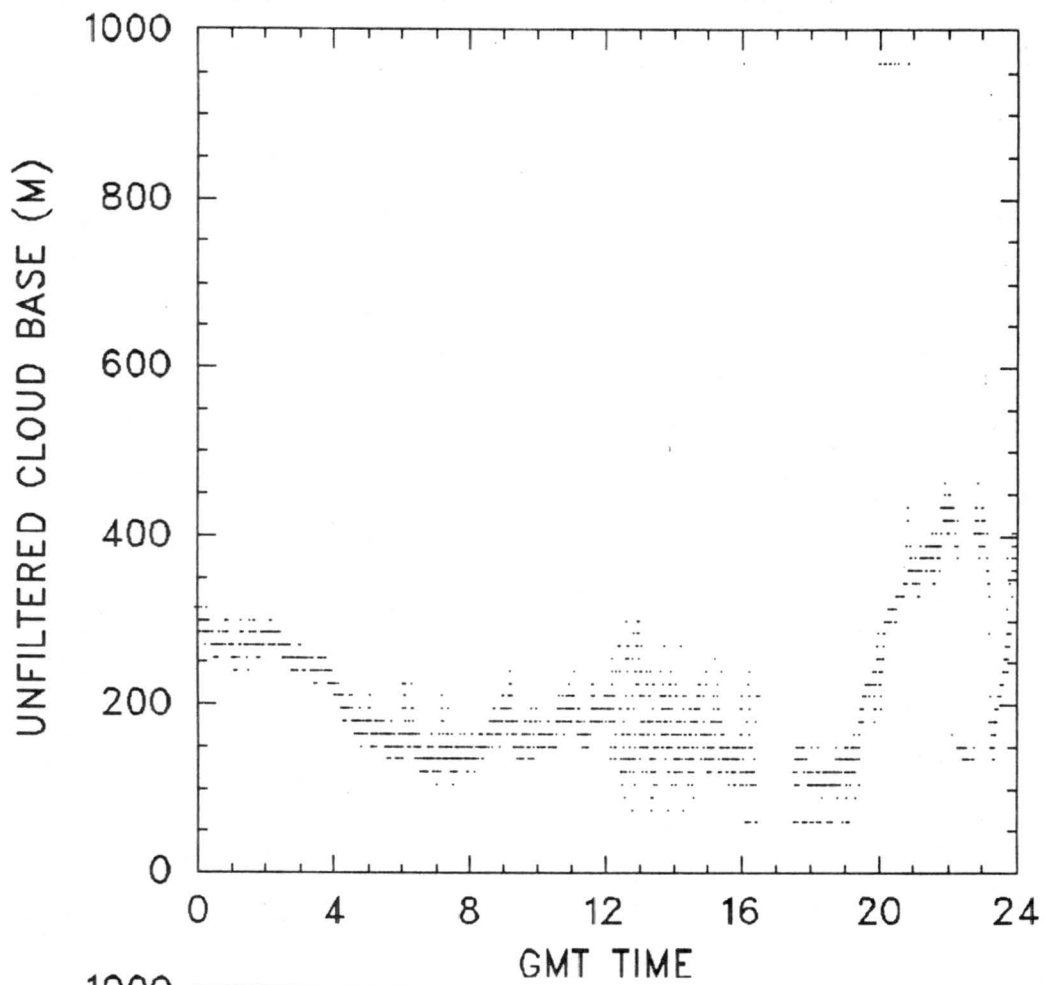
JULY,12

JULY,13
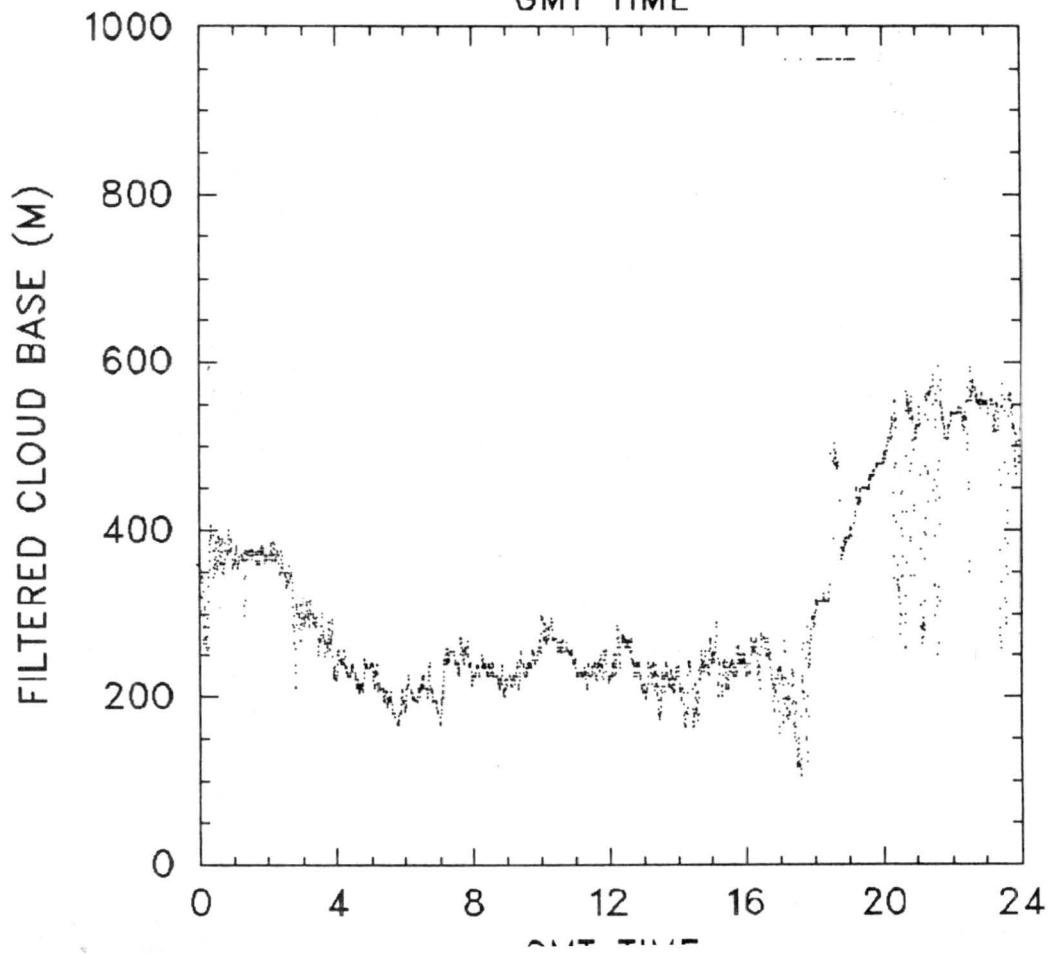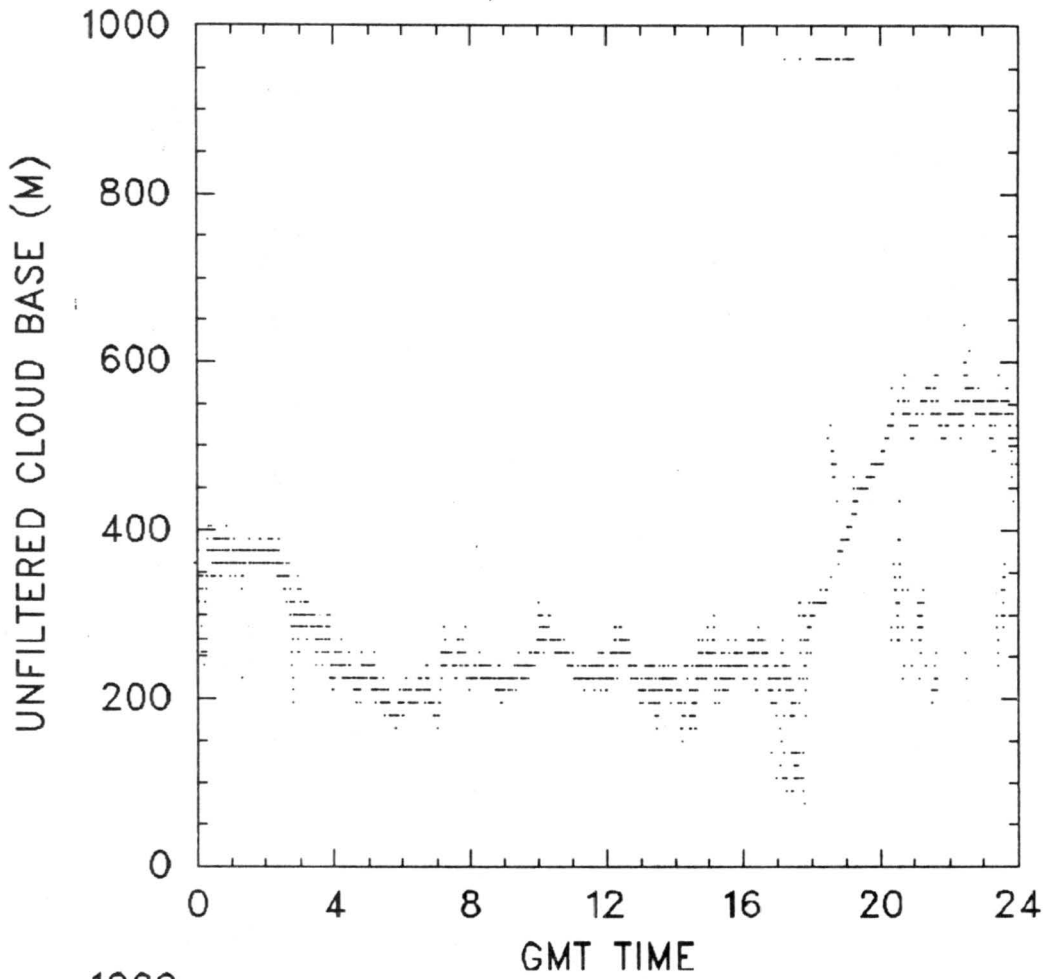
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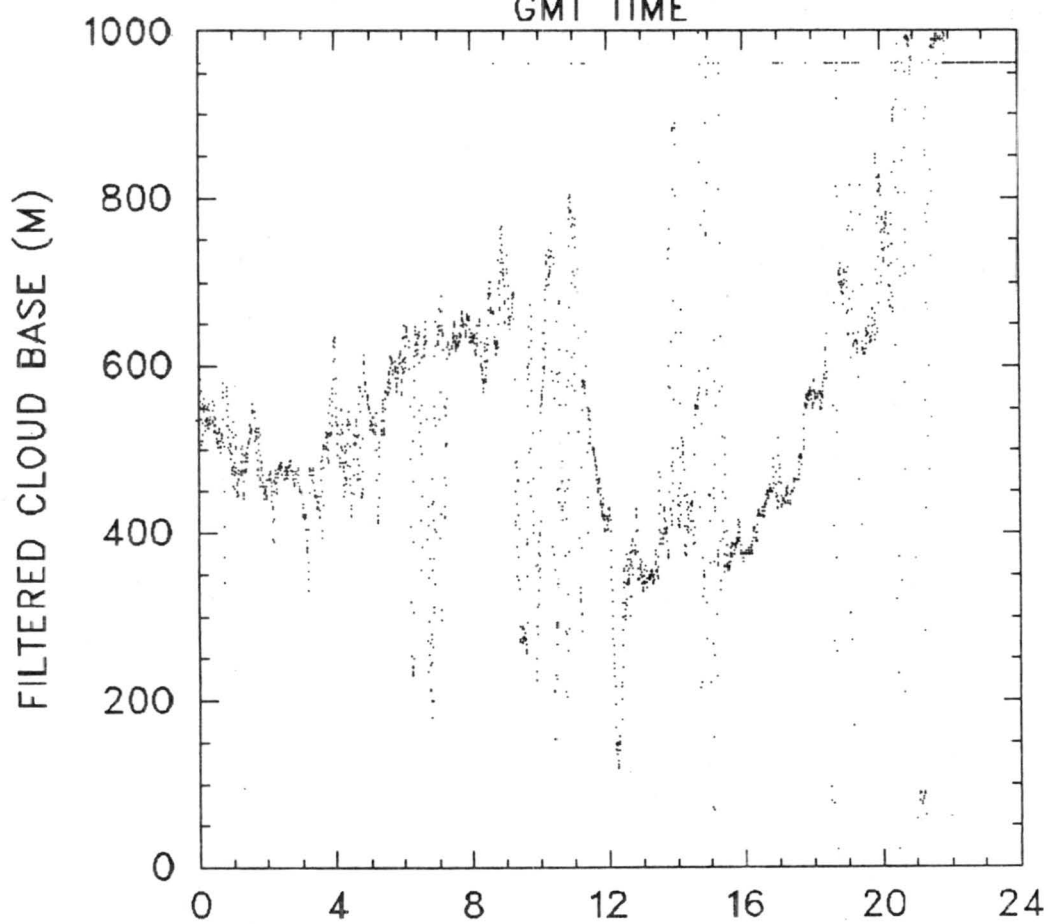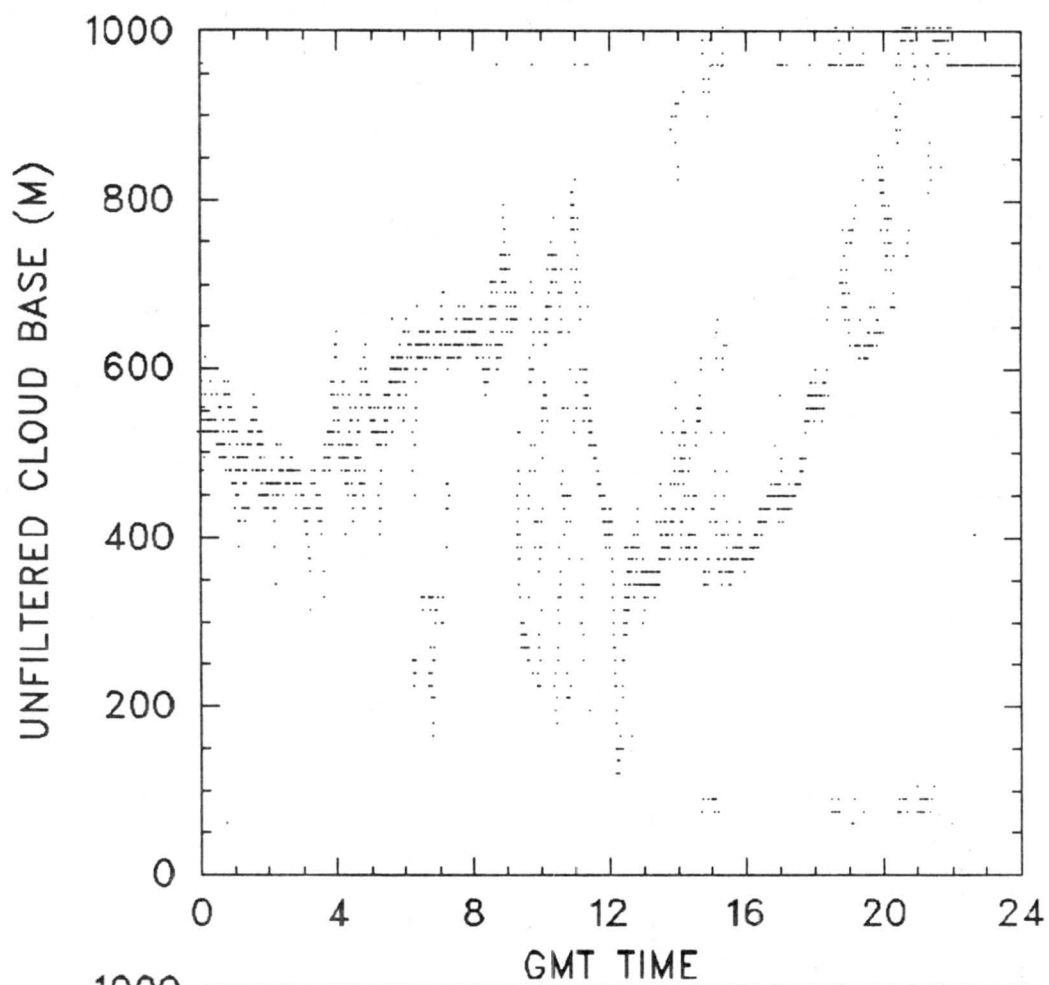
JULY,15
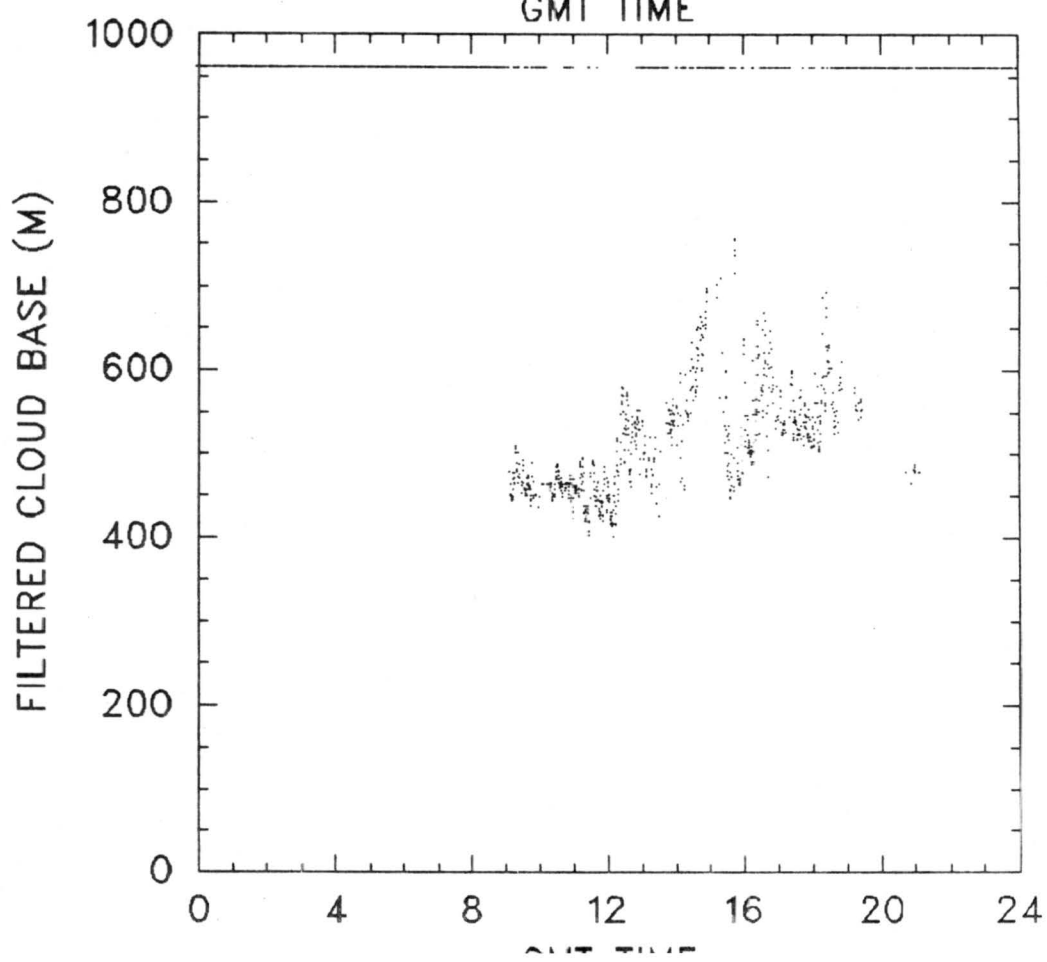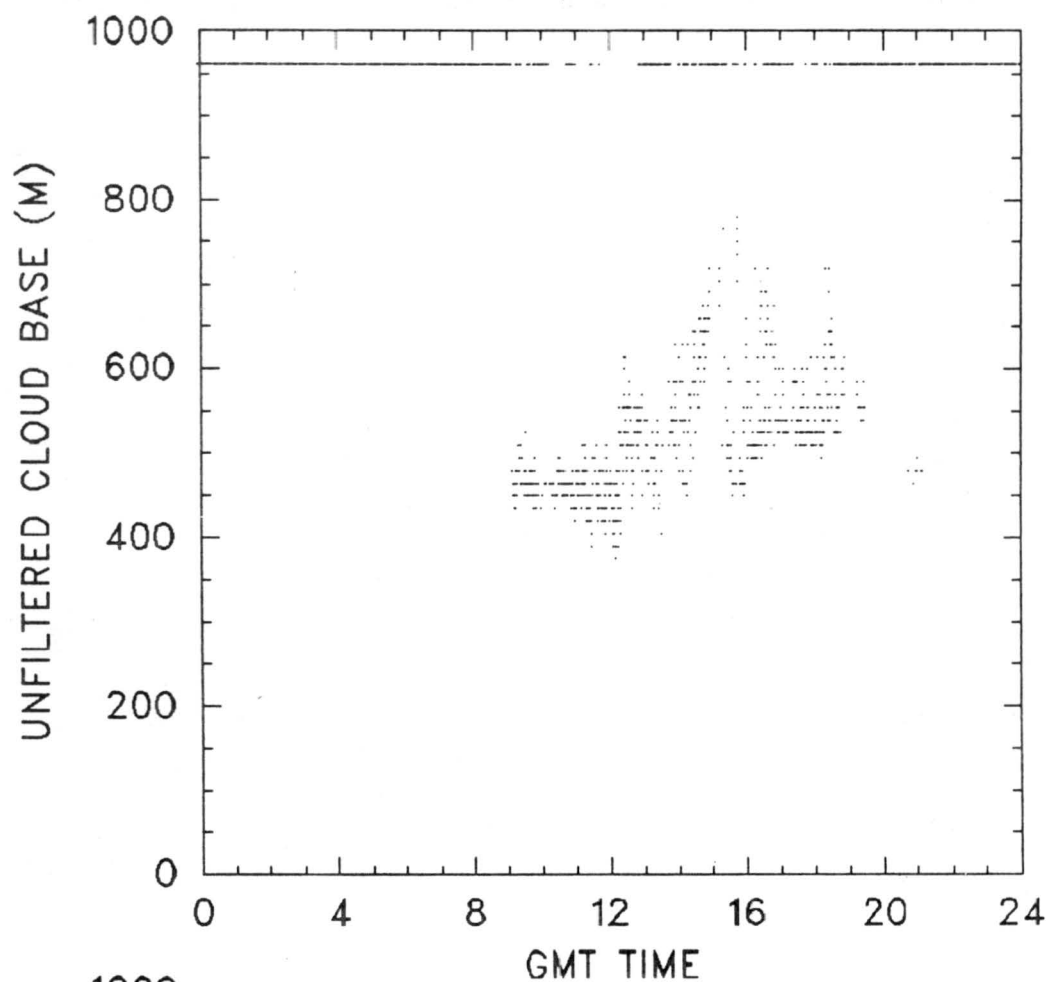
JULY,16

JULY,17

JULY,18

JULY,19
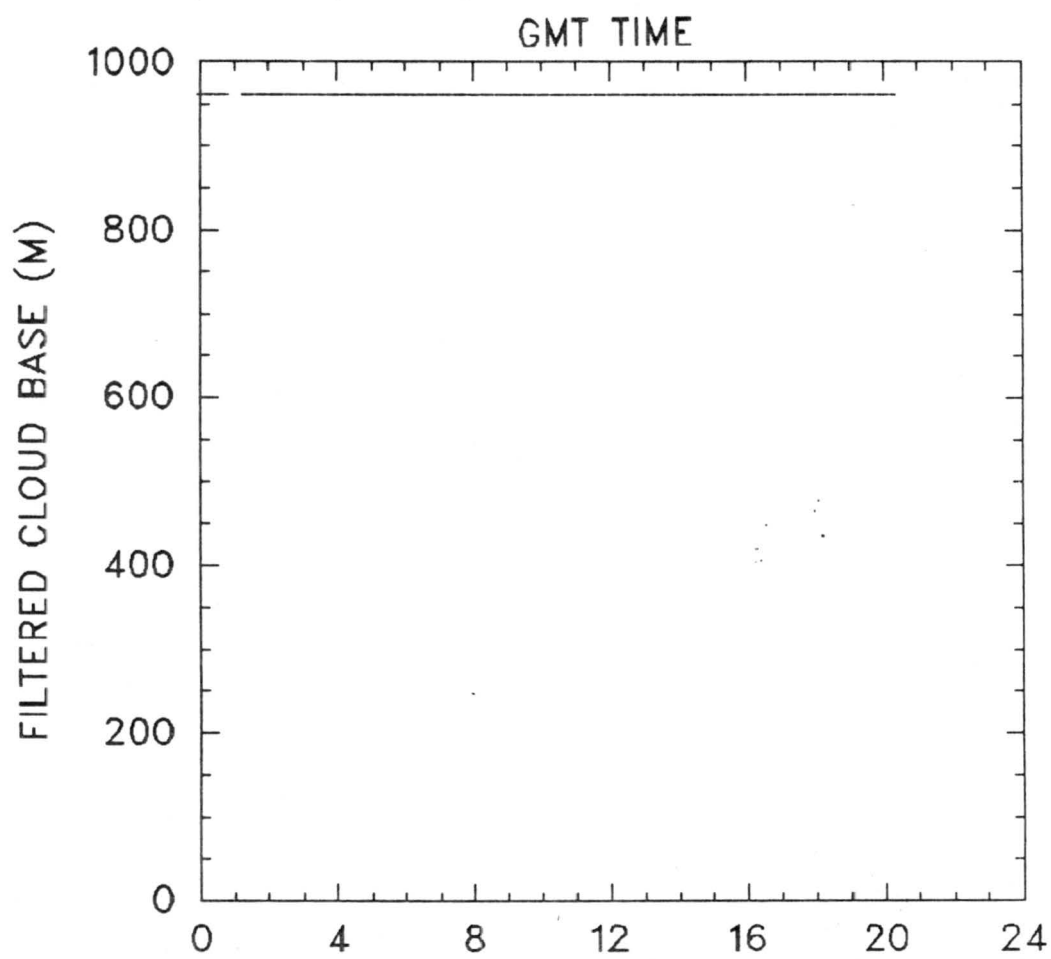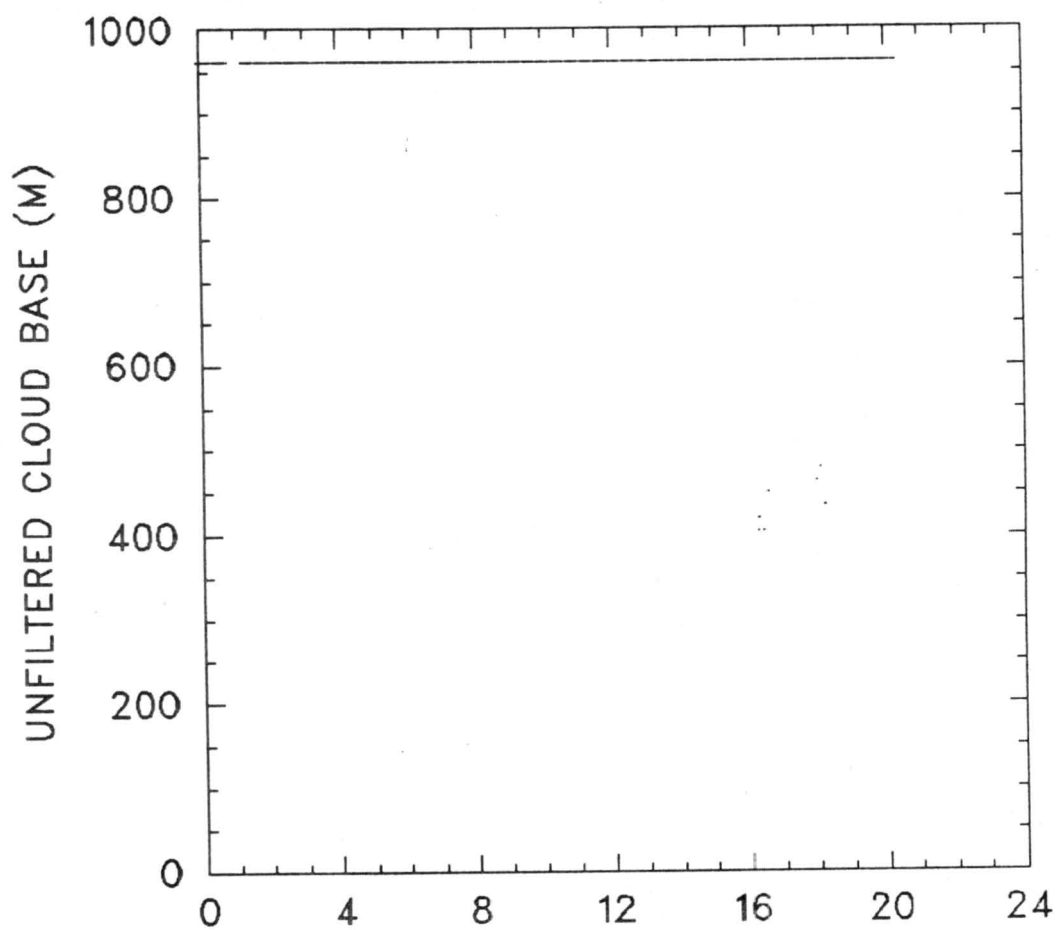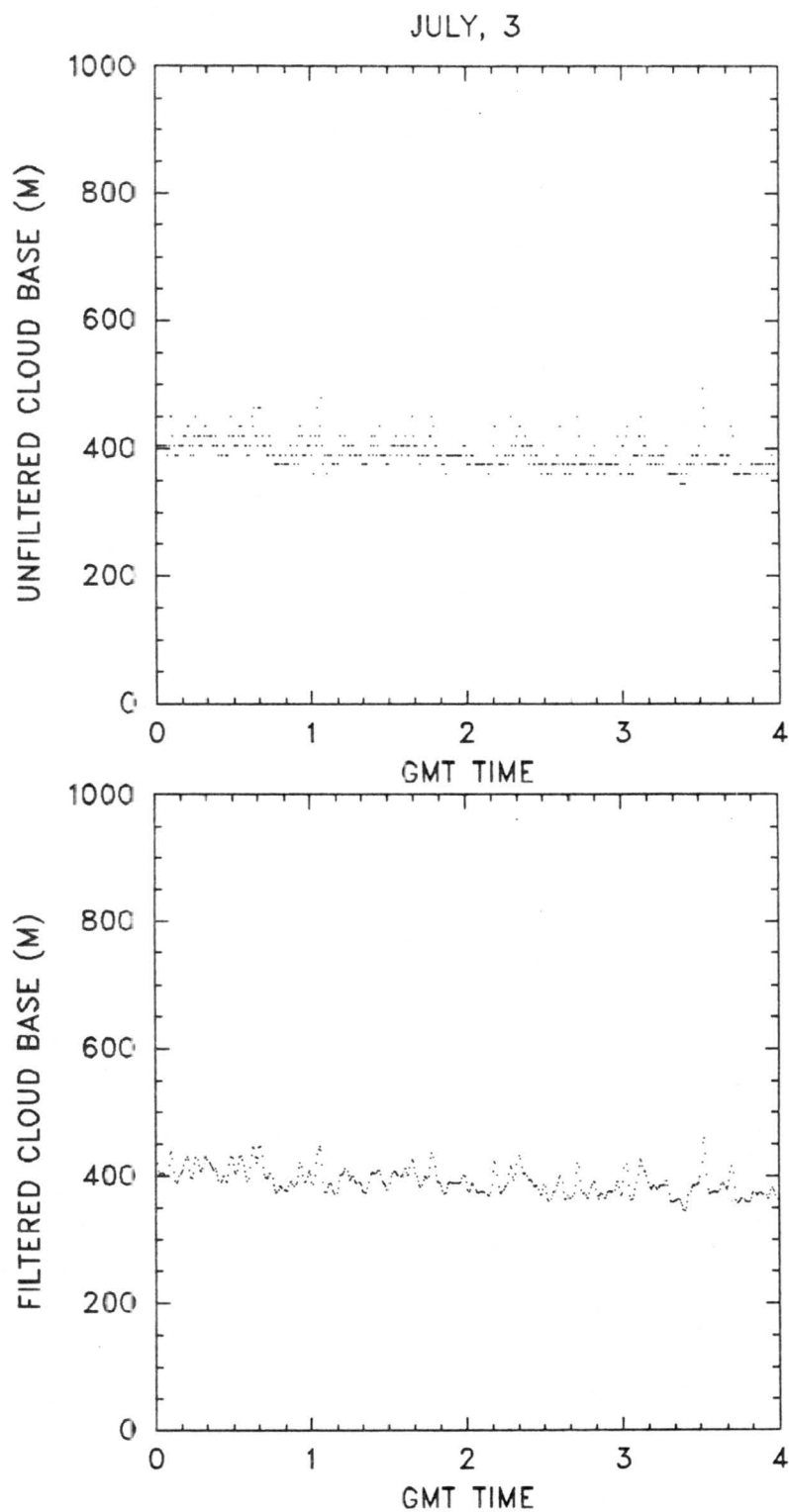
Figure 5. Unfiltered (top) and filtered (bottom) cloud base height for selected 4 hour period on 3 July (Julian Day 184) 1987. Time scale has been expanded by a factor of 6 relative to graphs in Fig. 4.

APPENDIX A

General format of data message

```
STX
<status line 1>
<status line 2>
<data line 1>
.
.
.
<data line 13>
ETX
```

where

STX = ASCII Start-of-text, character (02 hex)

ETX = ASCII End-of-text, character (03 hex)

Status line 1 format

NSB H1H1H1H1H1 T1T1T1T1T1 H1H2H2H2H2H2 T2T2T2T2T2 S1S2S3S4S5S6S7S8S9S10

where

N =	0	no echo (clear air)
=	1	one layer detected
=	2	two layers deteced
=	3	no cloud base can be detected for echo signal received (e.g., fog or heavy rain)
S =	0	all alarm status bits in OK state
=	1	at least one alarm status ON
B =		that is, a space if S = 0
=	BEL	if S = 0, where BEL is ASCII character (07 hex). Because BEL is a non-printing character, the line appears one character shorter than normal.

N =	0:	$H1=H2=T1=T2=$	/////
=	1		
or	2:	H1H1H1H1H1=	the lowest detected cloud height in 5 digits. Leading zeroes not supressed.
		T1T1T1T1T1=	range of reflection of first layer; ///// if not defined
=	2:	H2H2H2H2H2=	second cloud height; ///// if not defined
		T1T1T1T1T1=	range of reflection of second layer; ///// if not defined
=	3:	H1H1H1H1H1=	estimate vertical visibility
		T1T1T1T1T1=	range limit
		H2H2H2H2H2=	(/////)
		T2T2T2T2T2=	(/////)

S1 = 0: Hardware alarm OFF
1: Hardware alarm ON
S2 = 0: Supply voltage alarm OFF
1: Supply voltage alarm ON
S3 = 0: Laser power adequate
1: Laser power low
S4 = 0: Temperature alarm OFF
1: Temperature alarm ON
S5 = 0: Solar shutter OFF
1: Solar shutter ON
S6 = 0: Blower OFF
1: Blower ON
S7 = 0: Heater OFF
1: Heater ON
S8 = 0: Unit in feet
1: Unit in meters
S9 = 0: Data is height-square normalized only
1: Data is height-square and extinction normalized
S10 = Spare

Status line 2 format
G   F   NN

where

G = 0 Gain used is 250
  = 2 Gain used is 930

F = 0 Laser pulse frequency used is 620 Hz (minimum).
1 Laser pulse frequency used is 660 Hz.
2 Laser pulse frequency used is 710 Hz.
3 Laser pulse frequency used is 770 Hz.
4 Laser pulse frequency used is 830 Hz.
5 Laser pulse frequency used is 910 Hz.
6 Laser pulse frequency used is 1000 Hz.
7 Laser pulse frequency used is 1120 Hz (maximum).
The control circuitry attempts to keep average laser power constant.
Consequently, a high frequency indicates a low single pulse energy.

NN = Noise factor 0...16, where leading zeroes omitted. Factor is achieved by
computing the average of 254 samples (one scan) and subtracting the minimum
sample from the average. (0 - sky noise small, 16 - sky noise large)

Data line format

```
HHHHHDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
```

where

HHHHH is the height (in meters) of the first value in the line. Five digit; leading zeroes replaced by space characters.

DDD represents the processed data (cf. Eqn. (3.1)) scaled to decimal numbers $0 \ldots 99$, where leading zeroes are suppressed. Data values represent 30 m increments. The values presented in the data lines are averages of two 15 m range gate samples. Each data line except the last one, consists of ten 30 m values. The first line starts from 0 m, the next line from 300 m, etc. The last line has six values in the range 3600 m to 3780 m.

Data message example

```
STX
10 00450 00120 ///// ///// 0000011100
2 0 1
   0   2  3  0  0  0  0  0  0  0  0
 300   0  0  0  0  9 10  2  4  1  0
 600   0  0  0  0  0  0  0  0  0  0
 900   0  0  0  0  0  0  0  0  0  0
1200   0  0  0  0  0  0  0  0  0  0
1500   0  0  0  0  0  0  0  0  0  0
1800   0  0  0  0  0  0  0  0  0  0
2100   0  0  0  0  0  0  0  0  0  0
2400   0  0  0  0  0  0  0  0  0  0
2700   0  0  0  0  0  0  0  0  0  0
3000   0  0  0  0  0  0  0  0  0  0
3300   0  0  0  0  0  0  0  0  0  0
3600   0  0  0  0  0  0
ETX
```

The total length of the message is 523 characters (including the message format characters). Each of the above lines ends with the ASCII characters for a carriage return and line feed (0D hex and 0A hex, respectively).

The first line after the start of text message (STX) is status line 1. The first character of this line indicates that one cloud layer has been detected ($N = 1$) and the second indicates that alarm status is OK ($S = 0$). The next two numbers, 00450 and 00120, indicate that

the detected layer is at a height of 450 m and is 120 m thick. The two groups of slashes ($/////$ $/////$) indicate the absence of a second layer. The last group of ten decimal digits form the status bit group. The digits S6 = S7 = S8 = 1 indicate that the blower is on, the heater is on, and the units of the data are meters, respectively.

The next line is status line 2. The three numbers in this line indicate that the receiver amplifier gain is 930 (G = 2), the laser pulse repetition frequency is set at 620 Hz (F = 0), and the noise factor is quite low (NN = 1), respectively.

The following 13 lines are the data lines of the message. Most of the data line values are 0 indicating that no laser power is reflected from those heights. In the line beginning with 300 there are non-zero values beginning in column five which indicate the detected cloud layer. The line beginning with 0 also contains some non-zero values, but these values are lower than the cloud detecting limit so that no cloud layer is assumed.

APPENDIX B

The ceilometer data, corresponding to the data files in Table 1, can be obtained from the FIRE Central Archive by addressing your inquiries to:

> National Space Science Data Center
> Goddard Space Flight Center
> Greenbelt, Maryland 20771

A subset of the ceilometer data, which contains unfiltered cloud base and thickness information, is available on NCAR's Mass Storage System (MSS). Shown below is a sample NCAR job which will access the Mass Storage file CJ1A.DAT (i.e, a subset of file CEIL.J1A listed in Table 1) and dispose it to your IBM reader at NCAR.

```
JOB,JN=jjjjjj,T=10,*MS,CL=FG1.
ACCOUNT,AC=uuuupppppppp.
ACQUIRE,DN=CJ1A,MF=MS, ^
TEXT='USER=CIESIELS,FLNM=''FIRE/CEIL/CJ1A.DAT.01'''.
DISPOSE,DN=CJ1A,MF=IO,DC=ST,TEXT='FLNM=CJ1A,FLTY=DAT'.
\ EOF
```

where

jjjjjj is an arbitrary job name
uuuu is your user number
pppppppp is your project number.

Listed below are the files available at NCAR along with their corresponding Julian dates and times (GMT).

file name on MSS	Start Date/Time	End Date/Time
/CIESIELS/FIRE/CEIL/CJ1A.DAT.01	182/1500	182/1554
/CIESIELS/FIRE/CEIL/CJ1B.DAT.01	182/1705	183/1538
/CIESIELS/FIRE/CEIL/CJ2A.DAT.01	183/1723	184/0410
/CIESIELS/FIRE/CEIL/CJ2B.DAT.01	184/0420	184/1742
/CIESIELS/FIRE/CEIL/CJ3A.DAT.01	184/1835	185/0138
/CIESIELS/FIRE/CEIL/CJ4A.DAT.01	185/0203	186/1600
/CIESIELS/FIRE/CEIL/CJ5A.DAT.01	186/1610	186/2356
/CIESIELS/FIRE/CEIL/CJ5B.DAT.01	187/0016	187/1811
/CIESIELS/FIRE/CEIL/CJ6A.DAT.01	187/1814	188/1701
/CIESIELS/FIRE/CEIL/CJ7A.DAT.01	188/1704	189/1658
/CIESIELS/FIRE/CEIL/CJ8A.DAT.01	189/1703	190/1659
/CIESIELS/FIRE/CEIL/CJ9A.DAT.01	190/1756	191/2249
/CIESIELS/FIRE/CEIL/C10A.DAT.01	191/2252	192/1716
/CIESIELS/FIRE/CEIL/C11B.DAT.01	192/1737	193/2139
/CIESIELS/FIRE/CEIL/C12A.DAT.01	193/2216	195/1401
/CIESIELS/FIRE/CEIL/C14A.DAT.01	195/1403	196/0316
/CIESIELS/FIRE/CEIL/C14B.DAT.01	196/0419	196/1631
/CIESIELS/FIRE/CEIL/C15A.DAT.01	196/1734	197/1755
/CIESIELS/FIRE/CEIL/C16A.DAT.01	197/1758	199/1406
/CIESIELS/FIRE/CEIL/C18A.DAT.01	199/1409	200/0007
/CIESIELS/FIRE/CEIL/C18B.DAT.01	200/0114	200/2022

In addition, the file /CIESIELS/FIRE/CEIL/CFIL.FOR is a FORTRAN program, which can be accessed in a similar fashion to those above, and run in order to filter the data as described in Section 4.