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(2)

STUDIES OF ELECTRO-OPTICAL ATTENUATION IN THE VICINITY OF CLOUD BASE

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STUDIES OF ELECTRO-OPTICAL ATTENUATION IN THE VICINITY OF CLOUD BASE

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Principal
Investigator

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20. Abstract

Field measurements of atmospheric transmission in the 10.6 micron wavelength, the 3-5 micron and the 8-12 micron spectral regions over several seasons of the year have been conducted. EO weapon system designers must design for atmospheric effects predicted by these models. This research helps make improvements to the accuracy required. Field measurements were carried out under various atmospheric conditions including those which affect molecular absorption most. These measurements included the appropriate meteorological and optical parameters. Results of the measurements were used to improve empirically the transmission models and to develop theoretical models for the cloud base physics. Previous efforts by the principal investigator have provided some improvements to the AF Geophysics Laboratory's transmission models and to the British Ministry of Defence's sensor development program. This research effort enhances understanding of absorption of electromagnetic radiation in the atmospheric windows by pre-cloud aerosols and by molecular action.

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This report has been reviewed by the EOARD Information Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

JOHN D. WARBURTON, Lt Col, USAF
Chief, Geophysics and Space

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Chief Scientist

INTRODUCTION

Studies of the structure of clouds enveloping Great Dun Fell have been made, over a number of years, by the Atmospheric Physics group at UMIST and have demonstrated that the entrainment of under-saturated air into clouds may lead to substantial inhomogeneities in their water properties, Baker et al (1982). Generally, these inhomogeneities arise due to mixing across the upper cloud boundary and their magnitude depends upon factors such as the proximity of the upper cloud interface and the degree of atmospheric stability across it. Theoretical models of the airflow and cloud evolution over GDF have been developed and have proved capable of predicting detailed cloud microphysical structures from the prevailing meteorological conditions to a high degree of accuracy, Carruthers & Choularton (1983). The implications, for infra-red attenuation, of these substantial variations in cloud structure have been examined as part of a previous programme supported by the Ministry of Defence.

In the course of these cloud evolution studies, measurements have been made at the summit of the mountain both within cloud and in the region near cloud base, typically some 200m below. Often, fluctuations in cloud properties, over horizontal scales of up to a few hundred metres, are observed in this region which generally persist for a vertical extent of 100m or so, before merging into a more uniform cloud structure. Experimental evidence suggests that these variations are a consequence of relatively small-scale changes in the properties, such as cloud condensation nuclei concentration and mixing ratio, of the air entering the cloud. Since anomalous changes of visible and infra-red attenuation within this region have been reported, it would seem appropriate to investigate the microphysical processes, and concomitant attenuation of radiation, which occur as air ascends to form a cloud.

As part of this programme to examine the microphysical properties of clouds, a novel instrument (acronym HICUP) has been developed at UMIST by Dr C S Mill. This device, which is described in more detail in the main body of this report, is capable of measuring humidity/total water content within clouds and, therefore, is ideally suited to these studies.

At various times of the year, particularly late Spring and early Autumn, cloud forms overnight around the GDF laboratory and rises above the summit during the course of the following day. The altitude of cloud base relative to the station can be determined by an acoustic sounder and, thus, measurements of relative humidity and aerosol size distribution, as cloud base rises and lowers, can give information on the vertical structure. Such observations of humidity and total water content, together with associated meteorological measurements, are presented in this report. Fluctuations in liquid water content and droplet size distributions are also provided and illustrate the existence of structure on all scales. Up to the present time, attempts to relate these observations to attenuation measurements at various infra-red wavelengths, utilizing the Barnes transmissometer on loan from RSRE, have been largely inconclusive for the following reasons. Fluctuations in structure, on spatial and temporal scales less than those governed by the relatively long transmission paths required to give an appreciable attenuation, rendered it extremely difficult to correlate extinction with the simultaneous observations of cloud and aerosol properties. These problems were compounded by the slow response of the transmissometer and, also, measurements were limited to one wavelength band at a time, since the filters had to be changed manually. Modifications have been made to this instrument, under the sponsorship of the Ministry of Defence, which have involved the construction of a new detector unit, incorporating a multi-filter beam chopper and modern solid-state sensors. A dedicated micro-processor deals with the electronic signals and the unit, which is currently being field-tested, should provide attenuation measurements for several wavelengths and wavelength bands at a rate of 10Hz.

MEASUREMENT OF TOTAL WATER MIXING RATIO

The UMIST Humidity In Cloud Undersaturation Probe (HICUP), illustrated schematically in Fig. 1, has been developed to provide rapid measurements of total water mixing ratio, Q, both in and out of cloud. It exploits the fast response of carbon hygristors while overcoming the problems of long term drift associated with this type of sensor.

At the intake, an evaporator converts any cloud water to the vapour phase, and Q is inferred from the temperature T and humidity H of the resulting airstream, since

$$Q = H.\ P_s\ (T)/P_a\ (T)$$

where P_s (T) is the saturation vapour density at T, and P_a is the density of air at T and the prevailing pressure. The ambient humidity H_a may be determined given that the ambient temperature T_a is known since

$$H_a = H.\ P_s(T)/P_s\ (T_a)$$

where H and T are as before.

After passing through an evaporator, the sampled air is drawn into the hygristor housing where it is brought to thermal equilibrium with the hygristor prior to being passed over it. The temperature of this housing is controlled to provide a humidity at the sensor of betwen 30% and 50%., this being optimum for response time and resolution. The hygristor is ventilated at 25 m/s which gives a response time of less than one second for sensor temperatures above 0°C.

Long term drift in the sensor characteristics is corrected by periodic autocalibration. This is accomplished using two reference saturated air sources. These are provided by two humidifiers whose temperatures are servoed by thermoelectric heat pumps such that the total water contents of these airstreams span the range of ambient values being encountered. The temperatures of the humidifiers and the hygristor are measured using platinum film sensors. Control of the instrument, together with data acquisition, is accomplished using a Nascom 2 microcomputer operating remotely and linked to the instrument via a serial port.

Autocalibration by this method reduces the role of the hygristor to one of interpolation between the reference values. As a consequence the precision of the instrument is largely governed by the errors in these references, and hence by the uncertainty in the temperatures of the humidifiers.

Since

$$P_S \propto \exp(-B/T)$$

where B is 5400 K and T is the absolute temperature, the fractional error in P_S is given by

$$\Delta P_S/P_S = B\Delta T/T^2$$

where ΔT is the uncertainty in T. If this is of the order of 0.1 K and T = 273 K then $\Delta P_S/P_S$ = 0.7% which corresponds to $\Delta P_S \approx 0.03$ g/m^3. At T = 290 K the value of $\Delta P_S \approx 0.1$ g/m^3 for the same values of ΔT.

The instrument is now being operated at our field station on the summit of Great Dun Fell to investigate undersaturated regions occurring within cap clouds. A simplified version of this instrument has also been added to the equipment flown on the UMIST sailplane. In this case, calibration is performed on the ground before and after each flight since the payload and power consumption penalties of flying the autocalibration system in its existing form are too great.

STRUCTURE AT CLOUDBASE

The data herein presented were obtained on two separate occasions, on 26 October 1983 and 1 November 1983, when the site at the summit of Great Dun Fell (GDF) passed out of cloud. Each situation covered by a series of plots consisting of:

(a) 70 minutes of two-second averages of wind speed and direction, dry-bulb temperature (Td) and cloud liquid water content (l.w.c),

(b) an expanded 10-minute view around cloudbase of one-second averages of cloud l.w.c., cloud droplet number concentration and mean cloud droplet radius, obtained by an FSSP 100; and longitudinal and vertical velocities, and fluctuations in temperature about the mean, obtained by a sonic anemometer,

(c) a series of cloud droplet spectra obtained at 20 Hz showing small-scale structure down to the order of one metre within the cloud at cloudbase. These spectra occur in pairs and are comprised of the droplet size spectra and the inter-droplet temporal, or 'time-of-arrival', spectra.

(d) On 1 November 1983, the HICUP was operating at the site and the corresponding 70 minutes' total water mixing ratio (Q) data obtained by the instrument is included in the data set for that day.

The synoptic meteorological situations in existence at the times the observations were made were very similar to one another. In each case an anticyclone over France was affecting southern parts of the British Isles whilst a weak cold front progressed slowly southeast over northern Scotland. The flow over northern England was consequently south of west, and the winds were of moderate strength.

The data (a) of 26 October 1983, shown in Figs. 2 (i) & (ii), were obtained between 10:50 and 12:00 GMT on that day. The mean cloud l.w.c. was 0.2 g/m^3 until the approach of cloudbase caused the l.w.c. to drop intermittently to zero. The summit site went out of cloud at 11:13 GMT, after which the cloud l.w.c. was measured to be zero. A comparison of the plots contained in Figs. 2 (i) & (ii) reveals that, as the summit site passed through the cloudbase interface, the wind speed dropped sharply (from a mean of 20 kts to around 10 kts) before recovering (to a mean of 15 kts), and this was accompanied by a corresponding veer in the wind direction from 215 degrees to 230 degrees. At cloudbase the mean ambient Td rose by 0.5°C before returning to its former value of 3.7°C.

The plots contained in Figs. 3 (i) - (iii) and referred to as (b) above exhibit more detail of the cloudbase interface, [illegible] 11:08 to 11:18 GMT. The sonic anemometer temperature fluctuations are seen to be in phase with variations in the cloud l.w.c., over scales of a few hundred metres horizontally, and the longitudinal velocity measurements (roughly equivalent to wind velocity) also exhibit a tendency to follow the variations in cloud structure. The vertical velocity data would tend to reflect the existence of weak downdraughts in the cloudbase region, indicating a certain amount of turbulence along the interface.

An interesting feature of this cloud was its relatively 'sharp' edge. This is particularly noticeable from the plot of cloud droplet number density versus time, which indicates a reduction in drop concentration from a mean value of 350 per cm^3 to zero in less than 10 seconds. The spectra for this time interval (occurring between 11:12:37 and 11:12:47 GMT - see Figs. 4 (i) - (vi)) display a more or less monotonic spatial and mporal spreading of the cloud droplets as the cloud lifted, and suggest a rather homogeneous cloudbase structure at small scales.

The data (a) for 1 November 1983, shown in Figs. 5 (i) & (ii), were obtained between 12:20 and 13:30 GMT on that day. The summit was finally clear of cloud at 13:05 GMT, although previously the site went into and out of cloud on several occasions for various lengths of time. The HICUP was in operation for the full 70 minutes and the one-minute averages of Q are shown on the same plot as the cloud l.w.c. The value of Q obtained agrees well with the mean ambient humidity (97%) and temperature (7.0°C) measured independently. The decrease in Q contemporary with the lifting of cloudbase above the summit was accompanied by a temporary increase in wind speed (from a mean of 17 kts to a peak of 33 kts) lasting for about 15 minutes, and a corresponding backing of the wind (from 215 degrees to 200 degrees). The mean ambient Td increased by 0.5°C and then decreased by 0.5°C during this time, after which a slow rise was observed in the clear subcloud air. At 12:40 GMT cloudbase was observed to be about 200 m above the summit of GDF, indicating a relative humidity at the summit of around 87%. This value was borne out by the value of Q obtained by the HICUP.

The smaller-scale structure around cloudbase, displayed by the plots contained in Figs. 6 (i) - (iii), shows an in-phase relationship between the temperature and vertical velocity fluctuations measured at the summit, and an out-of-phase relationship with the longitudinal velocity fluctuations. This would suggest the origination of convective plumes breaking through cloudbase due to the effect of solar heating through the cloud which was by this time very tenuous (the mean l.w.c. was less than 0.05 g/m^3). The spectra plotted in Figs. 7 (i) - (vi), of in-cloud and cloud-

FIGURE 4(vi)

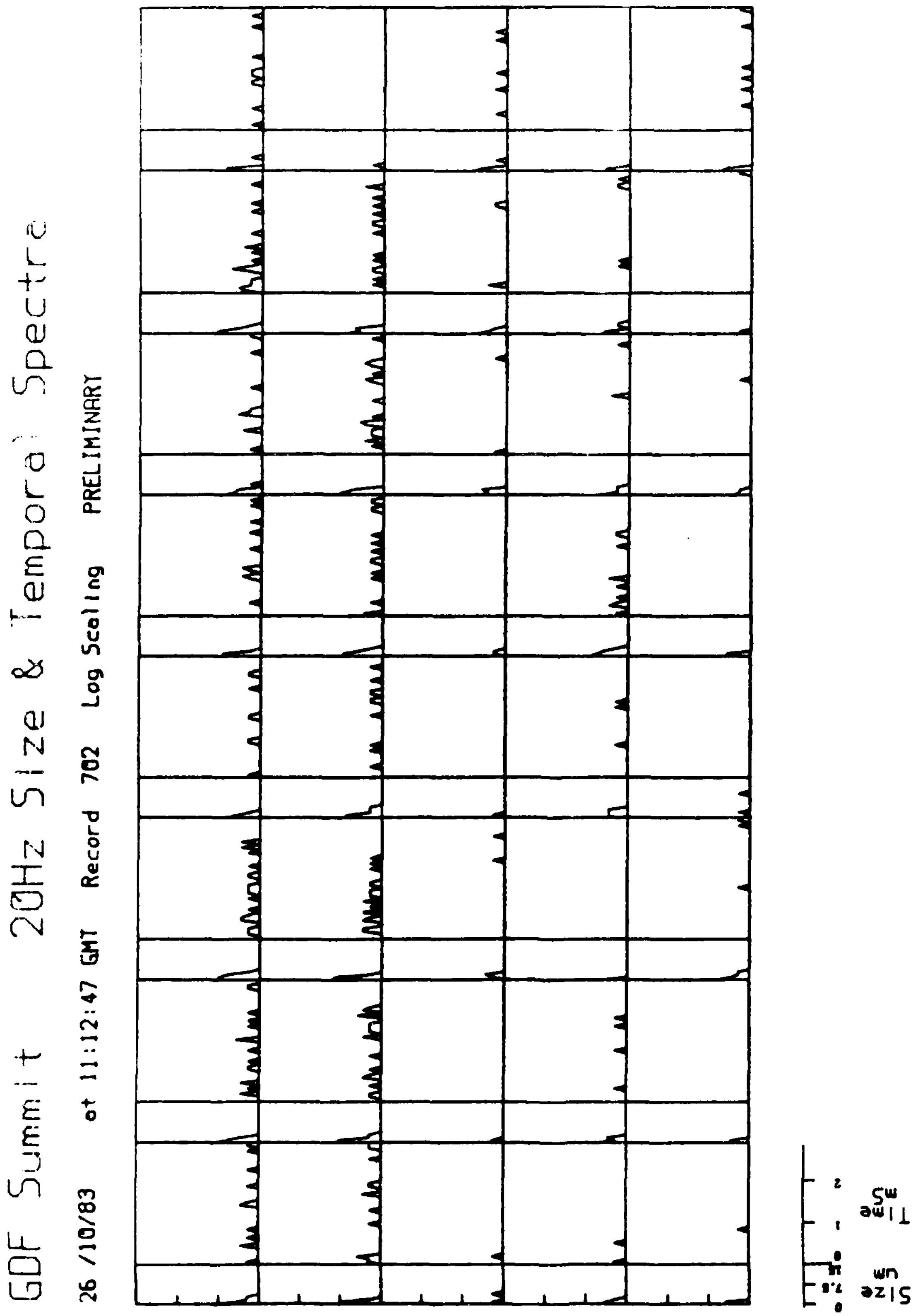

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:47 GMT Record 702 Log Scaling PRELIMINARY
Time mS
Size um

FIGURE 4(v)

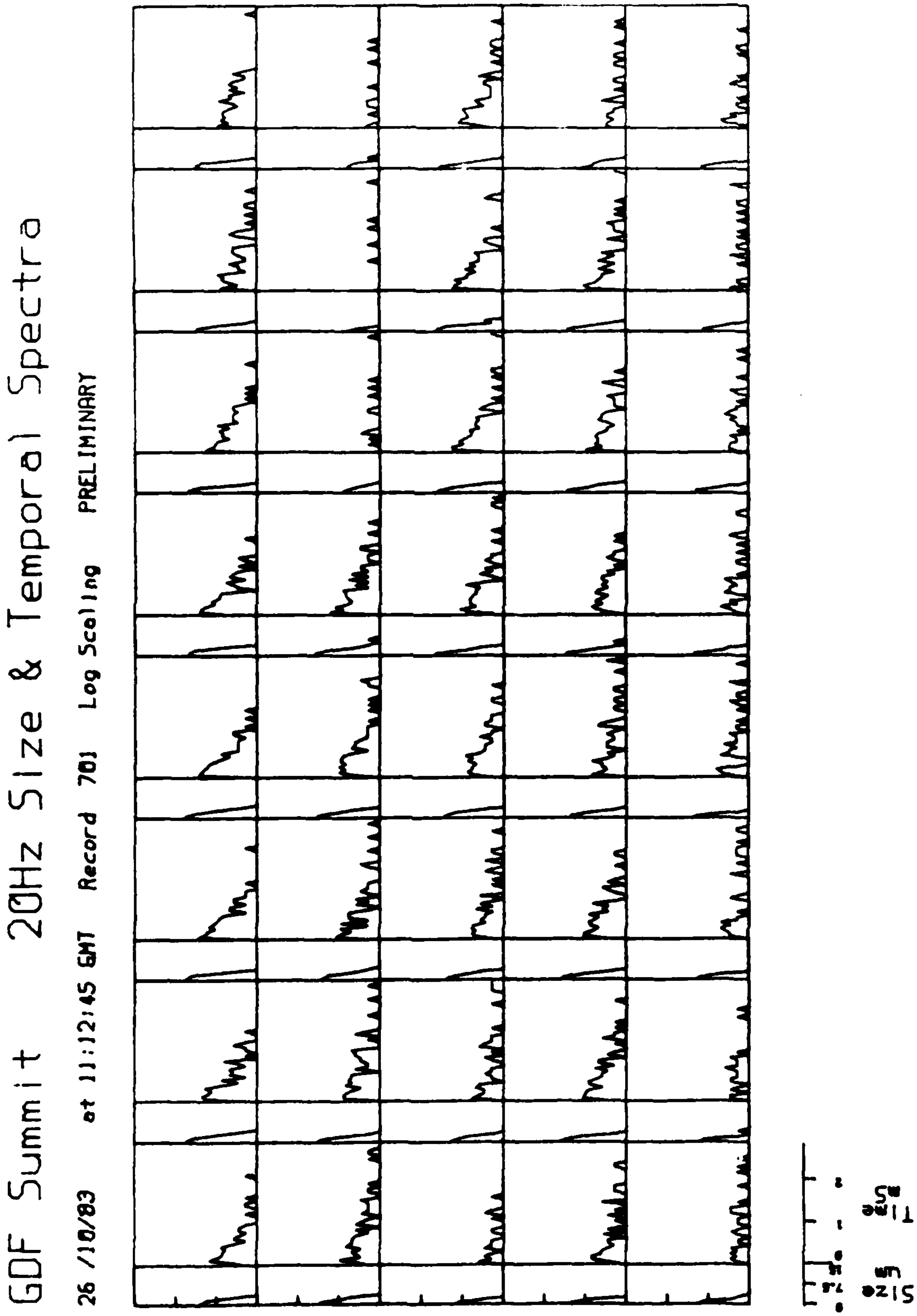

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:45 GMT Record 781 Log Scaling PRELIMINARY
Size um
Time mS

FIGURE 4(iv)

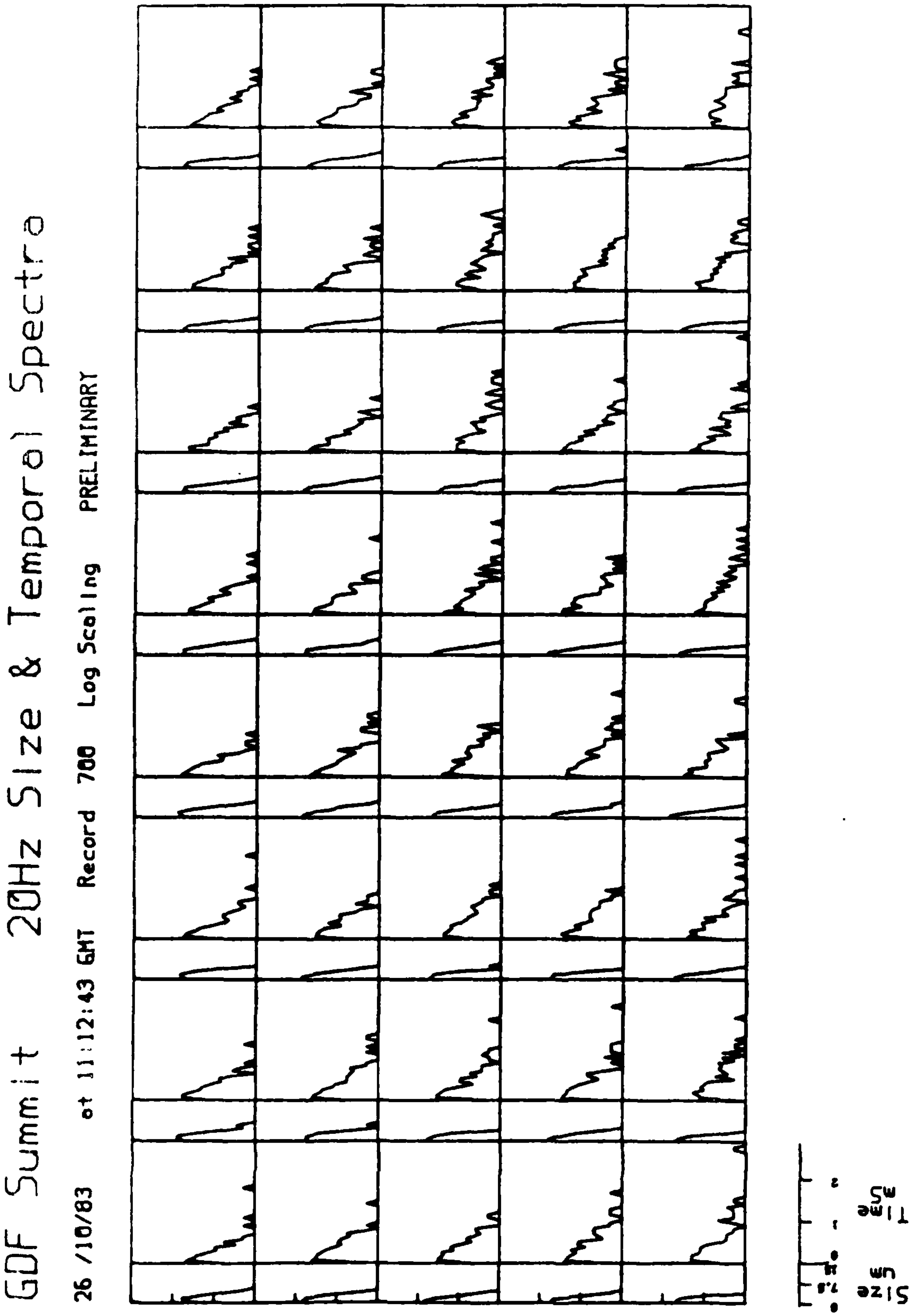

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:43 GMT Record 700 Log Scaling PRELIMINARY
Size um
Time ms

FIGURE 4(iii)

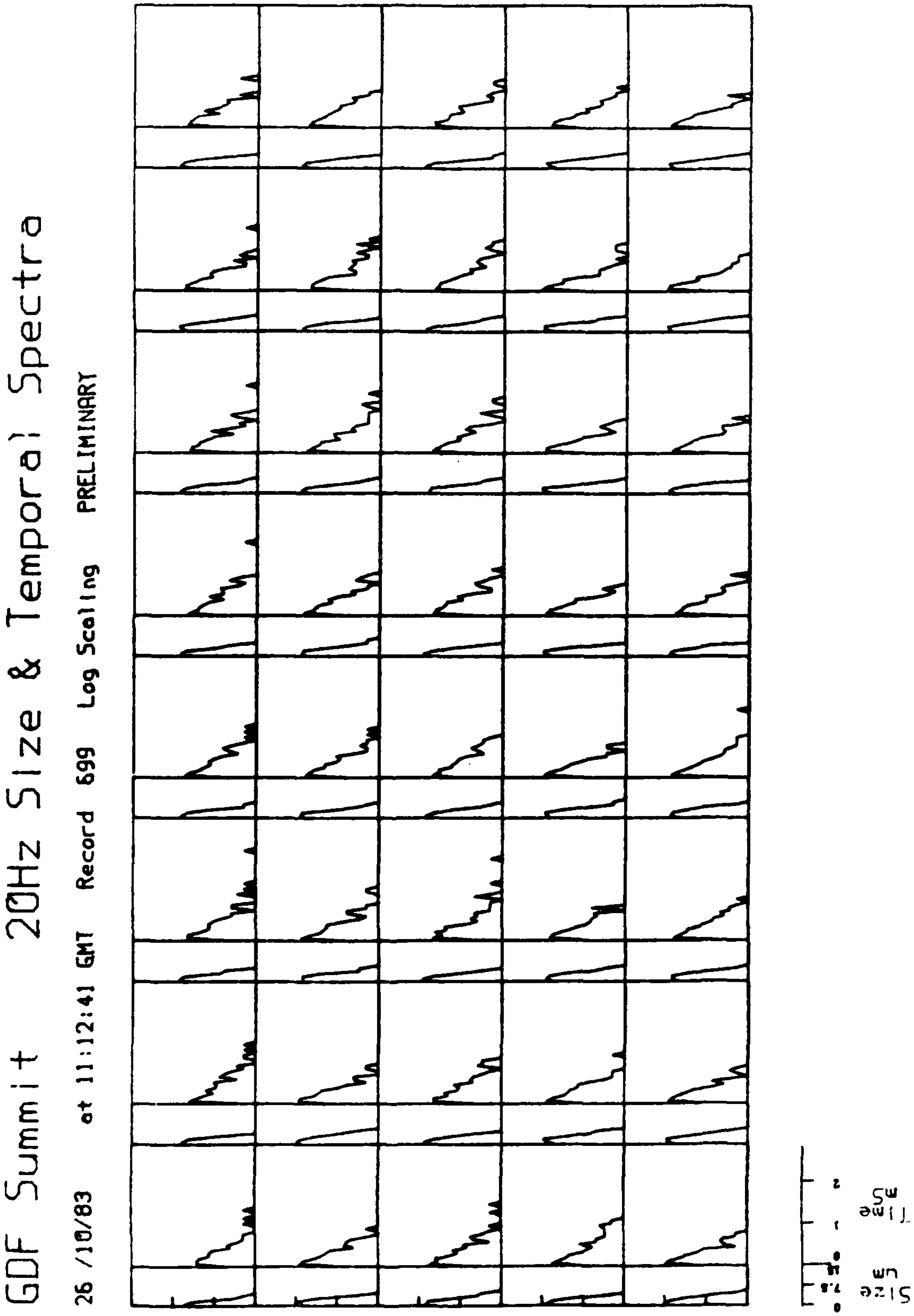

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:41 GMT Record 699 Log Scaling PRELIMINARY
Time mS
Size um

FIGURE 4(ii)

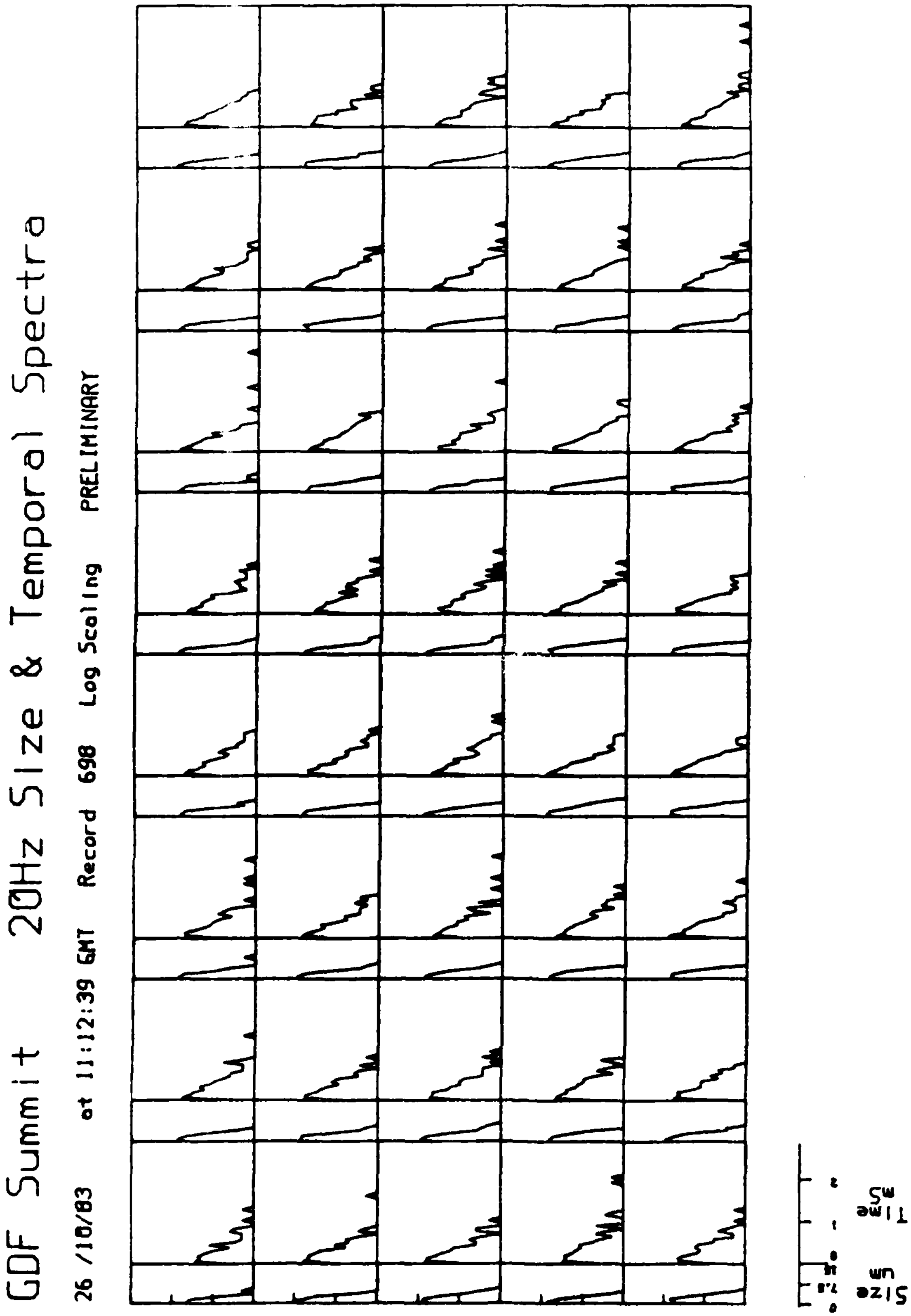

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:39 GMT Record 698 Log Scaling PRELIMINARY
Time mS
Size um

FIGURE 4(i)

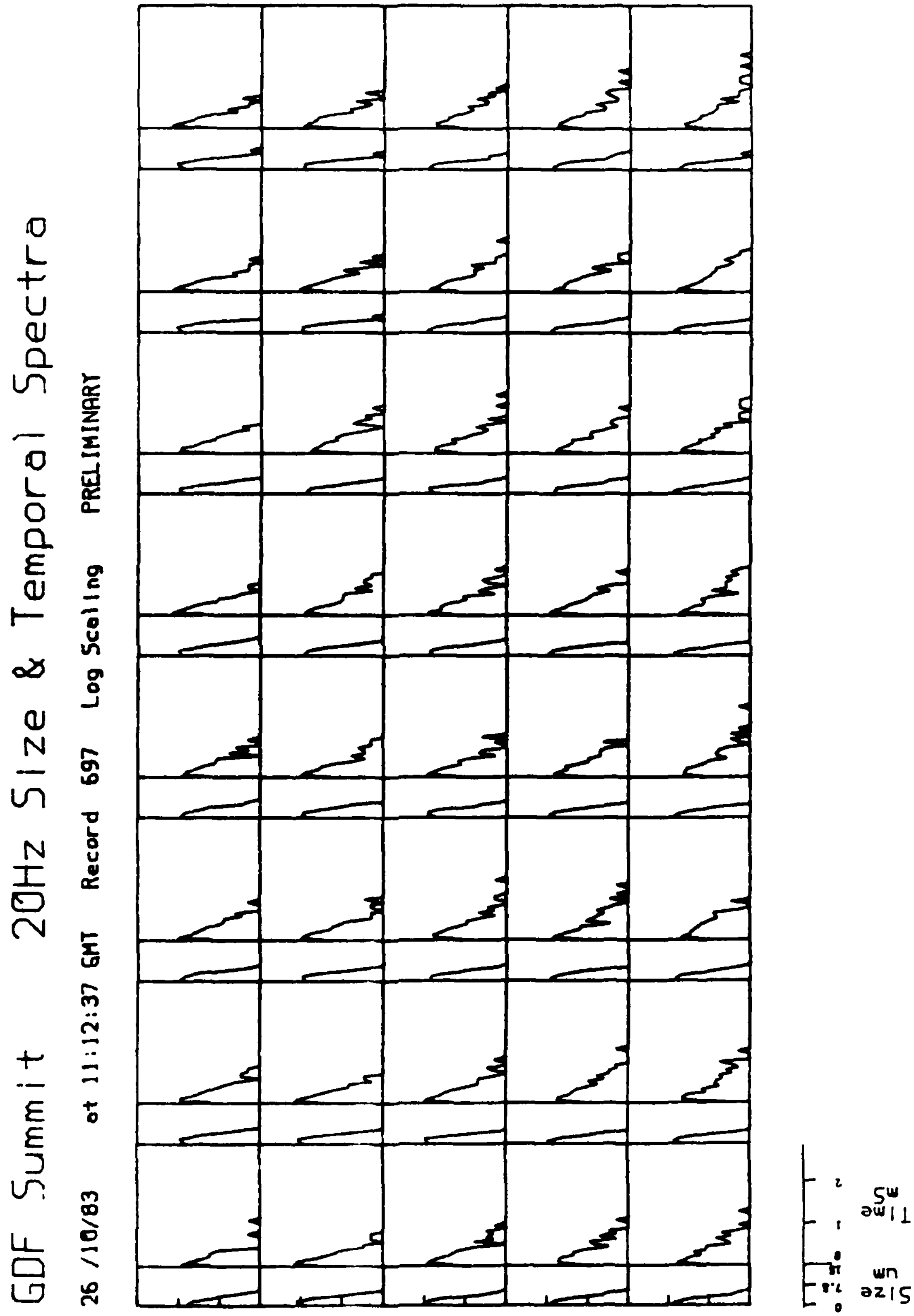

GDF Summit 20Hz Size & Temporal Spectra
26 /10/83 at 11:12:37 GMT Record 697 Log Scaling PRELIMINARY
Size um
Time mS

FIGURE 3(iii)

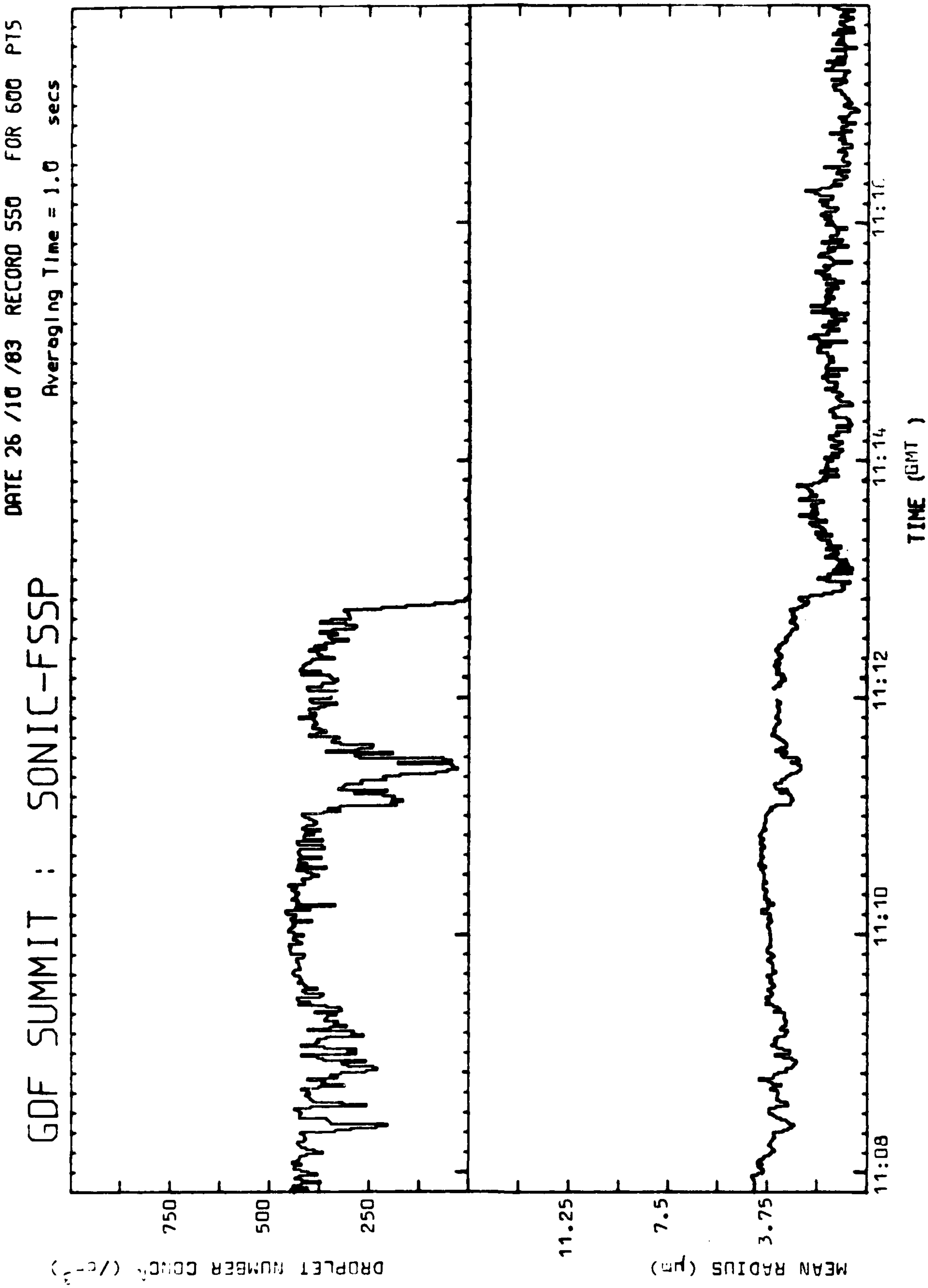
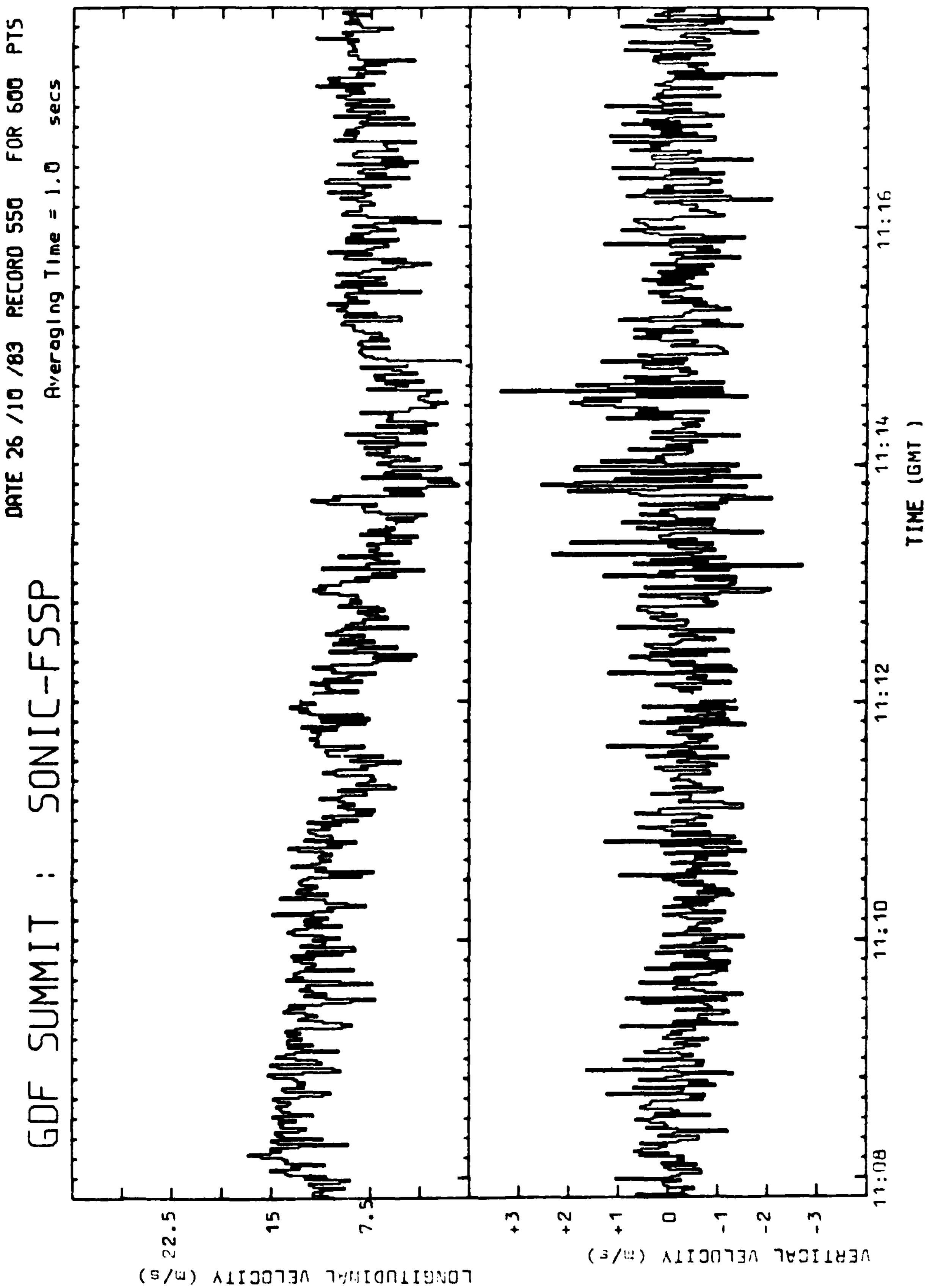

GDF SUMMIT : SONIC-FSSP
DATE 26 /10 /83 RECORD 550 FOR 600 PTS
Averaging Time = 1.0 secs
DROPLET NUMBER CONC
750
500
250
MEAN RADIUS (μm)
11.25
7.5
3.75
11:08
11:10
11:12
11:14
TIME (GMT)

FIGURE 3(ii)



GDF SUMMIT : SONIC-FSSP
DATE 26 /10 /83 RECORD 550 FOR 600 PTS
Averaging Time = 1.0 secs
LONGITUDINAL VELOCITY (m/s)
22.5
15
7.5
VERTICAL VELOCITY (m/s)
+3
+2
+1
0
-1
-2
-3
11:08
11:10
11:12
11:14
11:16
TIME (GMT)

FIGURE 3(1)

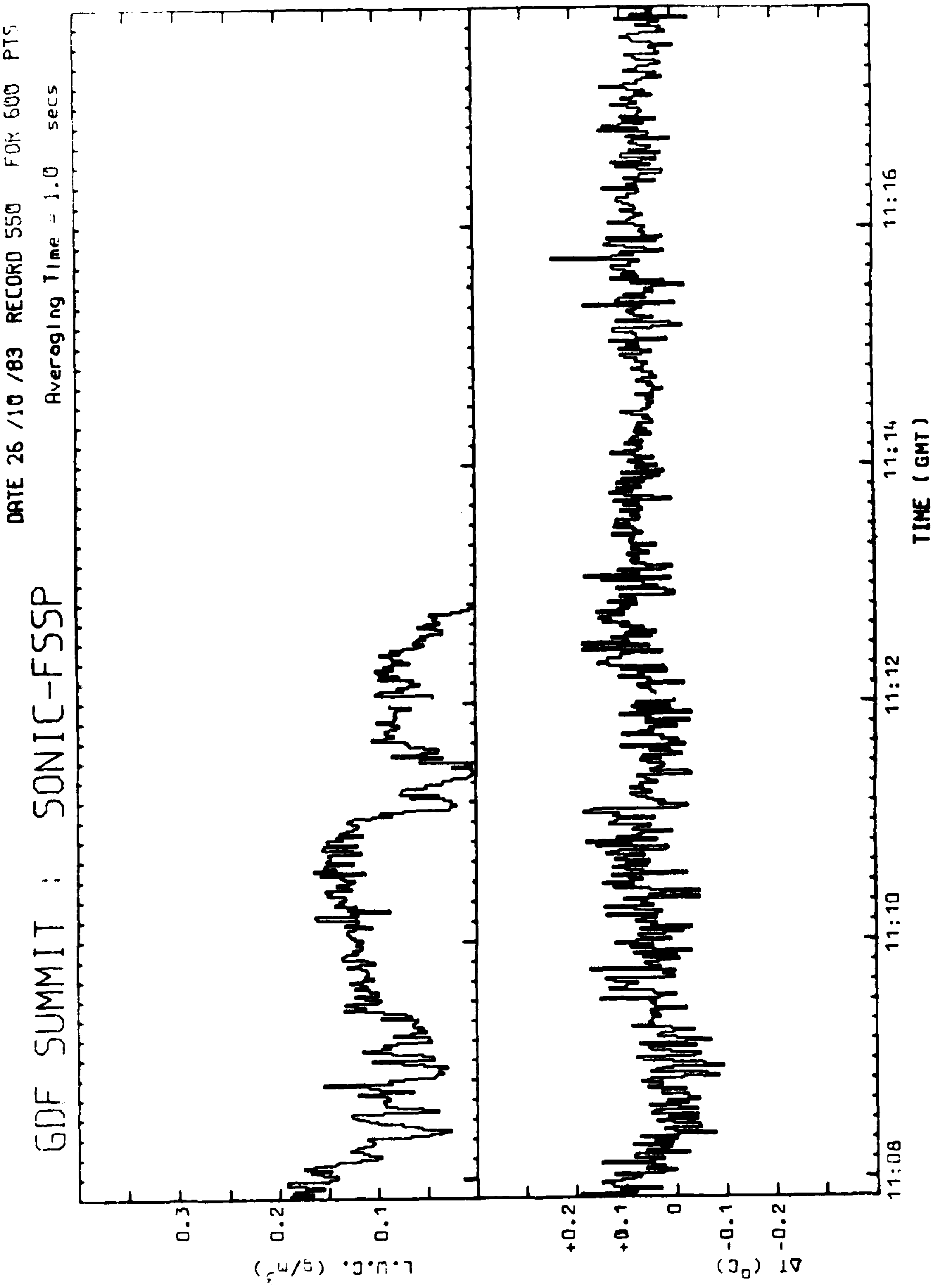
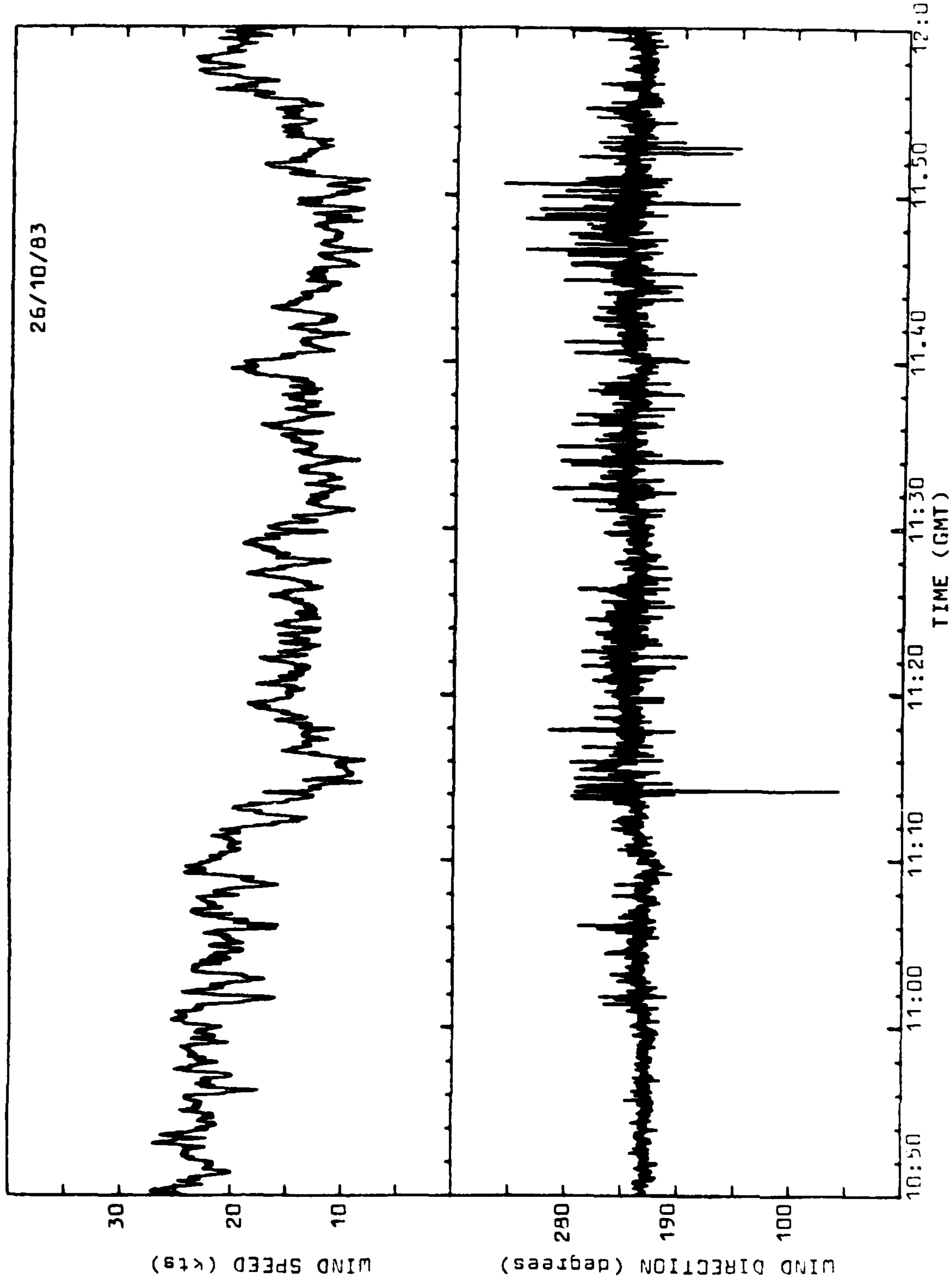
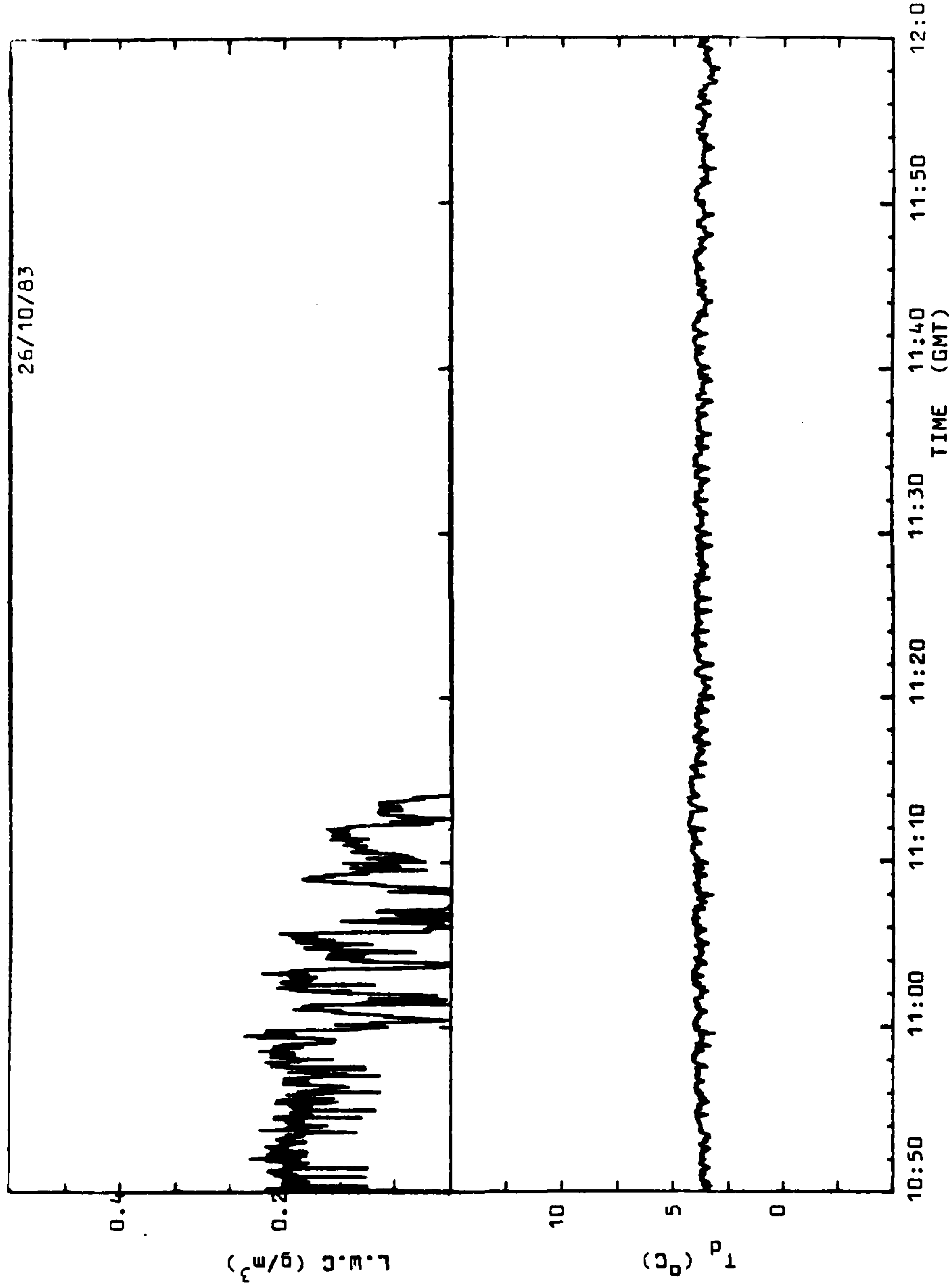

GDF SUMMIT : SONIC-FSSP
DATE 26 /10 /83 RECORD 550 FOR 600 PTS
Averaging Time = 1.0 secs
L.W.C. (g/m³)
0.3
0.2
0.1
ΔT (°C)
+0.2
+0.1
0
-0.1
-0.2
11:08
11:10
11:12
11:14
11:16
TIME (GMT)

FIGURE 2(ii)



26/10/83
WIND SPEED (kts)
30
20
10
WIND DIRECTION (degrees)
280
190
100
TIME (GMT)
10:50
11:00
11:10
11:20
11:30
11:40
11.50
12:00

FIGURE 2(1)


26/10/83
L.W.C (g/m³)
0.4
0.2
Td (°C)
10
5
0
10:50
11:00
11:10
11:20
11:30
11:40
11:50
12:00
TIME (GMT)

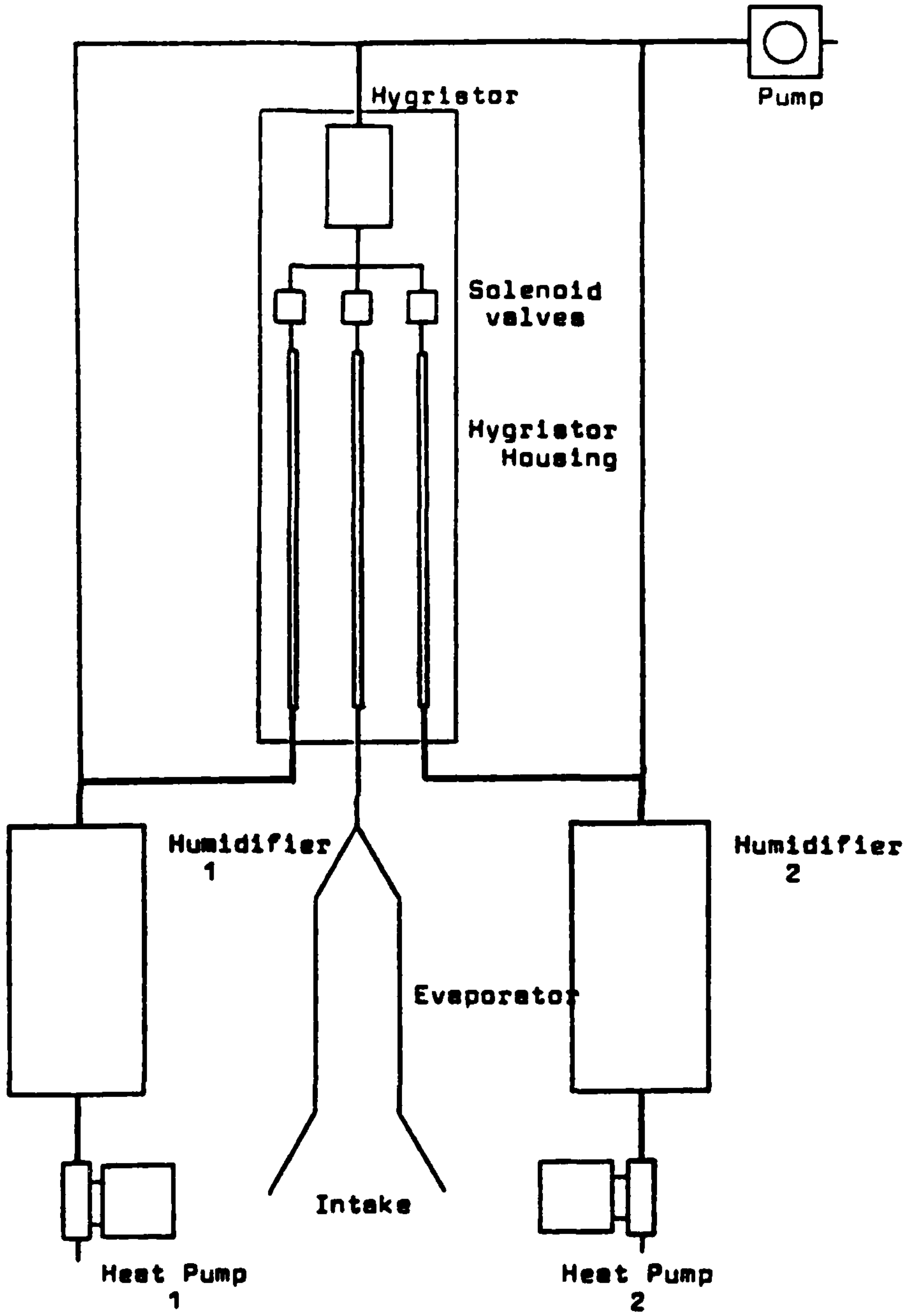

Hygristor
Pump
Solenoid valves
Hygristor Housing
Humidifier 1
Humidifier 2
Evaporator
Intake
Heat Pump 1
Heat Pump 2

Figure 1

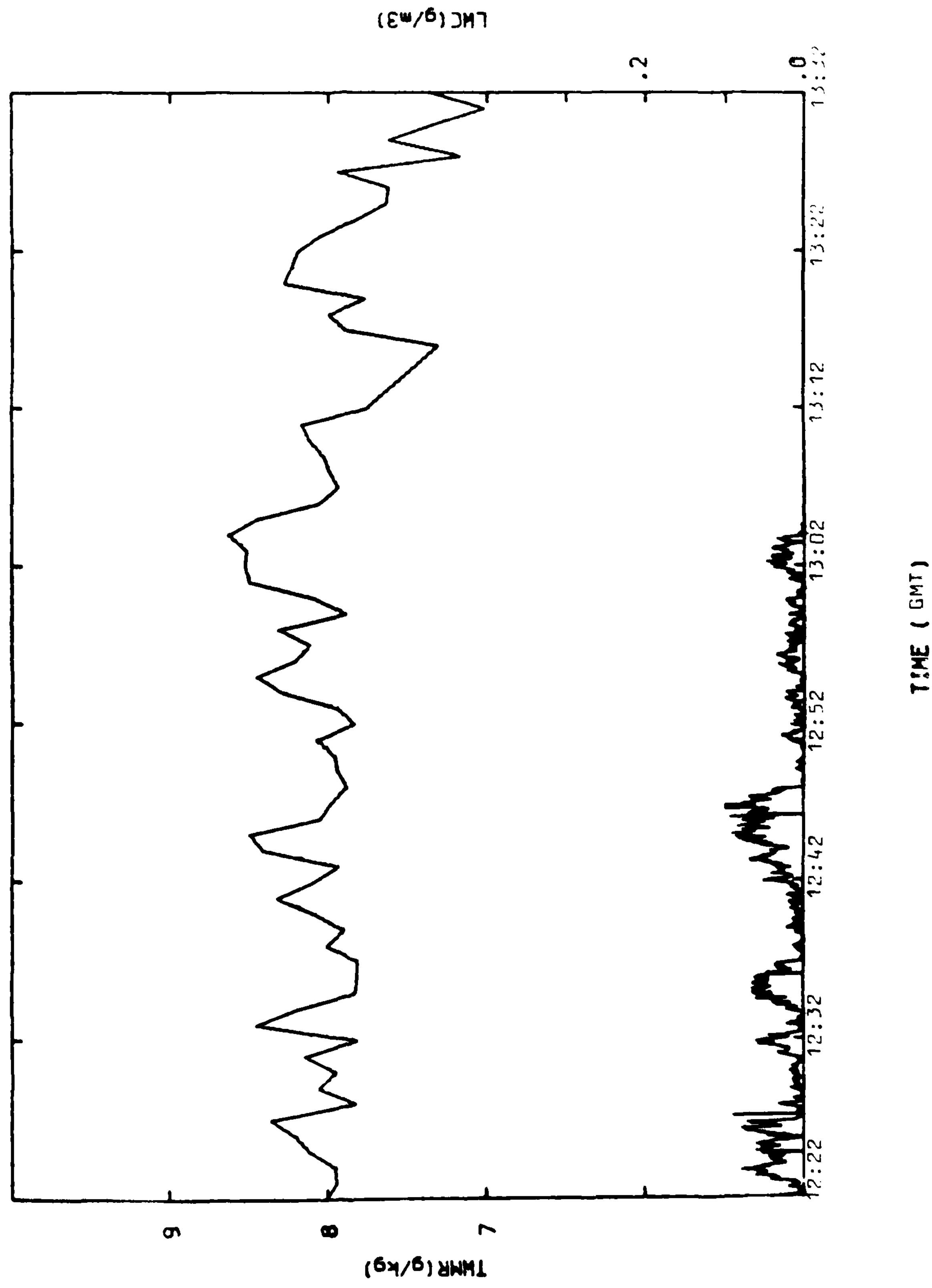
REFERENCES

Baker M B, Blyth A M, Carruthers D J, Caughey S J, Choularton T W, Conway B J, Fullarton G, Gay M J, Latham J, Mill C S, Smith M H and Stromberg I M 1982 Field studies of the effect of entrainment upon the structure of clouds at Great Dun Fell. Quart J Roy Met Soc, 108, 899-916

Carruthers D J and Choularton T W 1983 A model of the feeder-seeder mechanism of orographic rain including stratification and wind-drift effects. Quart J Roy Met Soc, 109, 575-588

base regions, reveal structure at cloudbase over scales of tens of metres and less as the cloud lifted and dissipated.

FIGURE 5(i)


LMC(g/m3)
.2
.0
TWMR(g/kg)
9
8
7
12:22
12:32
12:42
12:52
13:02
13:12
13:22
TIME (GMT)

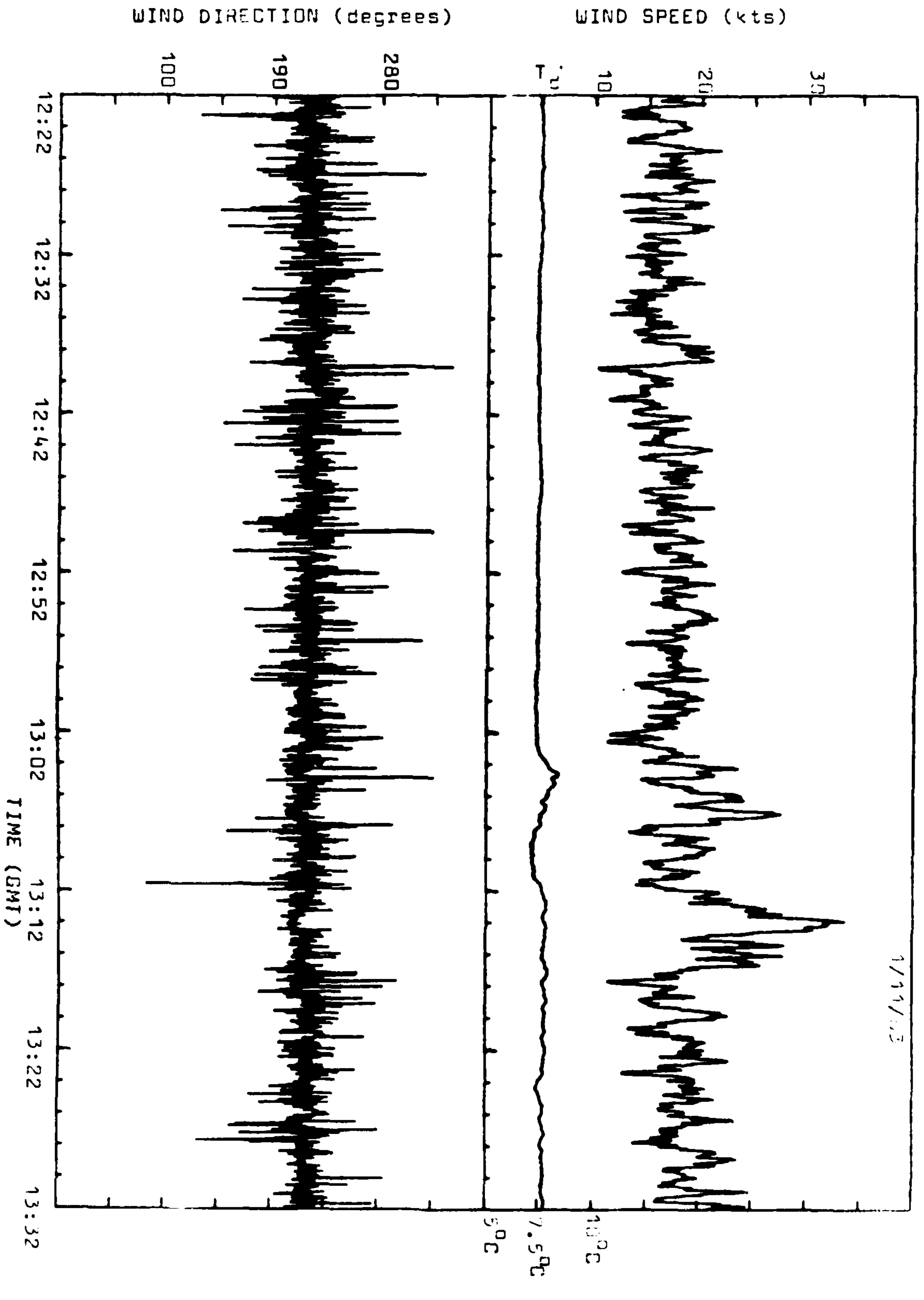

WIND DIRECTION (degrees)
WIND SPEED (kts)
100
190
280
10
20
30
12:22
12:32
12:42
12:52
13:02
13:12
13:22
13:32
TIME (GMT)
5°C
7.5°C
10°C

FIGURE 6(i)

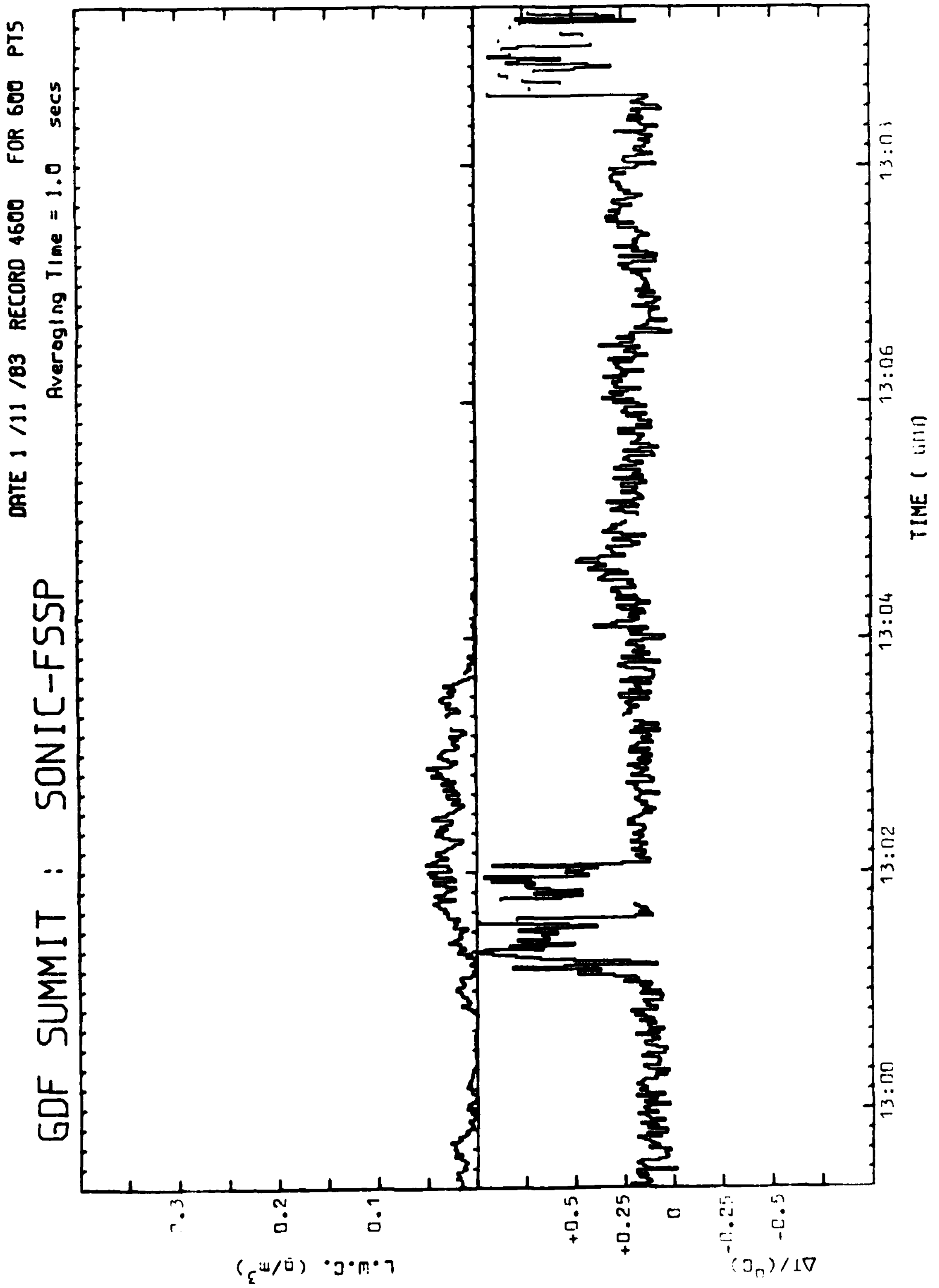

GDF SUMMIT : SONIC-FSSP
DATE 1 /11 /83 RECORD 4600 FOR 600 PTS
Averaging Time = 1.0 secs
L.W.C. (g/m^3)
0.2
0.1
ΔT/(°C)
+0.5
+0.25
0
-0.5
13:00
13:02
13:04
13:06
TIME

FIGURE 6(ii)

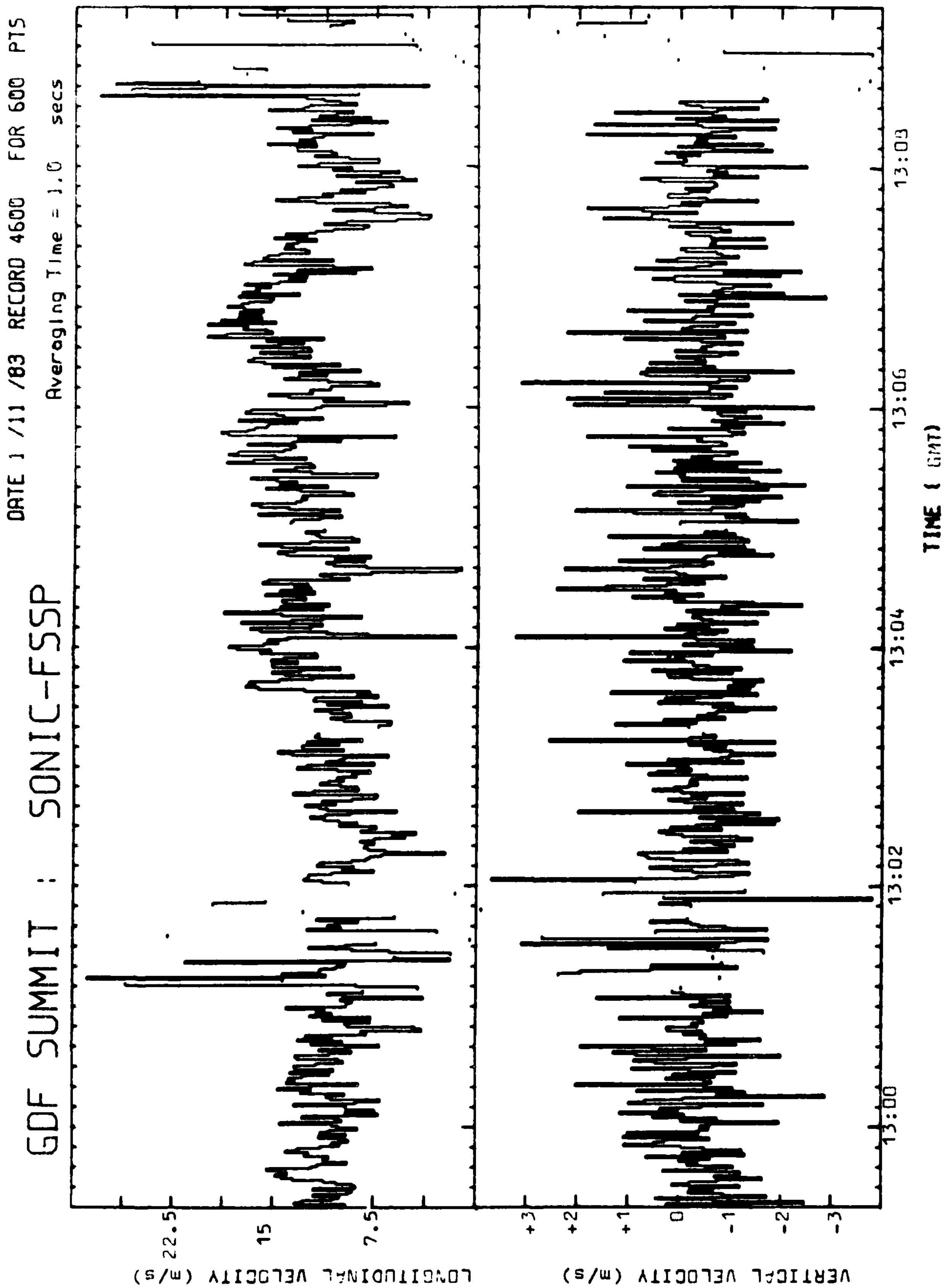

GDF SUMMIT : SONIC-FSSP
DATE 1 /11 /83 RECORD 4600 FOR 600 PTS
Averaging Time = 1.0 secs
LONGITUDINAL VELOCITY (m/s)
22.5
15
7.5
VERTICAL VELOCITY (m/s)
+3
+2
+1
0
-1
-2
-3
13:00
13:02
13:04
13:06
13:08
TIME (GMT)

FIGURE 6(iii)

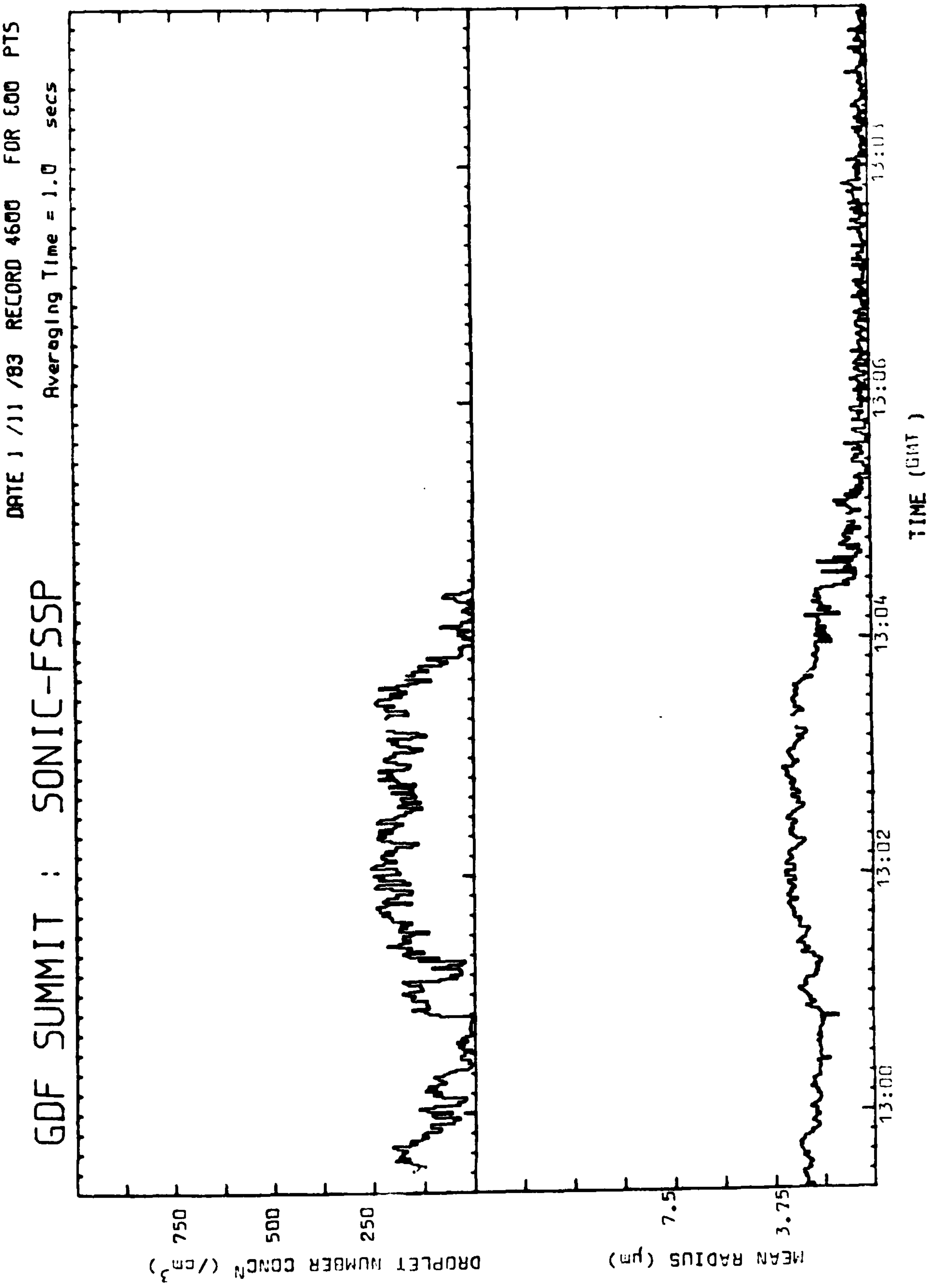

GDF SUMMIT : SONIC-FSSP
DATE 1 /11 /83 RECORD 4600 FOR 600 PTS
Averaging Time = 1.0 secs
DROPLET NUMBER CONC^N (/cm^3)
750
500
250
MEAN RADIUS (μm)
7.5
3.75
13:00
13:02
13:04
13:06
TIME (GMT)

FIGURE 7(i)

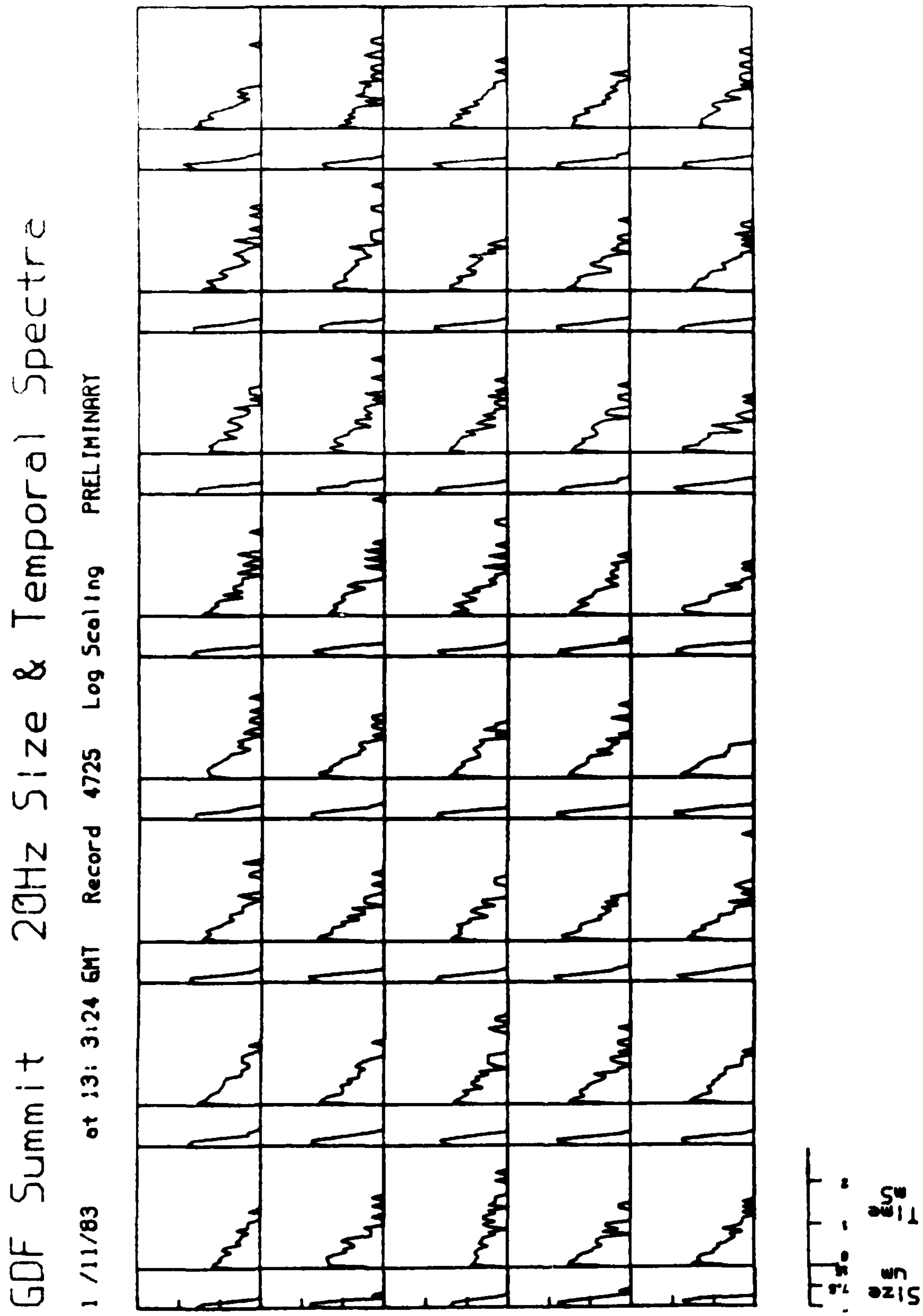
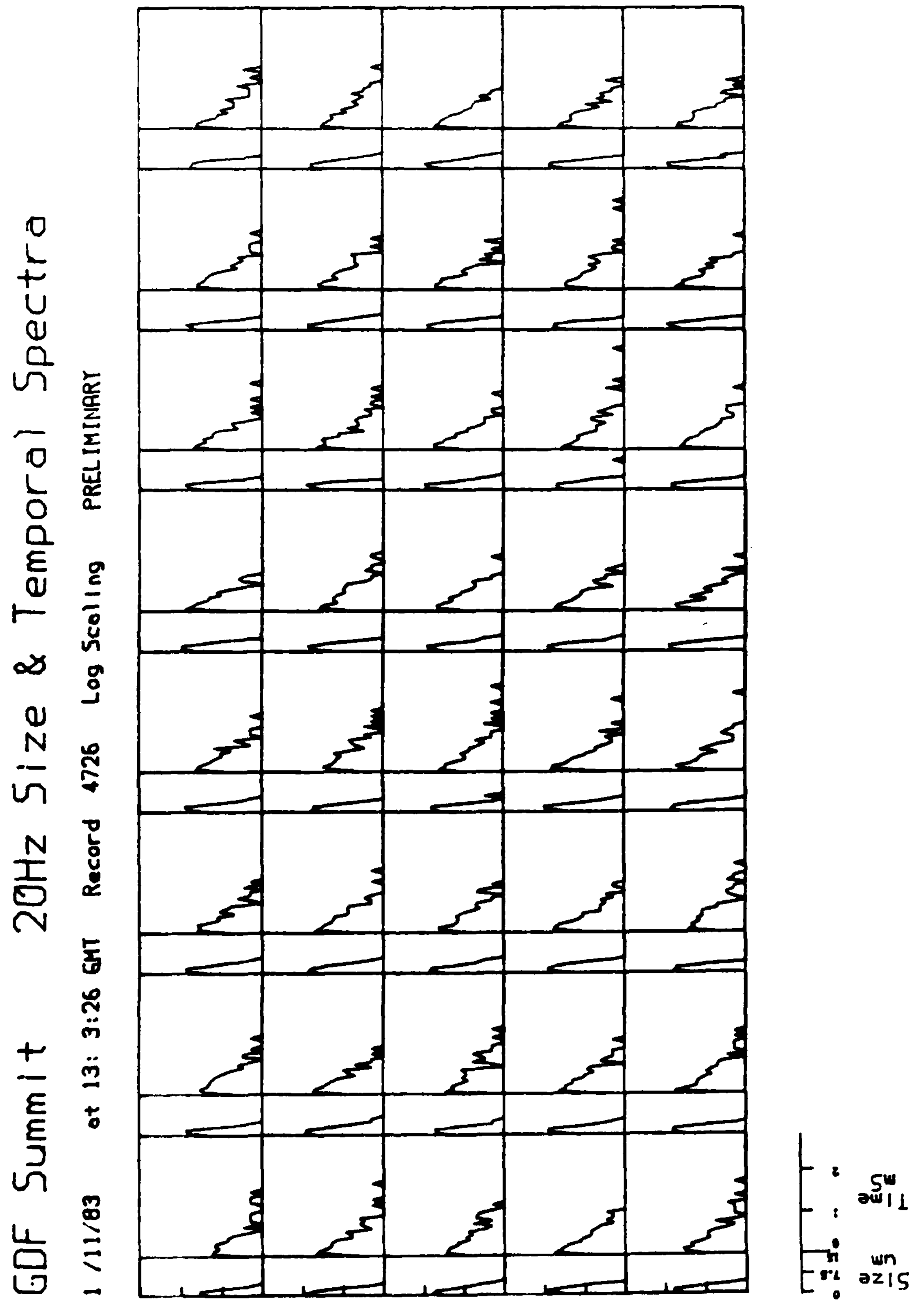

GDF Summit 20Hz Size & Temporal Spectra
1 /11/83 at 13: 3:24 GMT Record 4725 Log Scaling PRELIMINARY
Size um
Time mS

FIGURE 7(ii)



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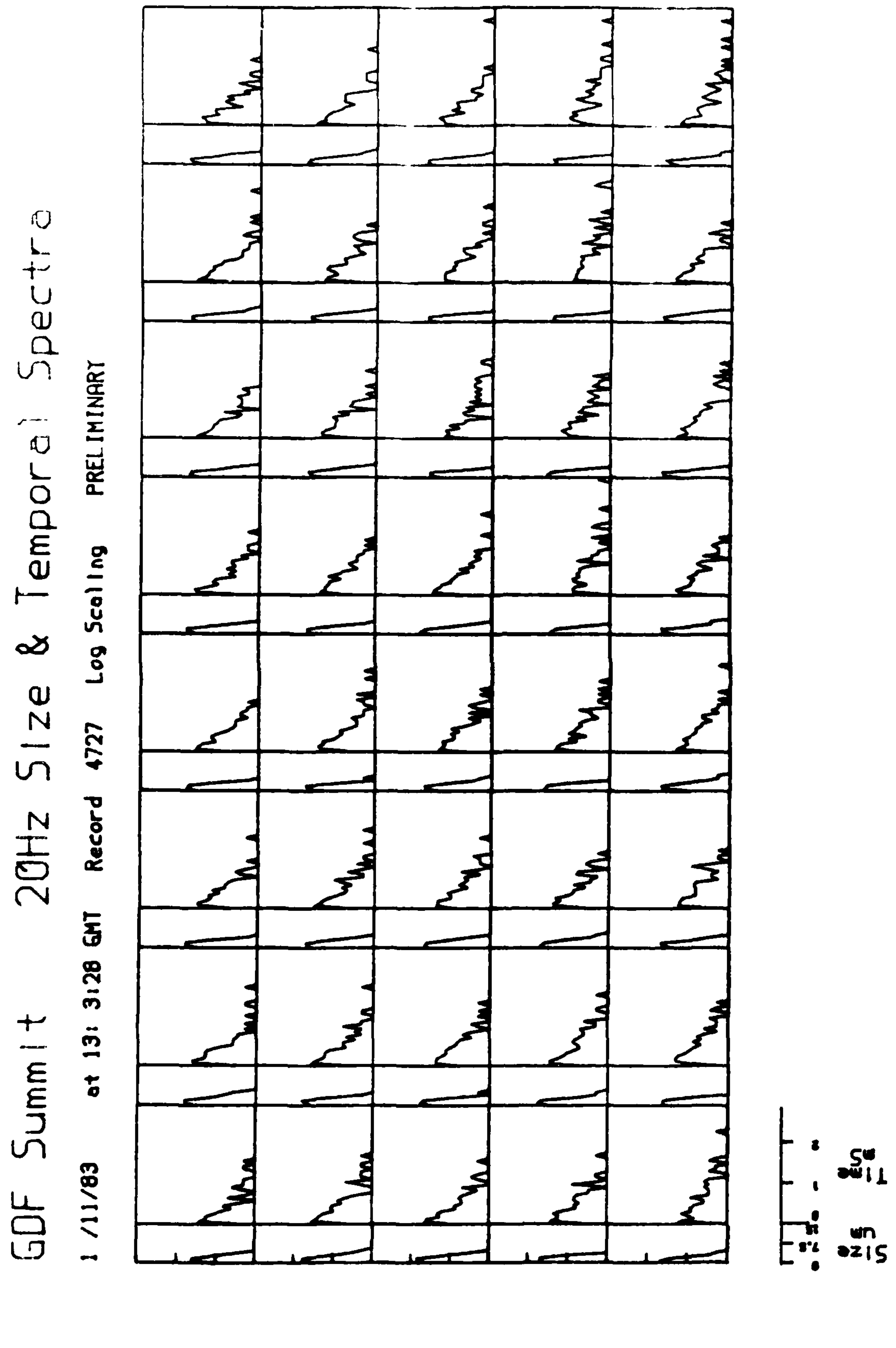
Size um
Time mS

FIGURE 7(iii)


GDF Summit 20Hz Size & Temporal Spectra
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Size um
Time ms

FIGURE 7(iv)

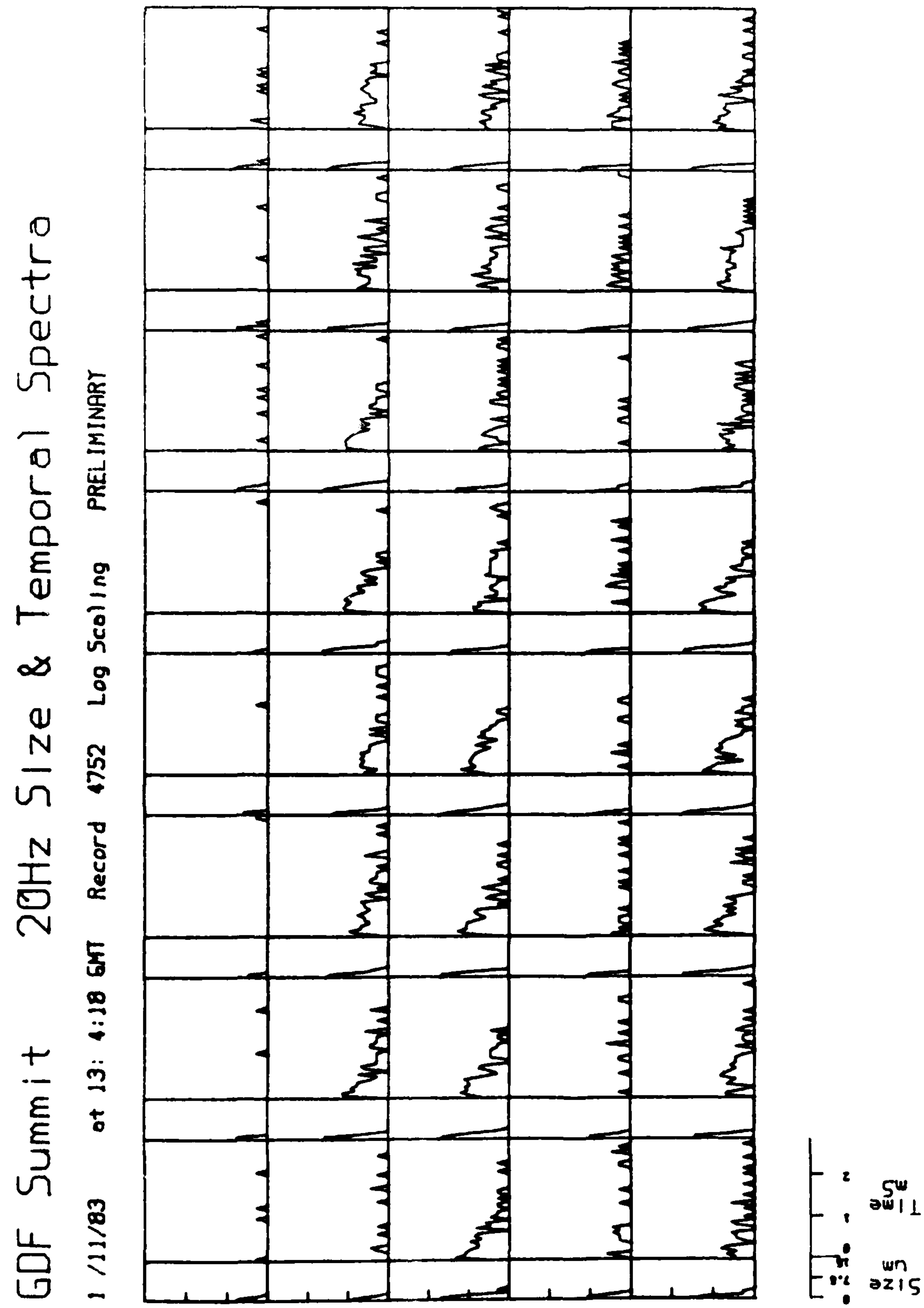
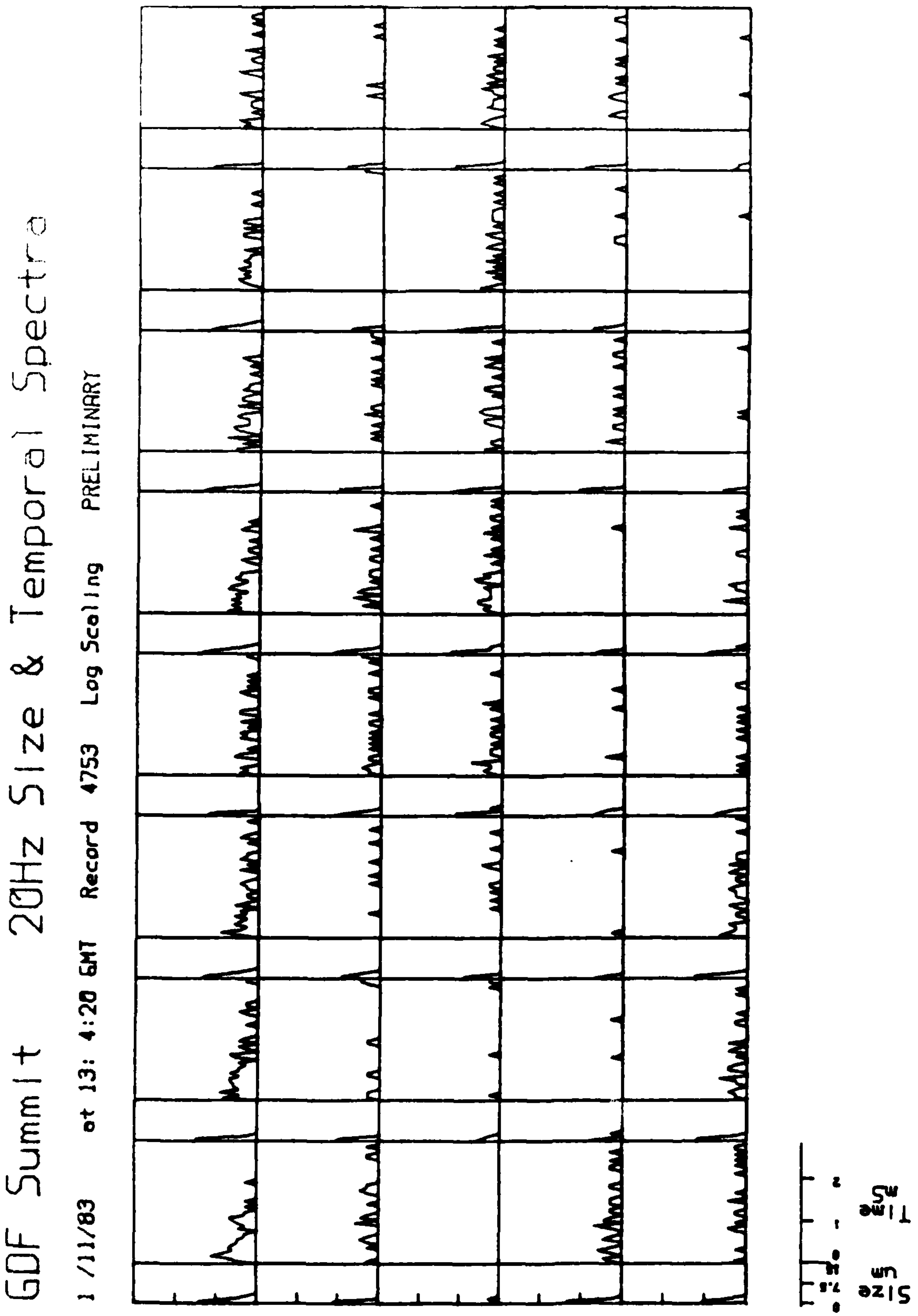

GDF Summit 20Hz Size & Temporal Spectra
1/11/83 at 13: 4:18 GMT Record 4752 Log Scaling PRELIMINARY
Size um
Time mS

FIGURE 7(v)


GDF Summit 20Hz Size & Temporal Spectra
1 /11/83 at 13: 4:20 GMT Record 4753 Log Scaling PRELIMINARY
Size um
Time mS

GDF Summit 20Hz Size & Temporal Spectra

1 /11/83 at 13: 4:22 GMT Record 4754 Log Scaling PRELIMINARY

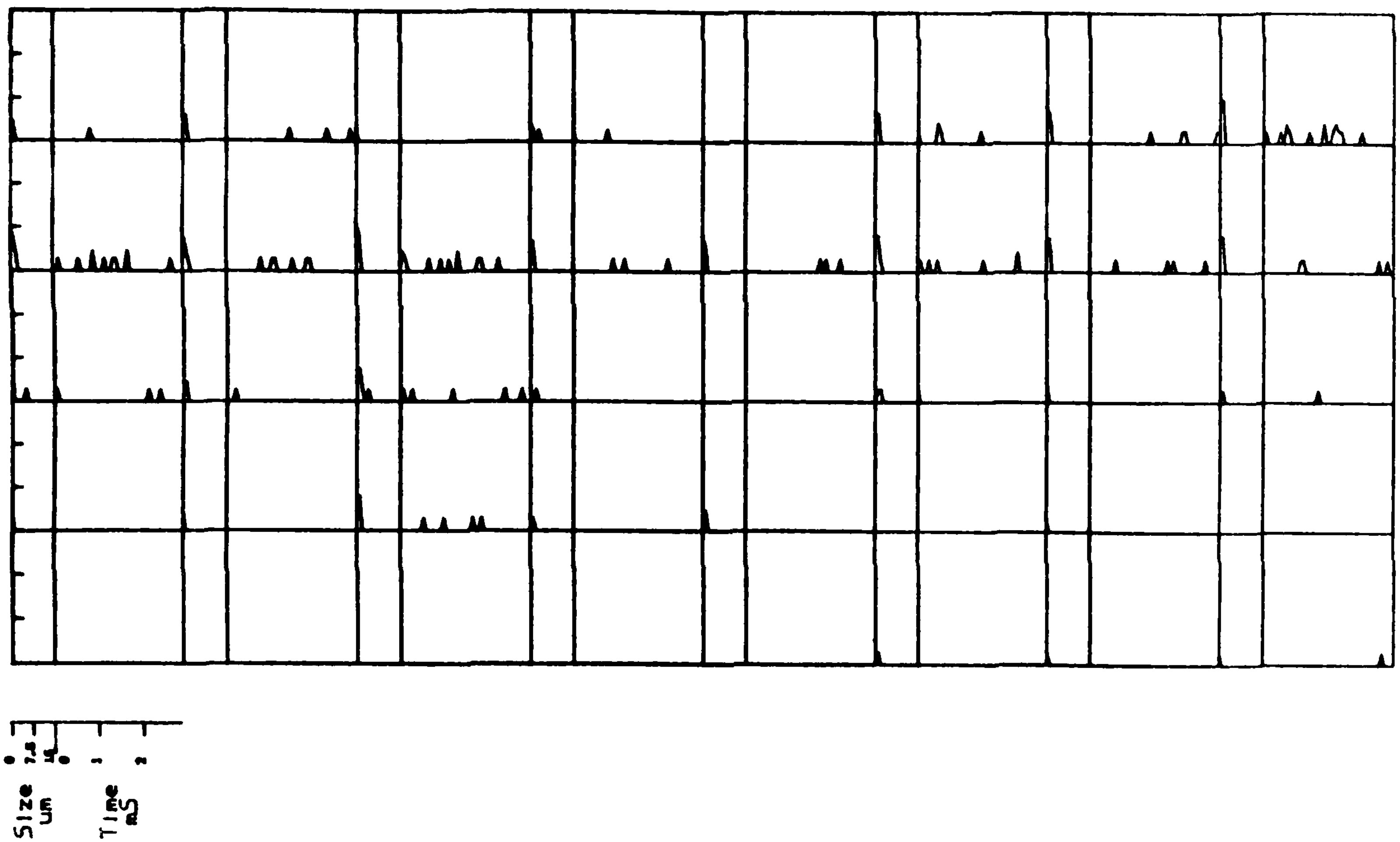


FIGURE 7(vi)