FOR FURTHER TRAN

RADC-TR-78-72
Interim Report
April 1978

TURBULENCE ENVIRONMENT CHARACTERIZATION

Avco Everett Research Laboratory, Inc.

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Air Force Systems Command
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TURBULENCE ENVIRONMENT CHARACTERIZATION

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This report presents discussions of a variety of activities and results relative to the characterization of atmospheric turbulence and its effects on optical propagation at the AMOS Observatory in Maui, Hawaii. The major emphasis is on experimental results obtained during the last six months. A brief discussion of the operational aspects and status of the instrumentation is also included.

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Data was obtained with the Seeing Monitor, Star Sensor, microthermal probes and/or acoustic sounder on more than twenty occasions during the period. Much of this data was of a simultaneous nature. A detailed comparative analysis of the data has not yet been completed.

Twenty-one nights of Seeing Monitor data yielded values of r_o in the range from 4.7 cm to 15.9 cm with an average of 9.8 cm.

Thirteen nights of microthermal data yielded values of C_n^2 in the range from $0.4 \times 10^{-15}\ m^{-2/3}$ to $39 \times 10^{-15}\ m^{-2/3}$ with an average of $6.2 \times 10^{-15}\ m^{-2/3}$.

Twelve nights of Star Sensor data yielded values of the log-amplitude variance in the range from 3×10^{-4} to 7.2×10^{-4} with an average of 5.1×10^{-4}. This device is a new model of the original instrument built by NOAA which was installed at AMOS in June 1977. The much shorter data collection cycle has virtually eliminated the nonstationarity problems encountered previously. However, there are significant differences between the data obtained with the two devices.

← sub 0
(C_n sub n) squared
.0003
.00072
.00051

3.9 X10 to the -14th power

6.2X10 to the -15th power

4.0 X10 to the -16th power

PREFACE

This report is submitted in compliance with the requirements of Contract F30602-76-C-0054 and covers work carried out during the period 15 March 1977 to 30 September 1977. Earlier work is reported in RADC-TR-77-70 (March 1977) and RADC-TR-77-232 (July 1977). Related work under a previous contract (F30602-75-C-0012) is reported in RADC-TR-75-185 (July 1975) and RADC-TR-76-189 (June 1976).

We would like to thank the staff of the AMOS Observatory for assistance in collecting the data. We also acknowledge the assistance and support of D. Tarazano of RADC and R. Lawrence and J. Ochs of the NOAA Environmental Research Laboratories.

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1.0 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The objective of this program, Turbulence Environment Characterization, is to provide data relevant to atmospheric turbulence at the AMOS Observatory. Of primary interest are the effects of turbulence on propagating electromagnetic waves in the visible portion of the spectrum. Such information is desirable for several reasons. From a fundamental point of view, it can provide data of use in verifying propagation theory and specifying those parameters which are not determined by theory. From a practical point of view, this measurements program can provide a data base useful in specifying the operational environment for a variety of optical systems. One of the most important of these is the Compensated Imaging Field System which is currently being designed and fabricated and will be deployed at AMOS.

During the period covered by this report, a variety of activities were carried out. These included: deployment and testing of new or modified instrumentation; instrument calibration and characterization tests; routine data collection; and reduction and analysis of the resulting data. The program status, accomplishments and the most significant results and conclusions are given below. Section 2.0 summarizes the experimental operations and instrumentation status. Included is a brief discussion of the new version of the NOAA Star Sensor. Section 3.0 summarizes the data obtained and processed during this reporting period.

This report assumes a reasonable familiarity with the instrumentation deployed and previously obtained results. A more detailed discussion of these topics will be found in Ref. 1 through 4.

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1. Miller, M.G. and Kellen, P.F., Turbulence Characterization and Control, Interim Technical Report, Contract F30602-75-C-0012 (Avco Everett Research Laboratory, Inc.), Rome Air Development Center, Technical Report #RADC-TR-75-185 (July 1975).
2. Miller, M.G., Zieske, P.L. and Dryden, G., Turbulence Characterization and Control, Final Technical Report, Contract F30602-75-C-0012 (Avco Everett Research Laboratory, Inc.), Rome Air Development Center, Technical Report #RADC-TR-76-189 (June 1976).
3. Miller, M.G. and Zieske, P.L., Turbulence Environment Characterization, Interim Technical Report, Contract F30602-76-C-0054 (Avco Everett Research Laboratory, Inc.), Rome Air Development Center, Technical Report #RADC-TR-77-70 (March 1977).
4. Miller, M.G., Zieske, P.L., Sofia, A.J. and Pepe, R.J., Turbulence Environment Characterization, Interim Technical Report, Contract F30602-76-C-0054 (Avco Everett Research Laboratory, Inc.), Rome Air Development Center, Technical Report #RADC-77- 232 (July 1977).

1.2 PROGRAM STATUS

As of the date of this report, the status of the instrumentation is as follows:

- The Seeing Monitor has continued to operate reliably.
- A new model of the Star Sensor has been installed and is operational.
- The PDP-8 Processing System has required some maintenance. A new teletype has been ordered.
- The new weather resistent microthermal probes appear to be working satisfactorily.
- The acoustic sounder is operational. However, data processing has become the pacing item for the measurement program.
- A barometric sensor has been added to the routine meteorological instrumentation.
- A data logger has been installed in the observatory to provide hard copy routine meteorological data.

1.3 RESULTS AND CONCLUSIONS

Data was collected with the Seeing Monitor, Star Sensor, microthermal probes and/or acoustic sounder on a number of occasions. Most of these operations were simultaneous. A detailed comparative analysis of this data has not yet been completed. However, some of the results are as follows:

- Microthermal data obtained on thirteen nights yields values of C_n^2 from 0.4×10^{-15} $m^{-2/3}$ to 39×10^{-15} $m^{-2/3}$ with an average of 6.4×10^{-15} $m^{-2/3}$.
- Seeing Monitor data obtained on twenty-one nights yields values of r_o from 4.7 cm to 15.9 cm with an average of 9.8 cm.
- Star Sensor data obtained on twelve occasions yields values for the log-amplitude variance from 3×10^{-4} to 7.2×10^{-4} with an average of 5.1×10^{-4}.
- The three minute data collection cycle of the new Star Sensor has virtually eliminated the nonstationarity problem seen with the previous model.

- The profiles obtained with the new Star Sensor indicate substantially higher turbulence at the lower two levels. This conflict casts doubt on the validity of one or both of the instruments.

- Preliminary analyses of the available simultaneous data suggests that a significant and variable amount of turbulence exists in those regions not covered by the present instrumentation.

2.0 OPERATIONS AND INSTRUMENTATION

2.1 OPERATIONS SUMMARY

Several types of operations and activities were carried out during this reporting period. Some routine data was collected with the Seeing Monitor during March and April. In addition, acoustic sounder and microthermal data was collected with the objective of establishing final calibration of the acoustic sounder. These activities were followed by a period of instrument maintenance and modification which lasted until mid-July. In addition to routine maintenance, a new model of the NOAA Star Sensor was delivered, installed and tested with the assistance of NOAA personnel. This new device is discussed in more detail in Section 2.3.

Routine operations were restarted in mid-July and continued to the end of this reporting period. Operations were scheduled on a two night per week basis. The instrumentation used included routine meterorological sensors, microthermal probes, acoustic sounder, Star Sensor and Seeing Monitor. While several nights of scheduled operations were curtailed by bad weather, data was collected with some or all the instrumental systems on the majority of occasions. A number of operational failures were encountered but were corrected within a reasonable period of time.

Several other test and hardware implementations were also accomplished. A data logger was procured and installed allowing hard copy printout of routine meteorological data on a continuing basis rather than the sporadic data obtained previously. Several nights of operation with the Seeing Monitor were devoted to investigating thermal pollution effects associated with observatory cooling equipment. The results were inconclusive.

Measurements and data collection operations are summarized in Table 1. All missions for which data collection was attempted are included; however, for a variety of reasons, useful processed data did not result from all missions. In addition, not all of the data is included in this report. There are several reasons for this. Because the routine meteorological data is only peripheral to the main objectives of this program and is now reported via a different mechanism, none of this data is included. Much of the early microthermal and acoustic sounder data was for calibration, checkout and training purposes; therefore, it is not reported. Because of time and manpower restrictions, much of the later acoustic sounder data has not been processed and hence cannot be reported. The remaining data has been reduced and is reported in Section 3.0.

TABLE 1. OPERATIONS SUMMARY

DATA- / DATE	RMET	μT	AS	SS	SM
23 MAR 77					X
31	X	X			X
07 APR 77	X	X			X
08	X	X			X
12	X	X	X		X
13	X	X	X		X
08 JUN 77	X	X	X		
09	X	X			
14	X	X	X		
15	X	X			
14 JUL 77			X	X	X
21	X	X	X	X	X
22	X	X	X	X	X
25	X	X	X	X	X
26	X	X			
02 AUG 77	X	X	X	X	X
03 AUG	X	X	X	X	X
12	X	X	X		X
18	X	X	X		X
19	X	X	X		X
26	X	X	X	X	X
01 SEP 77	X	X	X	X	
02	X	X	X		
08	X	X	X	X	X
09	X	X	X	X	X
15	X	X	X	X	X
16	X	X	X	X	X
22	X	X	X	X	X
23	X	X	X		X

RMET = Routine Met

μT = Microthermal Probe

AS = Acoustic Sounder

SS = Star Sensor

SM = Seeing Monitor

2.2 INSTRUMENT STATUS

Several additions and modifications to the hardware systems were made during this period. The most important was the installation of a new model of the NOAA Star Sensor which is discussed in the next section.

In order to provide for a routine and continuing collection of meteorological data, a Keithly model 70 data logger was procured and installed in the observatory. The seven routine meteorological signals (north tower wind speed and direction, south tower wind speed and direction, temperature, dew point and pressure) are sampled each hour and printed out on a continuous paper tape. These output voltages require only a sample scaling to provide the appropriate physical units. The advantage of this system is that this data can be collected on a non-interference basis because the PDP-8 processing system is not involved.

All other instrumentation is in substantially the same configuration as reported previously, however, several upgrades have been started. The PDP-8 teletype has become more unreliable, primarily due to its age; therefore a new or rebuilt device will be procured. The additional playback electronics for the Bell and Howell VR3700B tape recorder which will allow more latitude in acoutic sounder data recording and playback have been received. Weather resistant probes have been installed on one tower. The other tower is still equipped with the older design. Finally, a new and improved cuff for the acoustic sounder has been received but not yet installed.

2.3 NOAA STAR SENSOR

In early July, NOAA personnel were on site to install a new model of the Star Sensor. The device is mounted on the 36 cm Schmidt-Cassegrain Celestron telescope which is located in the Teal Amber dome. Outwardly, there is little difference between Model I and II, but internally several significant changes have been made. Reference 2 includes a discussion of Model I.

Both models of the Star Sensor produce a seven level C_n^2 profile based on an identical theory of atmospheric propagation. In Model II, the nominal altitudes of the seven levels are slightly different (2.2, 3.4, 5.2, 7.3, 9.4, 14 and > 18.5 km). These C_n^2 estimates are developed from the same four analog voltage which are proportional to σ_{If}, the standard deviation of the spatially filtered signal; σ_I, the aperture averaged log-irradiance standard deviation; d, the wavelength of the spatial filter; and I, the aperture averaged irradiance.

The principal differences between the two models are in the spatial filter and the speed at which it is scanned. Previously, twenty minutes were required to scan the rotating, linear picket fence reticle. In the new model, a two dimensional checkerboard reticle is used. Only 45 seconds is required to scan over the entire frequency range of interest. Because of the speed of the scan, four data collection runs are averaged in each cycle. This requires approximately three minutes and produces, in addition to the estimates of C_n^2, the average value of the aperture averaged log-amplitude variance and a quality factor. This latter quantity yields a measure of the amount of atmospheric non-stationarity which occurred during the three minute collection period. While different in definition, its function is the same as the standard deviation to mean ratio calculated by the Model I device for each twenty minute collection cycle. A more detailed description and discussion of the Model II Star Sensor can be found in Ref. 5.

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(5) G. R. Ochs, Ting-i Wang, and F. Merrern, Stellar Scintillometer Model II for Measurement of Refractive-Turbulence Profiles. NOAA Technical Memorandum ERL WPL-25 (April 1977).

3.0 EXPERIMENTAL DATA AND ANALYSES

3.1 ACOUSTIC SOUNDER AND MICROTHERMAL DATA

Since the start of simultaneous data collection with four sensor systems in mid-July, acoustic sounder data has been collected on eighteen occasions. Because of the limited capability of the PDP-8 processing system, this data could not be processed in realtime; therefore, the raw data was recoreded on magnetic tape using the Bell and Howell VR3700B tape recorder. Processing is accomplished using the PDP-8 and relevant software at some later data. This processing, when combined with the necessary calibration, requires a period of time in excess of that required by the data run. Because of this and the pressure of other site activities, none of the eighteen data runs have been processed.

Processed and apparently valid microthermal data was obtained on thirteen occasions during the period from 21 July 1977 to 23 September 1977. The run averages and ranges are given in Table 2. The data base for each of these runs varies. Some are the result of averaging all six probe pairs (three on each tower) while others involve only a single tower, or in some cases, a single probe pair. The reason for this is that during this two month period, several probes failed during a particular run. Others, on occasion, developed noise problems or displayed analomous behavior of one sort or another. Therefore, after processing, the results were carefully reviewed and obviously erroneous or suspicious results were eliminated.

3.2 SEEING MONITOR DATA

Reducible Seeing Monitor data was collected on twenty-one nights during the period. The results are given in Table 3 and Figures 1 through 7. All data corresponds to the average of 1350 samples of the Seeing Monitor analog output taken with a PDP-8 cycle time of ten minutes. The average value of the three hundred and sixteen points contained in this data set is 9.8 cm with a range from 4.7 cm to 15.9 cm. These results are very consistent with previously reported data.(3,4)

As with previous data, a variety of temperol behavior was observed. The data of 26 August (Figure 5) is somewhat unique in that it shows a strong trend towards improving seeing conditions early in the run followed by a more gentle down trend later in the evening. The data of 23 September is also interesting in that local meteorological conditions included intermittent mist sweeping out of the crater and over the observatory. As can be seen from Figure 7, the observed value of r_o was low on this occasion. While not a

TABLE 2. MICROTHERMAL DATA

		$C_n^2 \times 10^{-15} \left(m^{-2/3}\right)$	
Date	No. of Points	Average	Range
21 July	14	2.8	0.8 - 5.1
22 July	17	3.2	1.0 - 8.4
26 July	8	6.8	2.7 - 30.0
2 August	23	1.7	0.5 - 5.1
3 August	27	1.2	0.4 - 4.0
18 August	28	15.7	7.3 - 24.0
19 August	24	6.5	4.8 - 10.4
26 August	20	8.0	1.4 - 34.0
8 September	24	3.8	2.4 - 6.0
9 September	26	10.5	3.6 - 39.0
15 September	25	6.5	---
16 September	23	5.3	2.7 - 8.8
22 September	24	11.2	---

TABLE 3. SEEING MONITOR DATA

Date	No. of Points	r_o at 5000 Å (cm) Mean	Range
23 March	12	6.4	5.2 - 7.6
7 April	7	7.7	7.0 - 8.3
8 April	10	8.6	7.7 - 9.3
12 April	10	5.4	4.7 - 6.3
13 April	3	4.8	4.7 - 4.9
21 July	14	9.7	9.1 - 10.1
22 July	17	8.6	7.4 - 9.4
25 July	14	10.9	8.9 - 13.3
26 July	10	9.1	8.2 - 10.4
2 August	25	10.0	9.0 - 10.6
3 August	27	9.8	8.3 - 11.2
12 August	14	13.2	11.0 - 15.9
18 August	28	7.9	6.2 - 9.6
19 August	25	10.6	8.4 - 12.9
26 August	26	9.0	6.3 - 11.4
8 September	24	12.2	11.3 - 13.0
9 September	26	11.2	8.0 - 14.5
15 September	24	11.8	9.6 - 13.3
16 September	22	10.5	7.3 - 12.4
22 September	24	10.3	8.1 - 12.0
23 September	10	5.5	4.7 - 6.0

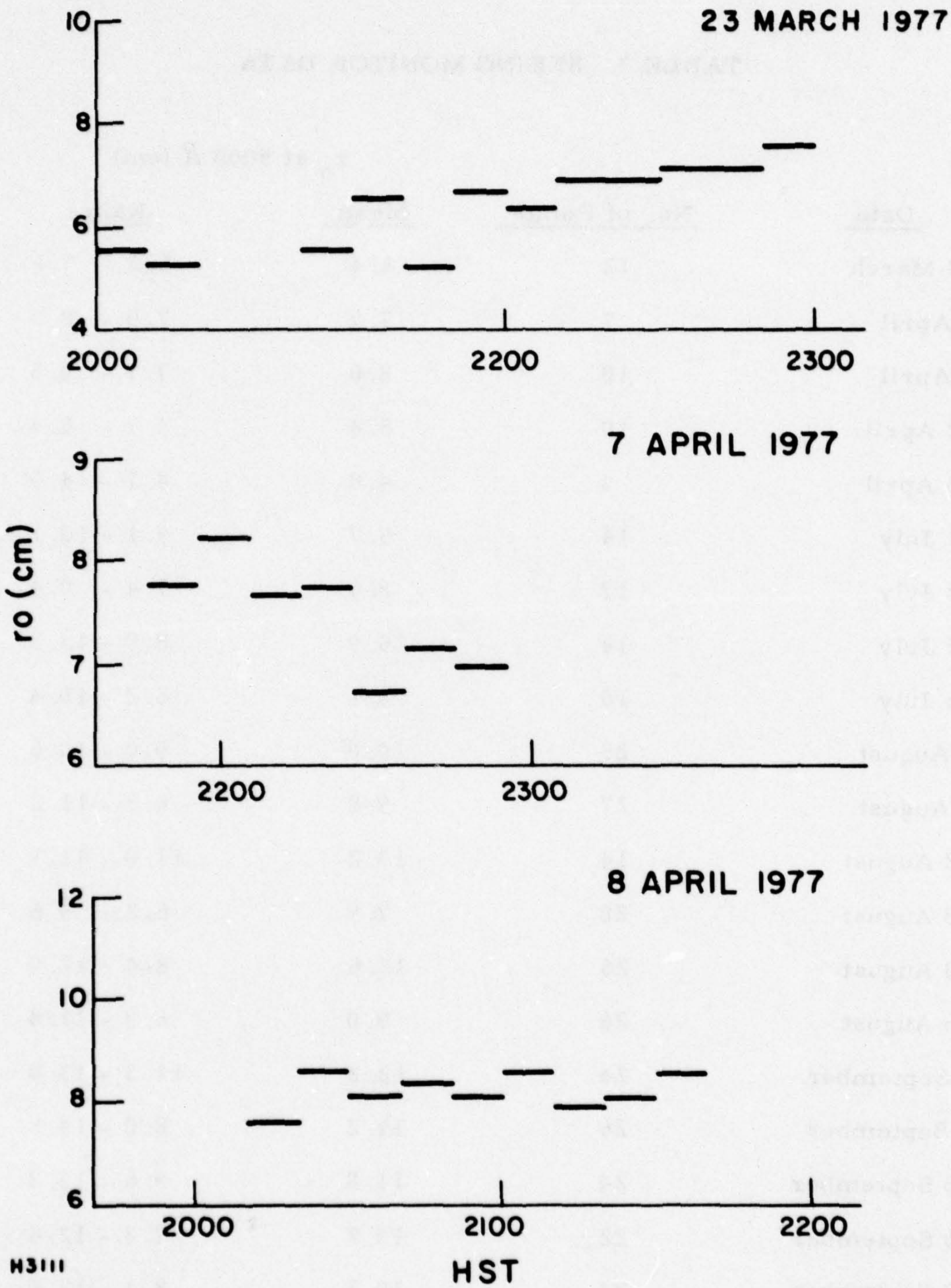

Figure 1 Seeing Monitor Data of 23 March, 7 April and 8 April 1977

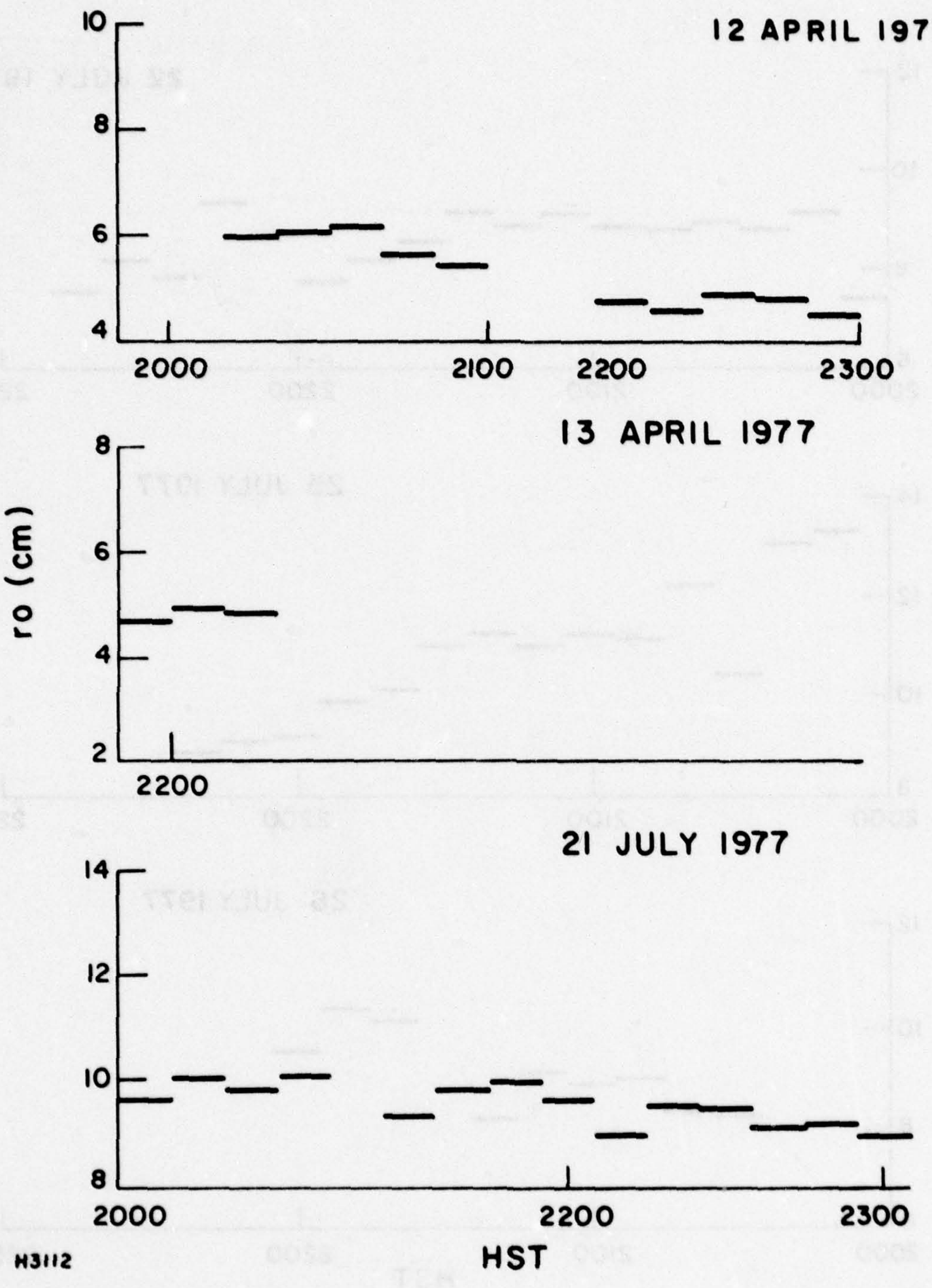

Figure 2 Seeing Monitor Data of 12 April, 13 April and 21 July 1977

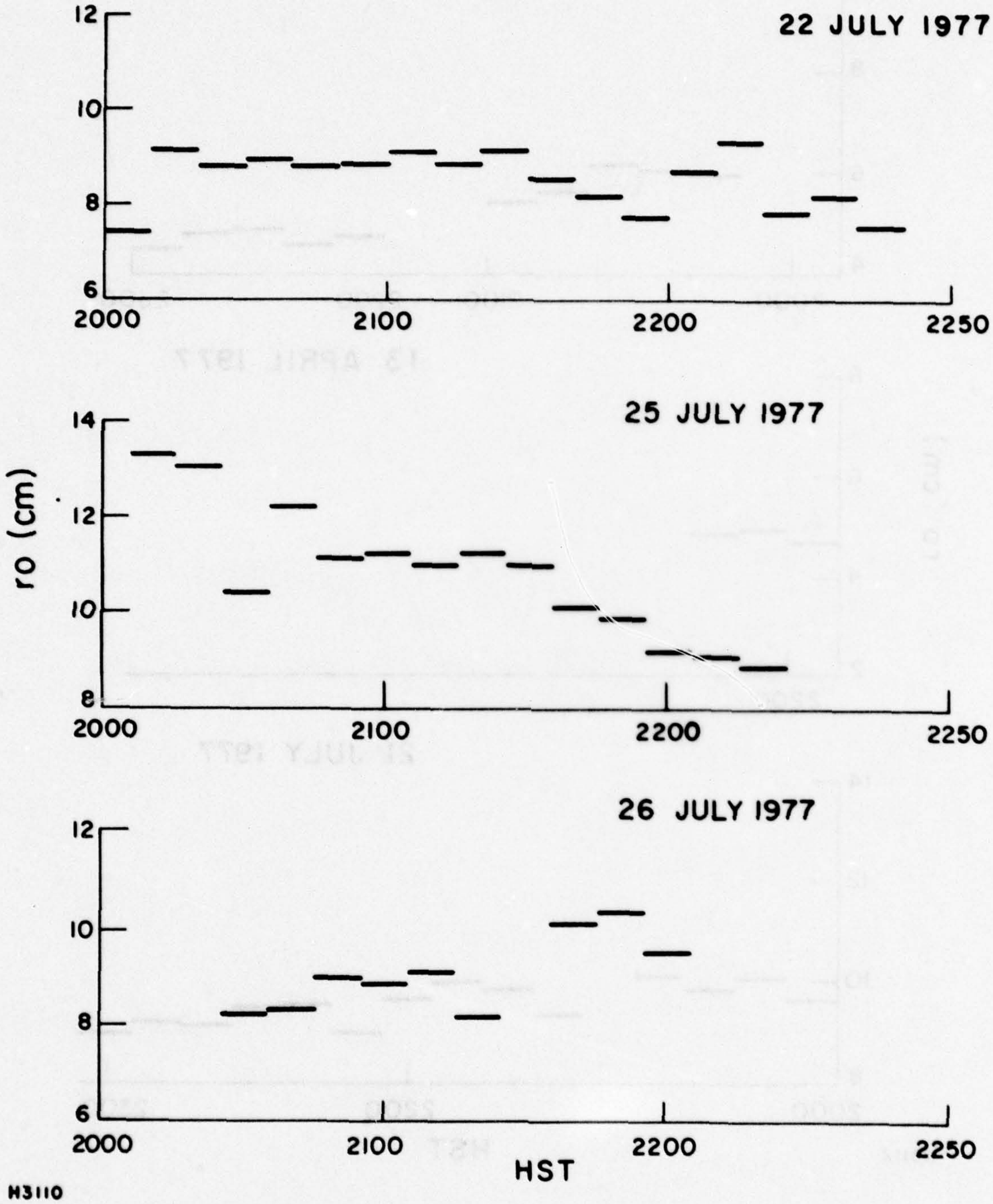

Figure 3 Seeing Monitor Data of 22 July, 25 July and 26 July 1977

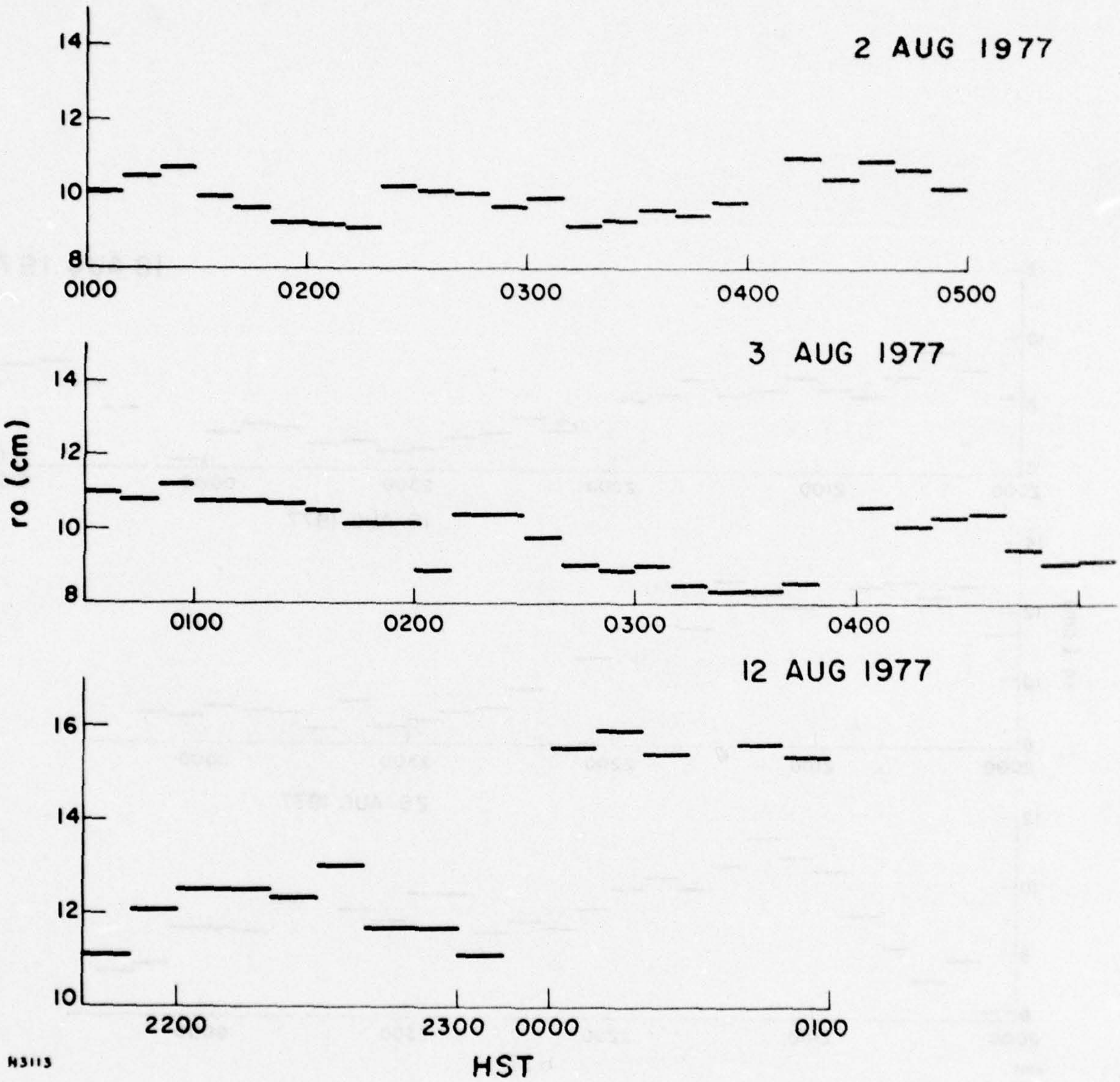

Figure 4 Seeing Monitor Data of 2 August, 3 August and 12 August 1977

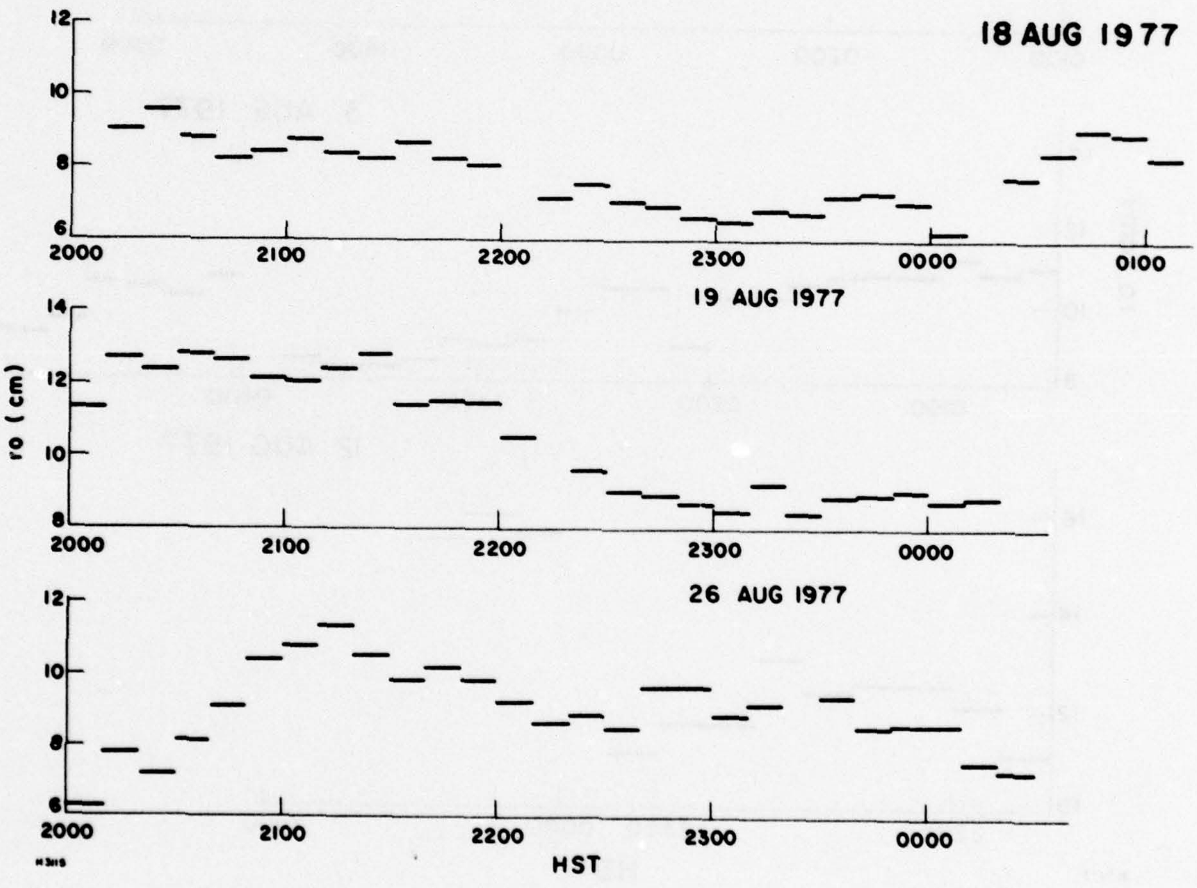

Figure 5 Seeing Monitor Data of 18 August, 19 August and 26 August 1977

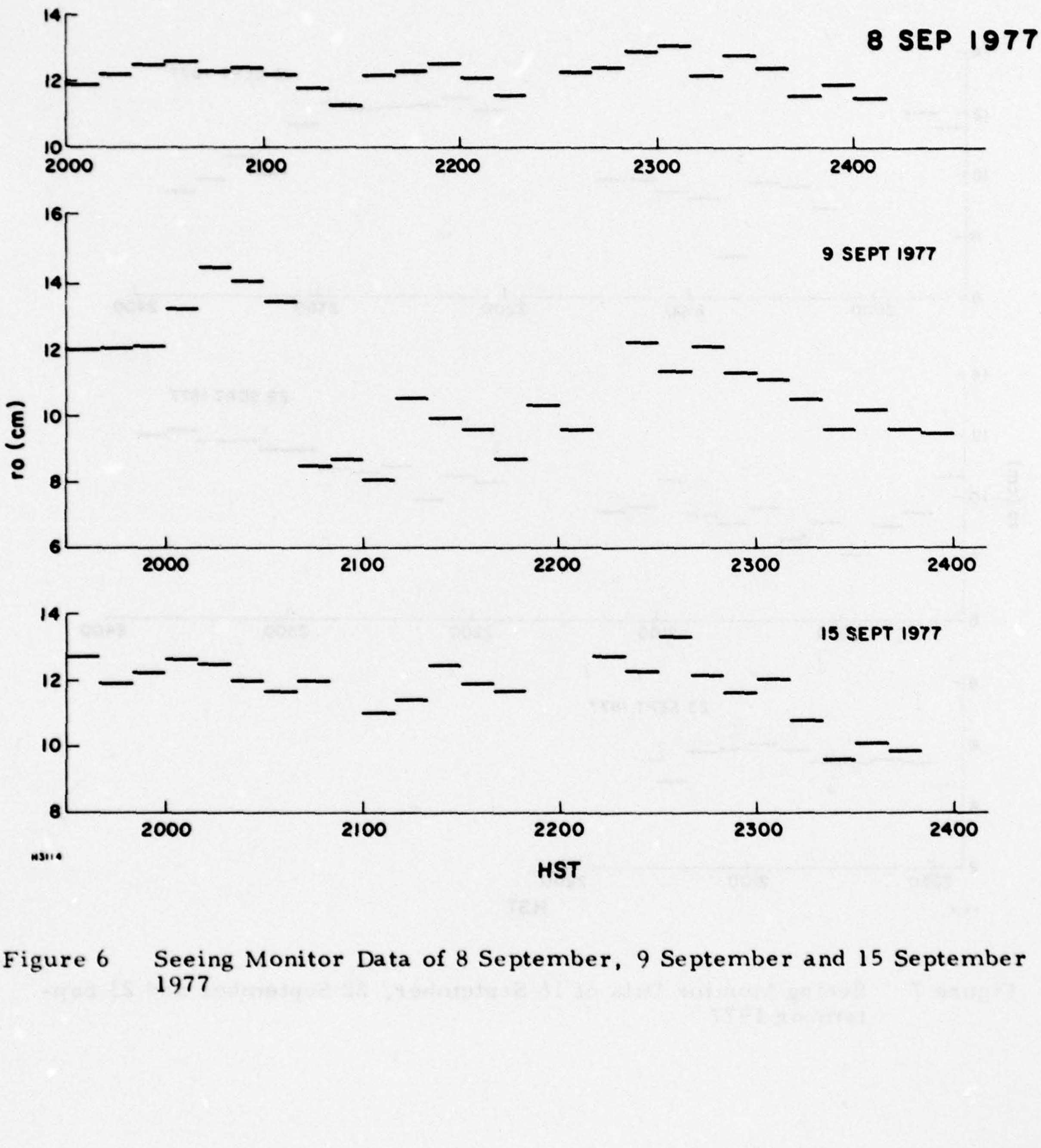

Figure 6 Seeing Monitor Data of 8 September, 9 September and 15 September 1977

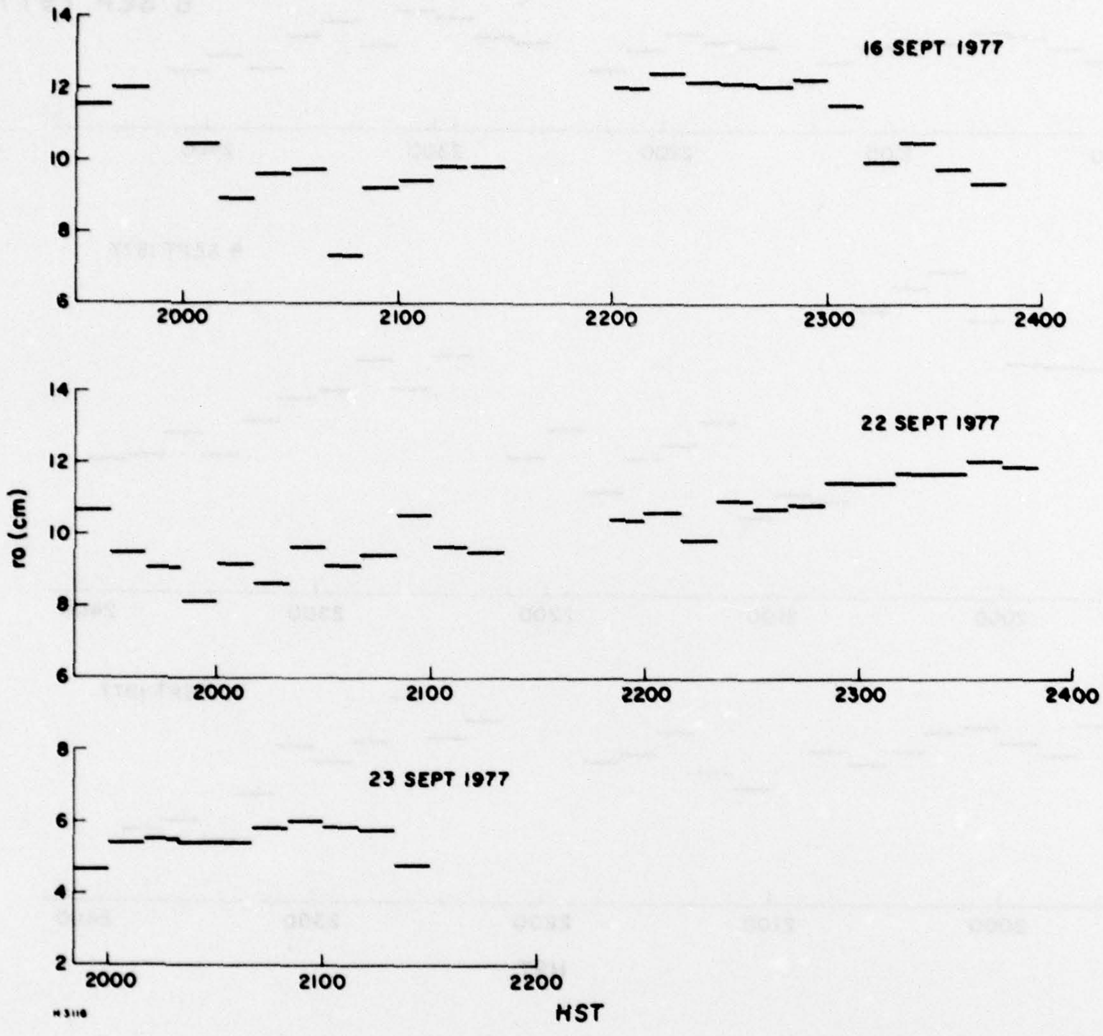

Figure 7 Seeing Monitor Data of 16 September, 22 September and 23 September 1977

firm objective conclusion, there appears to be a correlation between poor seeing conditions and the existence of crater mist near the observatory.

In general, these data also tend to show more uniform behavior than previously. Few large fluctuations from cycle to cycle or large variances within a single cycle were observed during this period. It is not known if these observations have any real physical significance.

Since the beginning of this program, Seeing Monitor data of this type has been collected on fifty-five occasions with two different telescopes. A comparison of data is given in Table 4. As can be seen, the results for the two telescopes are nearly equivalent. The average value of r_o at 5000 Å for the entire collection of existing data is 9.8 cm.

3.3 STAR SENSOR DATA

Data was collected with the new Star Sensor on twelve occasions during this period. The results are given in Table 5 and Figures 8 through 10. In total, four hundred and twenty-five, three minute profiles were obtained. Nightly averaged log-amplitude variances ranged from 3×10^{-4} to 7.2×10^{-4} with an average of 5.1×10^{-4}. These results are quite consistent with previously reported results.

The three minute cycle time associated with the new device has virtually eliminated the non-stationarity problems seen with the previous device which required twenty minutes of data collection for each profile. Based on the criteria that the quality factor for a given profile must be between 0.5 and 2.0, no profiles were eliminated.

The average profiles shown in Figures 8 through 10 are significantly different from those obtained with the previous model of the Star Sensor. All show relatively strong turbulence at the lowest level ($\geq 10^{-16}$ $m^{-2/3}$). A drop-off of approximately two decades occurs over the four lower levels. In all cases, the three higher levels show only a rather slow drop-off of the order of a factor of two. In contrast, the previously collected nightly averaged profiles show a wide range of behavior. Some have virtually no turbulence at intermediate levels while others show relatively strong turbulence at intermediate levels. In addition, no typical drop-off can be associated with the lower levels.

Significant differences are also seen in the average profile obtained from the complete data sets collected with each instrument. These two profiles are shown in Figure 11. The major differences are in the strength of turbulence observed at the lowest two levels. The new instrument (profile II) indicates values of C_n^2 larger than those obtained with the old instrument (profile I) by a factor of 8.3 and 3.1 at the first and second levels, respectively. In addition, the new profile does not start to flatten until an altitude of 7.5 km whereas the old profile starts to flatten at an altitude of 5.25 m

TABLE 4. SEEING MONITOR DATA SUMMARY

Telescope	No. of Nights	No. of Points	r_o at 5000 Å (cm) Mean	Range
1.2 M	24	228	9.6	5.3 - 17.8
1.6 M	31	442	9.9	3.6 - 17.6
1.2 M + 1.6 M	55	670	9.8	3.6 - 17.8

TABLE 5. NIGHTLY AVERAGED STAR SENSOR PROFILES

Date	No. of Profiles	$C_n^2(i) \times 10^{-18}\ M^{-2/3}$							σ_e $\times 10^{-6}$
		i = 1	2	3	4	5	6	7	
21 July 1977	11	105	15.1	5.22	2.34	2.44	2.32	1.65	6.4
22	51	120	17.5	5.39	1.72	2.03	1.98	1.74	5.4
25	6	185	34.0	10.0	1.3	1.02	1.13	1.34	4.5
26	36	194	33.8	9.82	2.23	2.23	1.62	1.28	4.8
02 Aug. 1977	58	317	65.6	18.6	3.02	3.18	2.40	1.86	7.2
03	12	134	31.2	9.67	1.69	1.36	1.11	0.940	4.5
01 Sept. 1977	15	59.0	13.5	6.44	4.44	2.21	1.05	0.969	-
08	40	45.8	12.4	4.1	0.987	0.895	0.782	0.626	-
09	60	133	31.6	9.67	1.61	1.36	0.958	0.716	3.0
15	51	106	25.4	4.24	1.18	0.905	0.657	0.568	-
16	29	54.6	9.87	3.63	1.89	1.28	0.934	0.816	5.3
22	56	160	34.6	12.5	4.32	3.70	2.09	1.28	-
Average	425	146	30.1	8.95	2.25	2.02	1.47	1.15	5.1

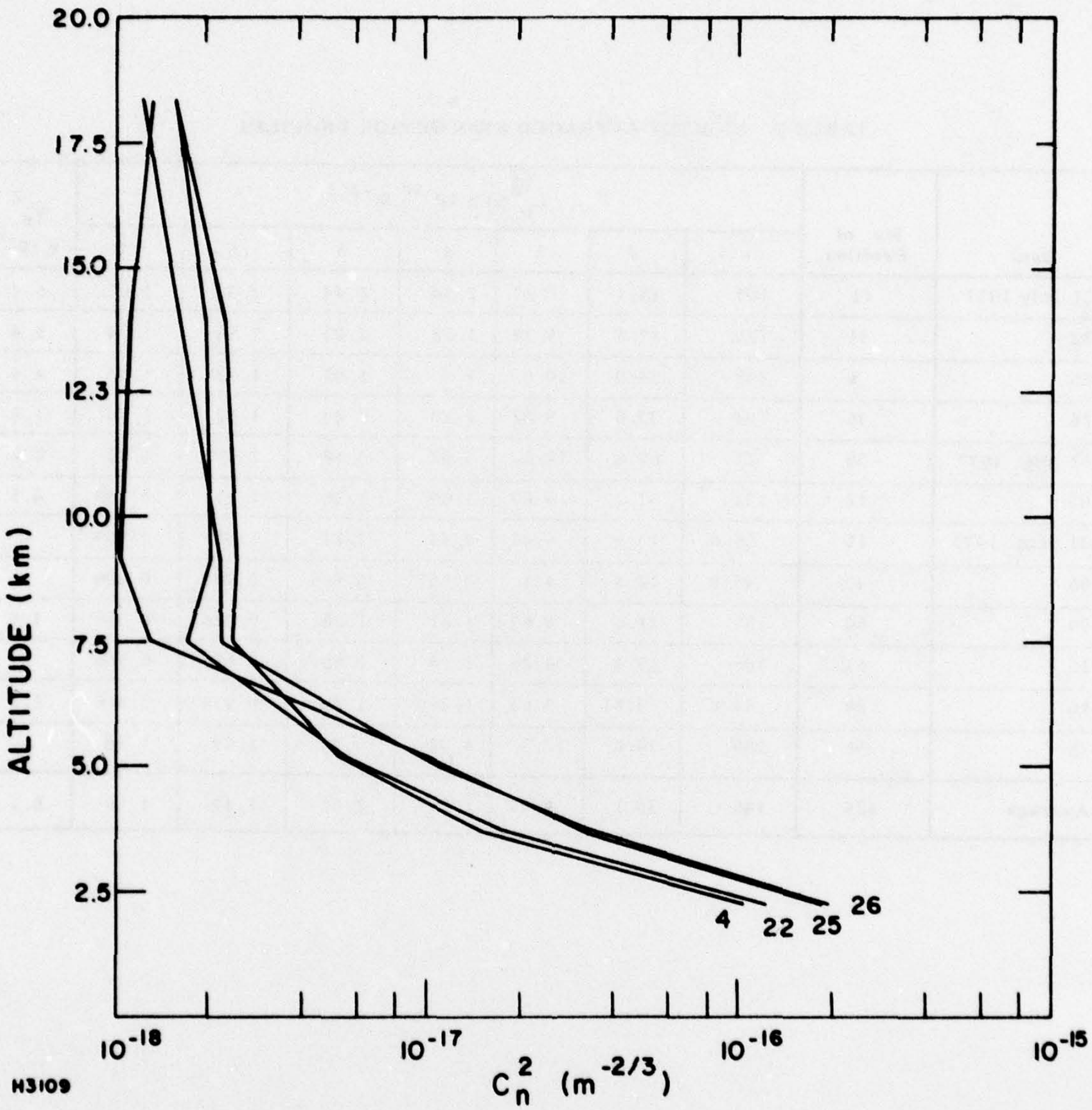

Figure 8 Nightly Averaged Star Sensor Profiles - July 1977

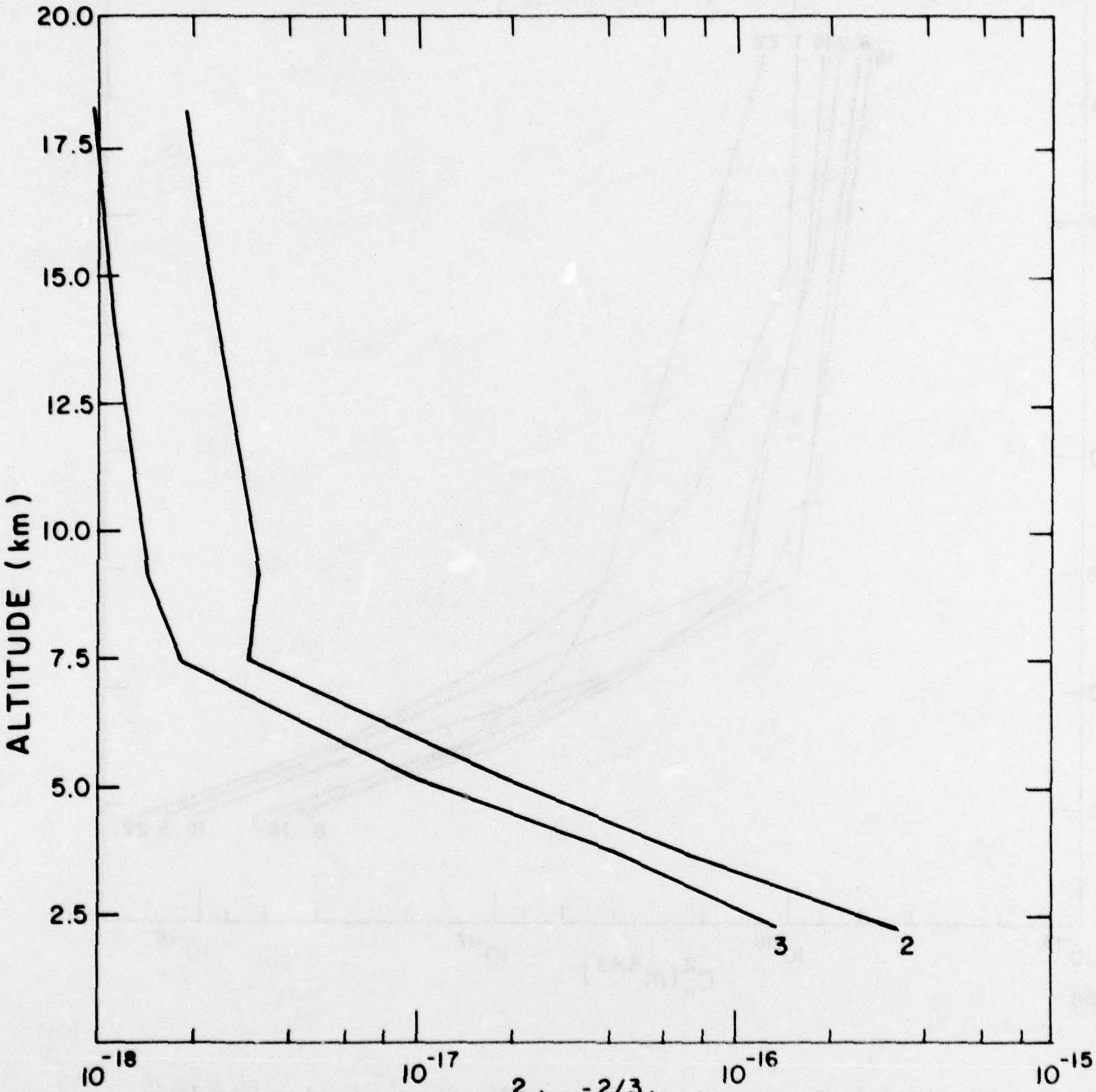

Figure 9 Nightly Averaged Star Sensor Profiles - August 1977

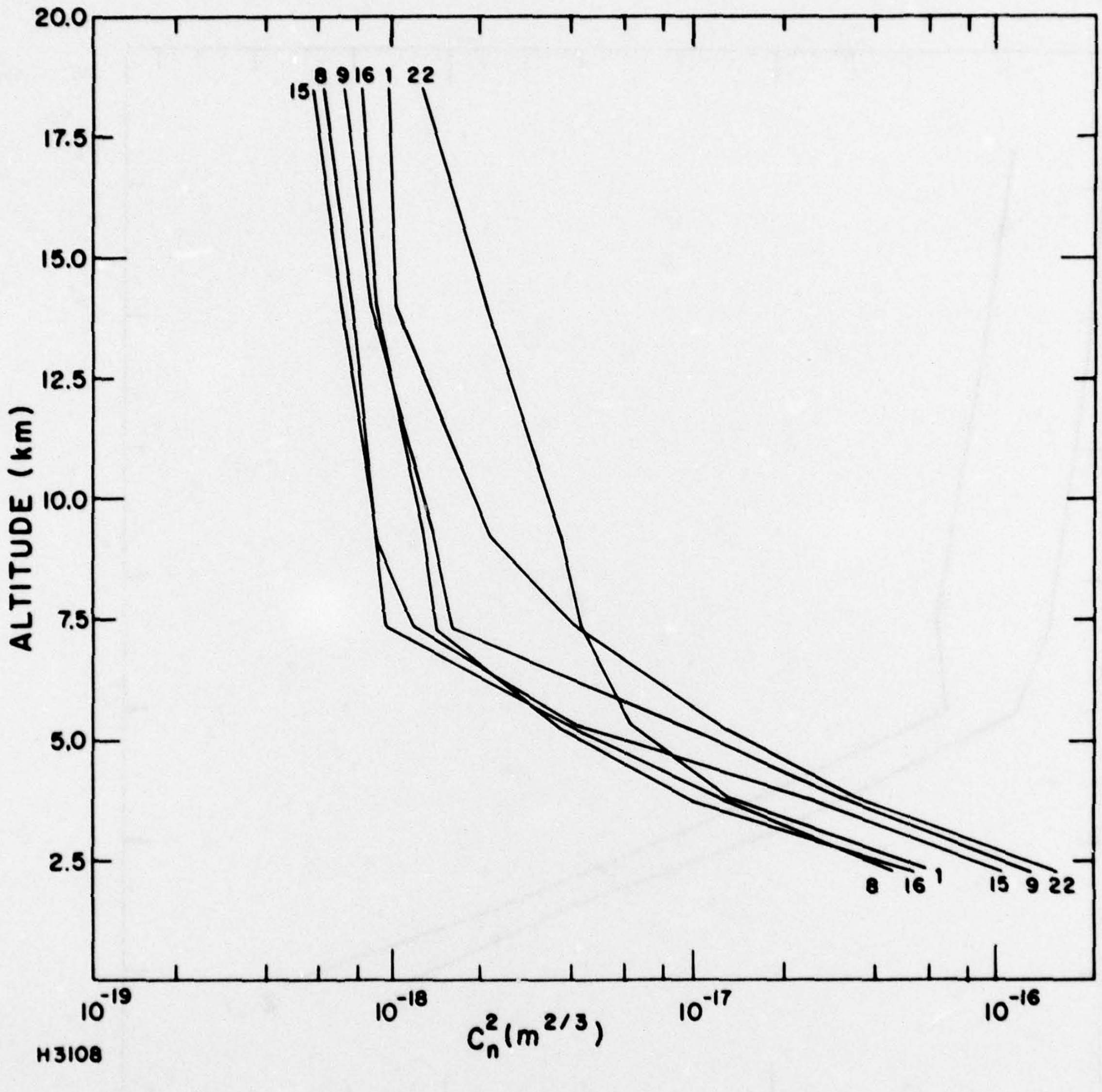

Figure 10 Nightly Averaged Star Sensor Profiles - September 1977

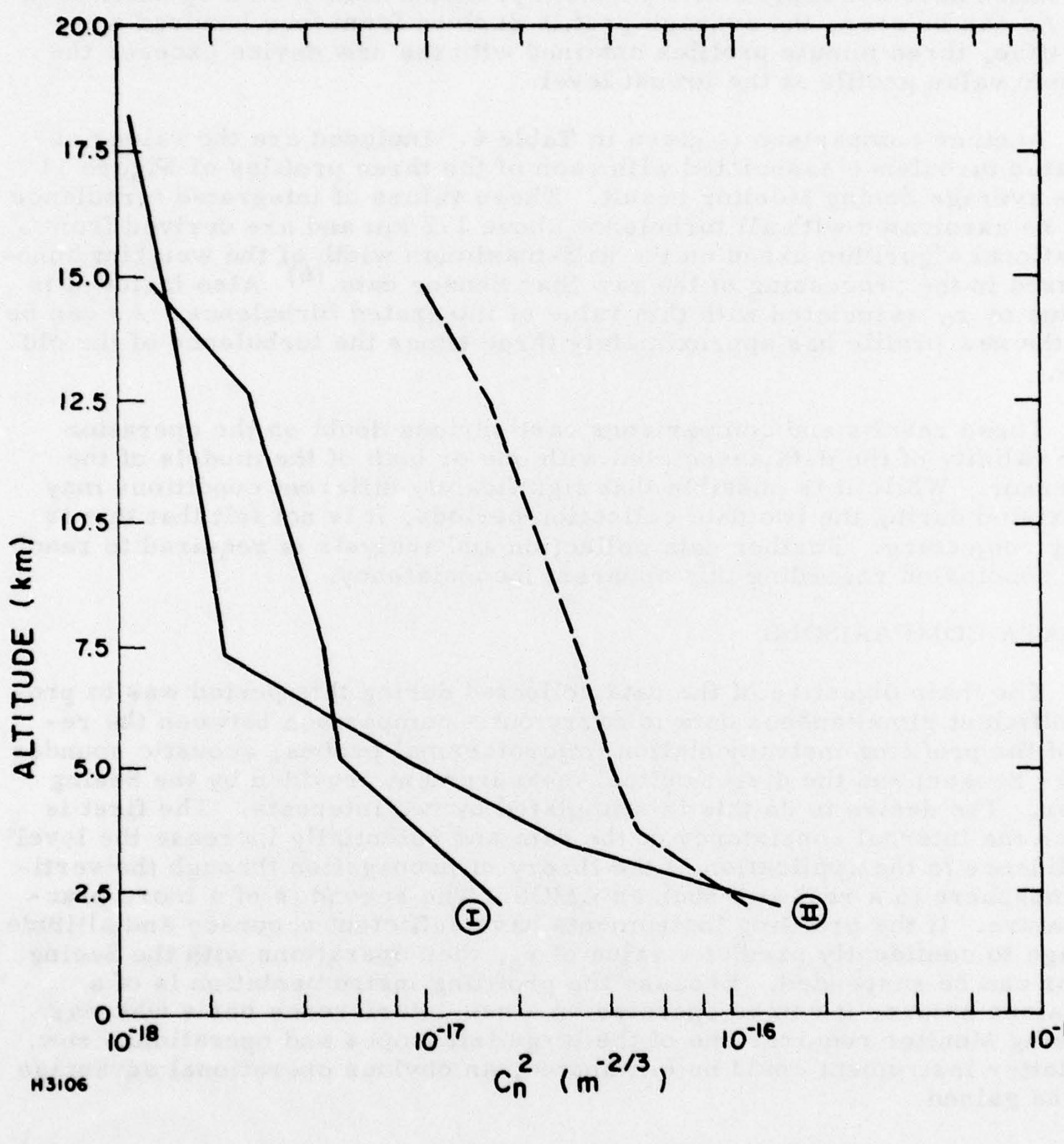

Figure 11 Average Star Sensor Profiles

above the site. The dashed line indicated the maximum value profile associated with the entire set of one hundred and sixty, twenty minute profiles taken with the first device. It was generated by taking the maximum value of C_n^2 seen at each level in the 160 samples. Therefore, it is only a mathematical result which does not represent a physical profile obtained on a specific occasion. As can be seen, the average profile derived from four hundred and twenty-five, three minute profiles obtained with the new device exceeds the maximum value profile at the lowest level.

Another comparison is given in Table 6. Included are the values of integrated turbulence associated with each of the three profiles of Figure 11 and the average Seeing Monitor result. These values of integrated turbulence should be assoicated with all turbulence above 1.2 km and are derived from a calculational algorithm based on the half-maximum width of the weighing functions used in the processing of the raw Star Sensor data.(6) Also included is the value of r_0 associated with this value of integrated turbulence. As can be seen, the new profile has approximately three times the turbulence of the old profile.

These results and comparisons cast serious doubt on the operation and/or validity of the data associated with one or both of the models of the Star Sensor. While it is possible that significantly different conditions may have existed during the two data collection periods, it is not felt that this is a likely conjecture. Further data collection and analysis is required to reach a firm conclusion regarding this apparent inconsistency.

3.4 DATA COMPARISONS

The main objective of the data collected during this period was to provide sufficient simultaneous data to carry out a comparison between the results of the profiling instrumentation (microthermal probes, acoustic sounder and Star Sensor) and the direct optical measurement provided by the Seeing Monitor. The desire to do this is stimulated by two interests. The first is to check the internal consistency of the data and potentially increase the level of confidence in the application of the theory of propagation through the vertical atmosphere to a real site such as AMOS. The second is of a more practical nature. If the profiling instruments have sufficient accuracy and altitude coverage to confidently predict a value of r_0, then operations with the Seeing Monitor can be suspended. Because the profiling instrumentation is of a stand-alone nature, it can be operated on a non-interference basis whereas the Seeing Monitor requires one of the large telescopes and operations crew. If the latter instrument could be eliminated, an obvious operational advantage would be gained.

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(6) R.S. Lawrence, private communication.

TABLE 6. INTEGRATED TURBULENCE LEVELS

Instrument	$\int C_n^2\, dz$: 10^{-13} $m^{1/3}$	r_o at 5000 Å cm
Star Sensor I - Average Profile	0.913	33.9
Star Sensor I - Maximum Value Profile	5.85	11.1
Star Sensor II - Average Profile	2.96	16.8
Seeing Monitor	7.24	9.8

The basis for this data comparison is the integrated value of turbulence from ground level to the "top" of the atmosphere. The value of r_o derived from Seeing Monitor data is related to the integrated turbulence by

$$r_o = \left[0.42\,(2\pi/\lambda)^2 \int_{path} dz\, C_n^{\,2}\,(z)\right]^{-3/5} \qquad (1)$$

Assuming a wavelength (λ) of 5000 Å yields

$$\int_{path} dz\, C_n^{\,2}\,(z) = 1.508 \times 10^{-14}\; r_o^{\,-5/3} \qquad (2)$$

where r_o is in units of meters and the integral of C_n^2 is in units of $m^{1/3}$.

NOAA has provided a simple calculational algorithm based on the half-maximum width of the weighing functions associated with the seven derived values of C_n^2. The resulting integral is appropriate for the altitude range above 1.2 km (above the site).

$$\int_{>1.2\,km} dz\, C_n^{\,2}(z) = 10^3 \Big\{ 1.4\, C_n^{\,2}(1) + 1.7\, C_n^{\,2}(2) + 2.0\, C_n^{\,2}(3) + 2.0\, C_n^{\,2}(4) + 3.2\, C_n^{\,2}(5) + 4.5\, C_n^{\,2}(6) + 4.0\, C_n^{\,2}(7) \Big\} \qquad (3)$$

The integral is again in units of $m^{1/3}$ if the values of C_n^2 are in units of $m^{-2/3}$. If the area of the weighing functions is used rather than the half-maximum width, the result is almost the same.

Because the microthermal probes yield a value of C_n^2 at a single height (18 m), a value of integrated turbulence cannot really be associated with it. In the past a path length of 10 m has been used. This is obviously only a rough approximation and really only means that it is probably not 1 m or 100 m. For this assumed 10 m path length

$$\int dz\, C_n^{\,2} = 10\, C_n^{\,2}\,(\mu T) \qquad (4)$$

where the units are the same as previously.

For a more accurate estimate of the low altitude contribution, acoustic sounder data is required. Obviously, until processed data is available, such an estimate cannot be obtained. Even when available, this data will not cover the entire altitude range up to 1.2 km (lower limit of the Star Sensor data). The maximum range of the acoustic sounder is 300 m but past experience indicates that noise often dominates the results above a height in the range of 150-200 m. Hence, the profile derived value of the integrated turbulence will not include the range from approximately 200 m up to 1.2 km.

A possible method of estimating the contribution under 300 m is to fit the slope of the combined microthermal and acoustic sounder data with a power low dependence on altitude and then integrate. For example, the data taken in August 1974[7] indicated an average slope of (-1.4). Matching the level of the power law to the microthermal result yields

$$\int_{18\ m}^{300\ m} dz\, C_n^{\ 2}(3) \simeq 30\, C_n^{\ 2}\,(\mu T) \qquad (5)$$

This result would indicate that the average behavior of the acoustic sounder and microthermal data can be associated with a layer 30 m thick of strength equal to the microthermal value. This result is obviously only an approximation which is probably not adequate for the detailed comparison desired. However, it is useful for the purpose of estimating the level of contribution to be anticipated.

Table 7 contains results for integrated turbulence levels for five selected data sets. These sets were selected for a variety of reasons, most important being the subjective judgment as to the quality of the data. Included are the average value of integrated turbulence seen by the Seeing Monitor and Star Sensor and the integrated turbulence associated with the average microthermal value for a slab of 10 m and 30 m thicknesses.

The data in this table indicates that the contribution to the total integrated turbulence for altitudes above 1.2 km ranges from 26% to 88% with four of the values under 50%. The "30 m" slab represents from 5% to 24% with four of the values under 15%. Adding the Star Sensor value to the "30 m" slab yields values from 37% to 95%. The high value is for 2 August and is almost all due to high altitudes. If these limited and rough estimates are at all representative of the results to be expected when the processed acoustic sounder data is available, one conclusion is quite obvious. The altitudes not covered by the profiling instrumentation (under 18 m and from approximately 200 m to 1.2 km) can have a significant and varied contribution to the total integrated turbulence. If this is indeed the case, additional instrumentation covering these missing altitudes will be required or else Seeing Monitor measurements will have to be continued if accurate estimates of r_o are required in the future.

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(7) D.P. Greenwood, D.O. Tarazano, D.A. Haugen, J.C. Kaimal, J. Newman, P.F. Kellen, and M.G. Miller, AMOS Seeing Quality Measurements, Rome Air Development Center In-House Tech. Report #RADC-TR-75-295 (January 1976).

TABLE 7. DATA COMPARISONS-INTEGRATED TURBULENCE

Date	Seeing Monitor $\int C_n^2\, dz \times 10^{-13}\ m^{1/3}$	Star Sensor $\int C_n^2\, dz \times 10^{-13}\ m^{1/3}$ >1.2 km	Microthermal $h\, C_n^2 \times 10^{-13}\ m^{1/3}$	
			h = 10 m	h = 30 m
21 July 1977	7.4	2.1	0.28	0.84
22 July 1977	9.0	2.3	0.32	0.96
26 July 1977	8.2	3.7	0.68	2.04
2 August 1977	7.1	6.3	0.17	0.51
3 August 1977	7.2	2.8	0.12	0.36

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6. R.S. Lawrence, private communication

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