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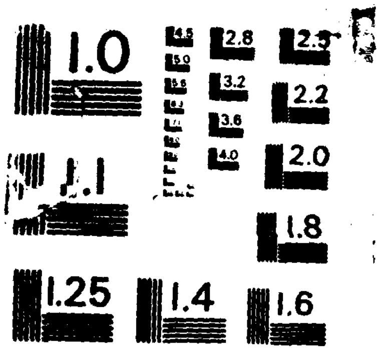
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AFGL-TR-86-0140

Development, Test and Evaluation of an Automated Present Weather Observing System

D.F. Hansen
W.K. Shubert

HSS Inc
1 Alfred Circle
Bedford, MA 01730

26 June 1986

Final Report
Period Covered: 26 May 1983 - 24 May 1986

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM, MA 01731

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A need exists for an Automated Present Weather Sensor (APWOS)for use at unmanned weather stations, or stations that are not manned on a round-the-clock basis. An APWOS has been developed by HSS Inc which utilizes a microprocessor to expand the measurement capabilities of a Model VR-301 Visibility Meter. The VR-301 is a forward-scatter nephelometer with a sample volume of 400 cm^3. The size and velocity of each particle of precipitation passing through the sample volume is measured and stored in a precipitation recognition matrix which has 20 size increments and 16

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) velocity increments. The various types of precipitation (rain, snow, drizzle, hail, etc.) are identified by pattern recognition algorithms based on the size/velocity distribution of particles. Amount of precipitation is determined from the size and number of particles passing through the sample volume in the sample time interval. The APWOS is 10 times more sensitive than a tipping bucket rain gauge, and a linear response to rain-rates up to 6 inches per hour has been demonstrated. The measuring precision is 0.001 in/hr for rain and 0.0001 in/hr for snow. Current algorithms identify rain as rain 98.8% of the time and snow as snow 92.4% of the time in the ambiguous temperature between 23°F and 41°F. The APWOS also measures visual range and can determine the presence of fog during any form of precipitation.

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PREFACE

In 1983 HSS Inc completed the development of a Laboratory Model Present Weather Observing System (APWOS) under contract to the Air Force Geophysics Laboratory (AFGL). Preliminary evaluation of the APWOS was conducted at the HSS Inc facility during the time period October 1983 to January 1984. In February 1984 the sensor was moved to the AFGL Weather Test Facility (WTF) at Otis ANBG on Cape Cod, Mass. where a full complement of meteorological sensors and a professional weather observer were on hand to provide comparison information. In 1984 AFGL exercised an option clause in their contract under which HSS Inc proceeded to fabricate a field model APWOS which was completed in January 1985, and also continued the evaluation of the HSS Inc APWOS technique. A field model APWOS was also fabricated for the Atmospheric Sciences Laboratory (ASL) of the White Sands Missile Range (WSMR) and installed at the AFGL Weather Test Facility in November 1984. The evaluation of the HSS Inc APWOS technique was then expanded to include the WSMR sensor. We wish to express our appreciation to the members of the ASL whose cooperation made possible the installation, operation and evaluation of their sensor at the Otis WTF: Mr. Gary Clayton, Mr. Robert Dickenshied, Mr. Marvin Duggan and the WSMR project technical monitor Mr. Fidel Tibuni.

Mr. Frederick Brousaides was the project technical monitor of the AFGL program under which the development and evaluation of the Automated Present Weather Sensor was performed. We express our deep appreciation to him for his unfailing support through the contract period. AFGL personnel stationed at the Otis WTF: Mr. Leo Jacobs, Mr. Ralph Hoar and Mr. Clyde Lawrence, extended the fullest possible cooperation and interest during the test and evaluation period for which we thank them.

Further, we extend our thanks to members of the HSS Inc technical staff who made invaluable contributions during the development and evaluation of the APWOS sensors: Mr. Marion Shuler, Mr. Vincent Logiudice, Mr. Albert Tuttle and Mr. Edward Goldman. To Janice Young and Patricia Henckler, our editor and typist, we give our grateful acknowlegement for their dedication and perserverance in the preparation of this document.

1.0 INTRODUCTION

1.1 Present Weather Definition

The term "Present Weather" as employed in the Federal Meteorological Handbook (Reference 1) includes a large class of atmospheric phenomena (e.g., tornadic activity, thunderstorm activity, precipitation, obstructions to vision, and "other" atmospheric phenomena such as aurora). For purposes of this program the term present weather refers to those atmospheric phenomena which are local to an Automated Present Weather Observing System (APWOS). These phenomena include: (1) all forms of liquid and frozen precipitation, e.g., rain, drizzle, snow, snow pellets, snow grains, ice pellets (formerly sleet) and hail, and (2) those suspended particles which are classed as obstructions to vision; namely, mist, fog, haze, dust and smoke.

1.2 Historical

As a result of an unsolicited proposal to the Air Force (AFGL) by HSS Inc in 1983 AFGL supported the development of an Automated Present Weather Observing System (APWOS) based on an HSS Inc invention for which patent rights are pending. The development of the first instrument was begun in July 1983 and completed in October 1983. This first APWOS was termed a Laboratory Model Instrument (as opposed to a Field Model) because it did not have an on-board microprocessor; rather it used a remotely located IBM personal computer (PC) to perform the data collection, analysis, real-time reporting functions and storage of data.

The Laboratory Model APWOS development program concluded in April 1984, but the contract had an option clause for continuing the development of the APWOS and for the conversion of an AFGL-owned VR-301 Visibility Meter into a Field Model Automated Present Weather System (i.e., a sensor system with an on-board microprocessor which analyzes the precipitation data at the end of each sample time period, sends its report to a user terminal, dumps the data and begins the process all over again).

Both the Laboratory Model APWOS and the field model APWOS were tested extensively at the AFGL Weather Test Facility (WTF) located at Otis ANGB, Ma. where they continue to operate.

A full field model APWOS, i.e., not a converted VR-301, was fabricated under separate contract to the Atmospheric Sciences Laboratory (ASL) of White Sands Missile Range (WSMR). The WSMR APWOS is capable of operating from either AC line power or from 24 VDC batteries. That instrument also underwent extensive testing at the AFGL WTF from November 1984 until December 1985. Data taken by the WSMR instrument are also included in this report.

The Air Force Geophysics Laboratory has a long-standing interest in the development of an automated present weather observing sensor to fulfill an Air Force requirement for such a sensor (or system). The reader is referred to the AFGL reports by H. Albert Brown (References 2 and 3) for an historical account of the AFGL efforts to develop a present weather observing system based on the use of an automated array of standard weather sensors coupled with a decision free computer program.

2.0 AUTOMATED PRESENT WEATHER

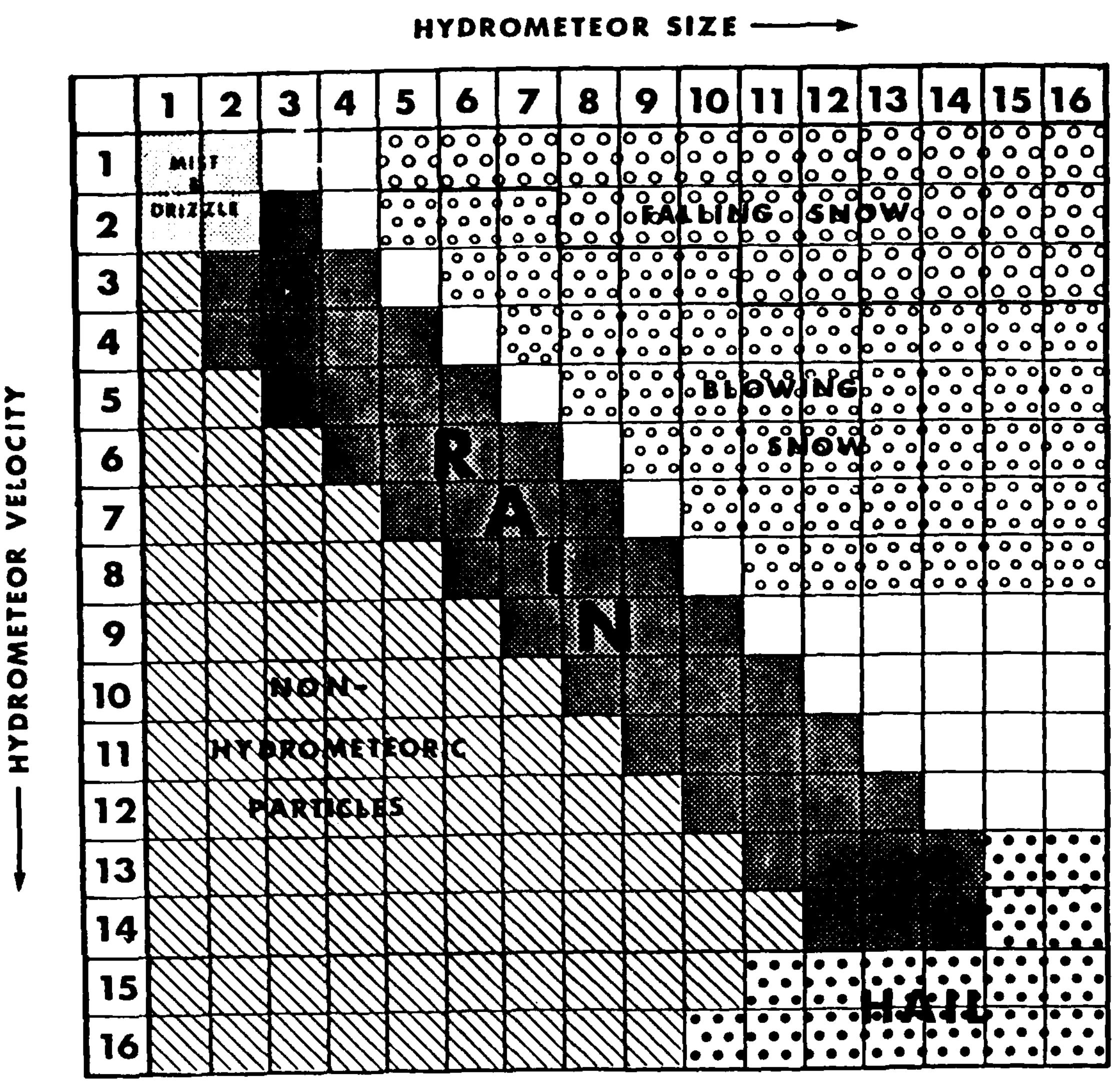
2.1 Description

The unique capabilities of the HSS Inc type of automated present weather system derives from its ability to measure the size and velocity of each precipitation particle that passes through the sample volume of the instrument. After the passage of a precipitation particle through the sample volume the size and velocity information is stored in a data matrix by the data processing system. The particle size/velocity data is collected and stored for a time interval (the sample time period) adequate to provide a statistically significant and representative sample of particle sizes and velocities.

The size/velocity measurement capability was achieved by adding a microcomputer to an HSS Inc Model VR-301 forward scatter visibility meter. The computer processes the AC waveform related to the passage of a particle through the sample volume as well as the quasi-DC information in the output signal due to the time-integrated scattering effects of all particles, both suspended and precipitating. Because the VR-301 is a visibility meter, the HSS Inc present weather system is capable of measuring the atmospheric extinction coefficient as well as the size and velocity of precipitation particles. As a result, the instrument has three unique capabilities: (1) the detection, identification and quantification of the various forms of precipitation, (2) the ability to discern whether an obstruction to vision is caused by precipitating particles or suspended particles and (3) the ability to separate the fraction of the total atmospheric extinction coefficient due to suspended particles from that due to precipitation particles. The latter two functional capabilities follow from the first; i.e., the sensor can only perform these two functions because it is fundamentally a visibility meter with the added capability of performing the precipitation measurement functions.

A size/velocity matrix is a very convenient, although not essential, presentation for identifying various forms of precipitation. For this reason we have termed such a matrix the "Precipitation Recognition Matrix". Types of precipitation are identified from their "Signature" in the Precipitation Recognition Matrix. The "Signature" is the particle size/velocity distribution that is characteristic of each type of precipitation phenomena.

An example of a precipitation recognition matrix is shown in Figure 2.1. This figure portrays a 16 x 16 matrix array of particle sizes and velocities. Sizes are arranged in columns and velocities in rows. It is further convenient, but not essential, to establish



MATRIX SCALES

COLUMNS	
NO.	Equivalent Particle Radius (mm)
1	< 0.10
2	.100 - .199
3	.200 - .399
4	.400 - .599
5	.600 - .799
6	.800 - .999
7	1.00 - 1.19
8	1.20 - 1.39
9	1.40 - 1.59
10	1.60 - 1.79
11	1.80 - 1.99
12	2.00 - 2.39
13	2.40 - 2.99
14	3.00 - 3.99
15	4.00 - 5.00
16	> 5.00

ROWS	
NO.	Particle Velocity (m/sec)
1	< .75
2	.75 - 1.49
3	1.50 - 2.99
4	3.00 - 4.49
5	4.50 - 5.49
6	5.50 - 6.49
7	6.50 - 7.29
8	7.30 - 7.79
9	7.80 - 8.19
10	8.20 - 8.59
11	8.60 - 8.79
12	8.80 - 9.19
13	9.20 - 9.39
14	9.40 - 9.49
15	9.50 - 10.00
16	> 10.00

Figure 2.1. General size/velocity characteristics of various types of precipitation displayed on on the Precipitation Recognition Matrix.

the incremental values of each column and row in the size and velocity scales from the known characteristics of rainfall because rain is the most common form of precipitation in the geographic areas where automated present weather systems are likely to be employed. The choice of particle size increments for the columns is further constrained by the requirement to provide accurate measurements of rainrate and rainfall. The choice of velocity size increments for rows is constrained by the need to discriminate the velocities of liquid particles of precipitation from those of the various forms of frozen precipitation.

The upper and lower limits to the size and velocity scales of the matrix must encompass the full range of sizes and velocities of all forms of liquid and frozen precipitation --- from the smallest particles (drizzle) to the largest (hail). Figure 2.1 presents examples of size and velocity scales based on these considerations.

Marshall-Palmer models of raindrop size distributions (Reference 4) were a convenient means for a first attempt at establishing the optimum incremental dimensions of the column size scales. Marshall-Palmer models provide the size distribution of raindrops as a function of rainrate. Rainrates from 0.25 mm/hr to 100 mm/hr were used in the determination of the incremental size groups shown in Figure 2.1 for particle sizes with radii of up to 3 millimeters. (Nature places a physical limit to the diameter of raindrops of from 5 to 6 millimeters). Rainrate measurement accuracies of one percent were set as a goal during the process of selecting the drop size increments.

The framework for the initial velocity scale was established using the Gunn-Kinzer measured velocities for raindrops in stagnant air (Reference 5). That is, the Gunn-Kinzer velocities for Row 1 were assigned to the drop sizes in Column 1; the velocities for Row 2 correspond to drop sizes in Column 2, and so on up to drop radii of 3 millimeters. The remainders of the velocity scale and size scale were chosen to encompass the more common forms of hail. Snow velocities are known to be low (of the order of 0.5 to 3 meters/sec). Thus, they overlap the velocities of very small raindrops.

If rainfall behaved in the exact manner of the Marshall-Palmer and Gunn-Kinzer models all raindrop measurements would fall in the data bins along the diagonal of the Precipitation Recognition Matrix. In practice, several factors tend to disperse the size/velocity relationship from the idealized characterizations: (1) the Marshall-/ Palmer size distribution for raindrops is only a best-fit approximation, (2) winds and wind gusts can perturb the velocity/size relationship, (3) the shape of the sample volume can significantly influence the velocity/size characteristics of particles (i.e., particles falling through a portion of the sample volume other than the center, or falling in other than a vertical direction because of wind, will exhibit slightly different velocity/size characteristics depending upon the shape of the sample volume and the direction of the wind).

For the foregoing reasons one expects raindrop counts to show up in some off-diagonal bins of the Precipitation Recognition Matrix as shown in the schematic illustration given in Figure 2.1. Indeed this conjecture is substantiated in practice. Figure 2.1 is, however, a realistic portrayal of the use of the Precipitation Matrix to identify different kinds of precipitation. The locations of various forms of precipitation which are schematically illustrated in the matrix are also borne out in practice.

Size and velocity scales shown in Figure 2.1 were considered as preliminary at the outset of the development program and subject to change if changes could be identified which would improve the identification of the various types of precipitation. Later, several changes were made in the low and high ends of both scales. Also, a dual-value matrix scheme evolved which proved to be useful: the size scale of the first matrix covered the size range up to 1.5 millimeters and thus gave better size resolution for light and medium forms of precipitation. The second matrix handled the overflow into the domain of large particles when heavy precipitation occurred. At the conclusion of the program experiments were being conducted with a single matrix which had 16 velocity increments and 23 size increments.

2.2 The Laboratory Model APWOS

The basic sensor for both versions of the APWOS is a VR-301 Visibility Meter with slightly modified electronic circuits. Details of the VR-301 Visibility Meter may be found in Appendix A. A functional electronic block diagram of the sensor head of the VR-301 is provided in Figure 2.2. The source of light is a light emitting diode (LED) that is electronically modulated at a frequency of 2 KHz. When fog or haze, without precipitation, is present in the sample volume a quasi-steady scattered light signal is generated as shown in the figure. At the output of the detector both AC and DC signals are present; the AC signal is due to the modulated source radiation scattered by the suspended particles, the DC signal is due to any ambient light which reaches the detector.

The output signals from the silicon photovoltaic detector are AC-coupled to a bandpass filter/amplifier. The DC signal level is removed in the process leaving only the AC signal due to the suspended particles. The AC signal is synchronously rectified and passed through a lowpass filter/amplifier which provides a DC analog

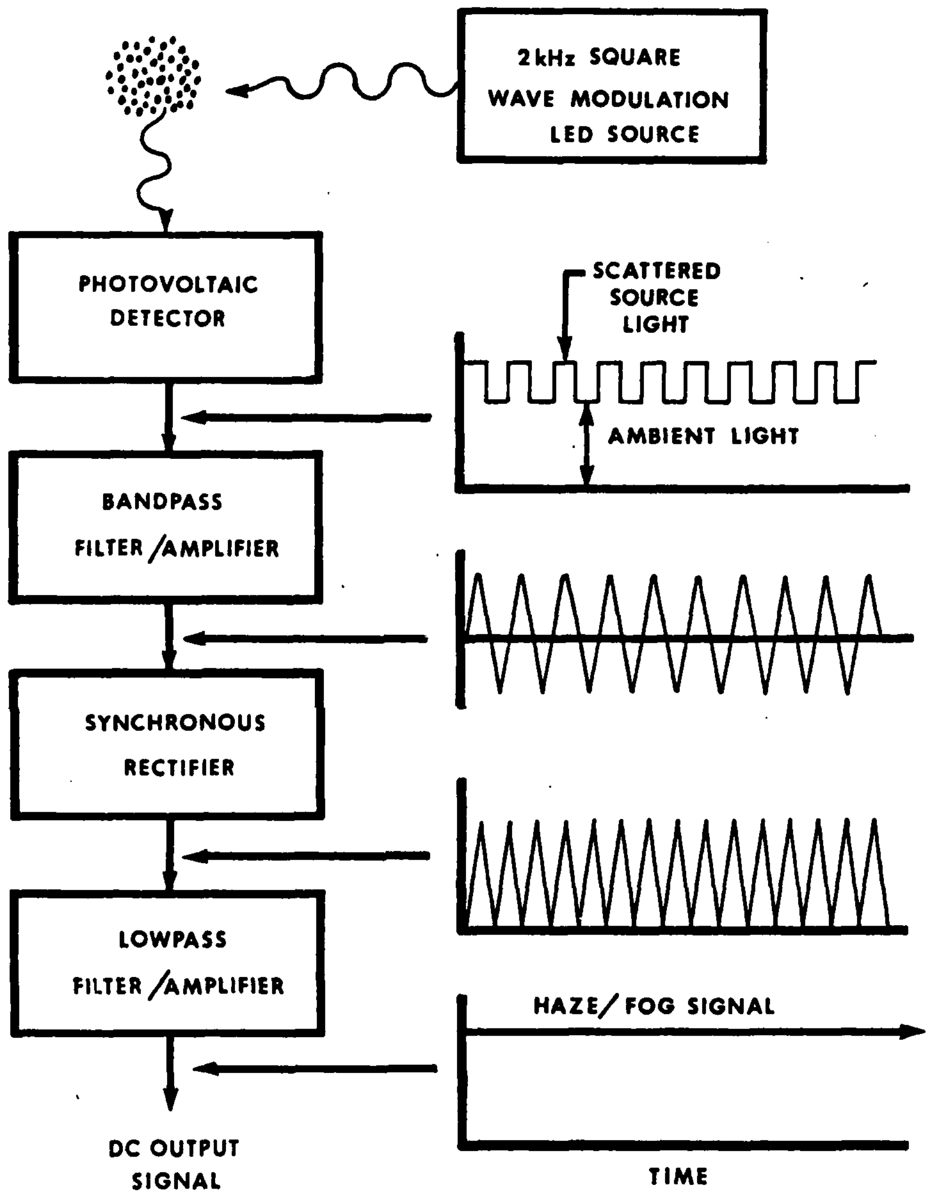


Figure 2.2. Block Diagram of the standard VR-301 Visibility Meter Signal Processing.

voltage that is proportional to the number of suspended particles in the sample volume. When properly calibrated the signal output is converted into a measurement of visual range via the atmospheric extinction coefficient.

The HSS Inc automated present weather system makes use of the AC signal which remains after the DC ambient light signal is removed; i.e., after the bandpass filter/amplifier and before synchronous rectification. Any AC signal present at this point is due to suspended particles or precipitation particles. In the case of suspended particles the AC signal has a constant peak value as illustrated in Figure 2.2. If the signal is due to particles of precipitation passing through the sample volume the signal will appear to be like those illustrated in the upper half of Figure 2.3. If fog or haze is present during precipitation the AC signals will appear as shown in the representation given in the lower half of Figure 2.3.

The VR-301 has a power/control unit through which all signals are passed on their way to the data recording/processing system. In the case of the Laboratory Model present weather system, the data processing system is comprised of an electronic interface unit fabricated by HSS Inc and an IBM PC computer as shown in Figure 2.4. The IBM-PC has since been replaced by a faster ATT Model 6300 PC because the IBM-PC could not handle the large drop rates of heavy rains whereas the ATT-PC has no problem.

From Figure 2.4 it may be seen that both the AC signal and DC signal are sent to the microcomputer via an analog multiplexer and A/D converter. Signals from a tipping bucket rain gauge and a MAWS temperature sensor are also sent to the computer via the same route. (NOTE: MAWS is an acronym for the AFGL Modular Automated Weather System).

A 12-bit A/D converter is used to digitize the analog signal from the VR-301 sensor and signals from other meteorological sensors. The multiplexer is directed by the microprocessor to continuously monitor the present weather AC signal except for a periodic momentary (once a minute or once every half minute, for example) when the atmospheric extinction coefficient signal and other meteorological sensor signals are to be sampled.

As indicated in Figure 2.4 all signals generated by the detector are processed by hardware up to and including the digitization of the DC and AC signals by the A/D converter.

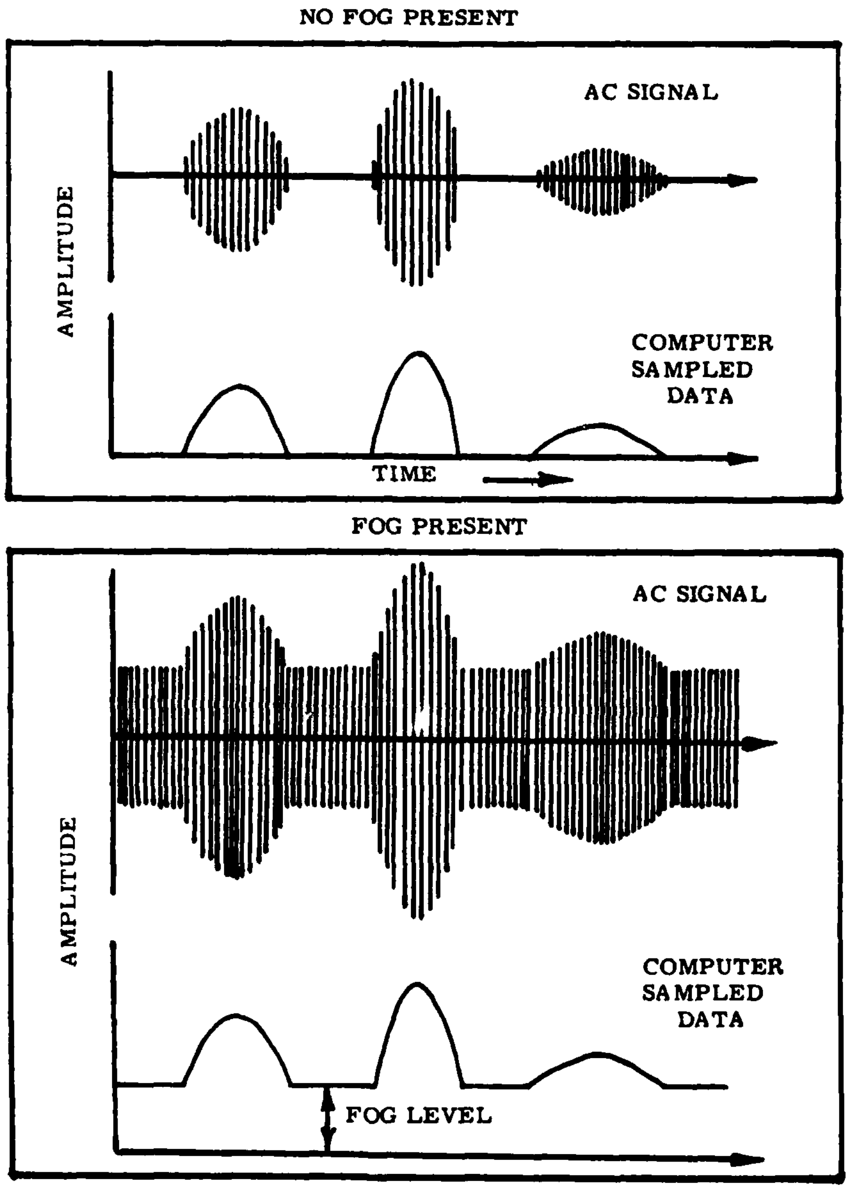


Figure 2.3. Representative signals produced by raindrops passing through the sample volume of the VR-301.

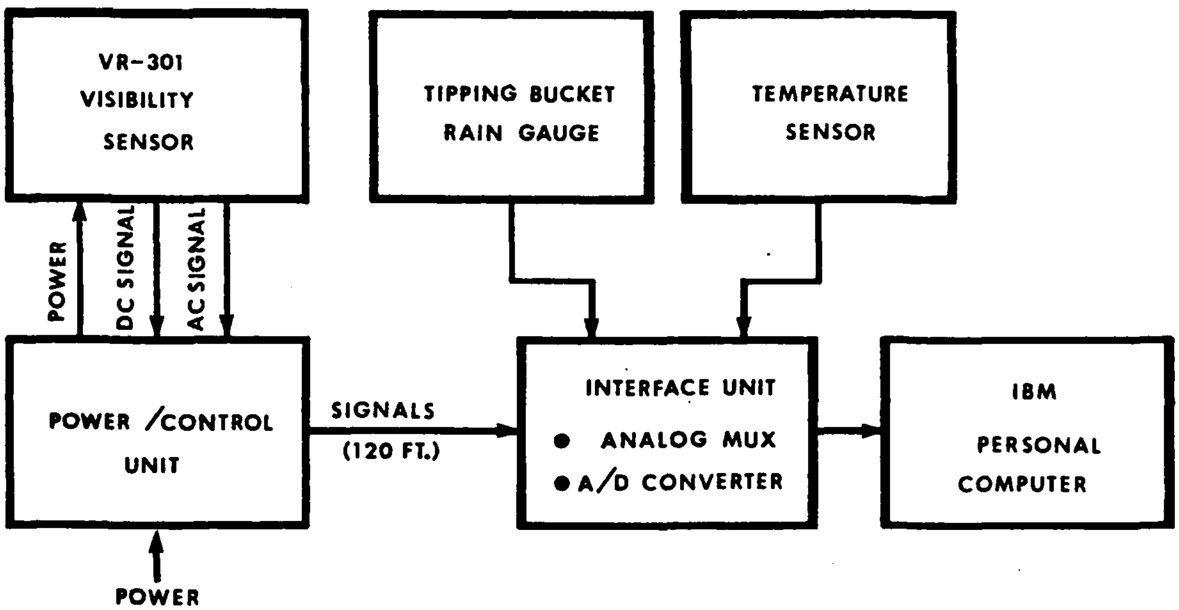


Figure 2.4. Block diagram of the Laboratory Model Automated Present Weather Observing System.

Digitization of the AC signal occurs at twice the modulation rate of the LED source. The time of digitization is governed by a sync-signal derived from the source modulator. The AC signal is digitally sampled only at the time of peak positive and negative values of the signal. After digitization all analog signals and the AC-Signal are processed by the microcomputer using software programs which are outlined in a later section of this report.

A typical automated present weather report generated by the Laboratory Model instrument is shown in Figure 2.5. In this instance, the report was produced every six minutes and consisted of the following data items:

Column 1 Date

Column 2 End Time of Sample Period

Column 3 Daytime Visual Range

Column 4 Precipitation Type and Intensity and/or Obstruction to Vision (Note: The International Visibility Code is used in classifying the obstruction to Vision; The Federal Meteorological Handbook Definitions are used to classify precipitation intensity)

Column 5 Number of Particles passing through the sample volume during the sample time period

Column 6 Number of tips of the tipping bucket rain gauge which occurred during the sample time period

Column 7 Temperature, Degrees F

Column 8 Total Atmospheric Extinction Coefficient derived from the DC analog signal of the VR-301 sensor

Column 9 The Atmospheric Extinction Coefficient due to Suspended Particles (The contribution to the total extinction coefficient by precipitation has been subtracted)

2.3 The Field Model APWOS

2.3.1 General

A functional block diagram of a Field Model Present Weather System is shown in Figure 2.6. As with the Laboratory Model instrument the AC and DC signals from the VR-301 sensor are sent to the microprocessor via an analog multiplexer and an

DATE	TIME	DAYTIME VIS RNG	PRESENT WEATHER	EVENT COUNT	RAIN TIPS	TEMP DEG F	TOTAL EXCO (1/KM)	EXCO-EVENTS (1/KM)	DISK BLOCK(S)
25 OCT 85	7 0	13 MI	VERY CLEAR	0	0	060.3	000.15	000.19	
25 OCT 85	7 6	15 MI	VERY CLEAR	0	0	060.1	000.12	000.17	
25 OCT 85	712	14 MI	VERY CLEAR	0	0	060.0	000.14	000.18	
25 OCT 85	718	11 MI	CLEAR	3	0	059.8	000.18	000.22	
25 OCT 85	724	20 MI	VERY CLEAR	0	0	059.8	000.10	000.12	
25 OCT 85	730	20 MI	VERY CLEAR	0	0	059.8	000.10	000.12	
25 OCT 85	736	14 MI	VERY CLEAR	0	0	059.8	000.14	000.16	
25 OCT 85	742	13 MI	VERY CLEAR	4	0	059.7	000.15	000.19	
25 OCT 85	748	3 MI	LT RAIN	882	0	059.5	000.54	000.41	186
25 OCT 85	754	3 MI	LT RAIN	554	0	059.3	000.60	000.51	187
DATE	TIME	DAYTIME VIS RNG	PRESENT WEATHER	EVENT COUNT	RAIN TIPS	TEMP DEG F	TOTAL EXCO (1/KM)	EXCO-EVENTS (1/KM)	DISK BLOCK(S)
25 OCT 85	8 0	7 MI	CLEAR	15	0	059.5	000.26	000.28	
25 OCT 85	8 6	5 MI	LT RAIN	253	0	059.3	000.41	000.37	188
25 OCT 85	812	1 1/4 MI	HVY RAIN	2197	2	059.2	001.51	000.97	189 190
25 OCT 85	818	3 MI	LT RAIN	449	0	059.1	000.58	000.54	191 192
25 OCT 85	824	2 1/2 MI	LT RAIN	899	1	058.8	000.71	000.51	193 194
25 OCT 85	830	1 3/8 MI	MOD RAIN	1887	1	058.5	001.40	000.78	195 196
25 OCT 85	836	5000 FT	HVY RAIN	2420	2	058.5	002.02	001.13	197 198
25 OCT 85	842	5 MI	LT RAIN	349	0	058.7	000.35	000.30	199 200
25 OCT 85	848	4 MI	LT RAIN	282	0	058.7	000.46	000.41	201 202
25 OCT 85	854	1 1/4 MI	HVY RAIN	2299	2	058.8	001.44	000.90	203 204
DATE	TIME	DAYTIME VIS RNG	PRESENT WEATHER	EVENT COUNT	RAIN TIPS	TEMP DEG F	TOTAL EXCO (1/KM)	EXCO-EVENTS (1/KM)	DISK BLOCK(S)
25 OCT 85	9 0	5 MI	LT RAIN	308	0	058.8	000.36	000.34	205 206
25 OCT 85	9 6	3 MI	LT RAIN	854	0	058.7	000.55	000.37	207 208
25 OCT 85	912	1 5/8 MI	MOD RAIN	1772	2	058.6	001.12	000.74	209 210
25 OCT 85	918	4 MI	LT RAIN	471	0	058.5	000.46	000.39	211 212
25 OCT 85	924	3 MI	LT RAIN	541	1	058.4	000.56	000.51	213 214
25 OCT 85	930	2 1/2 MI	LT RAIN	789	0	058.2	000.70	000.60	215 216
25 OCT 85	936	3 MI	LT RAIN	466	1	058.0	000.55	000.50	217 218
25 OCT 85	942	1 3/8 MI	MOD RAIN	2008	1	057.8	001.35	000.84	219 220
25 OCT 85	948	1 1/8 MI	HVY RAIN	2407	1	057.8	001.62	000.96	221 222
25 OCT 85	954	3 MI	LT RAIN	732	1	057.8	000.67	000.56	223 224
DATE	TIME	DAYTIME VIS RNG	PRESENT WEATHER	EVENT COUNT	RAIN TIPS	TEMP DEG F	TOTAL EXCO (1/KM)	EXCO-EVENTS (1/KM)	DISK BLOCK(S)
25 OCT 85	10 0	4 MI	LT RAIN	289	0	057.9	000.43	000.37	225 226
25 OCT 85	10 6	6 MI	TR RAIN	96	0	058.0	000.31	000.30	227 228
25 OCT 85	1012	9 MI	CLEAR	8	0	058.0	000.20	000.24	
25 OCT 85	1018	9 MI	CLEAR	5	0	058.1	000.21	000.25	
25 OCT 85	1024	12 MI	CLEAR	4	0	058.2	000.16	000.19	
25 OCT 85	1030	13 MI	VERY CLEAR	1	0	058.4	000.14	000.17	
25 OCT 85	1036	12 MI	CLEAR	3	0	058.3	000.16	000.19	
25 OCT 85	1042	12 MI	CLEAR	3	0	058.4	000.16	000.19	
25 OCT 85	1048	11 MI	CLEAR	1	0	058.2	000.17	000.21	
25 OCT 85	1054	11 MI	CLEAR	0	0	058.2	000.17	000.20	
DATE	TIME	DAYTIME VIS RNG	PRESENT WEATHER	EVENT COUNT	RAIN TIPS	TEMP DEG F	TOTAL EXCO (1/KM)	EXCO-EVENTS (1/KM)	DISK BLOCK(S)
25 OCT 85	11 0	12 MI	CLEAR	1	0	058.3	000.16	000.19	
25 OCT 85	11 6	11 MI	CLEAR	0	0	058.4	000.17	000.21	
25 OCT 85	1112	10 MI	CLEAR	0	0	058.3	000.19	000.22	
25 OCT 85	1118	9 MI	CLEAR	0	0	058.4	000.20	000.23	
25 OCT 85	1124	9 MI	CLEAR	0	0	058.4	000.21	000.25	
25 OCT 85	1130	8 MI	CLEAR	0	0	058.4	000.23	000.25	
25 OCT 85	1136	8 MI	CLEAR	0	0	058.3	000.24	000.26	

Figure 2.5. **An automated present weather report produced by the Laboratory Model APWOS during a brief rain episode.**

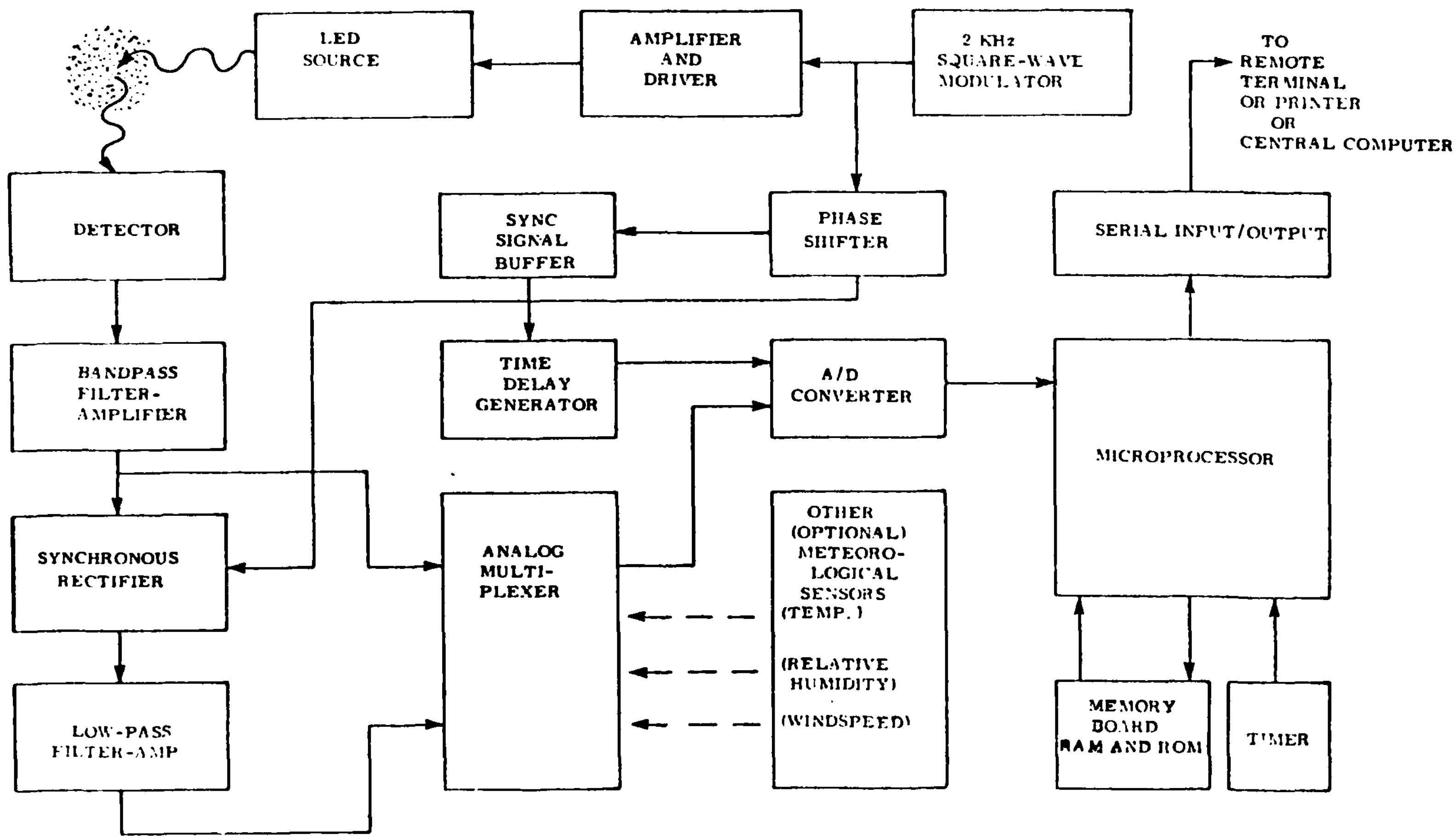


Figure 2.6. Block diagram of a Field Model Automated Present Weather Observing System.

A/D converter. In this case, however, the microprocessor is located in the control/power unit a few feet from the sensor head of the VR-301. Also installed in the control/power unit is a dedicated temperature sensor. Measurements from other meteorological sensors may also be sent to the microprocessor via the analog multiplexer and A/D converter. The microprocessor requires both RAM and ROM storage and an electronic timer. Data is collected, processed and stored by the microprocessor during each sample time period.

As before, a 12-bit A/D converter is used to digitize the analog signal from the VR-301 sensor and other meteorological sensors. The multiplexer is directed by the microprocessor to continuously monitor the present weather AC signal except for a periodic momentary interruption when the VR-301 DC signal and other meteorological sensor signals are to be sampled. Digitization of the AC signal occurs at twice the modulation rate of the LED source. The time of digitization is governed by a sync-signal derived from the source modulator. The AC signal is digitally sampled only at the time of peak positive and negative values of the signal. A minus sign is applied to the negative peak values causing the signal to be digitally rectified.

2.3.2 Digital Signal Filtering

2.3.2.1 Particle Digital Filter

The rectified AC signal is treated by three digital filters as shown in Figure 2.7. These three filters are identified as: (1) the large/fast particle filter, (2) the small/slow particle filter, and (3) the fog-tracking filter.

The function of the two particle filters is fundamentally different from that of the tracking filter. The function of the particle filters is to provide the best possible signal to noise for the particle size/velocity measurement process, with minimum introduction of error to the size and velocity measurements.

The function of the fog tracking filter is to adjust the threshold values of the two particle filters such that the value of the particle detection threshold is continuously set at a fixed amount above the quasi-steady value of the rectified AC signal produced by fog or haze.

The physical limitation to the detection of small particles by the automated present weather observing system is the noise generated within the photoelectric detector/amplifier sub-system. This noise is due to either ambient light incident on the detector during daytime, or the inherent noise of the detector during night-

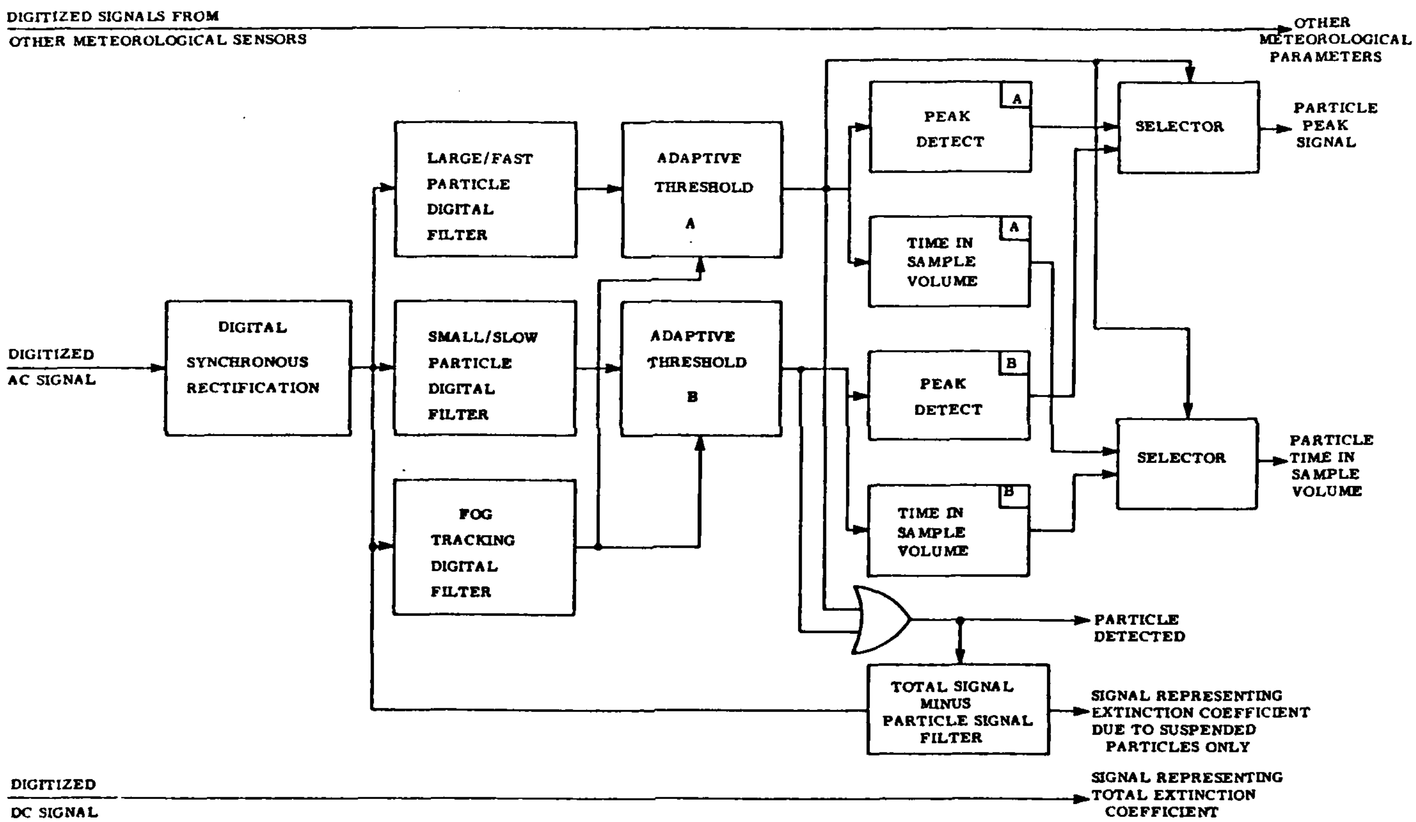


Figure 2.7. **Block diagram of the Microprocessor Computer Program for Particle Detection and Particle Sizing / Velocity Measurements.**

time. In analogy with analog filtering the noise of the detector can be minimized by narrowing the bandwidth with a digital bandpass filter. The possible penalty paid for narrowing the bandwidth is distortion of the pulse shape. In the present weather observing system distortion of the pulse shape leads to errors in the measurement of the size and velocity of precipitation particles. Size of a particle is determined by the signal pulse amplitude and velocity is determined from the pulse duration.

In a present weather observing system it is highly desirable to detect the small particles characteristic of drizzle. Drizzle particles and small raindrops are slow-moving hence a filter with narrow bandwidth can be employed for their detection and measurement. The filter intended for this purpose is labeled the Small/Slow Particle Filter in Figure 2.7. The equivalent electronic bandwidth of this filter is 0 - 40 Hz. The detection and identification of drizzle is an area which needs further attention in any follow-on development program. Large particle drizzles are detected by the present APWOS sensors, small particle drizzles are not.

It is not always the case that slow-moving particles are small. For example, most snowflakes have slow velocities. Snowflakes create signal pulses of sufficient amplitude to cross the detection threshold level of the Large/Fast Particle Filter. The selection rules on signal processing are such that if the threshold of the Large/Fast Particle Filter is crossed the size and velocity measurement of the particles are established by the A-chain of the software program (see Figure 2.7). The equivalent electronic bandwidth of the Large/Fast Particle Filter is 0 to 160 Hz. Because of its greater bandwidth this filter introduces less distortion to the signal pulses created by all naturally occurring precipitation particles. Also, because of its greater bandwidth this filter admits more noise, requiring the detection threshold to be set higher with subsequent loss of ability to detect small particles.

2.3.2.2 Fog-Tracking Digital Filter

The purpose of the fog-tracking filter is to generate a quasi-steady-state baseline for the particle detection system. When no detectable precipitation is present in the sample volume the filter retains an equivalent electronic bandwidth of approximately 5 Hz (i.e., a time constant of 0.03 seconds). This bandwidth permits the baseline of the measurement system to track variations in the AC signal due to changes in the concentration of haze and/or fog particles. Rapid variations in fog levels are accommodated by the 5 Hz bandwidth.

Whenever a precipitation particle is detected by either the A or B chains of the detection system the bandwidth of the tracking filter is switched to a narrower bandwidth. The purpose of the bandwidth change is to reduce the effect of precipitation particles on the baseline of the detection system. That is, the baseline is rendered relatively insensitive to the signals produced by precipitation particles. That is accomplished by changing the filter bandwidth to approximately 1/3 Hz, or viewed another way the response time constant of the filter is increased from 0.03 seconds to 0.50 seconds.

2.3.3 Adaptive Thresholds

The purpose of the adaptive thresholds indicated in Figure 2.7 is to discriminate between signal pulses due to precipitation particles and spikes due to noise generated within the detection process. Discrimination against noise at this early stage of the signal processing is based entirely on the amplitude of the pulses.

The adaptive filter operates by taking the output of the Fog-Tracking Filter and adding a constant value. Since there are two particle filters with differing bandwidths separate constant values are added, the constant value for Adaptive Threshold B being smaller than that for Adaptive Threshold A.

Figure 2.8 illustrates the point that not all precipitation particles are detected (small drizzle particles, for example), because their amplitude does not exceed the adaptive threshold level.

2.3.4 Peak Detect

Whenever a precipitation particle is detected the Peak Detect Routine of the software program compares the latest signal value with the previous signal value (taken 1/4000 second earlier). If the new signal value is greater than the previous value the routine adopts the new value as the maximum signal value. The process is repeated until the peak value of the rectified AC signal is found. This peak signal value is later converted to the particle size.

2.3.5 Time-In-Sample Volume

The time spent by a precipitation particle traversing the sample volume is measured by counting the number of data samples representing the rectified signal

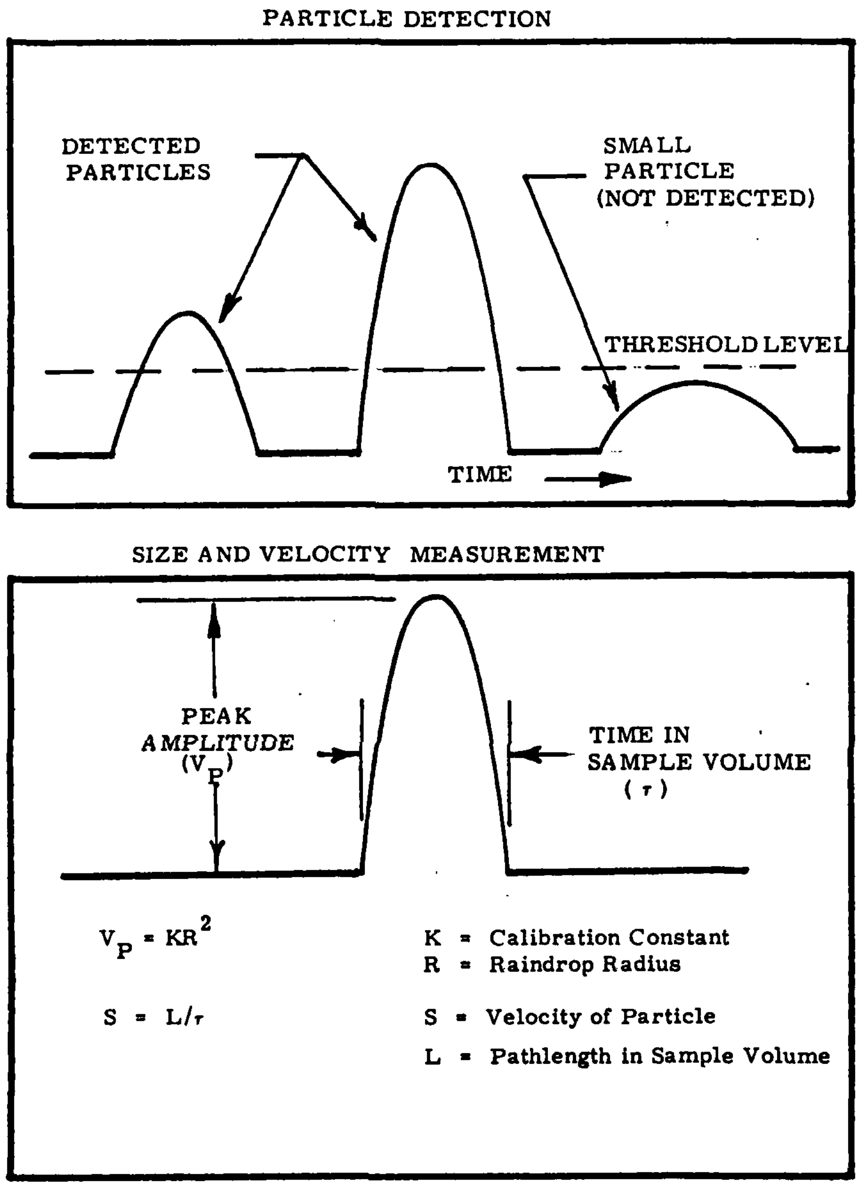


Figure 2.8. Techniques used in particle detection and particle size and velocity measurements.

pulse. A less accurate value of pulse duration is obtained by measuring the time from crossing the adaptive threshold value until the signal returns to the baseline value of the fog tracking filter. A more accurate value of the pulse duration is established by counting the number of samples from the time of occurrence of the peak value until the signal returns to the baseline value (a process which gives one-half the pulse duration) then doubling that value to obtain the entire pulse duration. This latter process assumes that the pulse shape is symmetrical about the peak value — an assumption which is borne out in practice.

2.3.6 Selectors

If a precipitation particle is detected by both Adaptive Threshold A and Adaptive Threshold B then the peak-signal-value and time-in-sample volume measured by Chain A of the software routine are adopted. Peak-signal-values and time-in-sample volumes measured by Chain B of the software routine are adopted only if Adaptive Threshold B is crossed and Adaptive Threshold A is not crossed.

2.3.7 Total-Signal Minus Particle-Signal Filter

The output of the digital synchronous rectifier is sent to the three filters, whose purpose was described earlier, plus a very narrow band (0.0053 Hz) filter whose purpose is to provide a filtered signal representing the atmospheric extinction coefficient with the effects of particles removed. To achieve this result the filter is directed by the OR-Gate, indicated in Figure 2.8, to ignore the rectified AC signal whenever either of the adaptive thresholds has detected a precipitation particle.

Figure 2.9 illustrates the method employed to separate the particulate signal from the non-particulate signal. The software routine removes the entire signal (i.e., particle signal plus haze or fog signal) during the time that the particle is in the sample volume.

In order to eliminate the signal during the entire time that the particle is in the sample volume the software routine must go backwards in time a slight amount to remove the fraction of the particle signal that precedes the crossing of the detection threshold.

The total extinction coefficient (EXCO) and the extinction coefficient minus the effects of particles (EXCO-EVENTS) are determined from an average of the signal taken every 30 seconds. In the case of the latter extinction coefficient the true

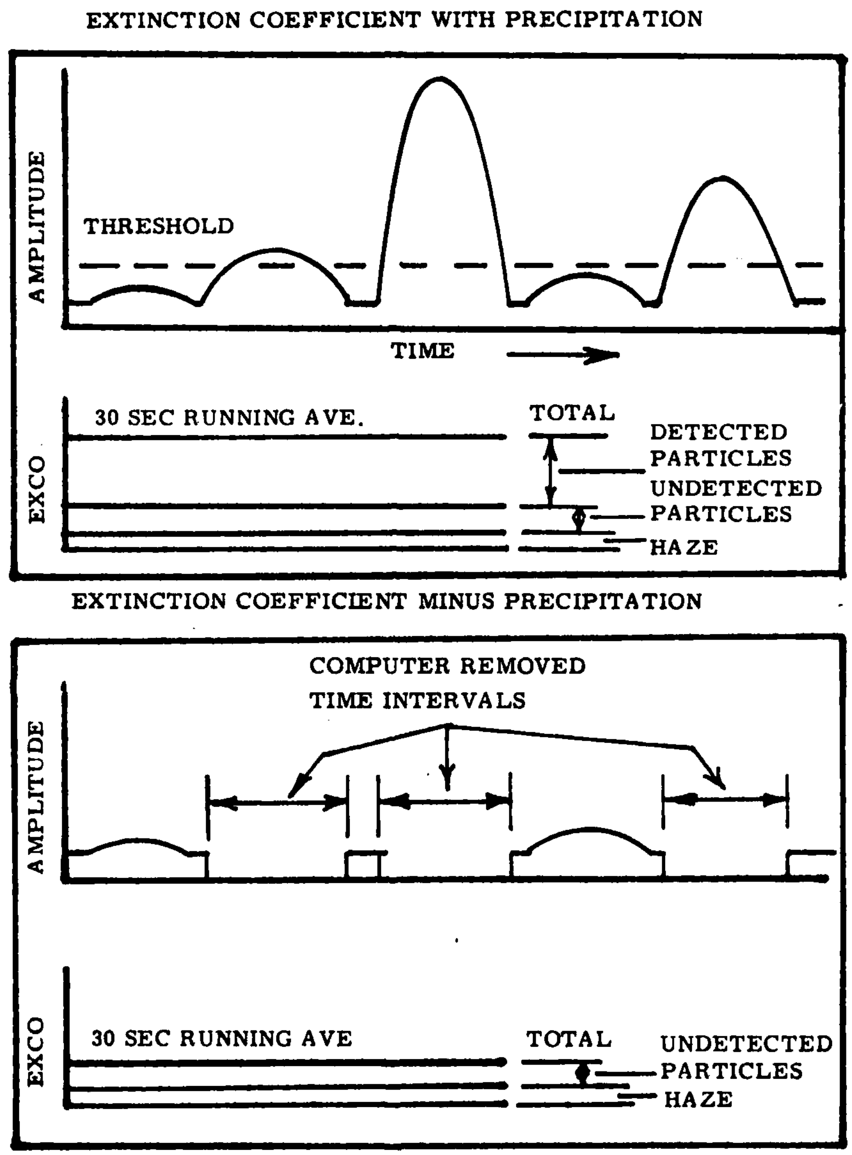


Figure 2.9. Method employed to separate particulate from non-particulate extinction coefficient.

average is obtained by summing all values of the signal remaining after the particle subtraction process and dividing by thirty seconds minus the time periods during which the particle signals were removed.

2.3.8 Particle Classification Process

The Particle Classification Process indicated in Figure 2.10 is the software routine that sorts particles of various sizes and velocities into bins as represented in the precipitation recognition matrix. The peak values are used to place particles in one of sixteen amplitude categories representing sixteen particle size groups. These groups include the smallest detectable particle to the largest particle that does not saturate the detector electronics. Similarly, time-in-sample volume values are used to categorize particle velocities in one of sixteen velocity groups.

Velocity is determined from the time-in-sample volume, using the vertical dimension of the sample volume as the distance traveled in that time.

Once the size and velocity of a particle are established the matrix bin appropriate to those values is identified and the particle number in that bin is incremented by one count.

2.3.9 Precipitation Amount Process

At the end of each sample time period (typically 1 to 6 minutes) the amount of precipitation accumulated during that time is determined.

Rainfall: The accumulated rainfall amount is determined by first calculating the water content (volume) of each detected drop and summing the volume of all drops to get the total amount of water passing through the sample volume. The final step in the process requires a knowledge of the area through which the drops fell and the application of an empirically established calibration constant.

The amplitude of the signal generated by a raindrop is proportional to the square of the drop radius. The constant of proportionality is established by allowing a water drop of known size to fall through the sample volume. The volume V of each drop is computed from a knowledge of the radius R using the following formula, and assuming a spherical shape for the drop,

$$V = \frac{4}{3}\pi R^3 \tag{1}$$

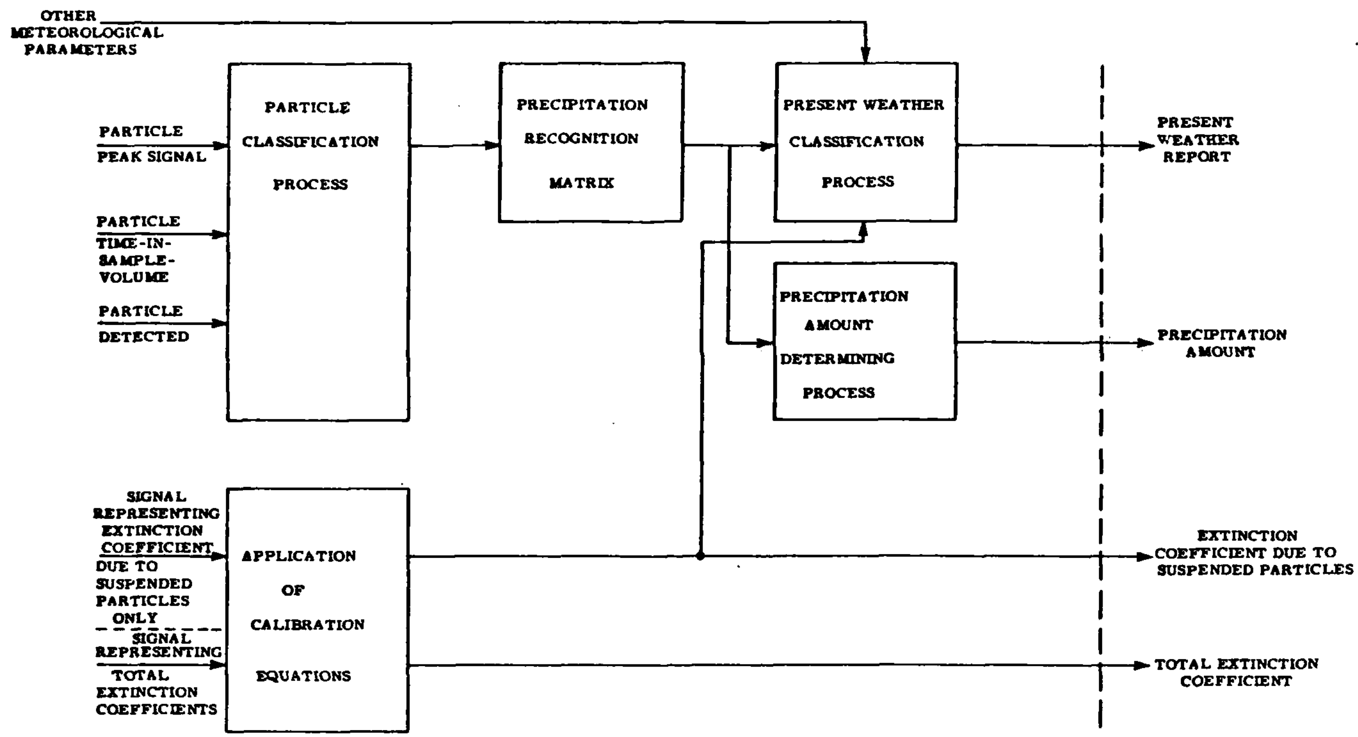


Figure 2.10. Block diagram of the Microprocessor Computer Program for generating the Present Weather Report and Other Meteorological Measurements.

The total quantity of water W falling during a given time period as given by the expression

$$W = \frac{K}{A} \sum_{R} \frac{4}{3} \pi \; R^3 . \; N(R) \qquad (2)$$

where A is the cross-sectional area of the sample volume (i.e., the area presented to the direction of rainfall) and N (R) is the number of raindrops of radius R that passed through the sample volume during the sampling time period. The constant K contains: (1) a calibration factor that is established either by comparison with an independent rain gauge or by dropping water drops of known size through the sample volume, and (2) a factor to convert the physical dimensions of the drops and cross—sectional area of the sample volume to provide the standard reporting unit for rainfall (i.e., inches of water.

Normally rainrate is reported on an hourly basis by meteorologists; i.e., inches of water per hour; rainfall accumulation is reported in 6 hour increments; i.e., 6, 12 and 24 hours. A field model present weather observing system will, in most applications, interface with a master computer which can perform and display the rainrate and rainfall accumulation data. The field model microprocessor will not normally perform the function of accumulating the amount of rainfall.

At present, the Field Model system reports only the amount of equivalent water measured during the sample time period. It would be an easy task to program the master IBM-PC computer, to which the Field Model is connected at Otis ANGB, so that 6, 12 and 24 hour rainfall reports are generated.

Snowfall: Because frozen precipitation comes in a myriad of shapes, crystalline structures and sizes there is not a direct correlation between any of the particular dimensions and signal amplitude as there is with raindrops. However, there is a distinct relationship between the amplitude of the signal pulse and that area of the particle illuminated by the transmitter which in turn scatters light toward the receiver. The distinct trend of that scattering relationship is such that the larger the particle the greater the signal amplitude produced.

Particles of frozen precipitation are "sized" by comparison with their raindrop signal equivalents. That is, a particle of frozen precipitation is arbitrarily taken to have the same size as a raindrop that produces the equivalent signal amplitude.

The rate of fall of snow or other forms of frozen precipitation is customarily measured in terms of equivalent water content as is the amount of snowfall. Before the Present Weather Observing System can determine the rate, or amount, of snowfall it must first identify the form of precipitation. The identification of particles is a process conducted by the section of the software entitled Present Weather Classification Process (see Figure 2.10).

Snowfall can be measured by the Present Weather Observing System to an accuracy of about ±20 percent using a very simple technique. The method utilizes an empirically established density factor applicable in general to all forms of snow (but not ice pellets). The value of that empirical density factor for snow has been found to be 0.1. Thus, if a given form of precipitation has been established as snow the equivalent water content is found by calculating the amount of water that has passed through the sample volume assuming spherical particles of the dimensions represented by each column of the precipitation recognition matrix then multiplying the result by the 0.1 density factor to find the equivalent water content.

A more accurate method of determining the equivalent water content of frozen precipitation requires that its basic form be established (i.e., snow, snow pellets, snow grains or ice pellets). An empirically determined density factor can then be established for each form of frozen precipitation. In principle, the various forms of frozen precipitation can be determined from the particle size/velocity distribution in the precipitation recognition matrix.

A similar approach can also be applied to mixed forms of precipitation (i.e., liquid/frozen or combinations of frozen precipitation). In principle, these mixed forms can be identified by their size/velocity distributions. An empirically established density factor for each type of mixed form can then be applied to determine the water content as for the case of pure snow.

Although snowflakes are easily identified by the APWOS some work remains in the area of identification of the other forms of frozen precipitation and in the areas of mixed precipitation. Small granular particles of snow (e.g., snow grains, snow pellets) fall at velocities faster than snowflakes. As a result, these types of particles can be misidentified as light rain. Ice pellets, when they fall, are invariably mixed with rain; but both forms of precipitation fall at approximately the same velocity. Techniques must be explored for identifying this and other forms of mixed precipitation. Also, techniques must be explored for identifying ice pellets alone and hail. Hail occurs so infrequently that simulation of hail offers an attractive alternative for the development of hail identification algorithms.

2.3.10 Present Weather Classification Process

The present weather classification process consists of a series of algorithms for identifying the type of precipitation plus a group of weather reporting codes.

The algorithms, which are empirically established from studies of precipitation recognition matrices taken during all forms of precipitation, are used to: (1) identify the type of precipitation based on the particle/velocity distribution in the matrix array, and (2) to discriminate against any false signals which may have exceeded the filter thresholds. Again, false signals are identified by the distribution of the "apparent sizes" and velocities of the "particles" developed in the precipitation recognition matrix.

Weather reporting codes are used to describe the type and intensity of precipitation whenever precipitation is present and also to identify the obstruction to vision and its general strength (e.g., heavy fog) when precipitation is not present. The reporting codes presently in use in the automated present weather observing system are drawn from a combination of U.S. National Weather Service reporting codes and an International Visibility Code as shown in Table 2.1.

When precipitation and fog are both present the algorithms separate the total extinction coefficient into its two components, i.e., that which is due to precipitation and that which is due to fog. The present weather report then states that both precipitation and fog are present (e.g., Light Rain + Fog).

2.3.11 Field Model Present Weather Report

A typical Field Model present weather report is shown in Figure 2.11. Also shown are entries from the AFGL weather observer's report. The significant differences between this report and the Laboratory Model report are as follows: first, the amount of precipitation accumulated during each sample time period (6 minutes) is reported (see Column 7 which has the misleading title of rainrate) and secondly: there is no tipping bucket input to the report as there is in the Laboratory Model report.

Whenever snow is identified by the Field Model instrument the density factor of one-tenth is applied in the calculation of accumulated amount of precipitation as is done by the Laboratory Model instrument.

Table 2.1. Various Reporting Codes Employed with the Automatic Present Weather Monitoring System.

(A) INTERNATIONAL VISIBILITY CODE

Daytime Visual Range	Obstruction to Vision	Extinction Coefficient (km^{-1})
< 50 m	Dense Fog	>60
50 - 200 m	Thick Fog	60 - 15
200 - 500 m	Moderate Fog	15 - 6. 0
500 -1000m	Light Fog	6. 0 - 3. 0
1 - 2 km	Thin Fog	3. 0 - 1. 5
2 - 4 km	Haze	1. 5 - 0. 75
4 -10 km	Light Haze	0. 75- 0. 30
10 -20 km	Clear	0. 30- 0. 15
20 -50 km	Very Clear	0. 15-0. 06
>50 km	Exceptionally Clear	<0. 06

(B) INTENSITY OF RAINFALL

Classification	Rate-of-Fall (inches per hour)
Trace	Less than 0. 005
Light	Trace to 0. 10
Moderate	0. 11 to 0. 30
Heavy	More than 0. 30

(C) INTENSITY OF SNOWFALL

Classification	Visual Range (statute miles)
Light	More than 5/8
Moderate	5/16 to 5/8
Heavy	Less than 5/16

HSS PRESENT WEATHER SYSTEM

TIME mody	hrmi	INST NO	REP INT	VISUAL RANGE MILES	WEATHER AND/OR OBSTRUCTION	RAIN RATE INCHES	AIR TEMP F	TOTAL OF EVENTS	TOTAL EXTINCTN COEF	EXTINCTN COEF LESS EVENT
513	3	2	6	1.76	HAZE	0.0000	47.8	1	1.06	1.06
513	15	2	6	1.86	HAZE	0.0000	47.7	0	1.00	1.00
513	21	2	6	2.12	HAZE	0.0000	47.8	0	0.88	0.88
513	27	2	6	2.30	HAZE	0.0000	47.8	0	0.81	0.81
513	33	2	6	2.96	LIGHT HAZE	0.0000	47.7	0	0.63	0.63
513	39	2	6	3.06	LIGHT HAZE	0.0000	47.9	0	0.61	0.61
513	45	2	6	3.01	LIGHT HAZE	0.0000	48.0	0	0.62	0.62
513	51	2	6	3.21	LIGHT HAZE	0.0000	48.0	0	0.58	0.58
513	57	2	6	3.39	LIGHT HAZE	0.0000	48.1	0	0.55	0.55
513	103	2	6	2.87	LIGHT HAZE	0.0000	48.0	0	0.65	0.65
513	109	2	6	2.87	LIGHT HAZE	0.0000	48.0	0	0.65	0.65
513	115	2	6	2.87	LIGHT HAZE	0.0000	48.2	0	0.65	0.65
513	121	2	6	2.91	LIGHT HAZE	0.0000	48.2	0	0.64	0.64
513	127	2	6	2.55	LIGHT HAZE	0.0000	48.1	0	0.73	0.73
513	133	2	6	2.82	LIGHT HAZE	0.0000	47.8	0	0.66	0.66
513	139	2	6	3.06	LIGHT HAZE	0.0000	47.8	0	0.61	0.61
513	145	2	6	2.96	LIGHT HAZE	0.0000	47.8	0	0.63	0.63
513	151	2	6	2.82	LIGHT HAZE	0.0000	47.8	0	0.66	0.66
513	157	2	6	2.52	LIGHT HAZE	0.0000	47.8	1	0.74	0.74
513	203	2	6	2.78	TR RAIN	0.0001	47.8	33	0.67	0.67
513	209	2	6	3.01	LIGHT HAZE	0.0000	47.8	15	0.62	0.62
513	215	2	6	2.91	LIGHT HAZE	0.0000	47.8	2	0.64	0.64
513	221	2	6	2.96	LIGHT HAZE	0.0000	47.8	0	0.63	0.63
513	227	2	6	2.66	LIGHT HAZE	0.0000	47.8	0	0.70	0.71
513	233	2	6	2.39	HAZE	0.0000	47.8	1	0.78	0.78
513	239	2	6	2.27	HAZE	0.0000	47.8	9	0.82	0.82
513	245	2	6	2.00	TR RAIN	0.0001	47.8	78	0.93	0.93
513	251	2	6	1.65	TR RAIN	0.0011	47.6	808	1.13	1.04
513	257	2	6	1.21	LT RAIN	0.0076	47.4	2516	1.54	1.17
513	303	2	6	0.94	MOD RAIN	0.0135	47.4	3097	1.98	1.30
513	309	2	6	1.00	MOD RAIN	0.0123	47.4	3229	1.86	1.21
513	315	2	6	1.26	LT RAIN	0.0096	47.4	2346	1.48	1.03
513	321	2	6	1.08	LT RAIN	0.0078	47.5	2800	1.72	1.11
513	327	2	6	1.42	LT RAIN	0.0028	47.6	1244	1.31	1.10
513	333	2	6	1.74	TR RAIN	0.0009	47.8	705	1.07	0.98
513	339	2	6	1.86	TR RAIN	0.0005	47.8	427	1.00	0.94
513	345	2	6	1.47	LT RAIN	0.0024	47.8	1584	1.27	1.05
513	351	2	6	1.14	LT RAIN	0.0031	47.8	2151	1.64	1.26
513	357	2	6	1.52	LT RAIN	0.0018	48.0	1270	1.23	1.04
513	403	2	6	2.22	TR RAIN	0.0011	48.1	747	0.84	0.75
513	409	2	6	3.06	TR RAIN	0.0002	48.2	180	0.61	0.59
513	415	2	6	3.58	TR RAIN	0.0003	48.2	218	0.52	0.49
513	421	2	6	3.88	TR RAIN	0.0006	48.2	415	0.48	0.43
513	427	2	6	4.78	TR RAIN	0.0001	48.2	99	0.39	0.38
513	433	2	6	5.65	LIGHT HAZE	0.0000	48.2	10	0.33	0.33
513	439	2	6	6.90	CLEAR	0.0000	48.2	3	0.27	0.27
513	445	2	6	6.66	TR RAIN	0.0001	48.2	51	0.28	0.26
513	451	2	6	6.90	CLEAR	0.0000	48.2	0	0.27	0.27
513	457	2	6	3.73	TR RAIN	0.0001	48.1	46	0.50	0.49
513	503	2	6	3.06	TR RAIN	0.0002	48.1	176	0.61	0.59
513	509	2	6	1.07	LT RAIN	0.0034	48.2	2322	1.74	1.25
513	515	2	6	1.32	LT RAIN	0.0019	48.2	1468	1.41	1.15
513	521	2	6	1.38	LT RAIN	0.0016	48.2	1169	1.35	1.12
513	527	2	6	1.02	LT RAIN	0.0052	48.3	2775	1.82	1.14
513	533	2	6	2.07	TR RAIN	0.0011	48.6	850	0.90	0.75
513	539	2	6	2.96	TR RAIN	0.0001	48.7	62	0.63	0.61
513	545	2	6	5.04	LIGHT HAZE	0.0000	48.7	1	0.37	0.37
513	551	2	6	2.63	LT RAIN	0.0019	48.7	774	0.71	0.57
513	557	2	6	1.66	TR RAIN	0.0014	48.8	1093	1.12	0.94
513	603	2	6	2.66	TR RAIN	0.0001	49.0	83	0.70	0.67
513	609	2	6	3.45	LIGHT HAZE	0.0000	49.1	15	0.54	0.54
513	615	2	6	2.78	TR RAIN	0.0014	49.3	716	0.67	0.55
513	621	2	6	1.10	LT RAIN	0.0069	49.6	2901	1.78	0.94
513	627	2	6	1.78	LT RAIN	0.0027	49.6	1293	1.05	0.77
513	633	2	6	1.26	LT RAIN	0.0042	49.8	2480	1.48	0.94
513	639	2	6	2.42	TR RAIN	0.0006	50.0	401	0.77	0.68
213	645	2	6	3.01	LIGHT HAZE	0.0000	50.3	1	0.62	0.62
513	651	2	6	3.66	LIGHT HAZE	0.0000	50.5	0	0.51	0.51
513	657	2	6	3.27	LIGHT HAZE	0.0000	50.8	0	0.57	0.57
513	703	2	6	2.70	LIGHT HAZE	0.0000	51.1	5	0.69	0.69
513	709	2	6	2.78	LIGHT HAZE	0.0000	51.3	0	0.67	0.67
513	715	2	6	2.05	HAZE	0.0000	51.6	24	0.91	0.91
513	721	2	6	0.96	LT RAIN	0.0018	51.7	1115	1.94	1.70
513	727	2	6	0.64	LT RAIN+FOG	0.0064	51.9	1486	2.93	2.42
513	733	2	6	0.59	TR RAIN+FOG	0.0002	52.2	179	3.14	3.11
513	739	2	6	0.32	MOD RAIN+FOG	0.0260	52.2	4173	5.84	4.10
513	745	2	6	0.51	MOD RAIN	0.0167	52.2	3399	3.68	2.22
513	751	2	6	1.00	LT RAIN	0.0060	52.5	1621	1.87	1.38
513	757	2	6	1.71	LT RAIN	0.0029	52.6	1176	1.09	0.83
513	803	2	6	3.73	LIGHT HAZE	0.0000	52.8	11	0.50	0.50
513	809	2	6	2.66	TR RAIN	0.0005	53.0	420	0.70	0.63
513	815	2	6	2.07	TR RAIN	0.0010	53.1	702	0.90	0.81
513	821	2	6	2.17	TR RAIN	0.0003	53.2	246	0.86	0.83
213	827	2	6	0.26	HVY RAIN	0.0477	53.5	2443	7.05	2.67
513	833	2	6	0.38	MOD RAIN	0.0292	53.5	3276	4.95	3.19
513	839	2	6	0.84	LT RAIN	0.0106	53.6	2073	2.22	1.50
513	845	2	6	1.47	LT RAIN	0.0047	53.8	1282	1.27	1.01
513	851	2	6	1.90	LT RAIN	0.0029	53.9	652	0.98	0.83
513	8201	2	6	1.36	LT RAIN	0.0069	54.2	1109	1.37	1.06
513	903	2	6	1.74	LT RAIN	0.0052	54.8	1089	1.07	0.81
513	909	2	6	2.78	TR RAIN	0.0003	55.3	165	0.67	0.65
513	915	2	6	2.78	TR RAIN	0.0001	55.8	44	0.67	0.66
513	921	2	6	3.11	LIGHT HAZE	0.0000	57.2	10	0.60	0.60
513	927	2	6	2.82	LIGHT HAZE	0.0000	59.2	12	0.66	0.66
513	933	2	6	2.36	HAZE	0.0000	60.2	5	0.79	0.78
513	939	2	6	2.17	HAZE	0.0000	60.8	4	0.86	0.86
513	945	2	6	1.74	HAZE	0.0000	60.9	3	1.07	1.07
513	951	2	6	1.23	THIN FOG	0.0000	61.4	3	1.51	1.51
513	957	2	6	0.99	THIN FOG	0.0000	61.4	3	1.89	1.88
513	1003	2	6	0.94	THIN FOG	0.0000	61.1	2	1.99	1.99
513	1009	2	6	0.64	THIN FOG	0.0000	60.8	18	2.90	2.90
513	1015	2	6	0.55	TR RAIN+FOG	0.0001	60.5	35	3.36	3.34
513	1021	2	6	0.47	TR RAIN+FOG	0.0003	60.2	47	3.96	3.94
513	1027	2	6	0.36	TR RAIN+FOG	0.0003	59.5	195	5.13	5.06
513	1033	2	6	0.33	TR RAIN+FOG	0.0004	59.2	283	5.66	5.56
513	1039	2	6	0.33	TR RAIN+FOG	0.0003	58.7	263	5.69	5.59
513	1045	2	6	0.31	TR RAIN+FOG	0.0003	58.7	180	6.09	5.98
513	1051	2	6	0.30	TR RAIN+FOG	0.0003	58.4	208	6.21	6.15
513	1057	2	6	0.32	TR RAIN+FOG	0.0004	58.3	282	5.91	5.80
513	1103	2	6	0.31	TR RAIN+FOG	0.0004	58.3	270	5.96	5.86
513	1109	2	6	0.29	TR RAIN+FOG	0.0005	57.9	298	6.38	6.24
513	1115	2	6	0.29	TR RAIN+FOG	0.0003	58.0	224	6.48	6.39
513	1121	2	6	0.32	TR RAIN+FOG	0.0002	58.2	192	5.81	5.74
513	1127	2	6	0.33	TR RAIN+FOG	0.0003	58.3	184	5.63	5.56

Figure 2.11. Realtime Automated Present Weather Observations reported by the WSMR Field Model PW-402 at Otis ANGB during eleven hours on the morning of 13 May 1985 that included a Rain/Fog episode.

3.0 PRECIPITATION RECOGNITION MATRICES

3.1 Algorithm Development

Once the Laboratory Model APWOS was operational the task of developing the software algorithms began. Algorithms were needed for: (1) precipitation identification, (2) rate of precipitation (i.e., amount of water or water equivalent falling during the sample time period), (3) false alarm discrimination, and (4) the identification of fog in the presence of precipitation.

The Rate of Precipitation algorithms are rather straightforward as indicated in Section 2.3.9 of this report. However, their proper application requires that the type of precipitation be correctly identified. The identification of precipitation type was greatly aided by gathering and studying large numbers of Precipitation Recognition Matrices taken during precipitation episodes. In a similar manner, false alarm algorithms were derived from a study of matrices for which "particles" were detected, but for situations when an observer could definitely report that there was no precipitation.

Most of the algorithm development occurred during the time when the Laboratory Model instrument was the only operating present weather sensor. When the Field Model present weather sensors become operational the algorithms developed for the laboratory model instrument were incorporated verbatim into the field model instruments. Subsequently, from time-to-time the algorithms were modified to improve the performance of the instruments.

3.2 Large Scale Matrices

Figures 3.1 and 3.2 present precipitation recognition matrices for a light snow and a light rain episode respectively. The particle size scale of these two matrices, extending from radii of 244 microns to radii of 4472 microns (.244 to 4.472 millimeters), represents the larger of the dual-scale matrix approach. Early in the development program this particle size scale was the only scale used with the matrices. However, during light precipitation episodes approximately half of the matrices went unused as is the case of the matrices shown in Figures 3.1 and 3.2. This situation eventually led to the addition of an expanded scale matrix.

The particle velocity scale of the matrices has units of centimeters per second and extends from 0.30 to 20.00 meters per second in fifteen rows with an additional row provided for observing "particles" in the velocity range from 20 to 99.99 meters

PRESENT WEATHER DATA MATRIX - PWDC Version 00.22

30 JAN 84 Block No.: 218 End: 2205 Duration: 05 (min)
Tip bucket count: 00000 Drop total: 376
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
00203 02042 00160 00000 00000
Minute readings X1 chan: 00190 00239 00244 00185 00156
Minute readings X1 chan(no drops): 00146 00218 00190 00114 00134

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	244 387	387 460	460 548	548 651	651 775	775 921	921 1096	1096 1303	1303 1549	1549 1842	1842 2191	2191 2605	2605 3098	3098 3685	3685 4472	4472 --	ROW SUM
30- 66	55	14	10	4	1	1	0	0	1	0	0	0	0	0	0	0	86
66- 106	-81	-37	-18	-16	4	2	3	0	0	1	0	0	0	0	0	0	162
106- 134	27	15	8	10	-3	1	-1	1	0	0	0	0	0	0	0	0	66
134- 168	16	6	3	1	0	-3	0	0	0	0	0	0	0	0	0	0	29
168- 210	10	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	13
210- 262	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	6
262- 326	4	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	8
326- 410	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
410- 516	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
516- 640	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
640- 800	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
800-1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000-1230	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1230-1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL-SUM	197	77	42	35	10	7	5	1	1	1	0	0	0	0	0	0	
PROB-DENS	4592	3515	1590	1132	268	159	95	16	13	11	0	0	0	0	0		

Figure 3.1. DATA MATRIX DURING A LIGHT SNOW OCCURRENCE

PRESENT WEATHER DATA MATRIX - PWDC Version 00.22

04 FEB 84 Block No.: 218 End: 0240 Duration: 05 (min)
Tip bucket count: 00000 Drop total: 942
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
00100 01008 00070 00000 00000
Minute readings X1 chan: 00058 00053 00073 00112 00205
Minute readings X1 chan(no drops): 00050 00046 00042 00086 00126

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	244 387	387 460	460 548	548 651	651 775	775 921	921 1096	1096 1303	1303 1549	1549 1842	1842 2191	2191 2605	2605 3098	3098 3685	3685 4472	4472 --	ROW SUM
30- 66	38	5	7	8	5	1	1	0	0	0	0	0	0	0	0	0	65
66- 106	52	9	8	6	3	1	0	1	0	0	0	0	0	0	0	0	80
106- 134	44	4	2	8	2	4	1	1	0	0	0	0	0	0	0	0	66
134- 168	53	8	0	8	2	2	1	1	0	0	0	0	0	0	0	0	75
168- 210	-75	13	8	4	6	5	2	0	0	0	0	0	0	0	0	0	113
210- 262	77	17	11	4	5	0	0	0	0	0	0	0	0	0	0	0	114
262- 326	63	-31	21	-12	5	4	0	0	0	0	0	0	0	0	0	0	136
326- 410	30	33	-23	18	-11	-6	2	-1	0	0	0	0	0	0	0	0	124
410- 516	7	20	15	12	9	8	-5	2	0	0	0	0	0	0	0	0	78
516- 640	4	13	11	7	7	5	0	0	-2	0	0	0	0	0	0	0	49
640- 800	3	8	7	4	2	0	0	0	0	0	0	0	0	0	0	0	24
800-1000	2	4	4	0	1	0	1	0	0	0	0	0	0	0	0	0	12
1000-1230	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1230-1600	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-3333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL-SUM	452	167	117	91	58	36	13	6	2	0	0	0	0	0	0	0	
PROB-DENS	10536	7625	4431	2944	1559	821	247	96	27	0	0	0	0	0	0		

Figure 3.2. DATA MATRIX FOR A LIGHT RAIN OCCURRENCE.

per second. Events falling into this latter category represent either particles passing through the outer fringes of the sample volume or false particles generated by noise spikes or sun glints. It is highly unlikely that any particles of natural precipitation would have true velocities as great as those represented by this last row of the matrix.

The median velocity particle in each column is represented by a minus sign in front of that group of particles which includes the particle with median velocity. The median velocity represents that velocity for which fifty percent of the particles have a higher velocity and fifty percent have a lower velocity. The velocity of the median particle in each column is extremely valuable as an indicator of the type of precipitation. This fact is borne out by the two matrices shown in Figures 3.1 and 3.2.

The matrix displayed in Figure 3.1 presents the size/velocity distribution of 375 snowflakes which fell through the sample volume during the five minute time period ending at 2205 on 30 January 1984. The median velocity of particles in all columns is low (0.66 to 1.68 meters per second) and indicative of snow — which the algorithms properly identified.

The matrix displayed in Figure 3.2 presents the size/velocity distribution of 942 raindrops which fell through the sample volume of the laboratory sensor during the five minute sample time period ending at 0240 on 4 February 1984. The median velocity of the raindrops ranged from 1.68 meters per second for the smallest drops to 6.4 meters per second for the largest drops. This velocity distribution is clearly indicative of rain which the algorithms also correctly identified.

3.3 Expanded Scale Matrices

3.3.1 Rain and Snow Episodes

In this section we shall examine several matrices for which the size-scale has been expanded while the velocity scale remains unchanged. For these matrices the fifteenth size column has a maximum particle radius value 1.304 millimeters. Any particles with radii greater than 1.304 millimeters are placed in the sixteenth size column. If any particles show up in the sixteenth column of the expanded sale matrix then the large scale matrix for all of the particles detected during the sample time period is also recorded.

Figure 3.3 shows an expanded scale matrix recorded for a very light rainfall. Only 268 raindrops passed through the sample volume during the five minute sample

PRESENT WEATHER DATA MATRIX - PWDC Version 01.00

```
24 FEB 84        Block No.: 162        End: 0605        Duration: 05 (min)
Tip bucket count: 00000               Drop total:   268
                          VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN)  (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
  0029      00281          00019                      00000     00000
Minute readings X1 chan:               00024 00034 00024 00029 00034
Minute readings X1 chan(no drops): 00018 00022 00018 00018 00022
```

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	250 350	350 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1036	1036 1196	1196 1304	1304 --	ROW SUM
30- 66	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
66- 106	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4
106- 134	4	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	7
134- 168	7	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9
168- 210	31	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	44
210- 262	17	6	2	1	0	2	1	0	0	[illegible]	0	0	0	0	0	0	29
262- 326	-22	-12	6	1	3	1	0	1	0	0	1	0	0	0	0	0	47
326- 410	17	8	-5	-9	1	1	-2	-3	2	0	0	0	0	0	0	0	48
410- 516	6	5	6	4	-7	-2	1	1	-1	0	0	0	0	0	0	0	33
516- 640	6	3	1	3	1	1	0	1	0	1	0	1	0	0	0	0	18
640- 800	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
800-1000	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1000-1230	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1230-1600	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
COL-SUM	141	48	21	20	13	7	6	6	3	1	1	1	0	0	0	0	
PROB-DENS	4700	2222	1842	1550	962	466	370	338	156	46	43	40	0	0	0		

Figure 3.3. DATA MATRIX FOR A LIGHT RAIN OCCURRENCE

time period. Median particle velocities ranged from 2.6 to 5.2 meters per second, indicative of rain which the algorithms correctly identified.

An expanded scale matrix for a moderate rainfall occurrence is shown in Figure 3.4. A total of 1811 raindrops fell through the sample volume in the five minute time period. Median velocities ranged from 2.6 to 6.4 meters per second. In contrast to this matrix of a moderate rainfall is the matrix for a moderate snowfall with a comparable number of particles (1754) shown in Figure 3.5. In the snowfall episode median particle velocities ranged from a maximum of 1.7 meters per second down to 0.66 meters per second with the smaller particles in general falling faster than the larger particles. This latter behavior differs distinctly from the rainfall behavior where larger particles always fall faster than slower particles. Another obvious difference between rainfall and snowfall can be illustrated by the two matrices shown in Figures 3.4 and 3.5; that is, the particle size distribution. Rainfall has a very large number of small drops with a sharp falloff in the number of particles vs. size. For a moderate rainfall the drops seldom reach a size of 1.3 millimeter radius. Snowfall also has a large number of small particles, but after the initial (slower) falloff there is a long plateau-like behavior. Furthermore, for a moderate snowfall there are many particles with "sizes" larger than 1.3 millimeters in radius.

To illustrate the difference in the rate of size-falloff between a moderate rainfall and a moderate snowfall we note that in Figure 3.4 one-half of all the raindrops may be found in the first two columns of the matrix, whereas five columns of the matrix in Figure 3.5 are required to encompass one-half of all the snowflakes.

3.3.2 Frozen and Mixed Forms of Precipitation

As we have seen, pure rainfall and pure snowfall are clearly identifiable by the distinguishing characteristics of their particle size and velocity distributions. Frozen forms of precipitation other than snowflakes manifest some of the velocity characteristics of rain which makes this identification a greater challenge. These other forms of frozen precipitation; namely, snow pellets, snow grains, ice pellets and hail have aerodynamic shapes which permit them to fall faster than snowflakes. Depending upon their physical density and size some of these particle types fall as fast or faster than rain drops, e.g., ice pellets and hail; while the other forms, snow pellets and snow grains, have velocity characteristics midway between those of pure rain and pure snow.

Large hail particles are known to have velocities greater than those of raindrops.

PRESENT WEATHER DATA MATRIX - PWDC Version 01.00

24 FEB 84 Block No.: 226 End: 0920 Duration: 05 (min)
Tip bucket count: 00001 Drop total: 1811
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
00097 00975 00040 00000 00000
Minute readings X1 chan: . 00102 00078 00092 00112 00102
Minute readings X1 chan(no drops): 00048 00039 00039 00039 00035

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	250 350	350 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1096	1096 1196	1196 1304	1304 --	ROW SUM
30- 66	11	5	2	2	3	3	4	2	2	0	0	0	0	0	0	0	34
66- 106	36	15	5	5	2	1	2	2	1	0	0	0	0	0	0	0	69
106- 134	24	14	5	3	3	4	1	2	2	1	0	0	0	0	0	0	59
134- 168	40	12	5	12	5	2	3	1	3	0	1	1	1	0	0	0	86
168- 210	58	28	9	6	11	11	4	3	4	2	0	0	0	0	0	0	136
210- 262	84	28	11	11	8	4	8	7	4	2	0	1	0	0	0	0	168
262- 326	-111	-51	23	18	13	12	8	10	2	1	1	0	1	0	0	0	251
326- 410	94	31	21	-25	18	20	7	8	7	2	1	1	2	0	0	0	237
410- 516	47	29	-35	30	-20	-30	-22	-22	-14	-5	2	0	-3	0	0	0	259
516- 640	29	50	38	25	34	22	21	26	13	9	-4	-3	1	1	0	0	276
640- 800	21	23	15	18	9	12	7	5	0	1	4	0	0	0	0	0	115
800-1000	26	9	6	2	4	2	1	1	0	0	0	0	0	0	0	0	51
1000-1230	12	0	2	3	1	0	0	0	0	0	0	0	0	0	0	0	18
1230-1600	35	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	37
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
COL-SUM	643	296	178	160	131	123	88	89	52	23	13	6	8	1	0	0	
PROB-DENS	21433	13703	15614	12403	9703	8200	5432	5028	2708	1079	570	240	293	33	0		

Figure 3.4. DATA MATRIX FOR A MODERATE RAIN OCCURRENCE.

PRESENT WEATHER DATA MATRIX - PWDC Version 00.20

22 DEC 83   Block No.: 291   End: 1200   Duration: 05 (min)
Tip bucket count: 00002   Drop total: 1754
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
00575 05840 00125 00000 00000
Minute readings X1 chan: 00522 00595 00620 00517 00620
Minute readings X1 chan(no drops): 00078 00154 00138 00106 00150

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	200 387	387 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1036	1036 1196	1196 1304	1304 --	ROW SUM
30- 66	78	27	23	25	30	29	30	35	21	28	15	19	12	16	8	28	424
66- 106	90	33	29	29	17	-36	-23	-13	13	-19	15	-18	-10	-5	-14	22	386
106- 134	68	-20	-13	-16	-16	15	8	14	-10	10	-9	6	5	7	4	-16	237
134- 168	-52	12	8	7	14	8	6	6	7	7	7	8	5	5	6	15	173
168- 210	47	13	11	7	7	16	7	7	5	4	13	9	3	2	5	17	173
210- 262	48	6	4	11	3	4	6	2	3	3	0	3	2	3	1	5	104
252- 326	42	8	7	6	12	7	5	1	5	3	3	2	1	2	0	5	109
326- 410	20	9	6	4	4	2	3	2	1	2	1	1	1	0	0	1	57
410- 516	21	1	1	2	2	1	3	1	1	2	0	1	1	0	2	1	40
516- 640	8	1	2	3	5	2	1	4	1	2	1	0	0	0	0	0	30
640- 800	2	2	3	1	3	0	1	0	0	0	1	1	0	0	0	0	14
800-1000	1	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	7
1000-1230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1230-1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL-SUM	477	133	109	113	114	120	93	85	67	80	65	68	40	40	40	110	
PROB-DENS	8502	12666	9561	8759	8444	8000	5740	4802	3489	3755	2850	2730	1465	1333	1234		

Figure 3.5. DATA MATRIX FOR A MODERATE SNOW OCCURRENCE

Large hail particles are known to have velocities greater than those of raindrops. It is this characteristic that we hope to eventually utilize for the identification of hail. Ice pellets (sleet) will require concentration on characteristics other than the velocity distribution for their identification. Snow pellets and snow grains with velocities intermediate between pure rain and pure snow are expected to be identified with a high probability of certainty when new algorithms are implemented. As of now, they are recognized as snow with only a fair degree of accuracy.

Mixed forms of precipitation also present an identification challenge. Figure 3.6 displays the matrix of a mixed precipitation episode; in this case, wet snow mixed with sleet (ice pellets). It is not difficult to attribute certain of the characteristics to snow; e.g., the slow velocities of the large particles and the unmistakable plateau in the size distribution. The characteristic which is unlike that of pure snowflakes is the high velocity of the small particles. Clearly, the development of algorithms for identification of this form of mixed precipitation will not be a difficult task.

Mixed forms of precipitation although not rare are invariably brief and almost always occur during a transition from higher to lower temperatures or vice versa. A catalog of mixed precipitation occurrences is required to provide a solid foundation for the development of their identification algorithms. The key to this catalog, however, is a trained weather observer on hand and fully alert to the brief times that such episodes occur.

3.3.3 Drizzle

One form of liquid precipitation sometimes confused with snow by the current algorithms is drizzle. The reason for the confusion is obvious, if one studies the matrix displayed in Figure 3.7. Here we see that the median particle velocities are quite low, falling into the velocity domain customarily attributable to snowflakes.

The current algorithms attempt to identify drizzle as rain vs. snow or precipitation primarily on the basis of the median particle velocity. For that reason they sometimes misidentify drizzle as snow. New algorithms under development, but not fully implemented at the conclusion of the present program rely more heavily on particle size distribution for the identification of drizzle as rain. A high probability of achieving correct identifications is expected when those algorithms are fully implemented as may be inferred from a study of the matrix in Figure 3.7. When drizzles are recorded they, almost without exception, have an extremely rapid fall-off in particle size distribution. Note that for this matrix in which 1235 particles were

PRESENT WEATHER DATA MATRIX - PWDC Version 00.22

10 JAN 84 Block No.: 285 End: 2340 Duration: 05 (min)
Tip bucket count: 00000 Drop total: 2275
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
00423 04357 00096 00000 00000
Minute readings X1 chan: 00444 00425 00434 00434 00410
Minute readings X1 chan(no drops): 00082 00110 00090 00102 00098

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	244 387	387 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1096	1096 1196	1196 1304	1304 --	ROW SUM
30- 66	14	3	4	5	5	14	16	23	17	16	18	9	2	7	1	0	154
66- 106	22	11	17	20	21	29	25	34	28	26	19	5	2	3	4	2	268
106- 134	33	8	12	12	16	17	31	24	24	13	13	12	1	3	-2	1	222
134- 168	33	10	16	15	8	19	20	25	-24	14	-7	8	5	-3	1	-4	212
168- 210	37	27	25	21	24	-28	-22	-21	15	-16	10	-8	-5	5	0	1	265
210- 262	35	-14	15	-15	-22	25	25	23	14	14	14	6	2	4	0	0	228
262- 326	-70	23	-23	24	19	20	26	18	25	19	9	7	4	1	1	0	289
326- 410	47	8	22	15	15	15	13	16	9	12	9	4	1	2	0	3	191
410- 516	59	14	15	19	11	9	8	9	9	8	0	6	2	0	0	1	170
516- 640	20	8	16	8	8	7	14	6	7	6	4	4	1	0	1	0	110
640- 800	11	6	10	5	9	7	10	8	6	2	3	2	1	0	0	0	80
800-1000	8	5	7	6	10	6	5	5	1	1	1	0	1	1	0	0	57
1000-1230	5	2	2	1	0	0	1	1	0	0	0	0	0	0	0	0	12
1230-1600	5	2	2	2	3	1	1	1	0	0	0	0	0	0	0	0	17
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL-SUM	399	141	186	168	171	197	217	214	179	147	107	71	27	29	10	12	
PROB-DENS	9300	13428	16315	13023	12666	13133	13395	12090	9322	6901	4692	2851	989	966	308		

Figure 3.6. DATA MATRIX FOR A MIXED WET SNOW AND SLEET OCCURRENCE

PRESENT WEATHER DATA MATRIX - PWDC Version 01.00

17 FEB 84 Block No.: 218 End: 0850 Duration: 05 (min)
Tip bucket count: 00000 Drop total: 1235
VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN) (X1 CHAN NO DROPS) [AC CHAN: NO DROPS-INCL DROPS]
0281 02846 00229 00000 00000
Minute readings X1 chan: 00293 00273 00278 00273 00288
Minute readings X1 chan(no drops): 00231 00223 00231 00227 00235

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	250 350	350 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1096	1096 1196	1196 1304	1304 --	ROW SUM
30- 66	113	67	18	11	4	1	1	0	0	0	0	0	0	0	0	0	215
66- 106	155	43	-15	-7	1	0	1	0	0	0	0	0	0	0	0	0	222
106- 134	115	-29	6	4	-1	-1	-1	0	0	0	0	0	0	0	0	0	157
134- 168	-82	36	9	3	2	0	0	0	0	0	0	0	0	0	0	0	132
168- 210	86	22	5	3	1	0	0	0	0	0	0	0	0	0	0	0	117
210- 262	77	21	4	0	0	0	0	0	0	0	0	0	0	0	0	0	102
262- 326	81	21	4	2	0	0	0	0	0	0	0	0	0	0	0	0	108
326- 410	57	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	64
410- 516	44	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
516- 640	22	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29
640- 800	15	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	17
800-1000	12	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
1000-1230	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1230-1600	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9399	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
COL-SUM	867	261	63	30	9	2	3	0	0	0	0	0	0	0	0	0	
PROB-DENS	28900	12083	5526	2325	666	133	185	0	0	0	0	0	0	0	0		

Figure 3.7. DATA MATRIX FOR A DRIZZLE OCCURRENCE; IDENTIFIED AS SNOW BY THE CURRENT ALGORITHMS.

detected two-thirds of the particles were recorded in Column 1. Also, note that no plateau in the size-distribution is present, another indication that the type of precipitation responsible for this matrix was liquid rather than snow.

Another observation about drizzles that should be noted is that not all forms of drizzle are detected by the present configuration of the automated present weather sensor. When particles in the drizzle all have radii smaller than 0.25 millimeter the drizzle goes undetected. We have noted that when such an episode occurs the amount of water accumulated during the entire episode is negligible. A tipping bucket rain gauge for example, never registers a single tip. HSS Inc plans to improve the particle detection capability of the Present Weather sensor by increasing its signal-to-noise ratio. This will be accomplished mainly by substituting a more powerful LED for the present light source.

3.3.4 False Alarms Discrimination

Several types of phenomena, both natural and man-made, produce pulses of light that may exceed the discrimination threshold of the system. Among these are sunglints from windshields, flying insects, flashing lights and detector noise. Some of these occurrences are readily remedied (e.g., sunglints and flashing lights' by pointing the receiver section of the sensor head in a direction where it does not view the offending sources of light. This is not always possible, of course. For those physically uncorrectable situations and for other sources of false alarms, such as insects and detector noise, the false alarm algorithms must be capable of identifying and rejecting the false data. This the false alarm algorithms are now capable of doing with a very high degree of accuracy.

Figure 3.8 displays the data matrix for a false alarm occurrence due to detector noise. Note, that the threshold particle size has been lowered to a radius of 0.20 millimeters. When this was done 51 noise pulses exceeded the threshold level during the five minute sample time period. All 51 pulses appeared in the first column of the matrix which of and by itself is indicative of a false alarm occurrence. But, the fact that the median particle velocity for such small particles was over 10 meters per second is irrefutable evidence of a false alarm occurrence. Most other types of false alarms have strange characteristics which are as easily recognizable as is the case of detector noise.

PRESENT WEATHER DATA MATRIX - PWDC Version 00.22

```
08 JAN 84      Block No.: 194      End: 1005      Duration: 05 (min)
Tip bucket count: 00000            Drop total:    51
                          VR-301 Readings (mV)
(X1 CHAN) (X10 CHAN)  (X1 CHAN NO DROPS)  [AC CHAN: NO DROPS-INCL DROPS]
  00014     00121          00012                    00000     00000
Minute readings X1 chan:                 00014 00014 00014 00014 00014
Minute readings X1 chan(no drops):       00014 00014 00010 00010 00014
```

[Column headings: Radius interval (microns)] [Row headings: Velocity interval (cm/sec)]

	200 387	387 422	422 460	460 503	503 548	548 598	598 652	652 711	711 775	775 846	846 922	922 1005	1005 1096	1096 1196	1196 1304	1304 --	ROW SUM
30- 66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66- 106	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
106- 134	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
134- 168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
168- 210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210- 262	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
262- 326	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
326- 410	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
410- 516	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
516- 640	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
640- 800	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
800-1000	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1000-1230	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1230-1600	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
1600-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000-9999	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
COL-SUM	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PROB-DENS	909	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Figure 3.8. DATA MATRIX FOR A FALSE ALARM OCCURRENCE

4.0 PRECIPITATION OCCURRENCE

4.1 Comparison with a Tipping Bucket Rain Gauge

Tipping bucket rain gauges are the most commonly used instruments for detecting and measuring the accumulated amount of precipitation. In spite of its inherent problems, which are well known, the tipping bucket rain gauge has become a reference standard by which other precipitation monitoring instruments are currently evaluated.

The automated present weather observing system has a demonstrated capability for detecting precipitation which far exceeds that of a tipping bucket rain gauge. This capability is illustrated in Figure 4.1 through 4.4. These illustrations present a four day sequence of measurements made by the APWOS during a rain episode at Otis ANGB commencing on 17 March and ending on 20 March 1986. The measurements of a tipping bucket rain gauge, with a sensitivity of 0.01 inch per tip, are shown for comparison purposes.

In the illustrations presented in Figures 4.1 through 4.4, the smallest abscissa interval of the grid represents the five-minute sample time interval of the APWOS. The scale of the ordinate is in thousands of particles detected during a five-minute sample time interval. Each tip of the tipping bucket rain gauge which occurred during the sample time period is indicated by a solid vertical bar. On three occasions, (Figure 4.3) there were two tips of the tipping bucket during a sample time interval. These instances are indicated by hash marks within the bar.

The four day rain episode has intermittent periods of rainfall ranging from trace intensity to light and moderate rainfall intensities. The APWOS measurements indicate that a light rainfall began at 0025 on the morning of 17 March. The first tip of the tipping bucket rain gauge occurred one-half hour later at 0055. The last tip of the tipping bucket rain gauge on 17 March occurred at 1655. Although there were no more tips on that day, the APWOS registered a continuous rainfall of trace to light intensity for the remaining seven hours of that day.

The rain continued at trace and light intensities throughout the second day as indicated by the APWOS measurements. Not a single tip of the tipping bucket rain gauge occurred during that time! The next tip of the tipping bucket rain gauge occurred at 0125 on the morning of 19 March, thirty-two hours after the last tip on 17 March, during which time there was almost continuous rainfall of trace to light intensity.

On 19 March, there were several periods of moderately intense rainfall. Interspersed between these periods, were almost continuous periods of trace rainfall. During the

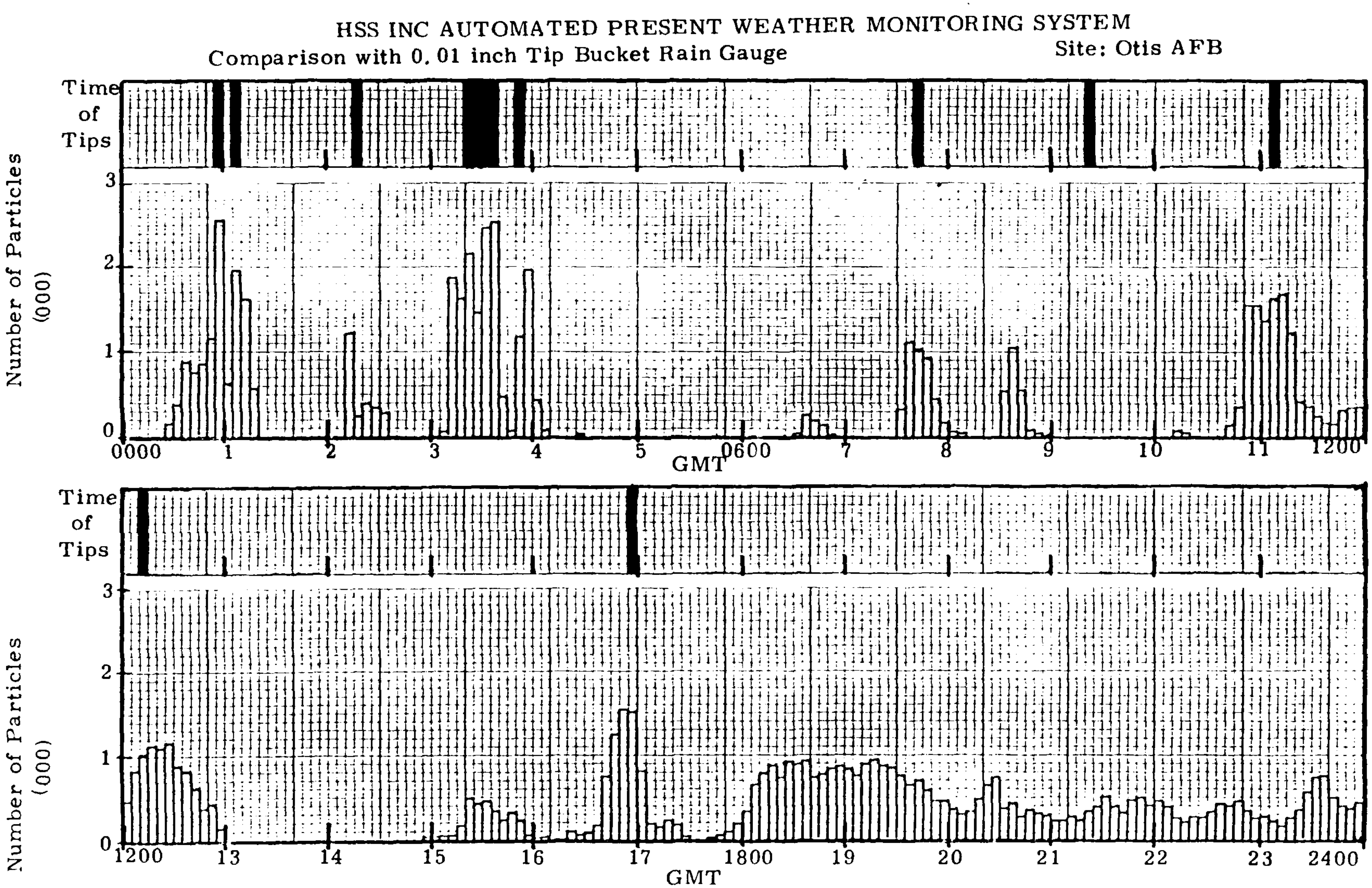


Figure 4.1. Precipitation Occurrence Measured During the Rain Episode of 17 March 1984.

HSS INC AUTOMATED PRESENT WEATHER MONITORING SYSTEM

Comparison with 0.01 inch Tip Bucket Rain Gauge Site: Otis AFB

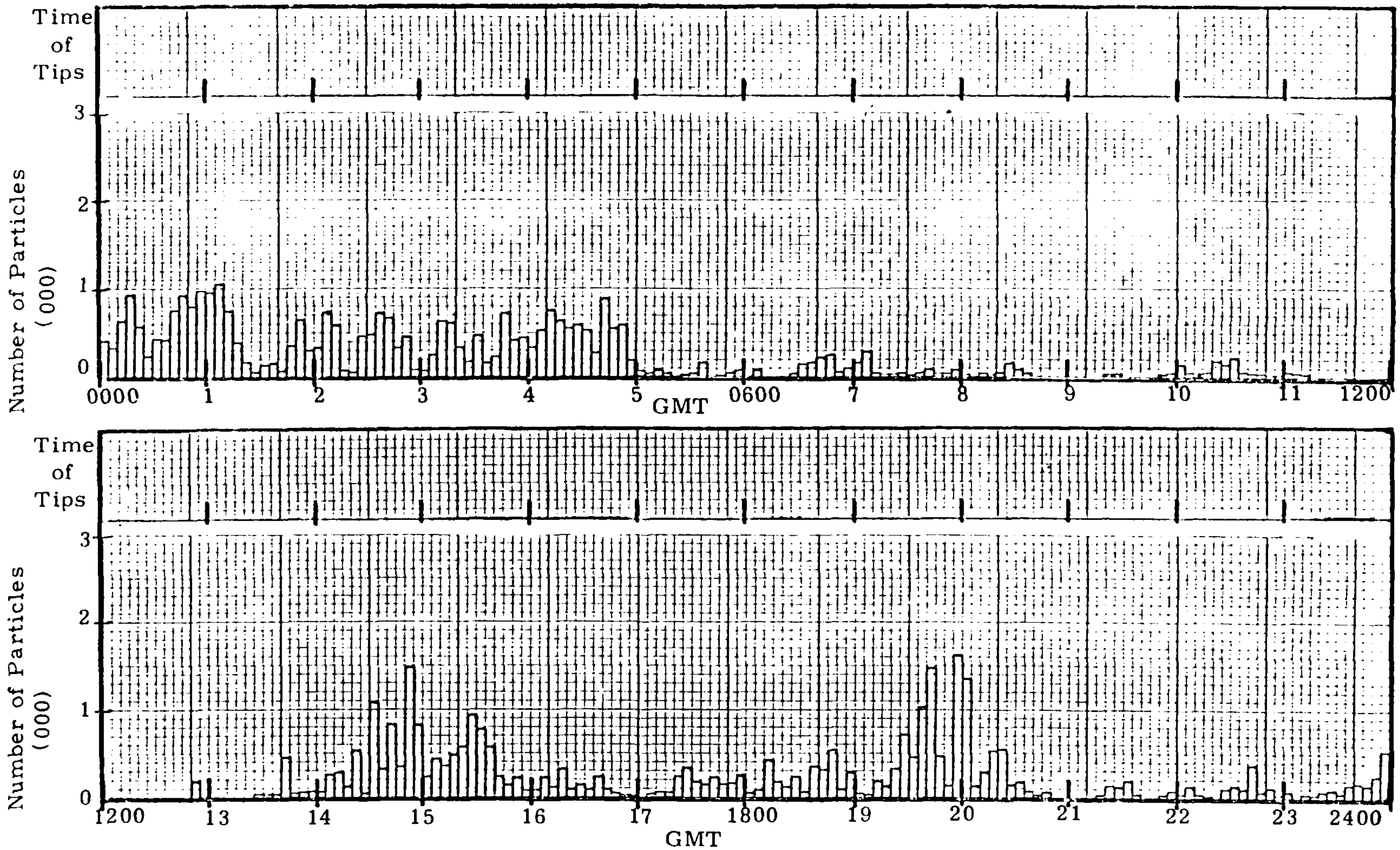


Figure 4.2. Precipitation Occurrence Measured During the Rain Episode of 18 March 1984.

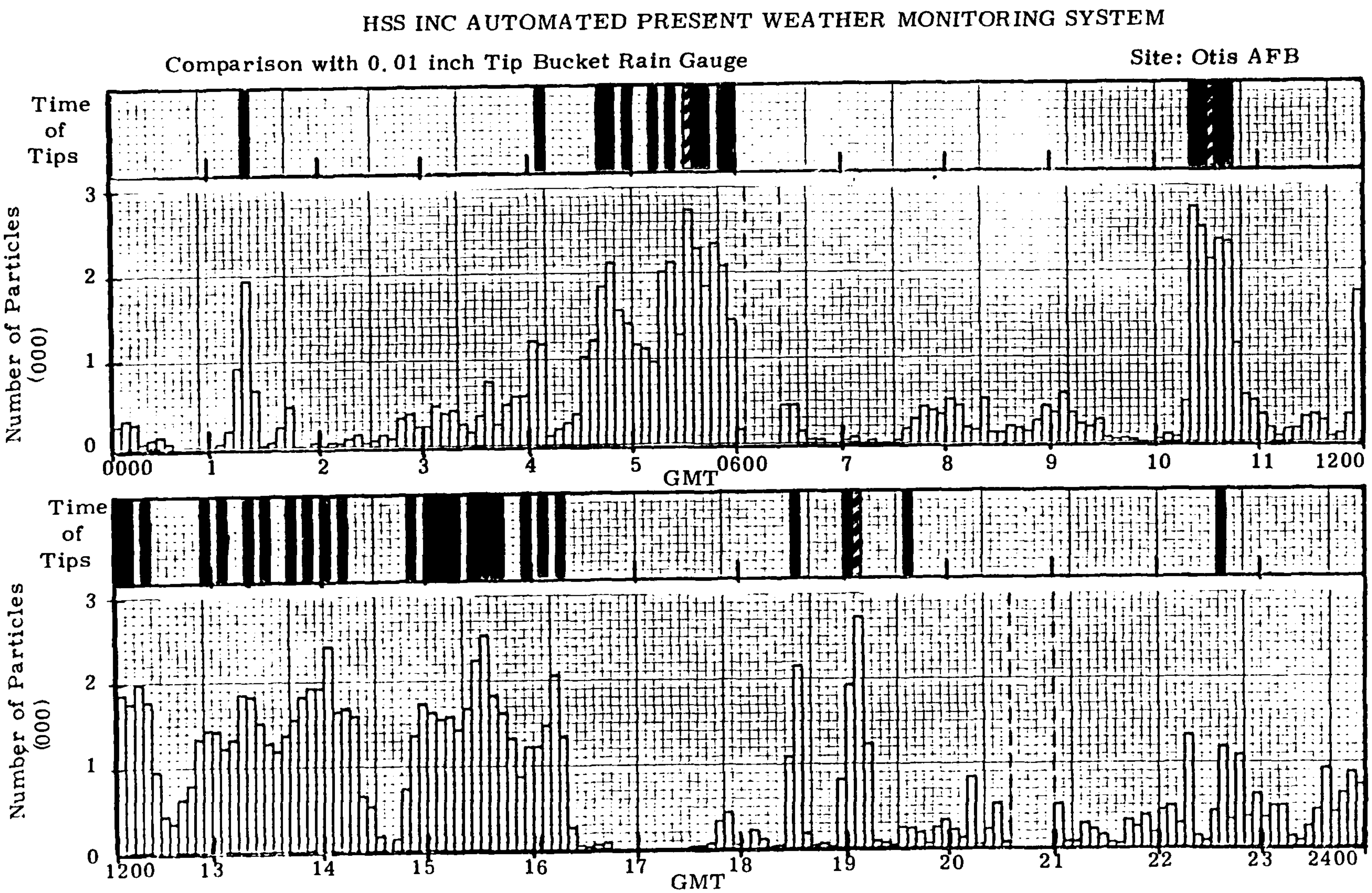


Figure 4.3. Precipitation Occurrence Measured During the Rain Episode of 19 March 1984.

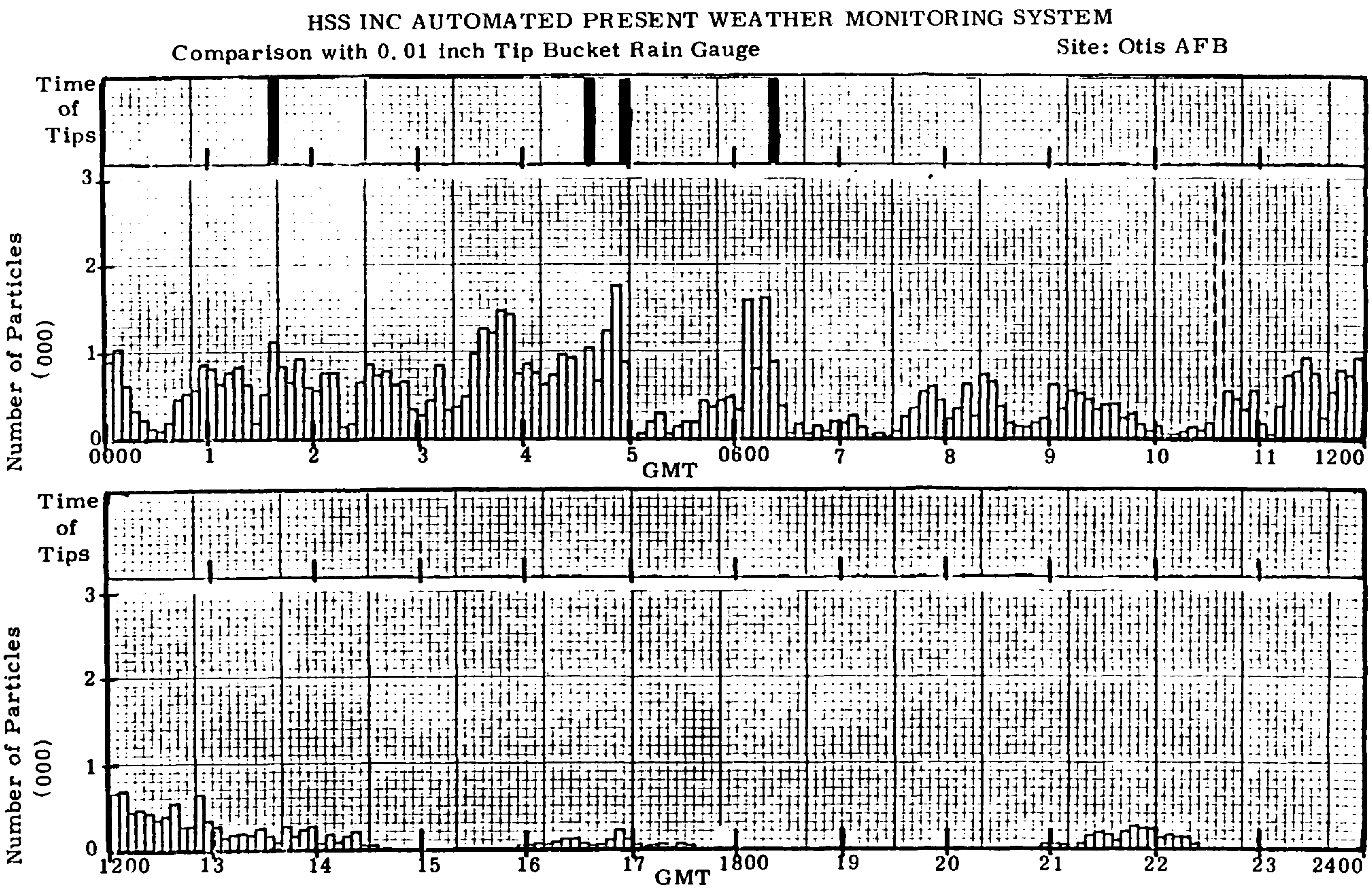


Figure 4.4. Precipitation Occurrence Measured During the Rain Episode of 20 March 1984.

periods of moderately intense rainfall the tipping bucket rain gauge was active, but lapsed into an inactive state during the trace rainfall periods.

During the morning of 20 March, the rainfall continued with light and trace intensities. Four tips of the tipping bucket occurred that morning, the last tip occurring at 0625. The rainfall petered out during the afternoon and evening with only intermittent trace intensities of rainfall. No tips of the rain gauge occurred during the afternoon and evening.

4.2 Performance Evaluation

An evaluation of the capability to detect precipitation is not concerned with the type of precipitation, only that precipitation has occurred. It is the role of the identification algorithms to determine the type of precipitation. The capabilities of these algorithms were evaluated independent of the capability to detect precipitation.

Thus, the evaluation of the APWOS capability to detect precipitation does not concern itself with the capability to detect one type of precipitation better than any other. The evaluation groups all forms of precipitation into one data base.

The precipitation detection performance of the APWOS was evaluated during two extended time periods. During the first evaluation period, from 6 December 1983 to 9 February 1984, the instrument was installed at HSS Inc where precipitation observations were made by HSS Inc personnel acting as observers. The second evaluation period covered the time period from 17 February 1984, when the laboratory model instrument was installed at Otis ANGB, until 16 July 1984. At the AFGL Otis Weather Test Facility (WTF), a trained observer maintained a weather log during normal working hours, and at most other times when a weather episode was occurring. Any gaps in the observations of the WTF observer's records were filled by obtaining the records of the Otis ANGB Control Tower located approximately one mile away. At the latter facility, weather observations are taken every hour during clear weather and more often during adverse weather conditions.

The data base for the evaluation of the APWOS precipitation detection performance is given in Table 4.1. The performance evaluation was conducted for two rainrates, 0.001 and 0.005 inches per hour. These rainrates are roughly equivalent to detection thresholds of 50 and 250 particles per five minutes respectively, as established by comparisons with tipping bucket rain gauges.

During the first evaluation, a total of 164 data hours were logged at the threshold detection level of 50 particles per five minutes. In the second evaluation period 393 data hours were logged at the same threshold level thus providing a total of 557 hours

Table 4.1. Data Base for the Precipitation Detection Performance Analysis of the APWOS

SECOND EVALUATION PERIOD

Time Period: 17 February 1984 to 10 July 1984

Threshold Level (Particles/5 Min)	Rain Rate* (In/Hr)	Total No. of Samp. Per.	Total No. of Data Hours
50	0.001	4725	393
250	0.005	3589	299

* Note: If the particles are snow, divide the rain rate by ten to find the approximate equivalent rain rate.

PREVIOUS EVALUATION PERIOD

Time Period: 6 December 1983 to 9 February 1984

Threshold Level (Particles/5 Min)	Rain Rate* (In/Hr)	Total No. of Samp. Per.	Total No. of Data Hours
50	0.001	1946	164
250	0.005	1412	118

of precipitation data with a detection threshold of 50 particles per five minutes. At the threshold detection level of 250 particles per five minutes a total of 417 hours of precipitation data was logged.

The results of the performance evaluation are presented in Tables 4.2 and 4.3. Because the error rates for the two evaluation periods do not differ significantly, we shall review only those of the longer evaluation period where the observations of trained observers were used for comparison with the automated observations.

Table 4.3 shows that of the total of 4725 sample periods where precipitation was detected, or should have been detected, at a threshold level of 50 particles per five minutes, the APWOS correctly detected precipitation in 4663 cases, did not detect the precipitation in 29 cases and falsely identified the presence of precipitation in 33 cases.

The rejection of a true occurrence is defined as a Type I statistical error, while the acceptance of a false occurrence is defined as a Type II error. At the threshold level of 50 particles per five minutes the Type I error rate was 0.61 percent and the Type II error rate was 0.70 percent. At the higher threshold level of 250 particles per five minutes, corresponding to a rainfall rate of 0.005 inches per hour, or a snowfall rate of 0.0005 inches of equivalent water per hour, the error rates were reduced to approximately one-half of those at the lower threshold level. The Type I error rate was 0.28 percent and the Type II error rate was 0.30 percent.

While the error rates for the APWOS are indeed quite small there is every reason to believe that they can be reduced even further. Type I errors, where the APWOS failed to detect precipitation can be reduced by improving the signal-to-noise ratio thus permitting the particle detection threshold to be lowered.

Type II errors must be reduced by refinements of the false alarm algorithms. Refinement of the algorithms must begin with the simple, but laborious task of culling through volumes of data where there are good weather records made by human observers, identifying the physical cause of the error, examining the precipitation recognition matrix, determining why the existing false alarm algorithms failed and finally constructing an improvement to the algorithms which will reject those false alarms in the future.

Table 4.2. Precipitation Detection Performance of APWOS: Summary Of Results

FIRST EVALUATION PERIOD

Time Period: 6 December 1983 to 9 February 1984

Threshold Level (Particles/5 min)	Results of Analysis		
	Precip. Detected	Precip. Not Detected	False Events Detected
50	1930	16	00
250	1409	3	00

Threshold Level (Particles/5 Min)	Type I Error(1) (Fraction of Samples)	Type II Error(2) (Fraction of Samples)
50	16/1946 = .0082	0/1946 = 0.0000
250	3/1412 = .0021	0/1412 = 0.0000

Note(1) Defined as the Rejection of a True Occurrence

Note(2) Defined as the Acceptance of a False Occurrence

Table 4.3. Precipitation Detection Performance of APWOS: Summary Of Results

SECOND EVALUATION PERIOD

Time Period: 17 February 1984 to 10 July 1984

Threshold Level (Particles/5 min)	Results of Analysis		
	Precip. Detected	Precip. Not Detected	False Events Detected
50	4663	29	33
250	3565	10	14

Threshold Level (Particles/5 Min)	Type I Error(1) (Fraction of Samples)	Type II Error(2) (Fraction of Samples)
50	29/4725 = .0061	33/4725 = .0070
250	19/3589 = .0028	14/3589 = .0039

Note(1) Defined as the Rejection of a True Occurrence

Note(2) Defined as the Acceptance of a False Occurrence

5.0 PRECIPITATION ACCUMULATION

5.1 Precipitation Amount Process

At the end of each sample time period the APWOS microprocessor examines the Precipitation Recognition Matrix and, if precipitation is detected, identifies the type of precipitation. If the identification indicates rain then the amount of rainfall in the sample time period just ended is calculated in accordance with the procedure outlined in Section 2.3.9 of this report. If snowfall is indicated, the calculation proceeds using the "sizes"of the raindrop signal equivalents. That is, a snowflake is taken to have the same size as a raindrop that produces the equivalent signal amplitude. The calculation then concludes by applying a density factor of 0.1 to the particle to obtain the equivalent water content.

If precipation is detected, yet the APWOS fails to identify the particles as being either rain or snow, then the APWOS identifies the particles only as precipitation. The ambiguous identification category "precipitation" is treated as rainfall. Experience has shown that when the category precipitation is used by the APWOS the true form of the precipitation is most likely to be trace amounts of rain where the accumulation is negligible, or nearly negligable or a form of frozen precipitation where the physical density of the particles is close to unity.

5.2 Precipitation Accumulation Measurements

The first evaluation of the APWOS as a rainfall accumulation sensor was made at HSS Inc shortly after the development of the Laboratory Model Instrument was completed. The results of that comparison are shown in Figure 5.1. Accumulated rainfall measurements of the APWOS are compared with the measurements of a tipping bucket rain gauge borrowed from the AFGL Weather Test Facility at Otis ANGB. Measurements for three light rain episodes are compared in the figure. Three different abscissa scales are employed to prevent overlapping of the plots. The comparison shows very good agreement between the two sets of accumulated rainfall measurements.

In that same time period a preliminary evaluation of the APWOS as a snowfall accumulation sensor was conducted. Those results are presented in Figure 5.2. The comparison was made on the basis of equivalent water content for two snowfall episodes which occurred during mid and late January 1984.

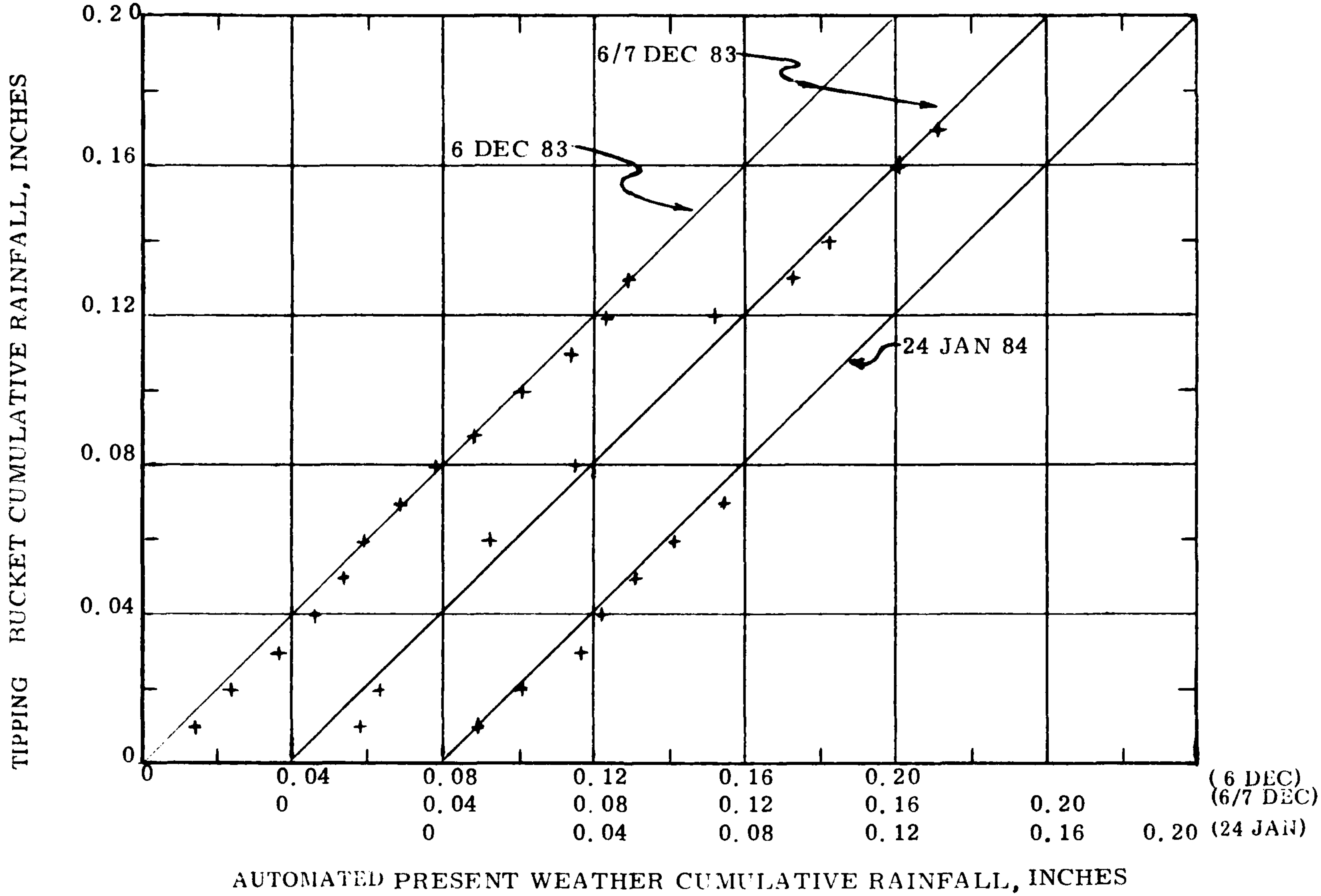


Figure 5.1. Comparison of cumulative rainfall measurements between a tipping bucket rain gauge and the APWOS for three light rainfall episodes.

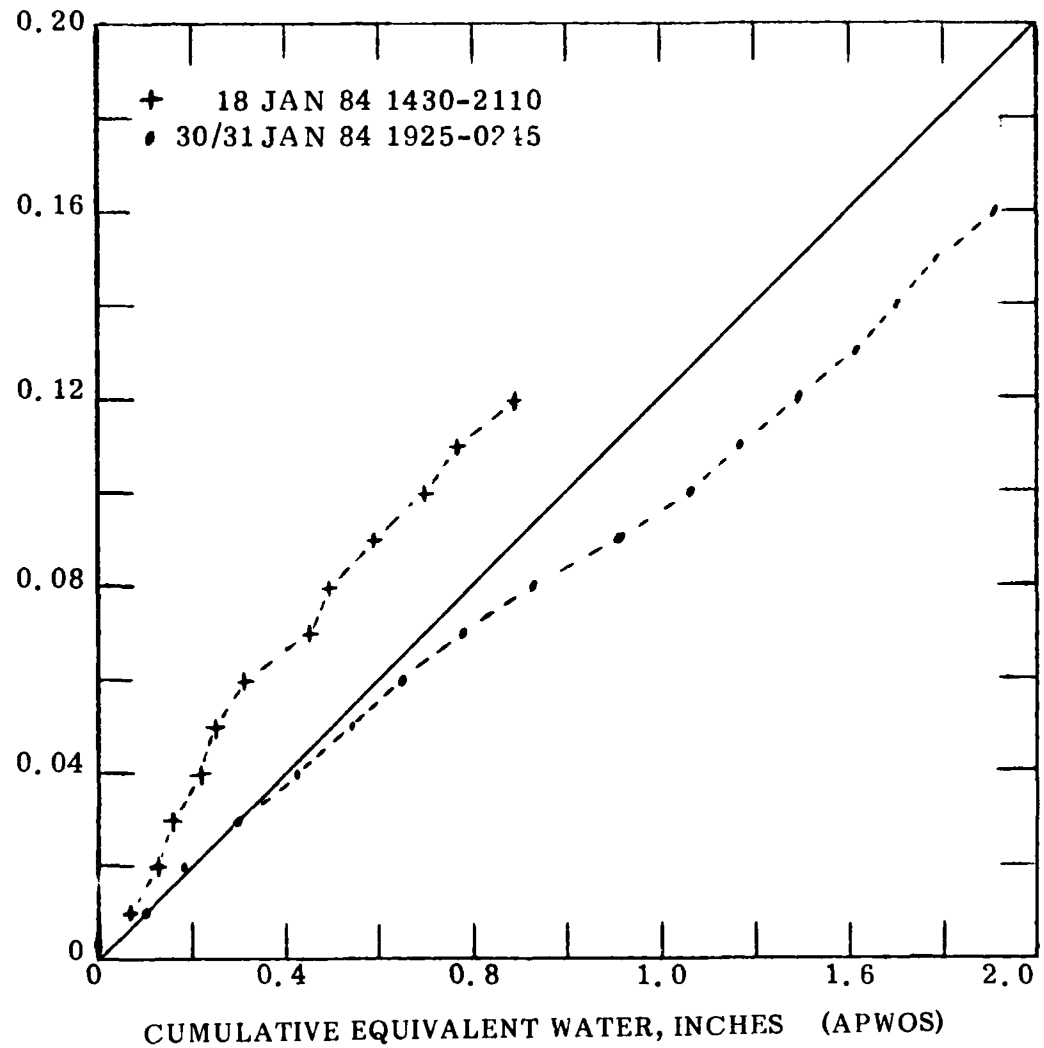


Figure 5.2. Comparison of cumulative equivalent water content between a tipping bucket rain gauge and the APWOS for two snowfall episodes.

The interesting feature of the snowfall measurements is that in one case (the 18 January episode) the APWOS measurements of accumulated equivalent water content were lower than those of the tipping bucket rain gauge while during the other episode (the 30/31 January) the APWOS measurements were higher. Assuming that the heated tipping bucket rain gauge behaved properly (not necessarily a good assumption) we can attribute such differences to the physical density of the snowflakes not being exactly equal to 0.1. In the earlier of the two episodes the particles appear to have had a density slightly greater than 0.1 while in the later episode the particle densities were greater than 0.1.

The data presented in Figure 5.2 indicate that the assumption of a density value of one-tenth for snowflakes provides accumulated precipitation measurements accurate to 20 percent or better.

One of the goals for future improvements of the APWOS is to develop algorithms for classifying the various forms of frozen precipitation thereby permitting more accurate measurements of precipitation accumulation. Achieving such a goal depends on the precipitation matrix of each precipitation form having sufficiently distinctive features for its recognition. The recording of such matrices plus the simultaneous determination of the densities of the different forms of frozen precipitation will also be necessary to achieve the goal. A rain guage (such as a visually well-monitored heated-tipping-bucket) can determine the true amount of water. The ratio of the true amount of water and the apparent amount of water determined by the sizes of particles in the precipitation matrix will establish the density of the particles.

To ascertain the accuracy of the APWOS as a rainfall accumulation sensor requires a comparison with a reliable reference standard. The most suitable commercial rain gauge suitable for that purpose is the tipping bucket rain gauge — in spite of the many universally recognized problems which beset that type of gauge. Obviously, when a comparison is to be made the conditions for the comparison must be chosen such that the measurements of the tipping bucket rain gauge can be relied upon. For purposes of the comparisons reported here a few selection rules were established to guide us in the choice of precipitation episodes to use for the comparison of measurements. These rules, which must be simultaneously obeyed, are as follows:

(1) Choose weather episodes where the accumulated precipitation exceeds 0.1 inch of water (or water equivalent).

(2) Eliminate those problem weather episodes where the accumulated precipitation eventually exceeds 0.1 inch, but the accumulation occurs at rates less than 0.1 inch/hour over half the episode time period.

(3) Avoid those weather episodes where strong winds were present.

(4) Rely on a weather observer to periodically inspect and test the tipping bucket gauge.

(5) When freezing rain conditions exist a weather observer must verify by inspection that the tipping bucket gauge is functioning properly and has not clogged up.

A formal evaluation of the precipitation accumulation capabilities of the APWOS was performed with the WSMR field model instrument. The WSMR APWOS was installed at Otis AFB on 30 October 1984 and was operated continuously there until November 1985. The instrument was located in the region of the test range now reserved for present weather sensors. Also located in that region was the AFGL laboratory model APWOS, which during the Winter/Spring of 1984/1985 was temporarily moved to Hanscom AFB to participate in an AFGL snow exercise.

The WSMR APWOS was located approximately 120 feet from the main building of the AFGL Weather Test Facility and transmitted its automated weather report over hardwire to an HP Model 9826 desktop computer accompanied by an HP Model 2631A printer, all located in that facility.

A typical automated present weather report from the WSMR instrument is shown in Figure 5.3. For comparison purposes, two columns of information have been added manually to that report. One of the appended columns provides the measurements of a tipping bucket rain gauge (.01 inch/tip) in terms of the number of tips which occur during each six minute sample time period. The second appended column provides the AFGL weather observers report for the entire episode.

The HP computer adds the date and time (Columns 1 and 2) to each present weather report. The computer had not been tasked with providing the accumulated precipitation which it could easily do. (It is planned to have the computer provide the accumulated precipitation at six hour intervals.)

The actual message sent by the APWOS begins with the instrument identification number (Column 3) followed by: the sample time interval (Column 4), the visual range (Column 5), the present weather description (Column 6), the amount of rain (or equivalent water content) that fell during the sample time interval (Column 7), air temperature in degrees Fahrenheit (Column 8), the total number of particles which passed through the sample volume in the six minute time period (Column 9), the total atmospheric extinction coefficient (Column 10), and finally in Column 11 the EXCO MINUS EVENTS; i.e., the atmospheric extinction coefficient minus the effects of the precipitation particles.

The last three columns of the APWOS message contains information of importance only to the persons involved with the development and improvement of automated present weather observing systems. This information is unlikely to be required in a formal automated present weather report.

Location: AFGL Weather Test Facility; Otis AFB

TIME mmdd	TIME hrmi	INST NO	REP INT	VISUAL RANGE MILES	HSS PRESENT WEATHER SYSTEM WEATHER AND/OR OBSTRUCTION	RAIN RATE INCHES	AIR TEMP F	TOTAL OF EVENTS	TOTAL EXINCTN COEF	EXTINCTN COEF LESS EVENT	TIPPING BUCKET TIPS	A.F.G.L. WEATHER OBSERVERS REPORT
108	400	2	6	11.65	CLEAR	0.0000	36.9	0	0.16	0.16		
108	406	2	6	11.65	CLEAR	0.0000	37.0	0	0.16	0.16		CLEAR
108	412	2	6	11.65	CLEAR	0.0000	37.0	1	0.16	0.16		
108	418	2	6	11.65	CLEAR	0.0000	37.0	13	0.16	0.16		
108	424	2	6	11.65	PRECIP	0.0001	36.9	64	0.16	0.16		
108	430	2	6	11.65	PRECIP	0.0001	36.9	88	0.16	0.16		
108	436	2	6	11.65	PRECIP	0.0001	36.9	102	0.16	0.16		
108	442	2	6	11.65	PRECIP	0.0002	36.9	156	0.16	0.16		
108	448	2	6	11.65	PRECIP	0.0002	36.9	129	0.16	0.16		
108	454	2	6	11.65	PRECIP	0.0001	36.9	82	0.16	0.16		
108	500	2	6	10.36	PRECIP	0.0002	36.9	101	0.18	0.17	0	VERY LIGHT RAIN
108	506	2	6	9.81	PRECIP	0.0001	36.8	46	0.19	0.19		
108	512	2	6	9.32	PRECIP	0.0001	36.9	55	0.20	0.19		
108	518	2	6	8.47	PRECIP	0.0001	36.9	45	0.22	0.22		
108	524	2	6	8.47	PRECIP	0.0001	36.9	79	0.22	0.22		
108	530	2	6	8.10	PRECIP	0.0002	36.9	118	0.23	0.22		
108	536	2	6	8.47	PRECIP	0.0001	36.8	42	0.22	0.22		
108	542	2	6	8.10	CLEAR	0.0000	36.9	11	0.23	0.23		INTERMITTENT
108	548	2	6	8.10	CLEAR	0.0000	36.8	1	0.23	0.23		VERY LIGHT RAIN
108	554	2	6	7.17	CLEAR	0.0000	36.9	2	0.26	0.26		
108	600	2	6	5.65	LIGHT HAZE	0.0000	36.8	4	0.33	0.33		LIGHT DRIZZLE
108	606	2	6	4.91	LIGHT HAZE	0.0000	36.8	19	0.38	0.37		
108	612	2	6	4.34	PRECIP	0.0005	36.8	198	0.43	0.41		
108	618	2	6	3.97	LT RAIN	0.0015	36.8	397	0.47	0.42		
108	624	2	6	3.66	LT RAIN	0.0018	36.8	413	0.51	0.45		LIGHT RAIN
108	630	2	6	3.52	LT RAIN	0.0027	36.9	566	0.53	0.45		
108	636	2	6	2.17	MOD RAIN	0.0125	36.9	1974	0.86	0.46	1	MODERATE RAIN
108	642	2	6	1.65	MOD RAIN	0.0114	36.8	3174	1.13	0.51	2	
108	648	2	6	1.79	LT RAIN	0.0084	36.8	3000	1.04	0.53	1	
108	654	2	6	1.35	LT RAIN	0.0077	36.7	2416	1.38	0.75	1	LIGHT RAIN
108	700	2	6	1.14	LT RAIN	0.0092	36.8	2172	1.64	1.06	1	
108	706	2	6	1.58	MOD RAIN	0.0134	36.5	2110	1.18	0.64	1	MODERATE RAIN
108	712	2	6	1.17	PRECIP	0.0336	35.7	3748	1.59	0.53	2	MOD. RAIN/SNOW
108	718	2	6	0.56	MOD.SNOW	0.0079	34.5	4077	3.31	0.85	2	MODERATE SNOW
108	724	2	6	0.76	LT SNOW	0.0054	33.6	3128	2.46	0.69	1	
108	730	2	6	1.07	LT SNOW	0.0040	33.1	2357	1.75	0.42	1	LIGHT SNOW
108	736	2	6	1.04	LT SNOW	0.0056	32.7	2037	1.79	0.31	1	
108	741	2	6	0.74	LT SNOW	0.0076	32.5	2270	2.52	0.34	0	
108	747	2	6	0.49	MOD SNOW	0.0165	32.5	2274	3.79	0.40	1	
108	753	2	6	0.50	MOD SNOW	0.0127	32.5	2078	3.73	0.41	1	
108	759	2	6	0.37	MOD SNOW	0.0171	32.5	3168	5.10	0.57	0	
108	805	2	6	0.37	MOD SNOW	0.0166	32.3	3375	5.06	0.73	1	
108	811	2	6	0.28	MOD SNOW	0.0263	32.0	2872	6.68	0.77	1	MODERATE SNOW
108	817	2	6	0.28	MOD SNOW	0.0196	31.5	2566	6.55	0.83	1	
108	823	2	6	0.25	MOD SNOW	0.0246	30.9	2965	7.39	0.78	1	
108	829	2	6	0.31	MOD SNOW	0.0193	30.7	2960	6.08	0.90	0	
108	835	2	6	0.34	MOD SNOW	0.0162	30.7	2491	5.49	0.70	1	
108	841	2	6	0.42	MOD SNOW	0.0145	31.0	2057	4.49	0.52	1	
108	847	2	6	0.47	MOD SNOW	0.0118	30.9	1651	3.95	0.42	0	
108	853	2	6	0.47	MOD SNOW	0.0077	30.8	2278	3.97	0.51	0	
108	859	2	6	0.38	MOD SNOW	0.0080	30.6	2813	4.92	0.69	1	
108	905	2	6	0.26	MOD SNOW	0.0181	30.2	3900	7.11	1.11	1	
108	911	2	6	0.26	MOD SNOW	0.0185	29.5	4398	7.11	1.31	0	
108	917	2	6	0.26	MOD SNOW	0.0129	28.6	4588	7.10	1.54	1	
108	923	2	6	0.25	MOD SNOW	0.0160	27.6	4884	7.33	1.51	0	
108	929	2	6	0.31	MOD SNOW	0.0085	26.7	4142	6.05	1.38	0	
108	935	2	6	0.63	LT SNOW	0.0026	25.8	3392	2.94	0.86	0	
108	941	2	6	0.62	MOD SNOW	0.0022	25.3	2904	3.02	0.82	0	
108	947	2	6	0.57	MOD SNOW	0.0031	24.9	2991	3.25	0.86	0	
108	953	2	6	0.38	MOD SNOW	0.0047	24.6	3018	4.85	1.14	1	
108	959	2	6	0.52	MOD SNOW	0.0043	24.2	2567	3.61	0.86	0	
108	1005	2	6	0.54	MOD SNOW	0.0049	24.1	2688	3.44	0.75	0	
108	1011	2	6	0.38	MOD SNOW	0.0046	23.7	2750	4.88	1.03	0	
108	1017	2	6	0.29	MOD SNOW	0.0046	23.5	3251	6.51	1.69	0	LIGHT SNOW
108	1023	2	6	0.34	MOD SNOW	0.0034	23.3	2961	5.44	1.61	0	
108	1029	2	6	0.28	MOD SNOW	0.0050	23.1	3156	6.65	1.89	0	
108	1035	2	6	0.31	MOD SNOW	0.0066	22.9	3318	6.02	1.68	0	
108	1041	2	6	0.33	MOD SNOW	0.0064	22.4	3137	5.65	1.41	1	
108	1053	2	6	0.28	MOD SNOW	0.0063	22.4	3289	6.57	1.70	0	
108	1059	2	6	0.36	MOD SNOW	0.0038	22.4	2842	5.13	1.37	0	
108	1105	2	6	0.36	MOD SNOW	0.0034	22.4	2986	5.17	1.29	0	
108	1111	2	6	0.35	MOD SNOW	0.0039	22.8	3239	5.27	1.31	1	
108	1117	2	6	0.38	MOD SNOW	0.0046	22.9	3157	4.89	1.07	0	
108	1123	2	6	0.39	MOD SNOW	0.0059	22.9	3138	4.73	0.86	0	
108	1129	2	6	0.47	MOD SNOW	0.0059	22.9	2985	4.08	0.68	0	
108	1135	2	6	0.44	MOD SNOW	0.0065	22.8	2683	4.24	0.71	0	
108	1141	2	6	0.53	MOD SNOW	0.0066	22.9	2244	3.51	0.56	0	
108	1147	2	6	0.67	LT SNOW	0.0064	22.9	1620	2.80	0.30	0	
108	1153	2	6	1.14	LT SNOW	0.0041	22.9	1023	1.64	0.27	0	
108	1159	2	6	2.14	LT SNOW	0.0017	22.9	699	0.87	0.21	0	
108	1205	2	6	1.35	LT SNOW	0.0049	22.9	808	1.38	0.23	0	
108	1211	2	6	2.87	LT SNOW	0.0008	22.9	725	0.65	0.23	0	VERY LIGHT SNOW
108	1217	2	6	12.43	LT SNOW	0.0000	22.9	33	0.15	0.14	28	
108	1223	2	6	16.95	VERY CLEAR	0.0000	22.9	3	0.11	0.11		INTMT. VERY LIGHT SNOW
108	1229	2	6	20.71	VERY CLEAR	0.0000	22.8	1	0.09	0.09		
108	1235	2	6	18.64	VERY CLEAR	0.0000	22.4	1	0.10	0.10		
108	1241	2	6	18.64	VERY CLEAR	0.0000	22.3	1	0.10	0.10		CLEAR
108	1247	2	6	18.64	VERY CLEAR	0.0000	22.1	0	0.10	0.10		
108	1253	2	6	18.64	VERY CLEAR	0.0000	22.2	0	0.10	0.10		
108	1259	2	6	18.64	VERY CLEAR	0.0000	22.2	0	0.10	0.10		

Accumulated H_2O = 0.5370 Inches

Figure 5.3. Automated present Weather report from the WSMR Field Model Present Weather Sensor for the Rain/Snow episode of 8 January 1985. Also shown are the tips of a heated tipping bucket rain gauge and the AFGL Weather Observers report.

The formal evaluation of the APWOS as a precipitation accumulation sensor was conducted during the time period from 24 October 1984 to 25 January 1985. During that time period 32 discrete precipitation episodes occurred; in some instances more than one occurred on the same day.

After invoking the selection rules pertaining to the tipping bucket rain gauge (to assure a reliable reference standard) nine episodes remained. An error analysis of the data from those nine episodes is presented in Table 5.1. The RSS measurement error for all nine episodes was 7 percent. If the one episode with the largest error (on 16 November) is removed from the analysis the RSS error drops to 4.9 percent. This latter result points out that for future performance analyses of this type two or more tipping buckets should be used as the reference standard to assure that anomalous behavior of the APWOS or of one of the tipping buckets can be properly assigned.

5.3 Heavy Rain Rate Capability

5.3.1 Natural Rainfall

It is important that the APWOS be capable of performing its precipitation measurement functions during extremely heavy rainstorms without reaching a saturation limit that would degrade its capability to provide accurate rainfall accumulation measurements. During the time period that the WSMR APWOS was in operation at Otis ANGB the heaviest natural rainrate occurred during a rainfall episode on 12 November 1984. The behavior of the APWOS during that episode is shown in Figure 5.4. The highest rainrate recorded was 1.5 inches per hour (15 tips of the tipping bucket during the six minute sample time period). Figure 5.4 indicates that the APWOS response is linear up to the highest rainrate recorded during that episode. Note that much of the scatter in data points at the lower rainrates can be attributed to the non-simultaneity of the sampling time periods of the time instruments.

5.3.2 Rainfall Simulation Facility

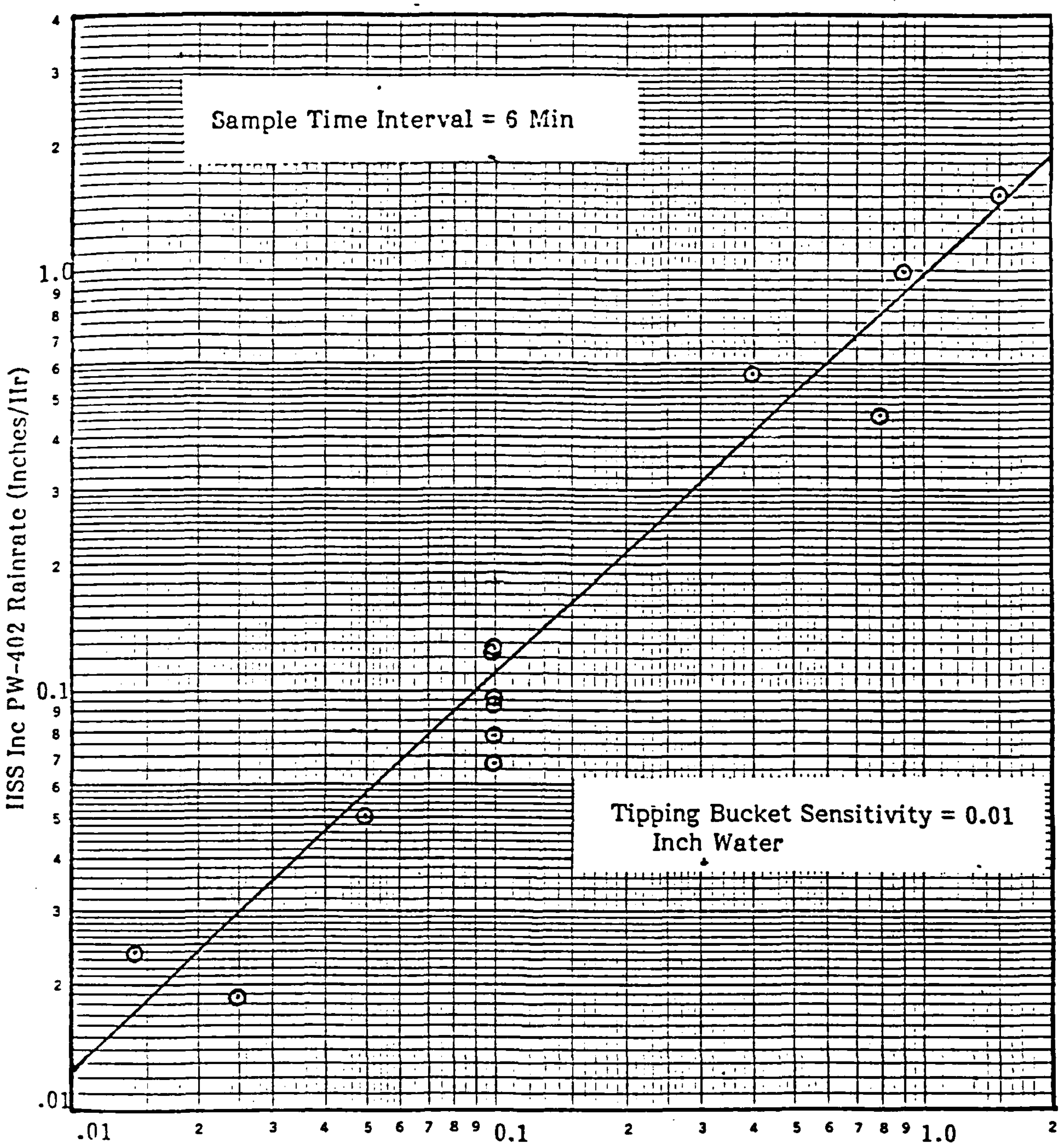
To determine the APWOS response for precipitation rates greater than 1.5 inches per hour it was necessary to build a rainfall simulation facility adjacent to the AFGL Weather Test Facility at Otis ANGB. Development of that facility was a joint effort between AFGL and HSS Inc. Using that facility rainfall rates as high as 6 inches per hour were achieved.

Table 5.1. Error Analysis of the APWOS Precipitation Accumulation Measurement for Nine Precipitation Episodes.

Episode Date 1984	Precipitation Accumulation (Inches of H_2O) APWOS	Tipping Bucket	Line of Regression Value	Relative APWOS Error	Precipitation Type
11 Nov	.26	.29	.302	-.14	Rain
12 Nov	.49	.48	.489	.002	Rain
16 Nov	.22	.12	.142	.55	Rain
29 Nov	.33	.37	.377	-.12	Rain
3 Dec	.23	.18	.199	.16	Rain
6 Dec	.72	.75	.733	-.02	Snow/Rain
10 Dec	.24	.27	.283	-.152	Rain
19 Dec	.30	.32	.330	-.09	Rain
21 Dec	.75	.70	.686	.093	Rain/Snow

RSS Relative Error = 0.070 (Nine Episodes)

RSS Relative Error = 0.049 (Eight Episodes)
(Excluding 16 Nov Episode)



RAIN EPISODE: 12 Nov. 1984 - 0353 to 1305 GMT

LOCATION: AFGL Weather Test Facility, Otis AFB

TOTAL RAINFALL ACCUMULATION:

Tipping Bucket ——— .48 inch

HSS PW-402 ——— .49

Figure 5.4. Comparison of Rainrate measurements; WSMR APWOS vs. a tipping bucket rain gauge.

AFGL personnel constructed an 18 foot tower just outside the WTF compound at Otis ANGB using sections of a surplus antenna tower as shown in Figure 5.5. HSS Inc selected and purchased a range of spray nozzles (see Figure 5.6) which, according to the manufacturer, Spraying Systems Co., would be capable of providing raindrop size distributions similar to those found in moderate to heavy rainrates. HSS Inc also purchased the necessary piping, valves, fittings, etc., and contracted to have the water line laid from the WTF to the tower.

A single nozzle was used for each rainfall simulation. The nozzle was extended from a boom approximately six feet outboards of the northern side of the open-frame work at a height of eighteen feet (see Figure 5.7). The sensor head of the present weather sensor was located eight feet below and directly underneath the nozzle as shown in Figure 5.8.

The variable parameters of the rainfall simulator were the type of nozzle and the water pressure. Water pressure was set by means of a water-pressure-regulator located at the top of the tower. A shut-off valve was located at the base of the tower. Nozzles were selected according to the manufacturer's specifications to give: (1) heavy or light rainfalls, (2) particular drop-size distributions and (3) various diameters of the spray patterns.

It was expected that the circular pattern of the rainfall would have a non-uniform radial distribution; namely, heavy at the center and lighter toward the perimeter. Diameters of the rainfall pattern were expected to be either eight or ten feet depending upon the particular nozzle selected. The manufacturer's specifications proved to be correct regarding the diameter of the rainfall pattern, but in error concerning intensity and the distribution of raindrop sizes.

The radial falloff of rainfall intensity was much more severe than expected. To determine the severity of the non-uniformity eight coffee cans were placed on another, six high foot, tower surrounding the sensor head to measure the amount of rainfall at selected points in the rainfall pattern at a height slightly below the sensor head. For each test the cans were arranged in two rows of four cans. The cans in each row were approximately two and one-half feet apart. The rows were separated by three feet and oriented parallel to the long arm of the instrument sensor head. The inner two cans in each row formed a square which encompassed the sensor head. At times the distribution of cans was modified slightly because of the ambient wind-speed and direction.

A standard dip-stick rain gauge was also employed to measure the amount of rainfall during each measurement time period. This gauge was usually located near the transmitter

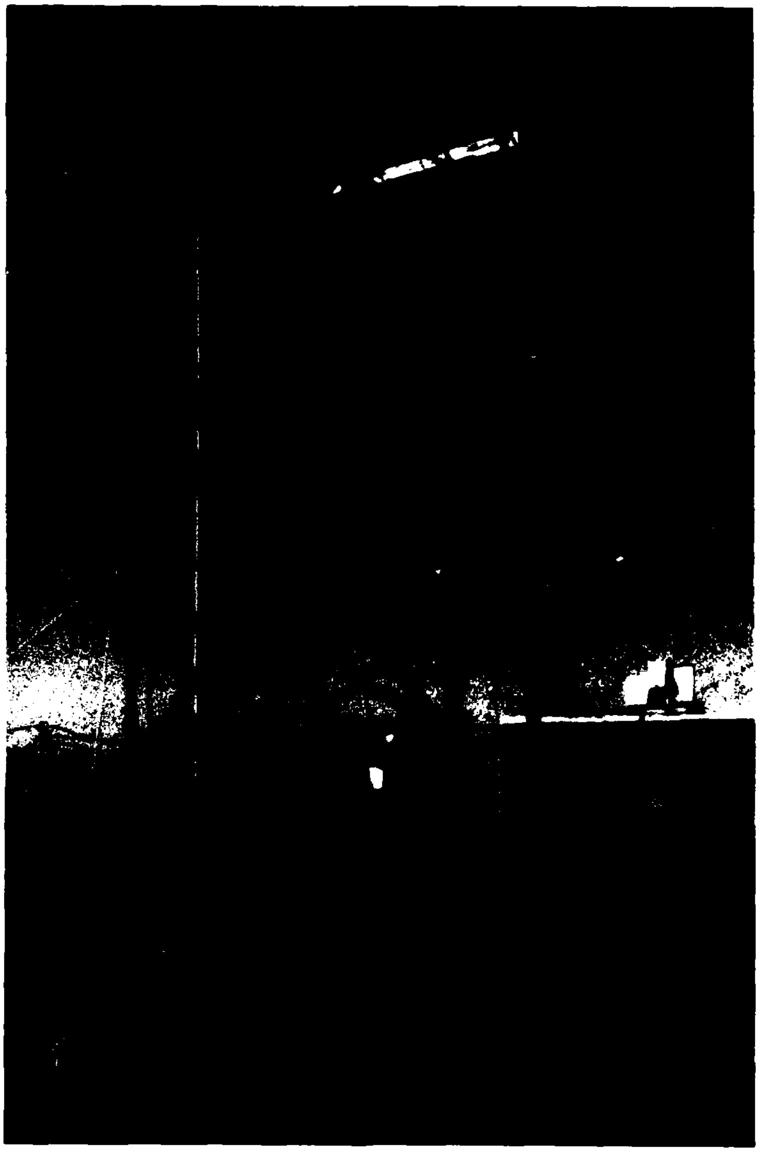


FIGURE: 5.5. OVERALL VIEW OF RAINFALL SIMULATION TEST SETUP AT THE AFGL WEATHER TEST FACILITY. SUPPORT STRUCTURE FOR THE RAIN GUAGE AND MEASUREMENT CANS HAS BEEN REMOVED.

FIGURE: 5.6. THE FIVE WATER NOZZLES SELECTED FOR SIMULATION OF A VARIETY OF RAINFALL RATES AND DROP SIZES.

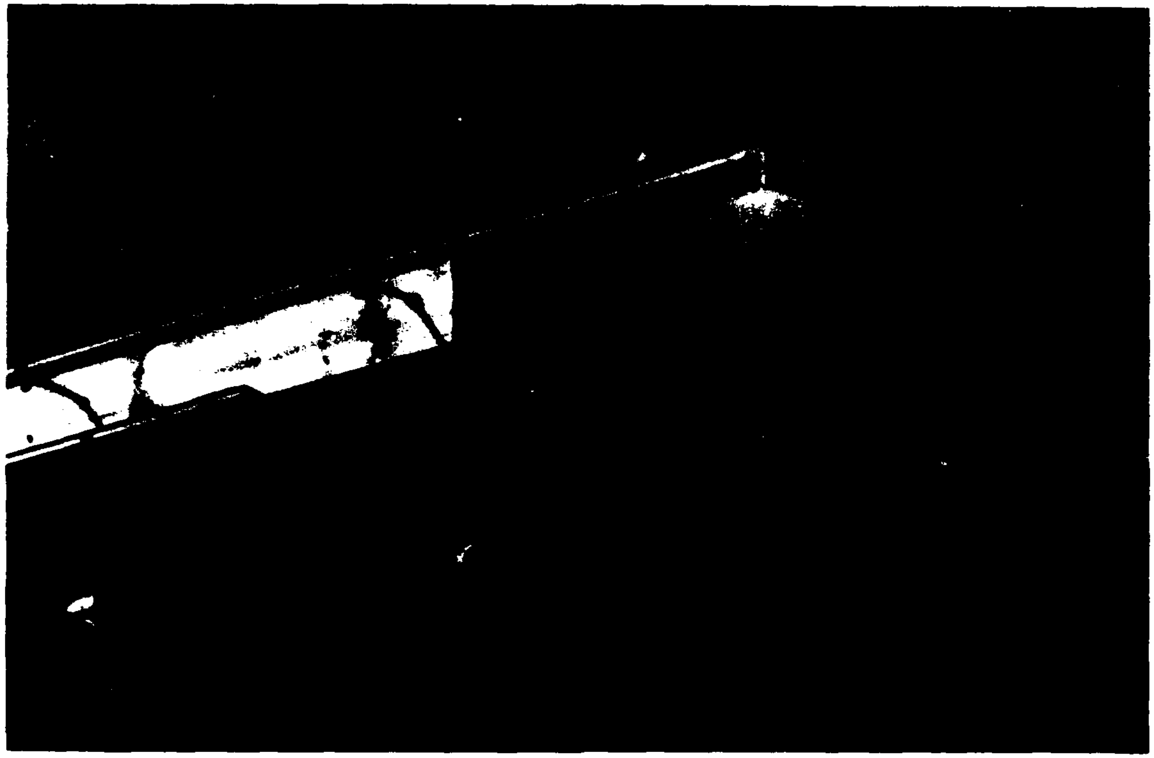


FIGURE : 5.7. FULL CONE SPRAY PRODUCED BY ONE OF THE WATER NOZZLES.

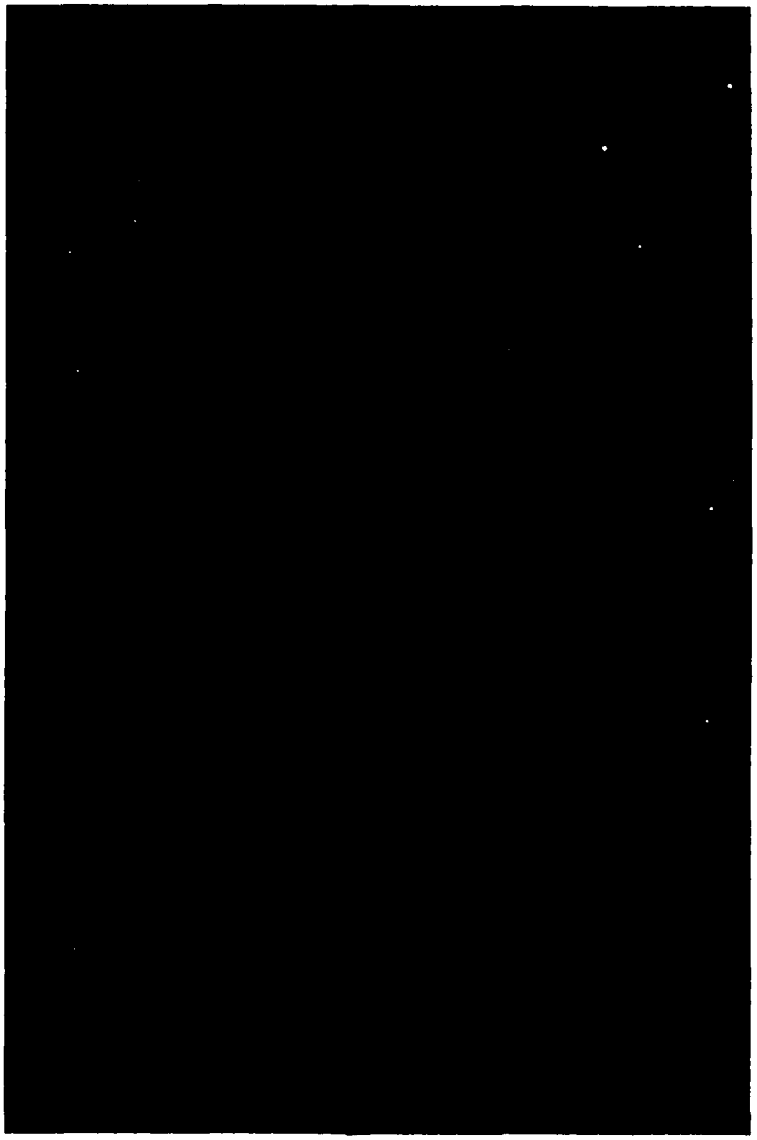


FIGURE: 5.8. VIEW OF SIMULATION SETUP SHOWING RELATIVE LOCATIONS OF WATER NOZZLE AND AUTOMATED PRESENT WEATHER MONITORING SYSTEM.

section of the sensor head, but on the opposite side of the transmitter from the sample volume so as not to introduce raindrop splatter into the sample volume; this would have perturbed the measurements of the present weather sensor.

Two APWOS systems were tested in the rainfall simulation facility: (1) the WSMR field model system and the AFGL laboratory model system. The reason for substituting the laboratory model instrument midway through the tests was to confirm some suspicions about the raindrop size distributions which arose during the testing of the WSMR field model instrument. The laboratory model instrument has the capability of providing size and velocity measurements of the raindrops produced by the spray nozzles — a capability not yet present in field model instruments. The laboratory model data did indeed confirm that: (1) the drop-size distributions from the nozzles were quite different from the distributions present in natural rainfall and, (2) the velocities of the drops were greater than the terminal velocities of natural rainfall indicating that the downward force exerted on the drops by the water pressure at the nozzles had not been dissipated by the time the drops reached the sample volume.

Natural rainfall has an approximate log-normal size distribution, implying that given two different drop sizes anywhere in the size-distribution there are always more of the smaller drops than the larger drops. The drop-sizes produced by the nozzles were shown to be quite anomalous, being more or less uniform in number over a large range of drop sizes. The drop-size situation was further aggravated by the ubiquitous winds present on Cape Cod. Because of the wind all, most, or some of the small drops would be blown away before they could fall through the sample volume of the instrument, depending upon the wind intensity.

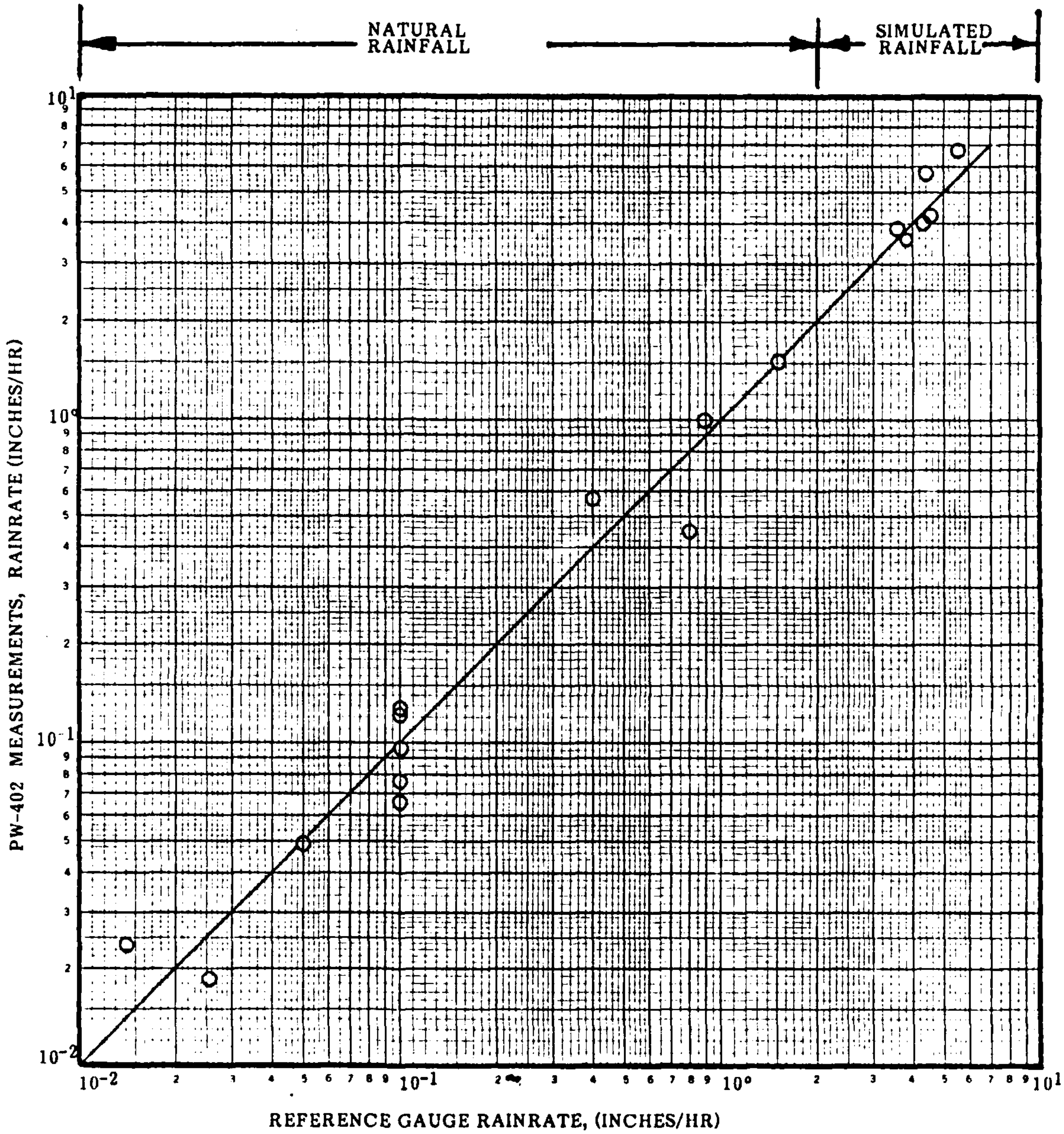
5.3.3 Simulation Test Results

The first measurements were begun in May 1985 with the WSMR instrument installed as the sensor under test. The months of May, June and part of July were devoted to optimizing the behavior of the simulation test facility while simultaneously generating the heaviest possible rains in an attempt to find the saturation point of the field model present weather sensor. In August, severe electrical storms damaged the small computers located inside the WTF which are used to record the data from the field model and laboratory model present weather sensors. Extensive damage also occurred to the AFGL MAWS system which is used to record the data from the entire complement of AFGL meteorological sensors. Further damage occurred to the computers located in the WTF which are used to record the present weather sensor data when the neutral line of the three-phase power network, to which the WTF is attached, floated free of ground. The net result of all the damage produced by the most severe occurrence of electrical storms in many years at Otis ANGB, was that no rainfall simulation tests were conducted after July because the HSS Inc contract for evaluation of the APWOS sensors ended before the damage to the recording systems at the WTF was repaired. It should be noted that the APWOS systems at the WTF did not themselves suffer any damage due to lightning because they are protected by internal voltage surge arrestors on both the power lines and signal lines.

Although only a small number of rainfall simulation tests were conducted they were sufficient to prove that the rainfall saturation point of the APWOS was greater than 6 inches per hour. The results of those tests are presented in Figure 5.9.

Figure 5.9 is a composite of two data sets, one obtained in natural rainfall at rates up 1.5 inches per hour where the reference instrument was a tipping bucket rain gauge. The other data set, representing extremely high rain rates, was taken at the Otis ANGB rainfall simulation facility. Each data point in the latter data set represents measurements made over a period of 30 to 40 minutes.

Figure 5.9 presents conclusive evidence that the APWOS can measure rainfall rates as great as 6 inches per hour without reaching the saturation limit of its measurement capabilities.



REFERENCE GAUGES:

(1) NATURAL RAINFALL: TIPPING BUCKET RAIN GAUGE (.01 IN/TIP)

(2) SIMULATED RAINFALL: STANDARD RAIN GAUGE

Figure 5.9. Comparison of a PW-402 Rainrate Measurements with those of Reference Rain Gauges.

6.0 PRECIPITATION IDENTIFICATION

6.1 Background

The two previous sections of this report were devoted to performance evaluations of the precipitation occurrence and precipitation accumulation capabilities of the HSS Inc type of automated present weather observing system (APWOS). The first of these sections (Section 4) demonstrated rather conclusively that the APWOS has a precipitation detection threshold for rain which is two orders of magnitude better than that of a standard tipping bucket rain gauge with a sensitivity of 0.01 inch per tip. The detection threshold of an APWOS is nearly an order of magnitude better for snow than for rain (on the basis of equivalent amounts of water) because the basis for detection is the number of particles passing through the sample volume during the sample time period.

The data presented in the second of these sections (Section 5) demonstrates that the APWOS measures rain accumulation in good agreement with a tipping bucket rain gauge for rain rates up to 6 inches per hour; the rate of 1.5 inches per hour being the highest rate of natural rainfall which occurred during the evaluation time period.

In this section we shall report on the accuracy with which the AWOS can identify the various forms of precipitation. (The accuracy with which precipitation can be identified is important not only as an explicit meteorological observable but also because it impacts the accuracy of rainfall accumulation measurements made by the APWOS technique.)

It was recognized that an evaluation of the precipitation identification capability of APWOS could best be addressed using archived APWOS data which spanned a fall-winter-spring time period, with the likelihood of a large number of precipitation episodes occurring in the ambiguous temperature range of 28°F to 41°F. The first evaluation of the accuracy of the APWOS precipitation identification algorithms, took place in February 1984. Room for improvement was noted. Updated algorithms, were expected to provide the needed improvement. The present evaluation has substantiated those expectations.

The precipitation identification capability of the APWOS was evaluated using a six-month data set collected over the time period from 1 November 1984 to 30 April 1985. This six-month data set was chosen because it includes a maximum of episodes during which the ambient temperature is in the ambiguous temperature range. The ambiguous temperature range is defined as that temperature range over which a precipitation identification sensor must rely entirely on its identification algorithms. Outside that temperature range the sensor is allowed the assistance of other sensors (e.g., a temperature sensor) to perform its identification functions.

The FAA has suggested that the ambiguous range be defined as being between 28°F to 38°F. However, AFGL meteorologists have pointed out that there are geographic locations and meteorological conditions where it will snow at temperatures above 38°F and rain at temperatures below 28°F. The same meteorologists recommended that the ambiguous temperature range be extended to include 23°F and 41°F.

The WSMR field model present weather sensor and a recently completed AFGL field model system have on-board temperature sensors. The AFGL laboratory model system does not. The software programs of the former two instruments utilize the wider ambiguous temperature range (i.e., 23°F to 41°F). Within that range they depend only on the size/velocity distributions of precipitation to perform the identification. Outside that range the temperature sensor reading is allowed to assist the identification. (**Note:** rejection of false alarms must be performed entirely by software algorithms both inside and outside the ambiguous temperature range). The laboratory model system relies entirely on algorithms to identify precipitation type.

During the six-month time period from 1 November 1984 to 30 April 1985, the only present weather sensor located at the AFGL WTF at Otis ANGB was the WSMR sensor. The AFGL field model instrument was still under fabrication and the AFGL laboratory model present weather sensor had been sent to AFGL for participation in a Snow Exercise which AFGL was conducting at Hanscom AFB. The decision to send the laboratory model system to AFGL was based on the fact that a video snow-monitoring system would be present at the site which would automatically record pictures of frozen precipitation so that the type of precipitation (i.e., snow grains, snow pellets, snowflakes, etc.) could be identified and sized.

The idea to send the laboratory model instrument to the Snow Exercise rather than the field model instrument was sound in principle because the former instrument can record the size/velocity distributions of precipitation essential to the development of precipitation identification algorithms, whereas the latter instrument cannot. Unfortunately, in practice it did not prove to be worthwhile. The video system recorded pictures for only two hours (unless someone was present to replace the video tape) and when the temperature was above 28° the motorized belt which transported the precipitation into the instrument for video recording melted the precipitation. Because of these factors, and the fact that there was no human observer, very little information of value was obtained from participation in the Snow Exercise.

Meanwhile, at the WTF at Otis ANGB there was a human weather observer who observed and recorded in detail all the forms of precipitation when he was present, which was most of the time because he staggered his work hours to be present during precipitation episodes. The observations of this observer form the primary reference for comparison with the automated identification reports produced by the WSMR APWOS. On the few occasions when the AFGL weather observer was not present, the Otis Tower observations were substituted as the comparison reference standard.

Based on this six-month experience, we believe that any evaluation of automated precipitation identification system should include: (1) a qualified weather observer, and (2) a location where the ambient temperatures during the winter reside primarily in the ambiguous temperature range. The WTF at Otis ANGB presented nearly ideal conditions from that standpoint during the winter of 1984/1985.

6.2 Evaluation of Results

An earlier evaluation of the precipitation identification capability APWOS had demonstrated the need to improve the identification algorithms. Prior to the evaluation reported here the algorithms were revised in a limited manner. Had the laboratory model instrument been at Otis ANGB considerably more could have been attempted in the way of improving the algorithms and testing their performance because the data recorded from that instrument includes the size/velocity distributions from each six minute sample time period.

In the field model present weather systems the size/velocity distribution of particles is evaluated at the end of each sample time period to determine the type and amount of precipitation. Upon completion of that task, the size/velocity information is discarded. Any application of new or revised identification algorithms to the WSMR data from the 1 November 1984 to 30 April 1985 time period had to be made manually and limited to measurement parameters other than the size/velocity distributions.

The data recorded by the WSMR field model present weather system includes all information that the laboratory model instrument does except the size/velocity distributions. It also included one real-time parameter which was obtained only off-line in the laboratory model instrument; that parameter was the amount of water contained in the precipitation which fell during each sample time period. That parameter and the number of precipitation particles which were detected passing through the sample volume were utilized to add one more identification criteria to the precipitation identification algorithms for the present evaluation.

Table 6.1 presents a summary of the data base which was used in the present evaluation. Two threshold criteria were used in the evaluation; namely, precipitation intensities of 0.01 inches/hour and 0.002 inches per hour. The number of total sample time periods

Table 6.1. Statistics of Precipitation Episodes Used in the Evaluation of the Precipitation Identification Capabilities of the Automated Present Weather Observing System.

PRESENT WEATHER SENSOR: PW-402 S/N 001 (WSMR)

TIME PERIOD COVERED: 1 Nov. 1984 to 30 April 1985

SAMPLE TIME PERIOD: 6 Minutes

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: AFGL & Otis Tower

RAIN EPISODES

TEMPERATURE RANGE	NO. SAMPLE PERIODS 0.01 IN/HR	NO. SAMPLE PERIODS 0.002 IN/HR
TEMP. ABOVE 41°F	610	869
23°F ≤ TEMP. ≤ 41°F	562	871
TEMP. BELOW 23°F	0	0
TOTALS	1172	1740

SNOW EPISODES

TEMPERATURE RANGE	NO. SAMPLE PERIODS 0.01 IN/HR	NO. SAMPLE PERIODS 0.002 IN/HR
TEMP. ABOVE 41°F	0	0
23°F ≤ TEMP. ≤ 41°F	422	806
TEMP. BELOW 23°F	63	102
TOTALS	485	908

shown in the table represents the number of six minute time periods that the precipitation intensity exceeded the threshold value. The evaluation extended from 1 November 1984 to 30 April 1985. All Precipitation Episodes during that interval have been included. For example, there were 2648 six minute time periods when the intensity of precipitation exceeded 0.002 inches per hour (i.e., 1740 rain periods and 908 snow periods).

Each of two categories of precipitation (rain and snow) is subdivided into three temperature zones: temperature above 41°F, temperature in the ambiguous zone from 23°F to 41°F, and temperatures below 23°F.

The performance of the revised identification algorithms for precipitation known to be rain is shown in Table 6.2 for the ambiguous temperature range. Performance is evaluated using the two intensity threshold previously described. The evaluation shows that for an intensity threshold of 0.002 inches per hour rain was correctly identified 96.9 percent of the time, and for a threshold of 0.01 inches per hour the correct identifications reached 98.8 percent.

Similarly, the evaluation for precipitation known to be snow, snow grains or snow pellets is shown in Table 6.3. The capability of the identification algorithms is obviously not quite as good for snow as for rain, but will (in the case of the intensity threshold of 0.01 inches per hour) meet the performance requirements for an FAA AWOS precipitation identification sensor. The poorer performance for snow episodes is due almost entirely to two or three brief episodes of snow grains. These particles fall faster than snowflakes and, thus are more difficult to distinguish from rain. It is believed that more sophisticated algorithms using the particle size/velocity distributions will improve this situation.

Tables 6.4 and 6.5 present the results of the performance evaluation for temperatures outside the ambiguous temperature range. Identifications are 100 percent correct in all cases. No false alarms occurred which might have reduced this achievement.

Table 6.2. Performance Evaluation of the Automated Present Weather Observing System for Identification of Rain in the Ambiguous Temperature Range.

TIME PERIOD COVERED: 1 Nov. 1984 to 30 April 1985

TEMPERATURE RANGE: 23°F to 41°F

SAMPLE TIME PERIOD: 6 Minutes

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: AFGL & Otis Tower

A. DETECTION THRESHOLD: 0.01 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
RAIN IDENTIFIED AS RAIN	555	98.8%
RAIN IDENTIFIED AS PRECIPITATION	4	0.7
RAIN IDENTIFIED AS SNOW	3	0.5
TOTAL NO. OF SAMPLES	562	100%

B. DETECTION THRESHOLD: 0.002 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
RAIN IDENTIFIED AS RAIN	844	96.9%
RAIN IDENTIFIED AS PRECIPITATION	11	1.3
RAIN IDENTIFIED AS SNOW	16	1.5
TOTAL NO. OF SAMPLES	871	100%

Table 6.3. Performance Evaluation of the Automated Present Weather Observing System for Identification of Snow in the Ambiguous Temperature Range.

TIME PERIOD COVERED: 1 Nov. 1984 to 30 April 1985

TEMPERATURE RANGE: 23°F to 41°F

SAMPLE TIME PERIOD: 6 Minutes

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: AFGL & Otis Tower

A. DETECTION THRESHOLD: 0.01 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	390	92.4%
SNOW IDENTIFIED AS PRECIPITATION	6	1.4
SNOW IDENTIFIED AS RAIN	26	6.2
TOTAL NO. OF SAMPLES	422	100%

B. DETECTION THRESHOLD: 0.002 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	658	81.6%
SNOW IDENTIFIED AS PRECIPITATION	53	6.6
SNOW IDENTIFIED AS RAIN	95	11.8
TOTAL NO. OF SAMPLES	806	100%

Table 6.4. Performance Evaluation of the Automated Present Weather Observing System for Identification of Rain in the Unambiguous Temperature Range above 41°F.

TIME PERIOD COVERED:	1 Nov. 1984 to 30 April 1985
TEMPERATURE RANGE:	Above 41°F
SAMPLE TIME PERIOD:	6 Minutes
LOCATION:	AFGL - WTF Otis ANGB
WEATHER OBSERVERS:	AFGL & Otis Tower

A. DETECTION THRESHOLD: 0.01 INCH/HOUR

IDENTIFICATION CATEGORY	**NO. SAMPLE PERIODS**	**FRACTION OF TOTAL**
RAIN IDENTIFIED AS RAIN	610	100%
RAIN IDENTIFIED AS PRECIPITATION	0	0
RAIN IDENTIFIED AS SNOW	0	0
TOTAL NO. OF SAMPLES	610	100%

B. DETECTION THRESHOLD: 0.002 INCH/HOUR

IDENTIFICATION CATEGORY	**NO. SAMPLE PERIODS**	**FRACTION OF TOTAL**
RAIN IDENTIFIED AS RAIN	869	100%
RAIN IDENTIFIED AS PRECIPITATION	0	0
RAIN IDENTIFIED AS SNOW	0	0
TOTAL NO. OF SAMPLES	869	100%

Table 6.5. Performance Evaluation of the Automated Present Weather Observing System for Identification of Rain in the Unambiguous Temperature Range above 41°F.

TIME PERIOD COVERED: 1 Nov. 1984 to 30 April 1985

TEMPERATURE RANGE: Below 23°F°

SAMPLE TIME PERIOD: 6 Minutes

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: AFGL & Otis Tower

A. DETECTION THRESHOLD: 0.01 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	63	100%
SNOW IDENTIFIED AS PRECIPITATION	0	0
SNOW IDENTIFIED AS RAIN	0	0
TOTAL NO. OF SAMPLES	63	100%

B. DETECTION THRESHOLD: 0.002 INCH/HOUR

IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	102	100%
SNOW IDENTIFIED AS PRECIPITATION	0	0
SNOW IDENTIFIED AS RAIN	0	0
TOTAL NO. OF SAMPLES	102	100%

6.3 The Ambiguous Temperature Range

For current APWOS instruments the ambiguous temperature range is defined as that range in which the APWOS must rely entirely upon its algorithms for the identification of precipitation and cannot be provided any assistance by other meteorological instruments such as a temperature sensor. Currently the ambiguous temperature range for the APWOS field model instruments was chosen to be from 23°F to 41°F.

The capability of the APWOS to identify precipitation in the ambiguous temperature range is best illustrated by comparing the APWOS automated reports with human observer's reports for episodes where the type of precipitation changes during the course of the episode. Two such examples are given below:

Snow Changing to Rain Episode:

Figure 6.1 presents a good example of the difficult task of identifying the type of precipitation at low precipitation rates in the ambiguous temperature range. The temperature at noon (GMT) on 13 March 1984 was 26°F and at 2400 GMT it was 36°F. This gradual rise in temperature brought about a change of precipitation type, as noted in the observer's log entries. The episode began as snow, changed to snow grains at 2225 GMT, then to ice pellets, then to light rain and ice pellets and finally to rain. We see that the APWOS had difficulty identifying snow when the rate of fall was very light; thus, it chose to use the uncertainty category; i.e., "Precipitation". (It should be remembered that when the cateogry "Precipitation" is chosen the particles are assumed to have a density of unity. Accordingly, accumulation is calculated as for rain. If the APWOS chooses to use the category "Precipitation" when indeed the actual precipitation is snow, then an error is introduced into the measurement of accumulation. During this entire episode only one tip of the heated tipping bucket rain gauge occurred, at 2310 GMT — some 10 hours after the snowfall began.

Rain Changing to Snow Episode:

Figure 5.3 of the previous section provided an example of a WSMR APWOS automated present weather report for this type of episode. The AFGL weather observer's report was added to the automated report to provide the comparison.

The episode began as very light rain (at 0424 GMT) and was detected simultaneously by the APWOS and the observer. The number of particles falling in each six minute sample time period was insufficient for the APWOS to identify the type of precipitation. When the number of particles increased sufficiently (at 0618) the APWOS identified the precipitation as light rain, in agreement with the observer. The light rain changed to moderate rain, varied in intensity between light and moderate then changed to moderate snow and light snow.

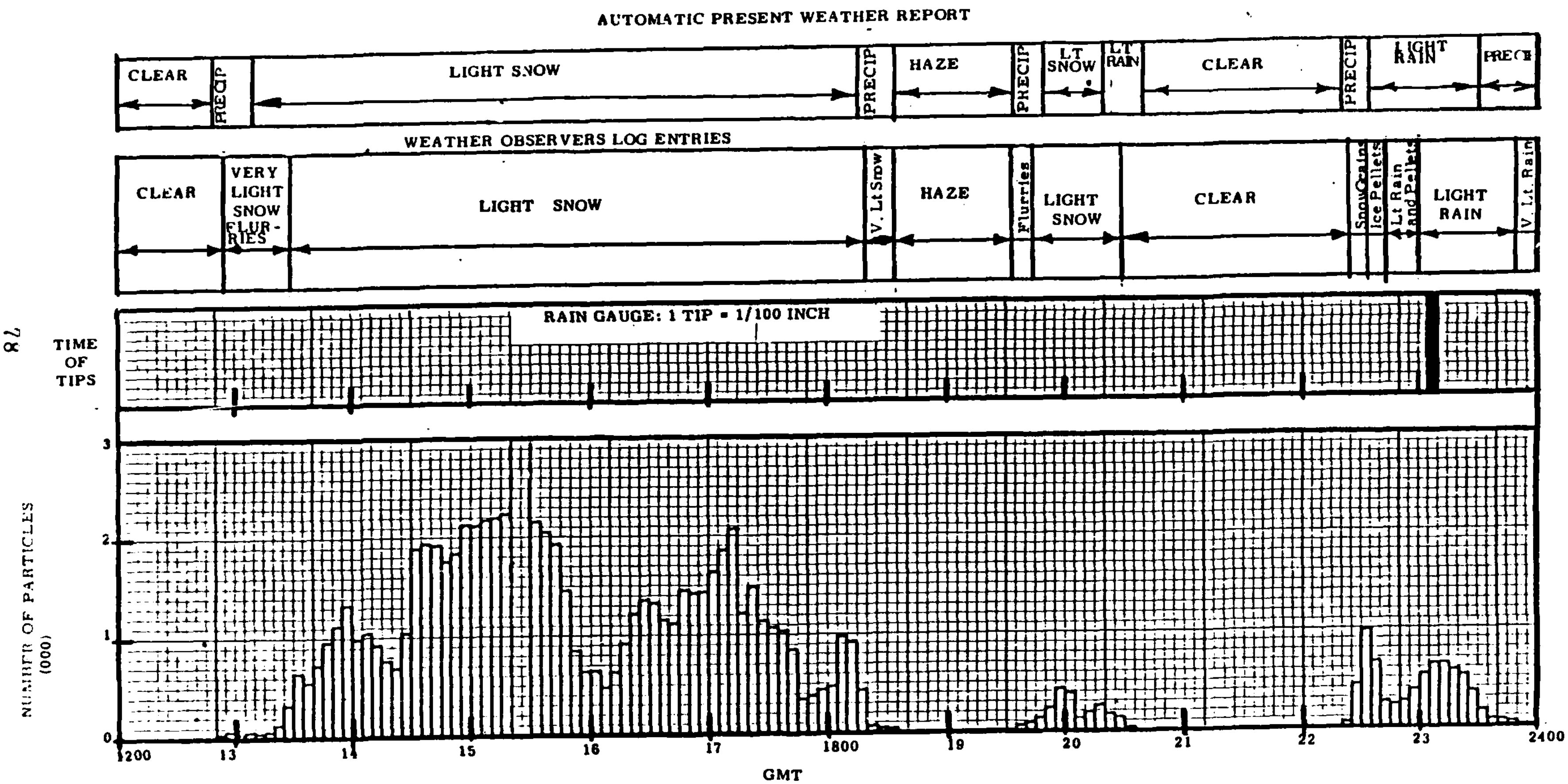


Figure 6.1. PRECIPITATION OCCURRENCE MEASURED DURING THE SNOW/RAIN EPISODE OF 13 MARCH 1984.

During the six minute sample time when the rain changed to snow the observer reported "moderate rain/snow". The APWOS, unable to report mixed precipitation, had to report the ambiguous identification "precipitation" in spite of 3748 particles in the precipitation recognition matrix.

When the observer reports the intensity of rain or snow his report is based on his past experience in similar situations. On the other hand, the APWOS intensity reports are based on accurate measurements of the parameters involved (rate of rainfall for rain and the visual range for snowfall). Both the observer and APWOS are using the definitions of intensity provided by the Federal Meteorological Handbook. Thus, when the observer reports light snow and the APWOS reports moderate snow the APWOS intensity description should be regarded as the more accurate description.

Figure 6.2 provides a comparison of the accumulated precipitation measurements of the AWPOS and a tipping bucket rain gauge for this same episode. Precipitation was detected some two hours prior to the first tip of the rain gauge. As the rain increased in intensity the APWOS and tipping bucket's accumulated rainfall measurements came ever closer to agreement. After the rain changed to snow the two instruments were still in agreement for over one-half hour until the tipping bucket began to clog up according to the observer. The total rainfall equivalent reported by APWOS was 0.537 inches; that reported by the tipping bucket was only 0.28 inches.

6.4 Hail

In the two years that the APWOS instruments have been in operation hail has occurred only twice and never where the Laboratory Model instrument was working. No attempt has yet been made to incorporate a hail identification algorithm in either of the two instruments for lack of any data with which to develop algorithms.

Simulation appears to be the best approach to developing a hail identification algorithm. A literature search is needed to learn more about the composition and light scattering properties of hail. Some information has already been collected about the fall velocity of various size hail particles. Based on more complete information we hope to find suitable non-frozen particles to substitute for hail and to eventually utilize these particles at the Otis ANGB simulation facility to simulate falling hail.

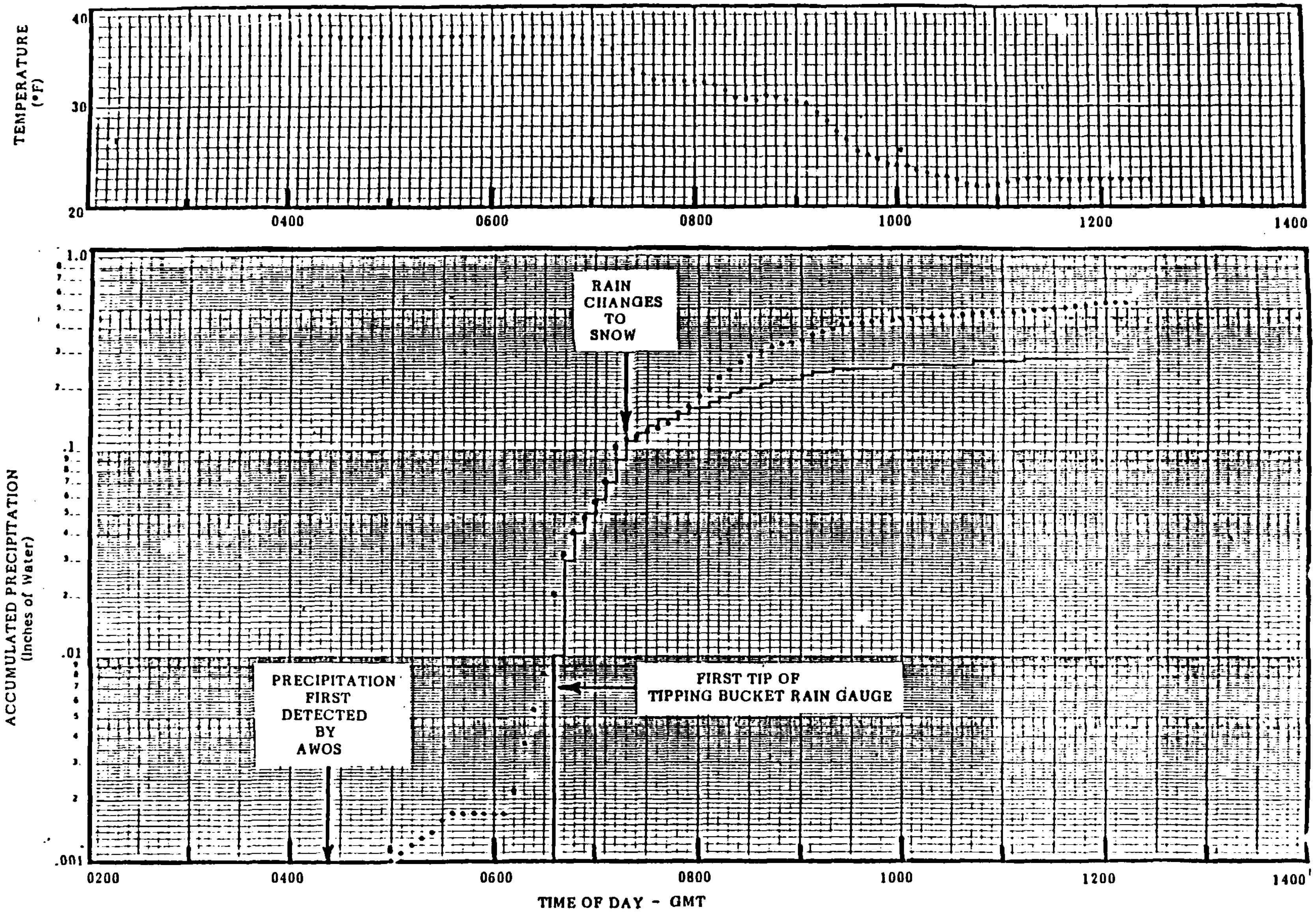


Figure [illegible] Rain/Snow Episode of 8 January 1985: Comparison of Rainfall Accumulation Measurements

6.5 Ice Pellets

Ice pellets (sleet) fall with essentially the same velocity as raindrops having the same mass, thus, they are difficult to distinguish from rain solely on the basis of their size/velocity distribution. It is apparent at this point in the development of APWOS that one of several possible hardware changes coupled with suitable algorithms might be effective in the identification of ice pellets.

Pattern recognition techniques alone may not be sufficient to identify some other difficult precipitation types, namely some forms of mixed precipitation. What may be needed in these cases also is more physical information than is provided by measurement of only the size and velocity parameters.

6.6 Mixed Precipitation

Mixed precipitation can take many forms. Combinations of various forms of snow and rain, ice pellets and rain, ice pellets and snow, drizzle and snow grains and/or snow pellets have been visually observed by us during the past two years. Some combinations of precipitation (e.g., mixed snow and ice pellets) produce recognition matrices which are *distinctly different from* those produced by either rain or snow. For such cases there is some justification in assuming that algorithms based entirely upon size/velocity distributions will be sufficient for identification purposes. On the other hand, there may be no justification for assuming that alogithms alone will be sufficient to identify mixed forms of precipitation where the size/velocity distributions are similar.

6.7 Drizzle

Figure 3.7 of Section 3 illustrates the problem of identifying drizzle as drizzle rather than as snow. The particle velocities are similar to those of snow, hence, there is a chance for misidentification when the algorithms depend heavily on the velocity distribution.

We have experimented with a recognition parameter defined as the number of particles required to produce 0.0001 inch of "apparent" rainfall ("apparent" meaning the application of a density of unity to the particles regardless of their true identity). Using this recognition parameter we have found that drizzle is clearly distinguishable from snow and reasonably well distinguished from rain. This finding is readily explained if one notes in Figure 3.7 the large number of particles in Column 1 of the matrix.

There is every expectation that a reasonably accurate drizzle identification algorithm can be developed. However, identification is only one of the problems associated with drizzle. The other problem is enough sensitivity to detect drizzle. Our experience is that there are different kinds of drizzle. In some forms of drizzle most the particles are large enough to be detected. In other forms many of the particles are too small to be detected. Hardware improvements will be required to improve the signal-to-noise ratio of the APWOS in order to detect all sizes of drizzle particles.

We expect that the rain simulation facility at Otis ANGB can be used to simulate drizzle, thereby, providing drizzles on demand rather than waiting for their chance occurrence. Appropriate spray nozzles will have to be obtained to generate drizzle size particles. The main problem associated with generating small particles at Otis ANGB is the ubiquitous winds — the particles all blow away before they fall through the sample volume of the instrument. We believe that this problem can be solved by lowering the spray nozzle and erecting a wind barrier. Normally the spray nozzle is mounted 8 feet above the instrument under test so that a degree of spatial uniformity can be achieved that will encompass rain gauges as well as the APWOS sensor head.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The performance of the HSS Inc type of Automated Present Weather Observing System has undergone sufficient evaluation at this point to determine its current capabilities and to establish goals, and approaches to these goals, for improving and expanding its capabilities. A brief summary of its current performance capabilities is provided in this section. In the next section we discuss the goals and approaches for improving performance of the APWOS. To date the APWOS has surpassed our original hopes and gives promise of approaching our best expectations.

Onset of Precipitation: As a precipitation occurrence sensor the APWOS is far more sensitive than the tipping bucket rain gauge with which it was compared. Onset of rain is detected with only 0.0001 inch of rainfall which makes it one-hundred times more sensitive to the onset of rain than a tipping bucket rain gauge with a sensitivity of 0.01 inch per tip. The APWOS is ten times more sensitive to snow than rain (on a equivalent water content basis) making it one-thousand times more sensitive than a heated tipping bucket rain gauge to the onset of snowfall.

Precipitation Occurrence: The precipitation occurrence capability of the APWOS was evaluated using standard error analysis parameters, the definitions of which are: Type I errors are the rejection of true occurrences, Type II errors are the acceptance of false occurrences. The evaluation spanned a five month time period encompassing both snow and rain episodes. An APWOS sample time period of five minutes was used along with a threshold precipitation intensity criteria of 0.001 inches of rain (or equivalent) per hour. The evaluation period contained approximately 41,000 sample time periods. During that time there were 4,696 five minute sample time periods when the intensity of precipitation exceeded the intensity threshold.

If we take as the universe of samples for Type I and Type II errors the sample time periods when the threshold intensity was exceeded plus that number of times (29) when the true occurrence went undetected, then the resulting Type I error was 0.61 percent and the Type II error (occurrences) was 0.70 percent.

If, however, we take as the universe of samples the 41,000 sample time periods comprising the entire evaluation period then the Type I error was 0.07 percent and the Type II error was 0.08 percent.

Either way that one evaluates the precipitation occurrance capability of the APWOS the error rates are exceedingly small and become even smaller if one raises the detection threshold intensity to the level of 0.005 inches per hour presently required to meet the FAA AWOS specifications.

Rainfall and Snowfall: It was demonstrated that the APWOS responds linearly to rain rate for rain intensities at least as high as six inches per hour. The measurement accuracy for rainfall was shown to be at least as good as 7 percent and probably better. The true accuracy of its measurements can only be established by employing several closely-monitored rain gauges operating under selected conditions which will guarantee the accuracy of the reference rain gauges.

The current APWOS measurement accuracy of the equivalent water content for snowfall is in the neighborhood of 20 percent. Most of this error, we believe, can be attributed to variability in the density of the different forms of snowflakes. Improvement in the measurement accuracy of snowfall water content must await the development of algorithms for identifying the various types of snow particles (e. g. flakes, grains, pellets).

Precipitation Identifications: With a precipitation intensity threshold of 0.01 inches per hour the APWOS can identify rain as rain 98.8 percent of the time and snow as snow 92.4 percent of the time in the ambiguous temperature range. (Note that the APWOS makes the identification decision immediately after a five minute sample time period when only 0.001 inches of precipitation has fallen. At the precipitation rate of 0.01 inches per hour it would take one hour for a single tip of a tipping bucket rain gauge to indicate it was precipitating.

There is room for improvement in the identification capability of APWOS for the two most common forms of precipitation, namely rain and snow. Other forms of precipitation for which identification is important are snow grains, snow pellets, drizzle, ice pellets (sleet) and hail. Improved identification algorithms for rain and snow and the identification of the less common forms of precipitation including mixed precipitation will be given a high priority in future work on APWOS. Proper identification of precipitation is important not only for safety considerations at airports but also to make accurate measurements of the equivalent water content.

7.2 Recommendations

7.2.1 Precipitation Identification Algorithms

There are four possible techniques and/or sources of data which could contribute to the development, testing, and evaluation of new precipitation identification algorithms.

These are: (1) archived data, (2) new natural-precipitation data (by data is meant precipitation recognition matrices), (3) simulation of some forms of precipitation, and (4) hardware (i. e. sensor upgrading). Each of these areas should be investigated and exploited to the fullest possible extent to improve the precipitation identification capabilities.

7.2.2 Software Changes

As a result of two and one-half years of operating the APWOS in several locations and many types of environments we recognize several software changes that would benefit potential users of APWOS. These recommendations include the visibility measurement capabilities of APWOS as well as its precipitation measurement capabilities. A listing and brief description of the purpose of the recommended changes is given below:

Change in Fog Classification Code:

The latest FAA AWOS specification requires that a Present Weather Sensor identify fog as the obstruction of vision if the visibility is 5 miles or less. At present, the APWOS algorithms utilize the International Visibility Code definition of fog (visibility of 2 kilometers or less in the absence of precipitation). Change to a new visibility code for fog is readily made. However, two problems immediately surface: (1) the identification of fog in the presence of precipitation, and (2) the need to distinguish fog from smoke or dust.

Fog in the Presence of Precipitation:

HSS Inc. has developed a technique for separating the extinction coefficient attributable to precipitating particles from the total atmospheric extinction coefficient, as described in Section 2 of this report. The residual that remains when this is done is attributable to suspended particles plus undetected very small precipitating particles. Also an empirical equation was developed for separating the extinction coefficient due to suspended particles from that due to undetected particles. To satisfy the FAA requirement the process must be repeated with a more stringent requirement, i. e., to separate out the contribution of undetected particles so that fog can be reported in the presence of precipitation when the visual range is less than 5 miles (8 kilometers).

Fog versus Smoke or Dust:

To distinguish fog from smoke or dust, we recommend the installation of a humidity gauge in each of the APWOS instruments. Fog will not be reported with a temperature-dew point spread greater than 4 degrees Farenheit. Instead, the APWOS will report haze or dust/smoke depending upon station climatology.

AD-A172 329 DEVELOPMENT TEST AND EVALUATION OF AN AUTOMATED PRESENT WEATHER OBSERVING SYSTEM(U) HSS INC BEDFORD MA D F HANSEN ET AL. 26 JUN 86 HSS-B-143 AFGL-TR-86-0140 2/2

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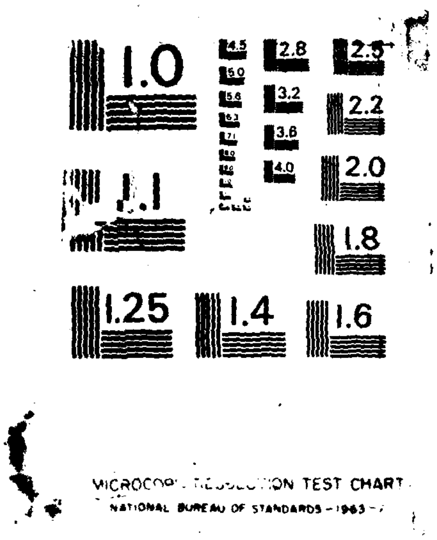
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Differences in Snow Particle Densities:

Once the ability to identify different types of snow particles is achieved, it should be a straightforward procedure to determine the density factor to apply to the APWOS data to derive an accurate value of water accumulation as opposed to utilizing the single density value of unity. As part of this process, heated tipping bucket rain gauges can (hopefully) be used to measure the equivalent water content of the snowfall.

Differences in Mixed Precipitation Particle Densities:

An attempt will be made to correct APWOS accumulation measurements when mixed precipitation occurs. This may prove difficult because the relative amounts of the two types of precipitation must first be determined.

Precipitation Alarm:

For many applications it is highly desirable to provide an alert within one minute after a significant precipitation rate is detected. Such a software modification can be readily performed.

Convert APWOS EXCO to Transmissometer EXCO in Rain:

If one accepts the unproven belief that transmissometers provide visibility determinations during rain that more closely represent those of a human observer, then the visibility measurements made by forward-scatter-meters should be converted to agree with those of transmissometers during rain. The APWOS is a derivative of a forward-scatter-visibility-meter. Because it has an on-board microprocessor, it is capable of providing the necessary correction once an algorithm is formulated. We recommend the formulation of such an algorithm.

Improved False-Alarm Discrimination:

Good false alarm discrimination has been achieved in the APWOS through a process of identifying false alarm situations, studying their data matrices and developing identification algorithms. Currently, the ability to identify sources of false alarms needs improvement in two areas: (1) on rare occasions some insects produce false alarms, and (2) in very heavy fogs the fluctuations in fog density sometimes give an appearance of particles that the APWOS identifies as trace rain. HSS Inc recommends the development of algorithms to improve both situations.

7.2.3 Hardware Changes

We recommend several hardware changes in the APWOS instruments. A brief description of the recommended changes follows:

Greater Source Intensity

The signal to noise ratio of the APWOS affects its ability to detect very small particles. We recommend a search for an IRED that will provide a factor of 2 or 3 more radiant power output than any IRED's used to date in any instruments developed by HSS Inc. If such IRED's are found, we recommend they be installed in the current APWOS instruments and all future instruments.

Improved Temperature Stability:

The IRED output in the VR-301 and APWOS instruments has up till now been stabilized by encasing the IRED in a miniature crystal oven (Ovenaire) which will hold the temperature of the IRED to 35°C ±3°C over the temperature range from -30°C to 35°C. Outside that range there is no stabilization.

HSS Inc has recently developed a printed circuit board for its new VR-301A Visibility Meter which allows the crystal oven to be eliminated and which will permit the stabilization of the source output power over the temperature range from -40°C to 85°C (with MIL SPEC components the stabilization range will be -60°C to 85°C). A temperature-stable photodiode is used to monitor the IRED power output and a feedback circuit is used to stabilize the power output. We recommend that this proven method be incorporated into the current APWOS instruments and all future APWOS instruments.

Self-Check of EXCO-Calibration:

We recommend the modification of the hardware (and software) such that an automatic calibration of the extinction coefficient can be performed by a person conducting routine maintenance on the instruments. The proposed method will require the purchase of an inexpensive remote terminal (e. g. Radio Shack Model 100). The self-check of the calibration would proceed as follows: the operator would clean the sensor windows, install the calibration reference standard, open up the door to the auxiliary unit, connect the remote terminal and enter the value of the extinction coefficient of the reference standard. The remote terminal would then make a zero check by turning off the IRED, then make a calibration check by turning on the IRED and comparing the output reading from the APWOS with the value of the reference standard. If required, new constants would automatically be inserted in the APWOS microprocessor software to adjust for any differences that show up during the check procedure.

Self-Check of Temperature Sensor:

We recommend the use of the same remote terminal, and procedures similar to those described above to check and reset, if necessary, the temperature readings provided by the electronic temperature sensor on-board the Field Model APWOS. The operator performing maintenance would be required to bring along an accurate temperature sensor.

On-Board Relative Humidity Sensor:

We recommend the installation of a Relative Humidity Probe on or near the bottom of the Auxiliary Unit of the APWOS instruments. The sensor would be protected by an inverted funnel as is the temperature sensor now installed on the Field Model APWOS. The relative humidity sensor would be used to provide inputs to the fog/dust-smoke identification algorithms.

Component Changes to Improve Temperature Range

The Microprocessor Board and the Interface Board now in the Field Model APWOS are boards made to meet Commercial Standards. Their guaranteed operating range is from 0°C to 70°C. We recommend the substitution of boards made to Industrial Specifications (-40°F to 85°C) because of problems that have been encountered during operation in hot summer weather.

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APPENDIX A

THE VR-301 VISIBILITY METER

A.1 DESCRIPTION

The VR-301 is a forward-scatter visibility meter; i.e., it belongs to the class of nephelometers which measures the amount of light scattered at angles less than 90 degrees by small particulates suspended in or passing through a sample volume. In the case of the VR-301, the sample volume is defined by the intersection of the transmitted beam of light and the ray-cone which defines the field of view of the receiver system. A photograph of a VR-301 Visibility Meter is shown in Figure A.1. The instrument has two major components: the sensor head located at the top of the mounting pole and an Auxiliary Unit located at a working height on the same pole. The Auxiliary Unit contains the power supply, a heater transformer and a number of protection features for the electronics. The sensor head has an optical transmitter and optical receiver and their associated electronics. The transmitter and receiver are oriented such that the central scattering angle is 35 degrees as shown in Figure A.2.

The geometry of the VR-301 has been carefully designed to provide an instrument of convenient size and weight and to optimize three of the most important measurement parameters: signal-to-noise ratio, accuracy and sample volume size. For a given set of transmitter and receiver optical parameters the S/N ratio and sample volume size become trade-off parameters; the larger the sample volume the smaller the S/N ratio. The optimum sample volume size is the minimum volume which will permit a statistically significant number of raindrops to pass through during the measurement time period. (In fogs and hazes the number of particles involved will be orders of magnitude greater). A careful study of the characteristics of rain has led to the conclusion that the 400 cm^3 sample volume and the electronic time constant of 30 seconds provided by the VR-301 are adequate to fulfill the statistical requirements for rain, especially when coupled with the integrating times of 1 minute to 3 minutes usually employed in the data-collection and evaluation systems which interface with visibility meters.

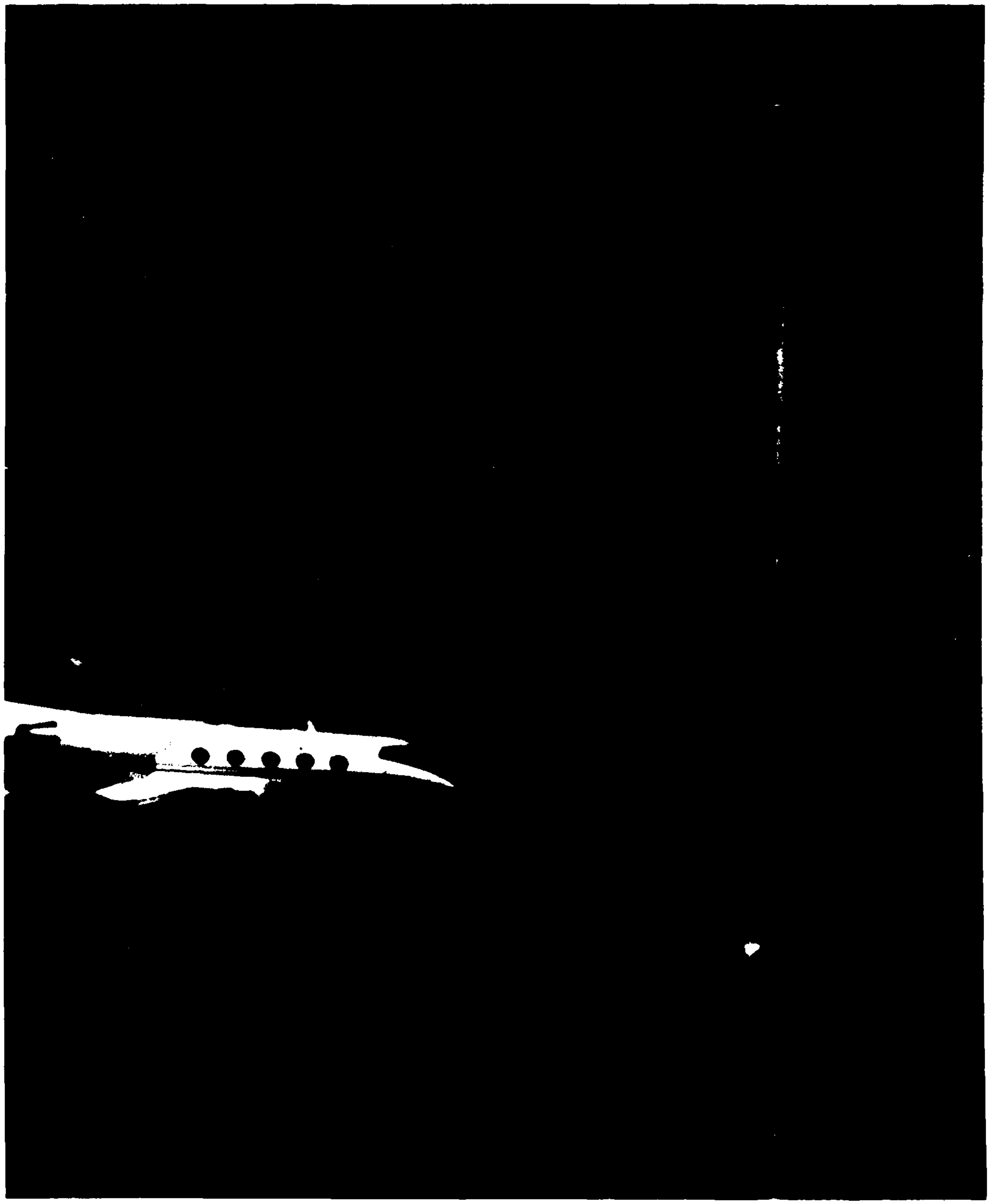

Figure A.1. The VR-301 Forward Scatter Visibility Meter.

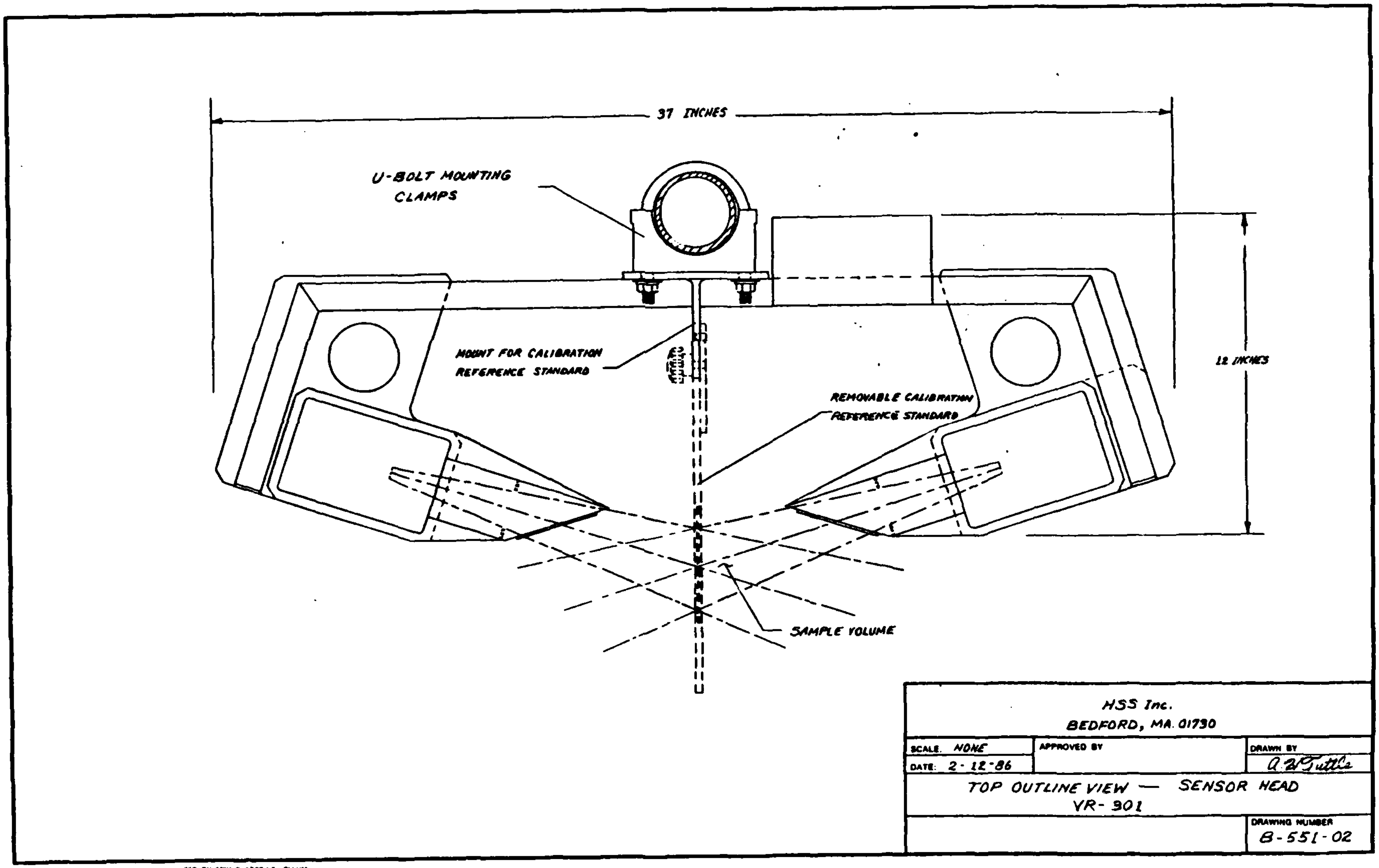

Figure A.2. Top View of the VR-301. The central scattering angle is 35 degrees; the total scattering angle coverage is from 27° to 42°.

A.2 ELECTRONIC FEATURES

The electronics of the VR-301 are all solid-state, utilizing high-reliability components. The light source is an infrared emitting diode (IRED) with peak emission at 880 nm for optimum spectral matching with the silicon hybrid detector/amplifier. A broadband optical filter further matches the spectral coverage of the detector to the radiant power bandwidth (80 nm) of the IRED thus suppressing unwanted daylight background radiation and enhancing the daytime signal-to-noise (S/N) ratio.

The IRED light source of the VR-301 has a life expectancy exceeding 10 years. It is electronically squarewave modulated at a 2000 Hz rate. At a 50 percent duty cycle its radiant power output is expected to decrease less than 10 percent over a ten year period of time. The radiant power output of IRED's is temperature dependent. The IRED source in the VR-301 is temperature stabilized by operating it in a small crystal oven. Its output is further stabilized by an electronic circuit which compensates for changes in the voltage/current relationship that results from temperature changes.

The receiver consists of a silicon detector with integrated pre-amplifier, a 2 KHz center frequency bandpass filter, the synchronous rectifier and a low-pass output filter. Each filter stage provides signal gain. The output voltage range of the standard VR-301 is 0 to 10 volts DC for input chopped optical signals of 0 to 6 nanowatts. Specifications for the VR-301 are given in Table A.1.

Table A.1. Specifications of the Model VR-301 Visibility Meter.

PERFORMANCE CHARACTERISTICS

The performance characteristics stated below are based on a time constant of 30 seconds for the electronic circuitry of the VR-301 and the ability of the readout or recording system to cover the full output signal range (0 to 10 volts) of the VR-301 with appropriate resolution.

Visual Range Coverage (Note 1)	
X .1 Gain Setting	3 m to 30 km
X 1 Gain Setting	30 m to 300 km
RMS Noise Voltage (At Output)	
Nighttime	< 1 millivolt
Daytime	< 2 millivolt
Linear Dynamic Range	10^4 to 1
Stability of Zero Setting	
Ambient Temperature Effects	≤ 2 millivolt
Long Term Drift	≤ 2 millivolt
Measurement Error (Std. dev.)	≤ ± 5%
(Includes All Calibration and Instrumental Errors)	
Maintenance	
MTBF	5.9 years
Calibration Check	Every 3 months
Clean Windows	Every 3 months

INSTRUMENT CHARACTERISTICS

Analog Output, proportional to the scattering coefficient	0 to 10 Volts
Scattering Angle Coverage	27° to 42°
Sample Volume	400 cm^3
Measurement Time Constant	30 sec

Spectral Features:

Central Wavelength	0.89 µm
Bandwidth	0.08 µm

Source Characteristics

Type	IRED
Lifetime	>10 years
Modulation Frequency	3000 Hz

Detector	Hybrid Si-Sensor/ Amplifier

Physical Characteristics (VR-301)

Weight	14 pounds
Length	36 inches

Physical Characteristics (Auxiliary Control Unit)

Weight	20 lbs
Size	16" L x 12" W x 6" H

Power Requirements

Basic Instrument	4 W
No-Dew Windows	6 W
De-Icer Heaters	100 W

Environmental

Temperature	-50° to +50°C
Altitude	0 to 10,000 ft
Weather	All Weather
Humidity	5% to 100%

Notes: (1) Visual range coverage can be optimized for specific applications by an internal potentiometer adjustment.

A.3 DYNAMIC RANGE

The dynamic range of the VR-301 as a visibility meter is determined at the high end of the range by the choice of the maximum output voltage (10 volts) and at the low end by detector noise. For low ambient light levels the rms output voltage of the VR-301 due to detector noise is conservatively less than 1 millivolt. During ambient daylight conditions the rms noise value is less than 2 millivolts. The linear dynamic range of the VR-301 is thereby established at about 10^4:1. This dynamic range is settable by an internal gain adjustment to provide visual range coverage from 3 meters to 30 kilometers or from 30 meters to 300 kilometers (with all other proportionately scaled combinations in between) as illustrated in Figure A3.

OUTPUT VOLTAGE	VR-301 INTERNAL GAIN SETTING			
	X0.1		X1.0	
Volts	β (km^{-1})	V_R (meters)	β (km^{-1})	V_R (meters)
10	1000	3	100	30
1	100	30	10	300
.1	10	300	1	3 km
.01	1	3 km	.1	30 km
.001	0.1	30 km	.01	300 km

Figure Visual Range Coverage of the VR-301; two options are illustrated.

A.4 VISUAL RANGE MEASUREMENTS

The term visibility is customarily used in two ways: (1) as a qualitative term to describe the clarity of the atmosphere, and (2) as a quantitative term to express the clarity of the atmosphere in units of distance. To avoid the ambiguity caused by this dual usage a more definitive terminology has gradually evolved (e.g., visual range, meteorological range, nighttime visual range, runway visual range, etc.). These terms are employed whenever the intent is to express visibility as distance under a given set of observation criteria.

Visual range can be determined by trained observers who view objects at known distances or from instrumental measurements of the atmospheric extinction coupled with the use of empirically established laws relating the atmospheric extinction to visual range. Estimating visual range by eye requires that black or dark objects be viewed against the daytime sky, or that unfocussed lights of moderate intensity be used at night.

Nearly all instrumental methods of determining visual range start with a quantitative measurement of the atmospheric extinction coefficient β. Because β is measured in the vicinity of the instrument an assumption must be made that the prevailing environmental conditions are uniform over the scale of visual ranges of interest. The extinction coefficient is then converted to daytime visual range by application of Koschmieder's Law.

$$C = C_o C^{-\beta R}$$

Koschmieder's Law gives the apparent contrast C of an object whose inherent contrast is C_o when that object is viewed against daytime sky, or a daytime fog background, by an observer at a distance R from the object. Koschmieder assumed a value of 0.02 for the contrast threshold of the human eye. For black objects ($C_o = 1$) viewed against the daytime sky or fog background the maximum distance at which the object can be observed is found by rearranging Koschmieder's Equation and inserting the two values of contrast,

$$R = \frac{1}{\beta} \ln\left(\frac{C_o}{C}\right) = \frac{1}{\beta} \ln\left(\frac{1}{.02}\right)$$

or

$$V_R = \frac{3.912}{\beta}$$

The maximum range at which the object can be observed (the daytime visual range) is denoted by V_R in the above expression.

Experience has shown that a contrast threshold value of 0.02 for the human eye is appropriate only to very large objects. Experiments have demonstrated that a threshold value of about 0.05 is more appropriate to small targets and to provide a degree of object recognition. As a result, the World Meteorological Organization recommends that a threshold value of C = 0.05 be used in computing daytime visual range from measurements of fog extinction coefficients. When that value of contrast threshold is used Koschmieder's relation is modified as follows:

$$V_R = \frac{1}{\beta} \ln \left(\frac{1}{.05}\right)$$

$$V_R = \frac{3.00}{\beta}$$

The concepts of nighttime visual range and runway visual range (RVR) make use of Allard's Law which relates the illumination produced by a source of light to the extinction coefficient β in a somewhat more complex fashion. Details of the application of Allard's Law will not be discussed here.

Koschmieder's Law and Allard's Law require the measurement of the <u>total extinction coefficient</u> (as evaluated in principle by a receiver which has the spectral response curve of the eye). The total extinction coefficient includes the extinction due to both gases and particulates. Transmissometers measure the total extinction coefficient, most other types of visibility meters do not.

Fortunately, for the other measuring techniques, the primary cause of atmospheric attenuation in the visible region is scattering of light by aerosols, fog droplets and the various forms of precipitation. Absorption by the gaseous constituents of the atmosphere and by particulates is negligible in comparison. This fact is essential to the application of nephelometers (or scatter meters as they are more popularly called) to the determination of visual range.

A.5 MEASUREMENT EQUIVALENCE TO TRANSMISSOMETERS

By their very nature, transmissometers measure the total atmospheric extinction coefficient. Also, by their own nature, forward scatter meters measure the angular scattering coefficients of the atmospheric constituents. We have noted that the application of Koschmieder's Law and Allard's Law to the measurement of visual range requires the measurement of the total extinction coefficient. Obviously, there must be an equivalence between the angular scattering coefficients measured by forward scatter meters and the total extinction coefficient measured by transmissometers. Today there can be no question of their equivalence. The equivalence has been demonstrated through years of comparison of measurements from the two types of instruments by members of the Air Force Geophysics Laboratory at their Otis ANGB Weather Test Facility.

The equivalence between the measurements of transmissometers and forward scatter meters in fogs and hazes is a consequence of two facts of nature: (1) the angular atmospheric scattering coefficients of all types of fogs and hazes, when measured within a specific range of forward scatter angles, (30 to 55 degrees) differs from the total scattering coefficients by only a constant of proportionality and, (2) in the visible and near visible spectral regions the total atmospheric scattering coefficient and the total atmospheric extinction coefficient are equivalent; (i.e., the absorption by atmospheric aerosols in the visible spectral region is negligible).

The VR-301 Visibility Meter performs its measurements in a near-visible spectral region centered at 0.89 nm. Visual range, by definition requires that the total scattering (extinction) coefficient be determined for the visual response of the human eye. Again, the equivalence between the measurements of the VR-301 (and other forward scatter meters) and those of transmissometers in low visibility situations (ranging from 100 feet to 5 miles), and an eye response televisiometer for higher visibility situations (from 5 to 50 miles) has been demonstrated by the AFGL test program at their Weather Test Facility at Otis ANGB. This equivalence implies that the attenuation of the atmosphere, at least for visual ranges as great as 90 miles, is primarily the result of scattering by aerosols however small in number density and not by molecular scattering.

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