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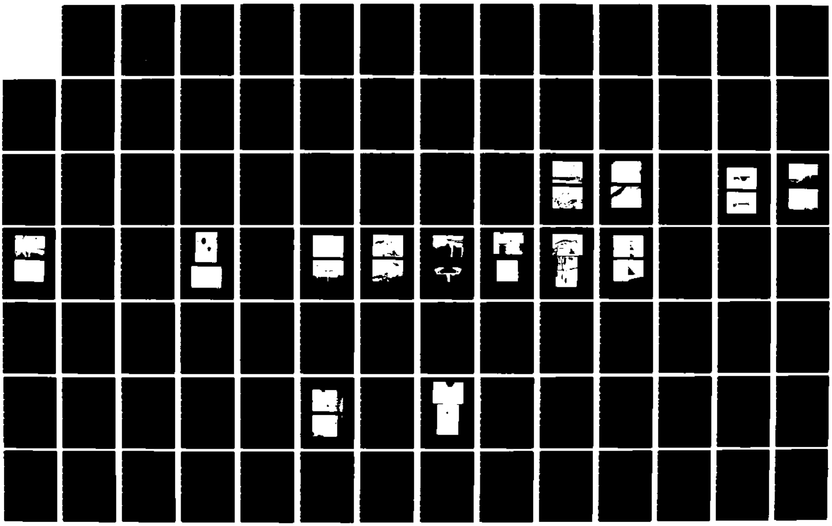

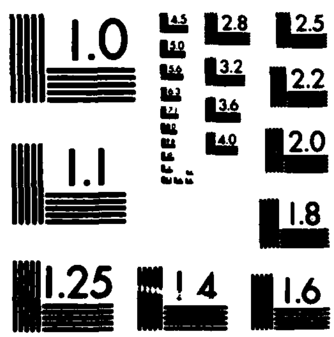

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Evaluation of Visibility Sensors at the Eglin Air Force Base Climatic Chamber

AD-A135 375

Dr. David C. Burnham

Transportation Systems Center
Cambridge MA 02142

October 1983
Final Report

U.S. Department of Transportation
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15. Supplementary Notes

16. Abstract

Three transmissometers and five forward-scatter meters were evaluated for measuring fog, haze, rain, and snow in the large test chamber of the Eglin Air Force Base Climatic Laboratory. Methods were developed for generating moderately uniform and stable fog and haze conditions. Fog densities equivalent to Runway Visual Range (RVR) values of 100 to 600 feet were achieved; such fog densities are rare in nature and were the primary reason for undertaking the chamber tests. No unusual characteristics of the chamber fogs were noted. Laser transmissometers with 40- and 250-foot baselines served as standard sensors for the tests. Because of inhomogeneities in the chamber, only the 40-foot baseline gave good correlations with most of the test sensors. Consequently, one of the forward-scatter meters, the EG&G 207, was used as a secondary standard for high visibility (RVR above 1000 feet) conditions. With appropriate corrections, all the test sensors met the 15 percent root-mean-square error pass-fail criterion for measuring dense fog.

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METRIC CONVERSION FACTORS

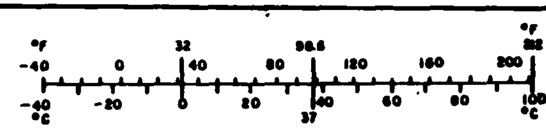
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The Federal Aviation Administration (FAA) is planning to extend the range of airport visibility measurements to both lower and higher values than are currently measured. In recent years new technologies have been developed for measuring visibility. Starting in 1980 the FAA has been conducting field evaluations of these new technologies. The work reported here examines the feasibility of testing visibility sensors under controlled laboratory conditions with the twofold goal of 1) examining visibilities lower than commonly experienced in nature and 2) accelerating the evaluation process.

The work reported here represents the cooperative efforts of many people whose contributions I would like to acknowledge. Many organizations were involved.

Al Thomas (currently APM-400) of the FAA secured the funding for the project. Jack Dorman was the FAA project manager and provided the initial organization and planning the of tests. After Mr. Dorman's retirement, Eric Mandel (currently APM-640) assumed the role of FAA project manager for the test period and the subsequent data analysis. The FY'83 review of the report was carried out under the direction of Leo Gumina, APM-340.

The Eglin Air Force Base Climatic Chamber personnel played an important role in the tests. Wayne Drake supervised the tests. Lorin Klein filled in when he was not available. Ulma Stabler was responsible for the data collection and recording. Richard Tolliver provided advise and direction.

A host of Transportation Systems Center (TSC) personnel took part in the tests. Andrew Caporale was responsible for getting the equipment to Eglin, installing it, and removing it after the tests. Irving Golini constructed the data collection interface electronics which were designed by Bruce Ressler. John Fantasia made the needed optical and mechanical modifications to the laser RVR calibrator while Peter Mauro corrected some electronic errors. Edward Spitzer and Melvin Yaffee assisted in setting up the equipment and checking it out. John Fantasia assisted in carrying out the tests and acted as TSC test coordinator for the low temperature and snow portion of the tests. Scott Heald carried out the initial data processing. Ian McWilliams assisted in later data processing and analysis.

The Air Force Geophysics Laboratory supplied the EG&G 207 forward-scatter meters used in the tests and allowed Leo Jacobs to spend two weeks at Eglin checking out sensors and providing expert advise. Richard Lewis of the National Weather Service Test and Evaluation Division also assisted in carrying out much of the test sequence.

Apart from the EG&G 207 sensors, all sensors tested were loaned by the manufacturer, who also carried out the initial installation and checkout. Three manufacturers, HSS, Wright & Wright, and Marconi, also participated during the execution of the tests, both in checking out their own sensors and in making suggestions about the conduct of the tests.

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1. SUMMARY

Visibility sensors capable of measuring Runway Visual Range (RVR) between 150 and 600 feet are needed to support Category IIIb operations. Because Category IIIb conditions are rare in nature, it is useful to generate such conditions in an environmental chamber. Three transmissometers and five forward-scatter meters were tested in the Eglin Air Force Base Climatic Laboratory's large test chamber. The FAA's laser RVR calibrator was used to make standard measurements. The primary goal of the tests was to study the sensor response to fog. The effects of haze, snow, rain, freezing rain, and temperature extremes were also studied.

1.1 FOG

All of the sensors tested were capable of measuring dense fogs. Some of them were found to require correction factors from their nominal calibration (see Table 1-1). The performance of the sensors under dense fog conditions is illustrated in Figure 1-1 which compares the corrected measurement of each test sensor with the measurement of the FAA laser RVR calibrator on a 40-foot baseline, which serves as a standard sensor. The sensor comparisons are made in terms of extinction coefficient. Table 1-2 shows how the graphed values of extinction coefficient are related to RVR. Different RVR values are obtained for day or night and for different runway light settings (e.g. L.S.3). The minus sign in front of an RVR value indicates that objects are more easily seen than the runway lights. Figure 1-1 is a composite of many scatter plots displaced vertically to allow comparisons between sensors. The diagonal dashed lines represent disagreements between the test sensor and the standard sensor of ± 15 percent. All plots except the top one are for the same fog event, which was selected for the most uniform conditions. A number of features can be noted in Figure 1-1. First, the transmissomters (top three plots) tend to give better agreement with the laser RVR calibrator than the forward-scatter meters since they average over much the same portion of the chamber. Second, the forward-scatter meters with small scattering volumes (bottom

TABLE 1-1. SENSOR CALIBRATION CORRECTION FACTORS

SENSOR	MANUFACTURER	LABEL	FOG	HAZE
RVR 500 (40-FOOT)	TASKER	RV40	1.07	
SKOPOGRAPH	IMPULSPHYSICS	SKOP	1.15	1.15
MET-1	MARCONI	MARC	1.10	0.90 (1.20*)**
EG&G 207	EG&G	EG12	1.00	0.70 (1.00*)**
FOG-15	WRIGHT & WRIGHT	FOG1	1.00	1.00* (0.70)**
VR-301	HSS	HSS	1.10	1.10* (0.80)**
FUMOSENS III	IMPULSPHYSICS	FUMO	0.90	1.30* (1.99)**
EV-1000	ENERTEC	ENER	1.20	1.40* (1.10)**

*Compared to the EG&G 207's rather than the RVR calibrator.

**The haze correction factors in parentheses are the result of compensating for the 1.30 factor difference in haze between the EG&G 207 and the RVR calibrator.

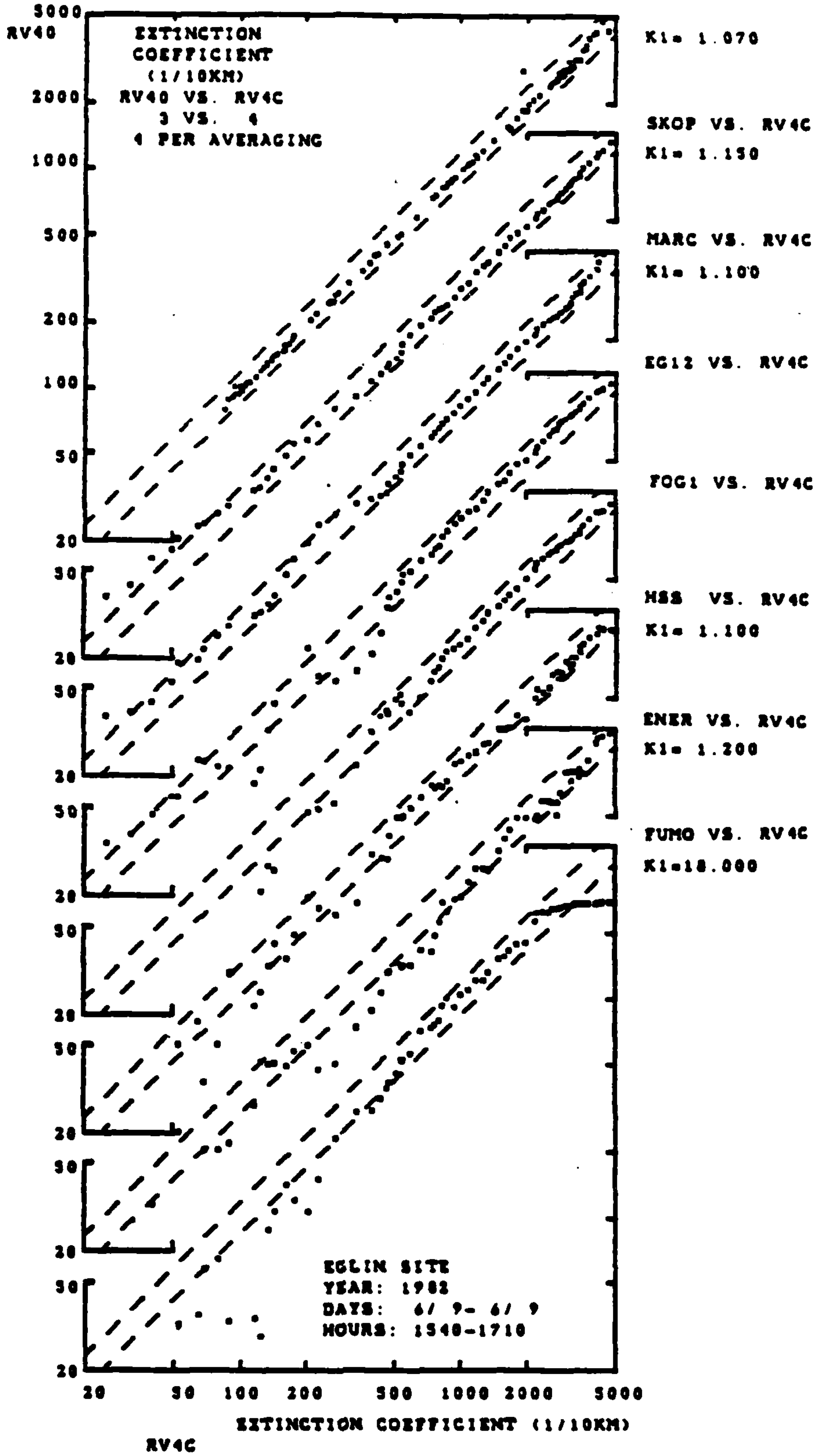


FIGURE 1-1. RESPONSE OF VISIBILITY SENSORS TO DENSE FOG.

TABLE 1-2. RUNWAY VISUAL RANGE (FEET) VERSUS EXTINCTION COEFFICIENT FOR DAY AND NIGHT AND THREE LIGHT SETTINGS.

EXTINCTION COEFFICIENT	DAY L.S.3	DAY L.S.4	DAY L.S.5	NIGHT L.S.3	NIGHT L.S.4	NIGHT L.S.5
10.	-9843.	-9843.	-9843.	11962.	15594.	19407.
20.	-4921.	-4921.	-4921.	7538.	9431.	11440.
50.	-1969.	-1969.	2495.	3881.	4690.	5531.
100.	-984.	1197.	1559.	2288.	2706.	3138.
200.	506.	700.	933.	1326.	1542.	1764.
500.	200.	356.	434.	590.	688.	788.
1000.	172.	211.	252.	333.	377.	423.
2000.	103.	123.	145.	186.	208.	231.
5000.	50.	59.	68.	85.	94.	103.

TABLE 1-3. VISIBILITY (MILES) VERSUS EXTINCTION COEFFICIENT FOR DAY AND NIGHT.

EXTINCTION COEFFICIENT	DAY	NIGHT
1.	18.02	17.58
2.	9.01	10.41
5.	3.60	5.05
10.	1.80	2.88
20.	0.90	1.62
50.	0.36	0.74
100.	0.18	0.41
200.	0.09	0.22
500.	0.04	0.10

three plots) show more scatter in the response that the large-volume forward-scatter meters (middle two plots). Third, the Fumosens III (bottom plot) saturates for high extinction coefficients.

1.2 HAZE

The measurement of low-density fog and haze conditions places more stringent demands on both the sensors being tested and on the standard of comparison. Because of nonuniform aerosol density in the chamber the 250-foot baseline transmissometers could not be used as a high visibility standard for comparison. Consequently, the EG&G 207 forward-scatter meters, which have an extensive field test record, were used as a secondary standard. As indicated in Table 1-1, some of the sensors, including the EG&G 207, exhibited a different correction in haze than in dense fog. The haze-fog difference (relative to the RVR calibrator) is smaller for the units using white light flashlamps (Fumosens III and EV-1000) than for all the other units which use considerable infrared light. The observed difference is opposite to the expected wavelength dependence of the haze extinction coefficient (i.e., lower in the infrared).

Figure 1-2 compares the test sensors with a standard for two fog/haze events which covered different ranges of extinction coefficient (note the break in data below 20 units). Table 1-3 shows the runway visibility values (RVV) corresponding to the extinction coefficients in Figure 1-2. The haze corrections listed in Table 1-1 have been applied to the data in Figure 1-2. All comparisons except the bottom plot use the EG&G 207 forward-scatter meter as a standard. The bottom plot compares the EG&G 207 to the RVR calibrator; the curvature in this plot is caused by a slight error in the calibration of the calibrator. Similar calibration errors are also noted in the plots for three other sensors: Marconi MET-1 (top plot), HSS VR-301 (second plot from top), and to a lesser extent Fumosens III (second from bottom plot). The Enertec EV-1000 (third plot from top) does not read below 4 units and therefore clips at that level. The EV-1000 shows considerably more scatter in the measurements than any of the other sensors.

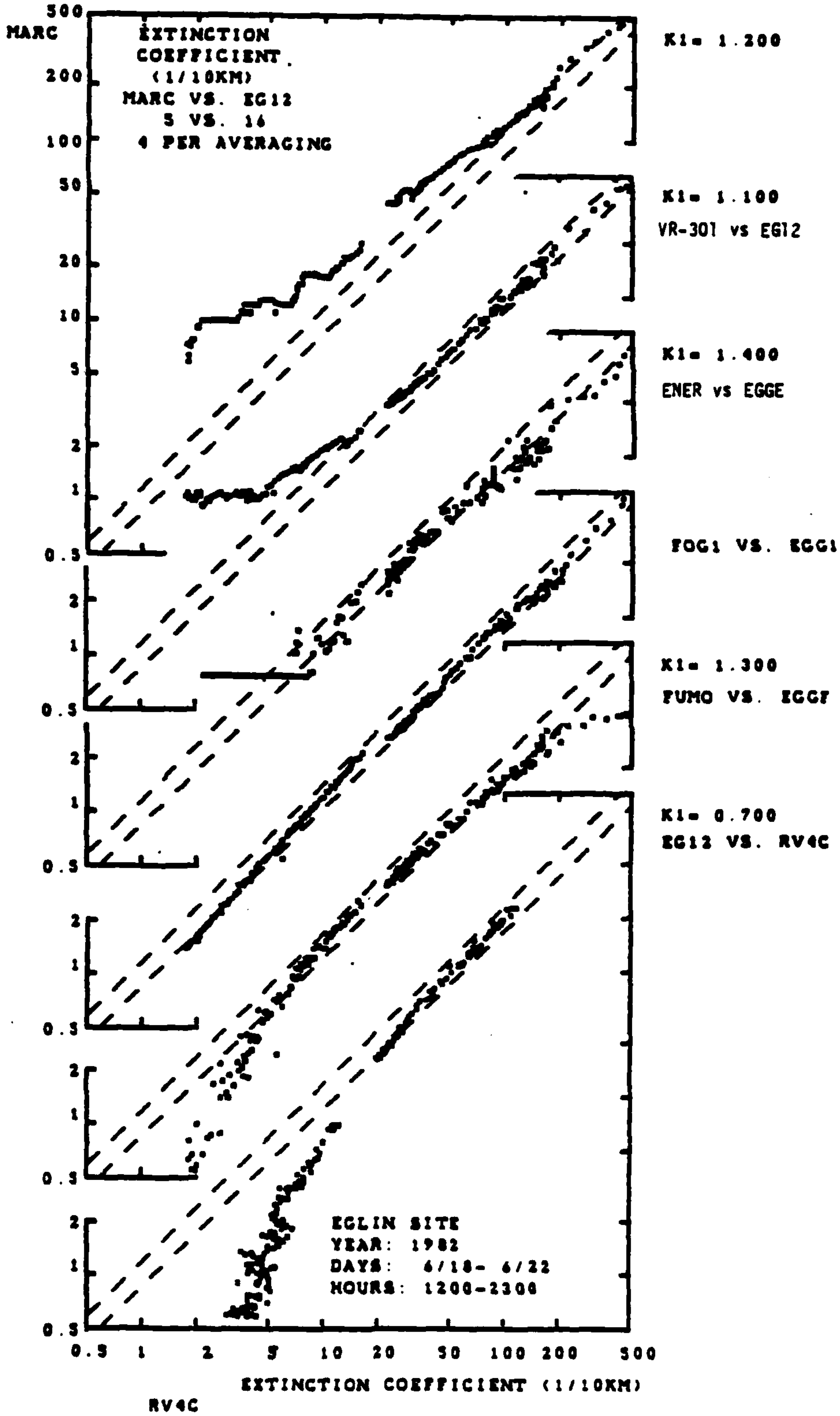


FIGURE 1-2. RESPONSE OF VISIBILITY SENSORS TO FOG/HAZE

1.3 PRECIPITATION

Many of the sensors exhibited problems under conditions of freezing and/or frozen precipitation. Table 1-4 summarizes the severity of the problems. Snow caused the most problems, affecting more than half the sensors. The snow conditions of heavy snow at $0^{o}F$ represented an extremly harsh environment.

TABLE 1-4. SENSOR ENVIRONMENTAL PROBLEMS

SENSOR	SNOW	FREEZING RAIN
TASKER RVR 500	MINOR	NONE
SKOPOGRAPH	NONE	NOT TESTED
MET-1	NONE	SOME
EG&G 207	SOME	NONE
FOG-15	SEVERE*	SOME
VR-301	NONE	NONE
FUMOSENS-III	SOME	NONE
EV-1000	SOME	SEVERE

*SATISFACTORY AFTER MODIFICATION

2. CONCLUSIONS

a) Methods were developed for generating reasonably uniform fogs over most of the desired range of fog densities.

b) Because of chamber inhomogeneities, the 250-foot transmissometers could not be used as visibility standards. Consequently no direct standard was available for RVR above about 1000 feet. The EG&G 207 forward-scatter meter was used as a secondary standard.

c) The candidate transmissometers gave excellent correlation with the laser RVR calibrator.

d) All the sensors tested show reasonable promise of measuring Category IIIb conditions.

e) On the basis of the field and chamber tests, the Tasker RVR 500 Dual-Baseline transmissometer system appears to be satisfactory for operational use with minor corrections: 1) a change in baseline and 2) a projector heater. This conclusion is based on the fact that the 250-foot baseline is already in operational use with known accuracy, required maintenance, and reliability. The evaluation has verified that the 40-foot baseline unit produces reasonably accurate measurements.

f) The operational use of a forward-scatter meter requires a method of checking the absolute calibration in the field. Two of the forward-scatter sensors (Fumosens III and EV-1000) have no absolute calibration method.

g) Many of the sensors exhibited problems with ice building up on windows or light baffles during the snow and freezing rain tests. Considerable care must be exercised in designing heaters to keep critical elements clear without affecting measurements by changing the local environment. For example, some heaters were observed to generate local fog during rain.

h) The chamber tests were inconclusive concerning the performance of visibility sensors above three-mile visibility. Although fog-haze conditions could be generated that were stable and locally homogeneous, the lack of a usable standard made satisfactory testing impossible. If the high visibility response and wall corrections of the EG&G 207 were better characterized, it could serve as a useful standard for transferring field calibrations into a test chamber.

i). The very dense fogs generated in the test chamber appeared to be similar in character (i.e., drop size distribution) to the lower density natural fogs observed at Arcata, CA in 1981 as far as visibility sensor response is concerned. The forward-scatter correction for the 40-foot RVR 500 transmissometer was similar in the two tests. This observation means that measuring the response to natural fogs, which rarely reach the Category IIIb region, is sufficient to characterize the sensor response over the entire Category IIIb region. It is not necessary to repeat the Eglin tests in future sensor validation work if some other method is available for assuring adequate sensor dynamic range (such as neutral density filters for transmissometers and calibrators for forward-scatter meters).

3. RECOMMENDATIONS

a) The Tasker dual-baseline system should be installed at a single airport to support Category IIIb operations during the coming winter.

> NOTE: The unsatisfactory results of following this recommendation are discussed in Section 7.

b) Forward-scatter meters should be installed at the airport with the transmissometers for comparison in order to verify the operational acceptability of forward-scatter meters.

c) The nonlinear high-visibility response of forward-scatter meters requires further study.

d) Field tests are needed to verify the performance of the instruments tested at high visibilities where no satisfactory standard was available in the chamber.

4. BACKGROUND

The current generation of aircraft and instrument landing systems are capable of supporting Category IIIb operations. The certification of Category IIIb operations must wait, however, until visibility sensors covering the Category IIIb range (RVR of 150 to 700 feet) have been deployed.

A variety of sensors are currently available to meet the need for Category IIIb visibility measurements:

1) Dual-Baseline Tasker RVR-500 Transmissometer

   The Tasker RVR-500 transmissometer is currently deployed at airports on a 250-foot baseline to measure RVR between 600 and 6000 feet. The RVR 500 signal processing and display equipment are designed to report RVR between 100 and 600 feet with the addition of a second receiver (on a 40-foot baseline) to the 250-foot baseline.

2) European Transmissometers
   Many countries in Europe are conducting Category IIIb operations using transmissometers manufactured locally.

3) Forward-Scatter Meters
   Forward-Scatter Meters (FSM) have been developed as low-cost alternatives to the transmissometer. They are particularly suited for Category IIIb where their drawbacks (small averaging volume and errors in rain) should have little effect.

4.1 ARCATA TESTS

In 1981 a number of sensors being considered for Category IIIb measurements were tested at a field site operated for the FAA at Arcata CA. Three forward-scatter meters (EG&G 207, Wright & Wright FOG-15, and Impulsphysics Fumosens III) and two dual-baseline transmissometers (Tasker RVR 500 and Impulsphysics Skopograph) were evaluated in a preliminary report (Appendix A) issued in December 1981. The RVR-500 and FOG-15 were identified as the most promising sensors and received the most detailed examination. The data anlysis identified a forward-scatter correction of about 7 percent for the 40-foot baseline RVR-500. Two practical problems were identified for the FOG-15: an excess signal variability and an unstable zero level.

4.2 RELATIONSHIP BETWEEN VISIBILITY AND EXTINCTION COEFFICIENT

Visibility sensors do not actually make a direct measurement of visibility. Instead, they measure the atmospheric extinction coefficient which will be designated by σ . Standardized equations, based on human observations, are then used to calculate the visibility from the extinction coefficient. The equation and the parameters to be used depend upon the object being viewed and the viewing conditions.

Runway Visual Range (RVR) is defined as the maximum distance for viewing the focused runway edge lights or the runway markings, whichever is easier to see. Figure 4-1 shows how RVR depends upon the extinction coefficient (here termed fog density) for runway light setting 5 (L.S. 5). The curves for day and night are shown. Table 1-2 relates RVR and extinction coefficient for other light settings.

Runway Visibility Value (RVV) is defined as the maximum distance for viewing omnidirectional runway edge lights or the runway markings, whichever is easier to see. Figure 4-2 shows the dependence of day and night RVV on the extinction coefficient. The unit of extinction coefficient in Figures 4-1, 2 is 1/10 km. Table 1-3 presents numerical values relating RVV and extinction coefficient.

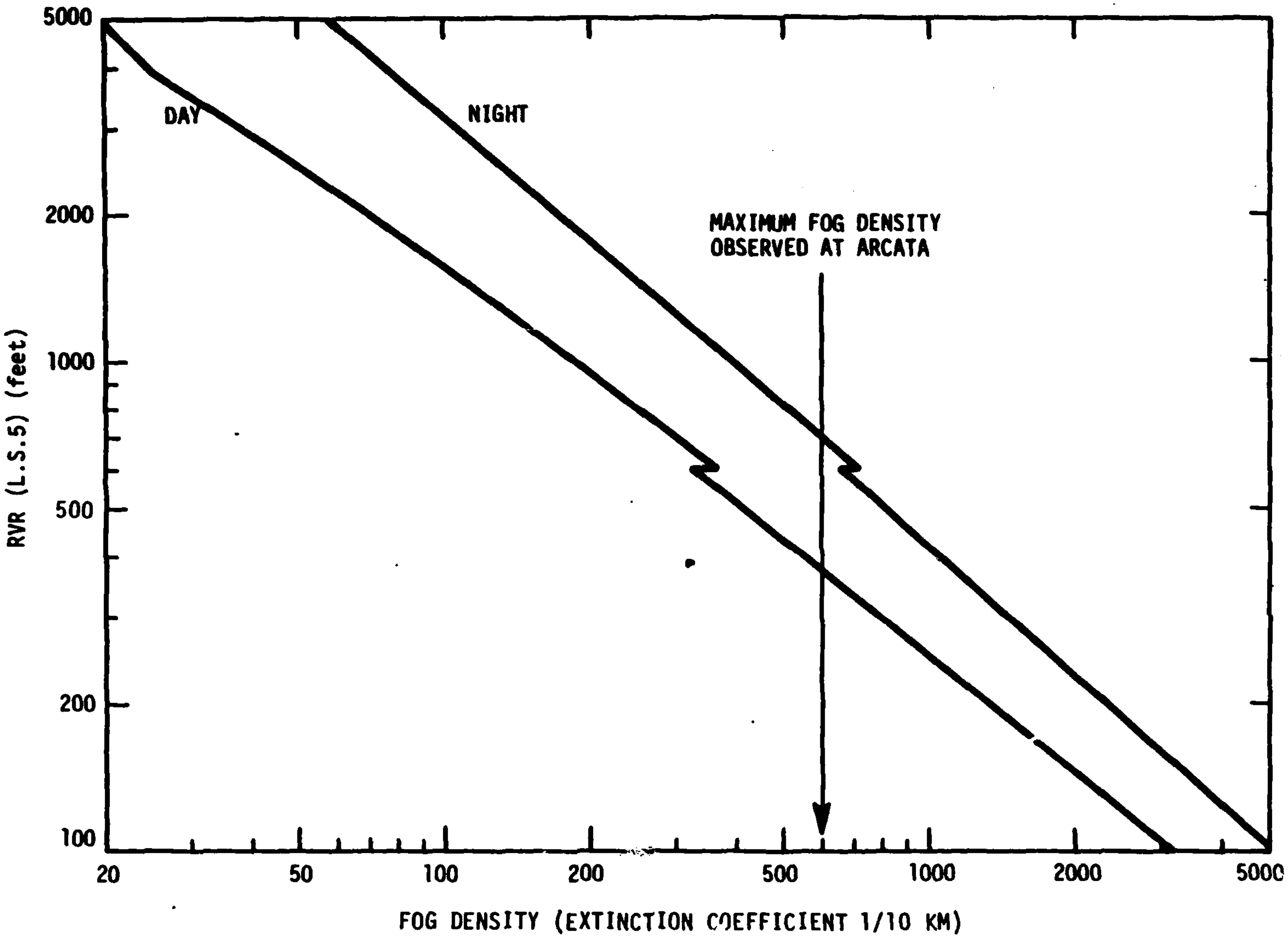


FIGURE 4-1. DEPENDENCE OF RUNWAY VISUAL RANGE (RVR) ON FOG DENSITY.

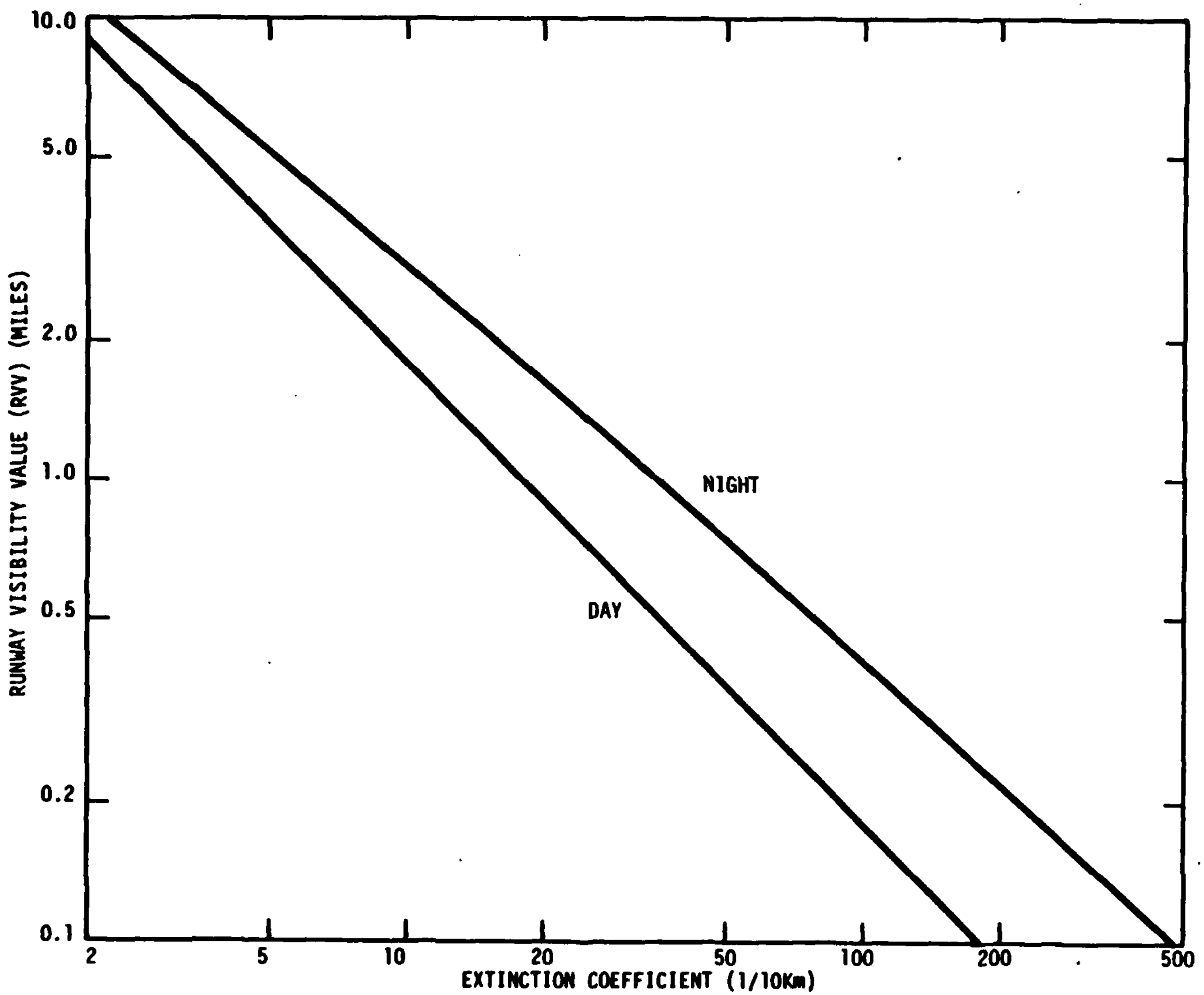


FIGURE 4-2. DEPENDENCE OF RUNWAY VISIBILITY VALUE (RVV) UPON EXTINCTION COEFFICIENT.

The maximum extinction coefficient observed at Arcata was about 600 units, which corresponds to RVR of about 400 and 700 feet for day and night, respectively. The highest extinction coefficient of interest is 5000 which corresponds to a night RVR (L.S.5) of 100 feet.

4.3 GOALS OF EGLIN TESTS

The first priority of the Eglin tests was to examine sensor response over the Category IIIb region of RVR between 100 and 700 feet. Chamber testing is particularly important for this region because of the rarity of natural fogs with densities high enough to reach the lower RVR limit at 100 feet.

The second priority of the Eglin tests was the remainder of the RVR range (RVR between 700 and 6000 feet). Some of the sensors tested (the MET-1 transmissometer and most of the forward-scatter meters) could be expected to cover the full RVR range (100 to 6000 feet) and therefore offer the possibility of replacing the entire RVR 500 dual-baseline system with a single unit.

The third priority of the tests was to examine the range of RVV required for Automated Weather Observing Systems (AWOS) (1/4 to 5 miles). In order to make optimal use of the climatic chamber test time, some sensors were installed which are primarily of interest to AWOS systems rather than Category IIIb measurements.

4.4 ACCEPTANCE CRITERIA

The original test plan (Appendix B) called for the use of a laser photometer as the "standard" visibility sensor. In practice, the laser photometer proved to be much less satisfactory than the FAA's RVR laser calibrator which had been modified by TSC to correct a number of optical and electronic problems. Consequently, the RVR laser calibrator will serve as the "standard" to which the other sensors will be compared. Calculations (Reference 1, Appendix E shows that the forward-scatter error of the calibrator is much less than that of a standard transmissometer. The RVR calibrator on a 40-foot baseline gives useful measurements up to an RVR of about 1000 feet. The 250-foot baseline can measure up to RVR = 6000 feet, but was not very useful for testing forward-scatter meters or short-baseline transmissometers because of the nonuniform visibility in the chamber. Thus, for RVR's above 1000 feet, another standard must be used. The only realistic candidate is the EG&G 207 forward-scatter meter which has an extensive performance record in field tests. Two EG&G 207 sensors were operated; they were placed at either end of a 40-foot long test region for most of the tests.

The pass/fail criterion adopted for RVR sensor accuracy was that the test sensor measurements have less than a 15 percent standard deviation with respect to the "standard" sensor measurements. In other words, the two sensors should disagree by less than 15 percent for at least 66 percent of the measurements.

Another sensor pass/fail criterion, which was not explicitly spelled out in the original test plan, is that the sensor should perform properly under weather conditions normally encountered at United States airports, e.g. snow, freezing rain, etc.

4.5 SENSOR SELECTION

The selection of the sensors for the chamber tests was based on three criteria:

a) The ability of the sensor to operate inside an enclosed chamber,

b) The reasonable expectation that the sensor could meet FAA all-weather sensing requirements, and

c) The willingness of the manufacturer (or government owner) to supply the sensor at no cost and to install and check it out in the chamber.

Each manufacturer set up his own sensor(s). No technical information about the sensors was required beyond the model number and the calibration equation. Thus, the evaluation was designed to be based on performance alone and did not include an examination of technical details, such as alignment sensitivity or installation difficulty, which may have important operational consequences.

5. TEST DESCRIPTION

The schedule of test activities in the chamber is listed in Table 5-1. The schedule was modified from the original plan (Appendix B) in order to reduce the duration and hence the cost of the tests. The cold cycle was moved from the end of the tests to a weekend earlier in the tests. Fog testing was done on two Saturdays and was concluded after the snow, rain and hot cycle were done. The primary difficulty introduced by this change was that one of the sensors (MET-1) appeared to be damaged by the cold cycle.

The original test layout is shown in Figure 5-1. The short-baseline transmissometers were clustered together at one end of the 250-foot baseline along with one EG&G 207 and one FOG-15. The other forward-scatter meters were located near the middle of the 250-foot baseline where it was hoped they could be compared with the longer baseline.

After it became obvious that the chamber uniformity was not good enough to use the 250-foot baseline as a standard, the layout was modified to move the sensors closer together. First, the second EG&G 207 and FOG-15 were moved closer to the 40-foot receiver tower. The final layout (Shown in Figure 5-2) was set on June 9. All sensors were clustered around the 40-foot baseline. The RVR calibrator, previously located on the top of the 14-foot RVR-500 tower, was lowered to the level of the other sensors. The two EG&G 207 sensors located on either end of the baseline served to check the uniformity of the fog in real-time. They were recorded on a dual-channel-stripchart recorder.

5.1.1 Transmissometers

5.1.1.1 Tasker RVR 500

The dual-baseline Tasker RVR 500 transmissometer was mounted on standard FAA 14-foot towers (Figure 5-3). The projector tower was raised slightly so that the view of the 250-foot receiver was not blocked by the 40-foot receiver. The transmissometer signals were run into a standard RVR 500 signal data converter unit to display the computed

TABLE 5-1: TEST SCHEDULE

ACTIVITY/ENVIRONMENTAL CONDITION	DATES
Set Up Equipment	5/24 - 6/5
Steam Fog (trials)	6/4 - 6/5
Steam Fog (test)	6/7 - 6/11; 6/21
Snow Machine Fog	6/17 - 6/19; 6/22
Snow	6/14 - 6/15
Rain/Freezing Rain	6/16 - 6/17
Cold Cycle	6/11 - 6/13
Hot Cycle	6/19 - 6/21
Take Down Equipment	6/23 - 6/25

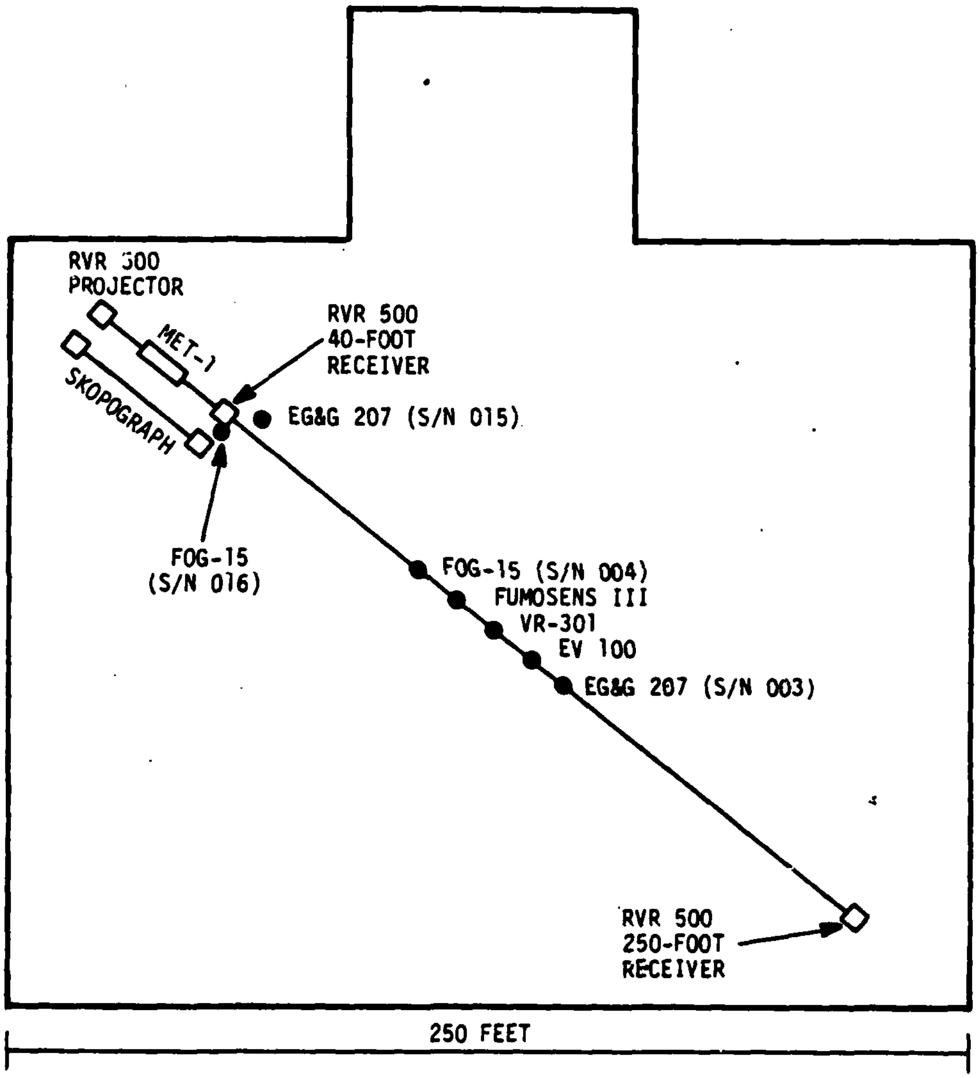


FIGURE 5-1. ORIGINAL SENSOR CONFIGURATION

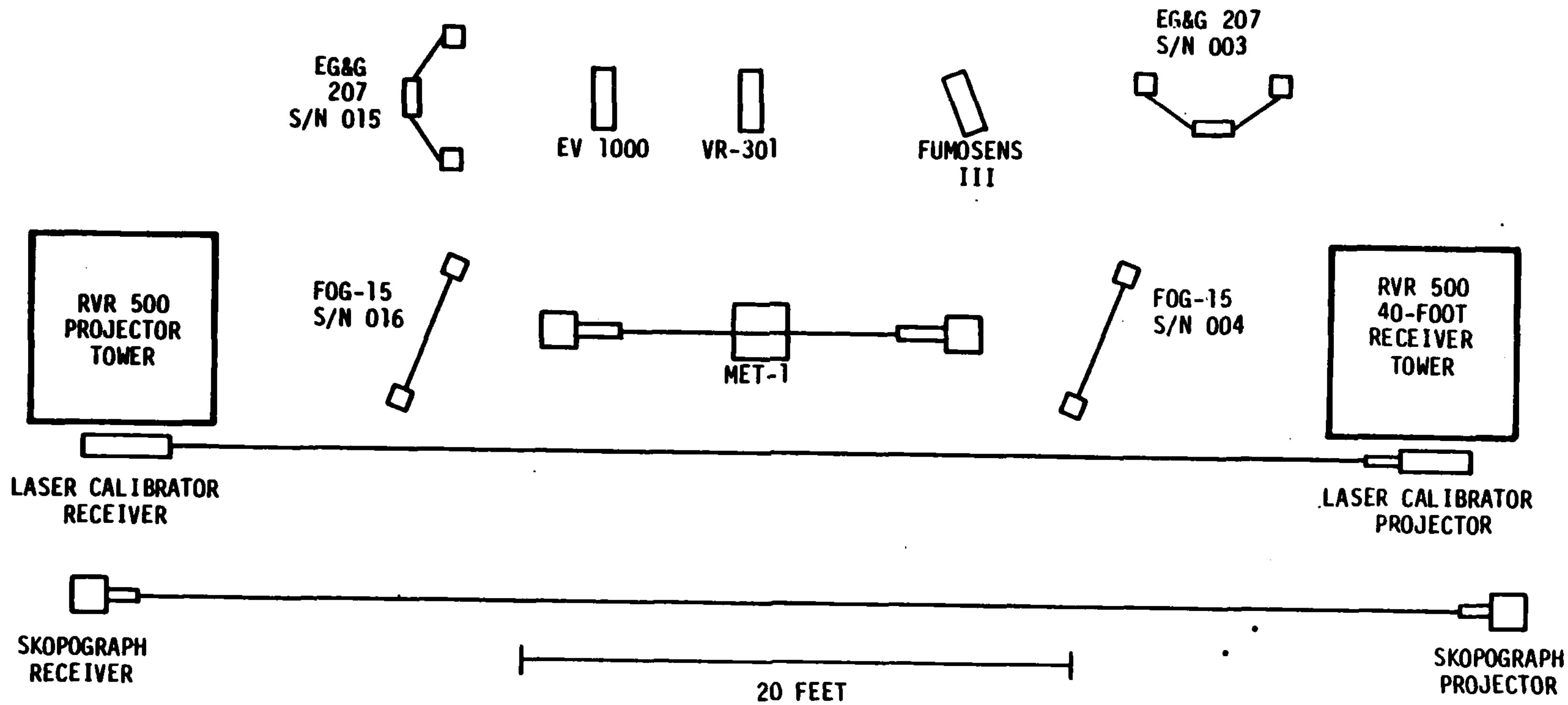
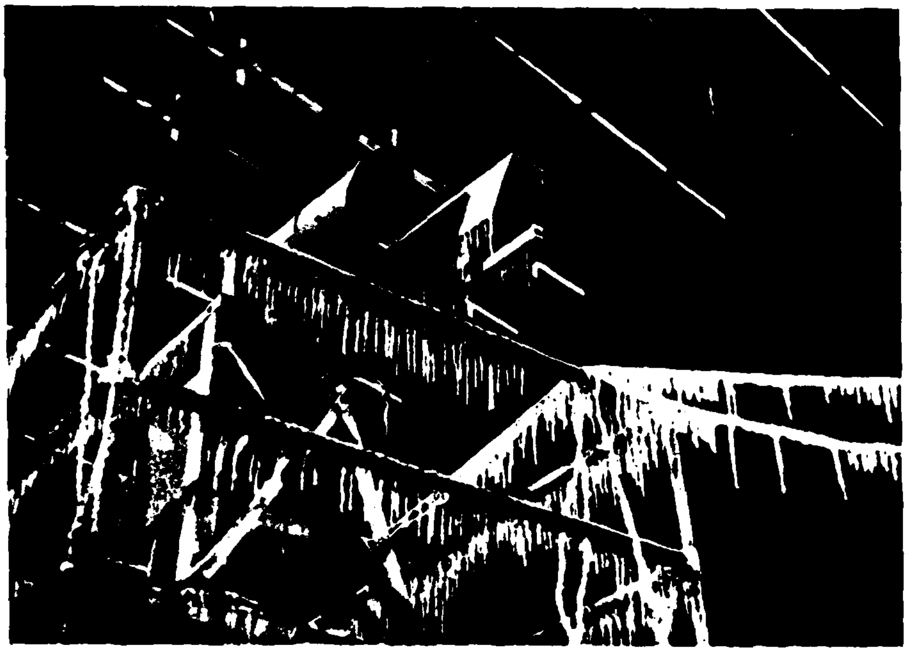


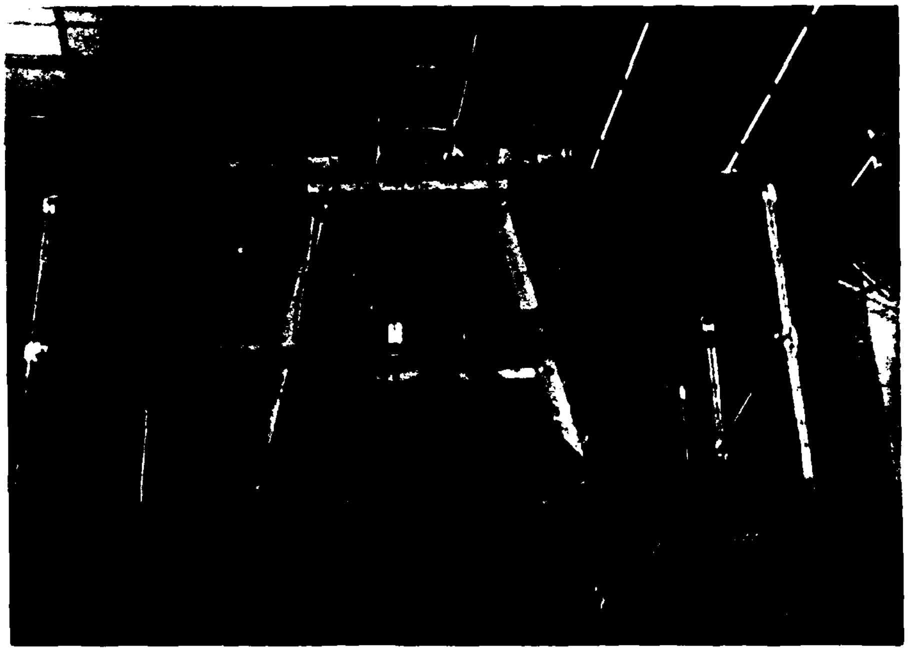
FIGURE 5-2. COMPACT SENSOR CONFIGURATION

(a)

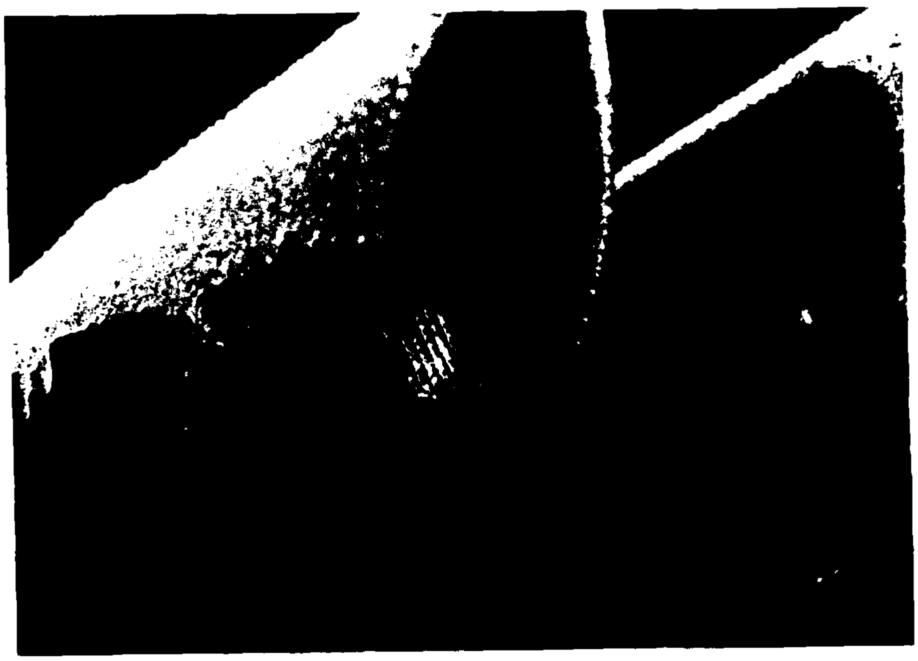


(b)

FIGURE 5-3. TASKER RVR 500 TRANSMISSOMETER:
(a) 14-FOOT TOWERS FOR 40-FOOT BASELINE, (b) PROJECTOR (Note RVR calibrator on right), (c) RECEIVER, (d) SNOW ON PROJECTOR GRID.



(c)



(d)

FIGURE 5-3. (CONCLUDED)

RVR. The signal data converter unit generated automatic background checks. The transmissometer signals were also recorded on a standard RVR 500 stripchart recorder.

5.1.1.2 Impulsphysics Skopograph

In contrast to United States transmissometers, the Skopograph uses a spark lamp pulsed light source. The Skopograph (Figure 5-4) was mounted on a nominal 45-foot baseline at a height of five feet. One change had been made in the unit since the Arcata tests. The projector hood was modified to reduce the area of the projector lamp and hence reduce the forward-scatter errors.

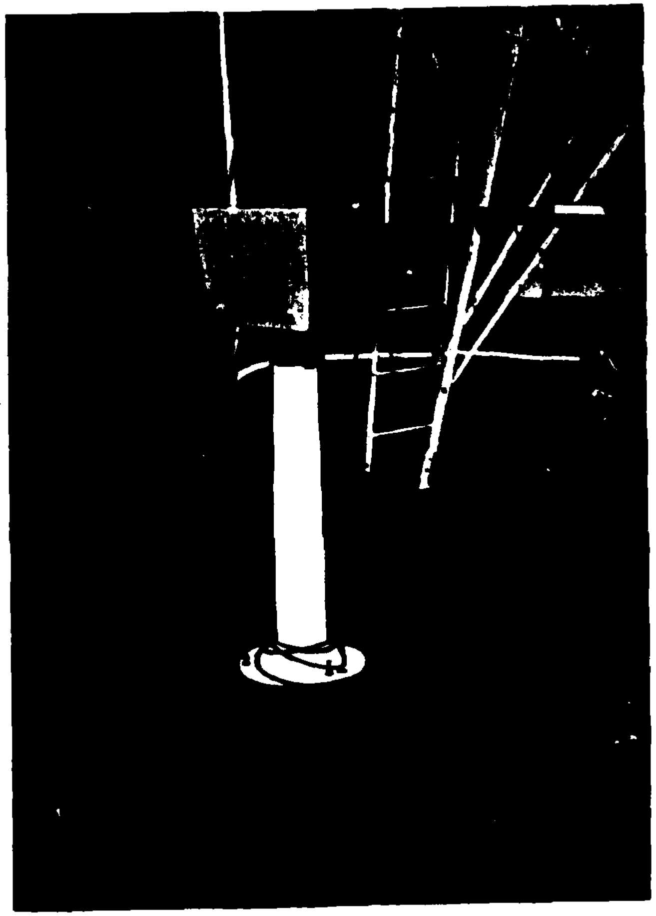
5.1.1.3 Marconi MET-1

The Marconi MET-1 (Figure 5-5) is a transmissometer with a six-meter folded baseline. In contrast to the other transmissometers, the MET-1 is mounted on a single base. The measurement height was about four feet. The MET-1 used a modulated light source (infrared light emitting diode) and self calibrating and correction techniques to achieve a much more accurate measurement of transmission than is achieved by conventional transmissometers.

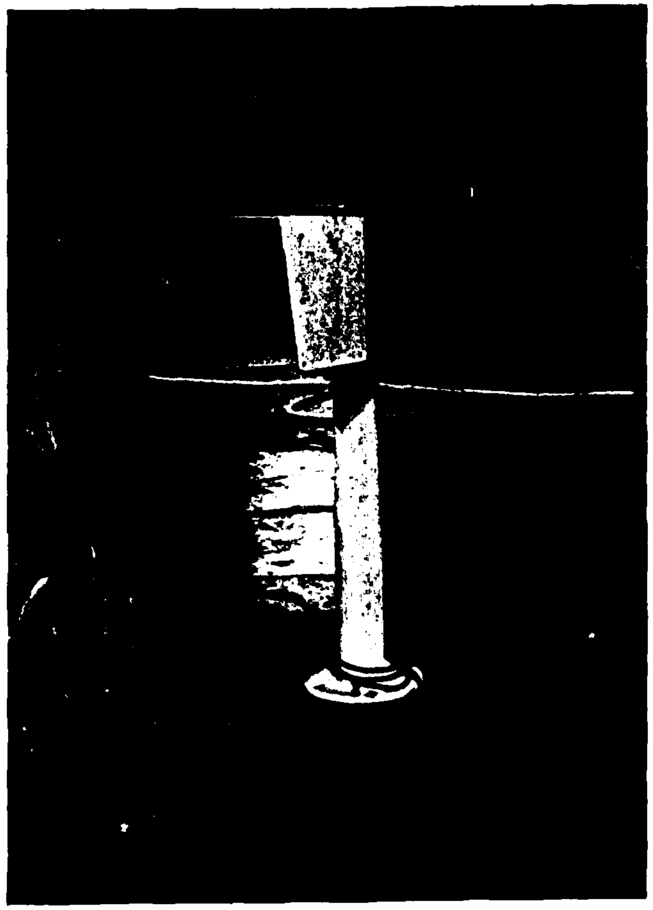
5.1.1.4 RVR Laser Calibrators

The RVR Laser Calibrator (Figure 5-6) was modified to eliminate the problems encountered in standard units:

1) New receiver windows with no interference errors were installed. A ring of resistance heaters was added around the windows to keep them from fogging up.
2) Hoods were added to both projector and receiver to keep rain droplets off the windows.
3) The pulse output electronics were modified to eliminate instabilities due to glitches in the count-down circuitry. Two calibrators were operated at any given time while a third was available as a back up and source of spares.

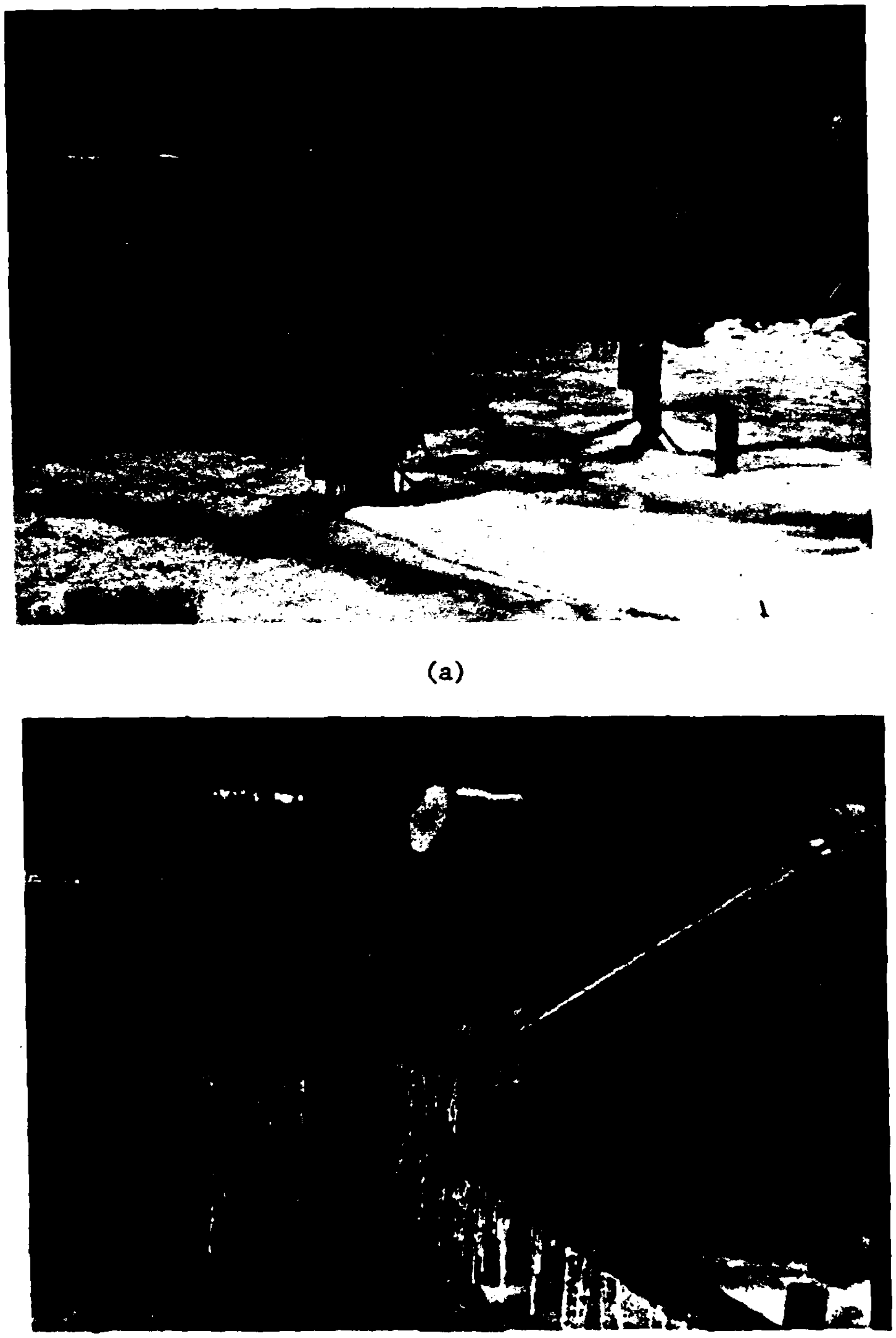


(a)



(b)

FIGURE 5-4. IMPULSPHYSICS SKOPOGRAPH TRANSMISSOMETER: (a) RECEIVER, (b) PROJECTOR.



(a)

(b)

FIGURE 5-5. MARCONI MET-1 TRANSMISSOMETER IN FREEZING RAIN.

(a)

(b)

FIGURE 5-6. RVR LASER RVR CALIBRATOR WITH HOODS IN SNOW:
(a) PROJECTOR, (b) RECEIVER.

At the start of the test the two calibrators were installed next to the two RVR 500 baselines. On 6/9 the 40-foot baseline unit was lowered to 5-foot height. On 6/21 the 250-foot unit was transferred to the 40-foot RVR-500 baseline for the final two days of testing in order to obtain more data on the 40-foot RVR 500.

The alignment stability, especially for the 250-foot baseline, was a recurring problem with the laser calibrators.

5.1.1.5. Laser Photometer

The laser photometer consisted of a 1-mW He-Ne laser shining into an EG&G Model 580 Radiometer with a narrow beam adapter and a hood. Because this configuration was very sensitive to background light, a narrower hood was installed after a few days operation. A 45-foot baseline was used. Because the laser photometer proved to be much less stable than the RVR laser calibrators, it was abandoned midway through the test.

5.1.2 Forward-Scatter Meters

In order for a forward-scatter meter to provide a measurement of extinction coefficient, its calibration must be compared to a transmissometer. Such a calibration is needed to set the initial signal gain and to check for subsequent drift in the sensor's response. The most practical method of providing such a calibration is to install a scattering device or "calibrator" into the forward-scatter meter's scattering volume. The scattering device produces a known signal level which is calibrated once against a transmissometer. It can then be used to simulate a known extinction coefficient for any sensor unit as long as 1) the amount of scattering is stable in time and 2) the scattering geometry of the sensor remains fixed. Because the signals produced by a scattering device are much larger than fog signals, a calibrator usually incorporates an optical attenuator to prevent saturation of the detector electronics.

Chamber testing of forward-scatter meters presents two fundamental technical problems which can affect the results:

1) Light scattering from the chamber walls can reach the detector.
2) Light from one instrument can interfere with the measurement of another.

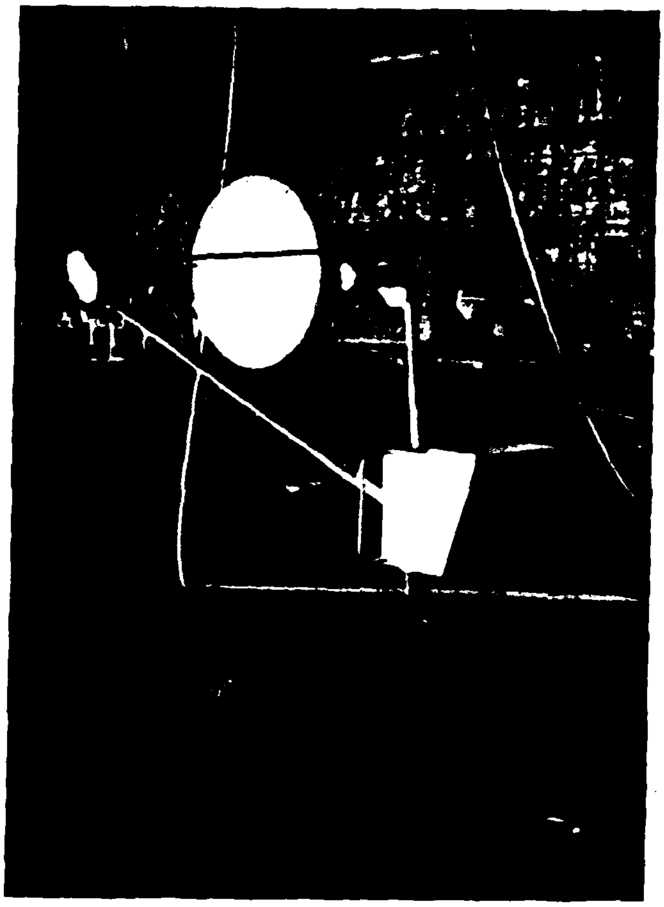
A third technical problem was also noted for two of the sensors, namely a sensitivty to the bright chamber lights which have a strong 120 Hz frequency component. Both the EG&G 207 and to a lesser extent the FOG-15 were affected. This type of interference could be avoided at an airport by proper siting. The signals produced by light scattering from the chamber walls was minimized by varying the sensor orientation. A light baffle was used for the same purpose for the HSS VR-301 during the entire test period and for one EG&G 207 unit and one FOG-15 unit on the last two days of testing.

The only interference between sensors noted in the tests was a beat signal generated by the two EG&G 207 units. Because the light chopping frequency of the two units was almost identical, a low frequency beat signal was produced when light from one unit was detected by the other. The orientation of the two units was adjusted to minimize the interference.

The main banks of chamber lights were extinguished during data collection to avoid disturbing the EG&G 207 and FOG-15 measurements. The data appeared to be unaffected by the three lights which remained on for general illumination.

5.1.2.1 EG&G 207

Two EG&G 207 forward-scatter meter (FSM) units (Figure 5-7) were made available for the tests. A calibrated scatterer with an attenuator is used to set the EG&G to an absolute calibration level. The Air Force has made extensive use of the EG&G 207 FSM for research studies during the last decade.



(a)

(b)

FIGURE 5-7. EG&G 207 FORWARD-SCATTER METER:
(a) WITH CALIBRATOR INSTALLED, (b) IN SNOW.

5.1.2.2 Wright & Wright FOG-15

The FOG-15 (Figure 5-8) uses a scattering geometry similar to that used by the EG&G 207. It incorporates a built-in calibration attenuator which cannot be referenced to an absolute standard. The FOG-15 gains were initially set for approximate agreement with the EG&G 207's and then were to be kept fixed for the rest of the tests. An absolute calibration for the FOG-15 was established after the tests were over.

The version of the FOG-15 tested at Eglin was found to exhibit an excessive nonlinear response in field tests at the Otis Air National Guard Base (Ref. 1). The problem was traced to a "soft" clipping circuit which also led to a variation in calibration with temperature and background light level. Since this circuit has been removed in current versions of the sensor, the Eglin data may not represent the current capabilities of the sensor.

5.1.2.3 HSS VR-301

HSS has constructed a single VR-301 unit (Figure 5-9) which was tested and calibrated at the Calspan test chamber. A calibrated scatterer was supplied with the unit to check its absolute calibration. The VR-301 uses a pulsed light emitting diode as the light source, and a side-scattering geometry.

5.1.2.4 Impulsphysics Fumosens-III

The Fumosens III (Figure 5-10) measures forward scattering with a pulsed Xenon flashlamp source and a downward-looking scattering geometry. It has no absolute calibrator.

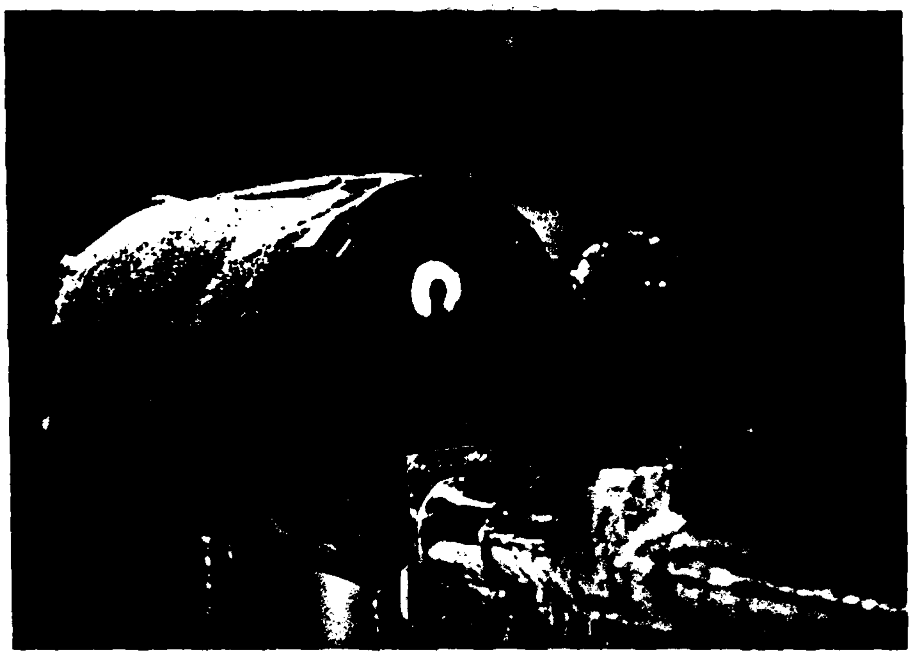
5.1.2.5 Enertec EV1000

The EV1000 (Figure 5-11) also uses a flashlamp source like the Fumosens III, but with a side-scattering geometry. The technique formerly used for absolute calibration has been abandoned as impractical. The EV1000 output is proportional to the logarithm of the meteorological range.

(a)

(b)

FIGURE 5-8. WRIGHT & WRIGHT FOG-15 FORWARD-SCATTER METER:
(a) IN SNOW, (b) IN FREEZING RAIN, (c) PROJECTOR, (d) RECEIVER.

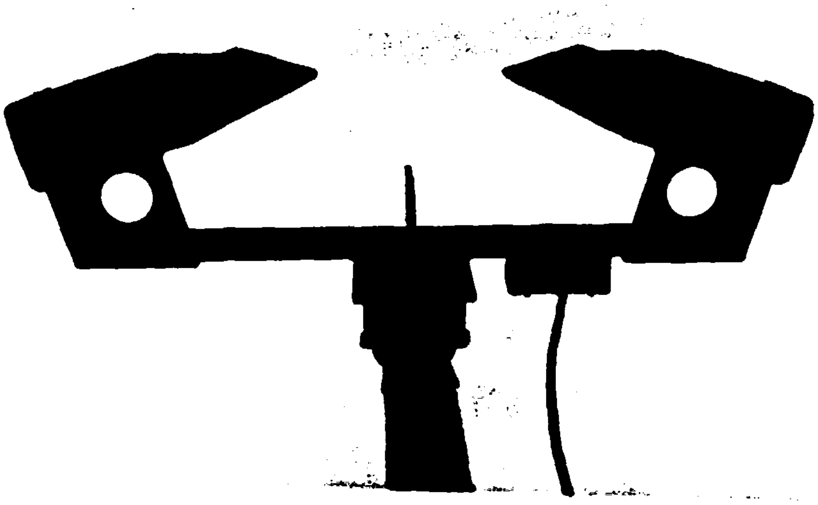


(c)

(d)

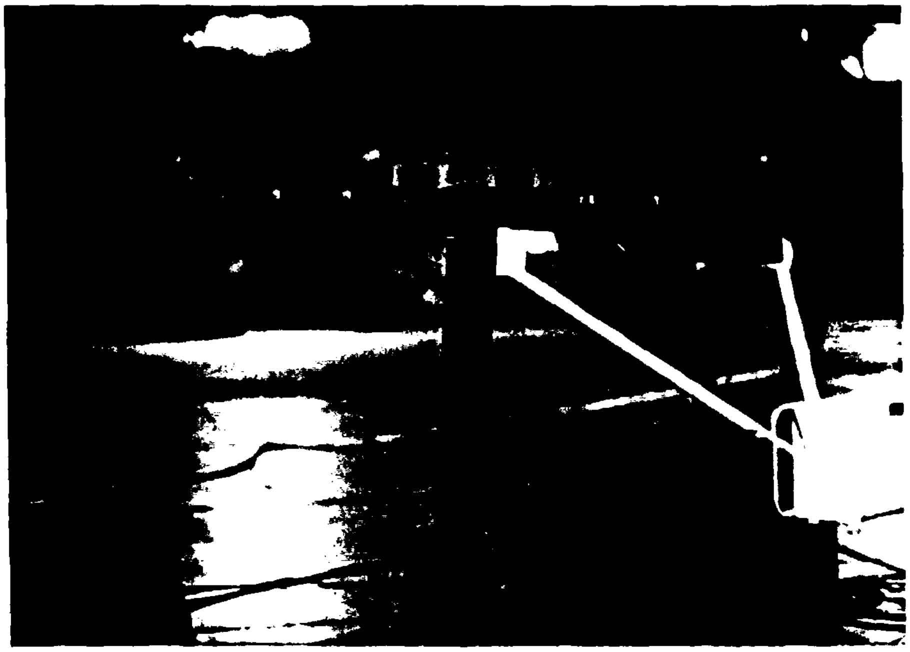
FIGURE 5-8 (CONCLUDED)

(a)

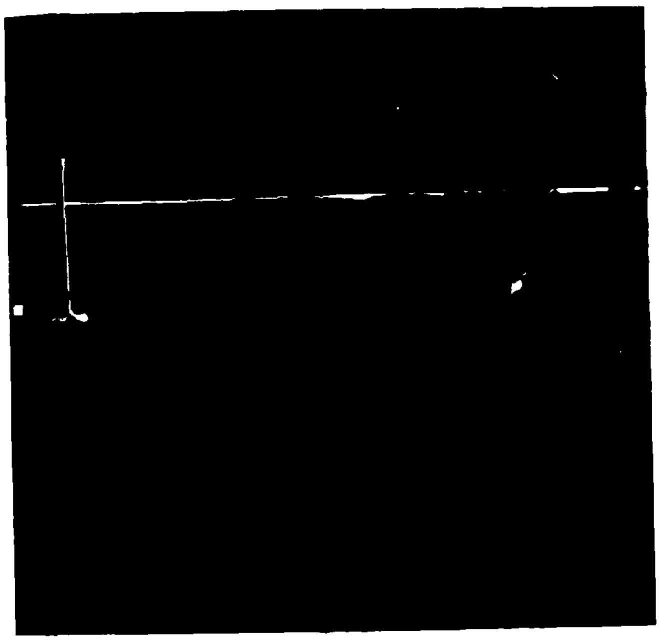


(b)

FIGURE 5-9. HSS VR-301 FORWARD-SCATTER METER:
(a) BEAM BAFFLE ON LEFT, (b) SCATTERING GEOMETRY.



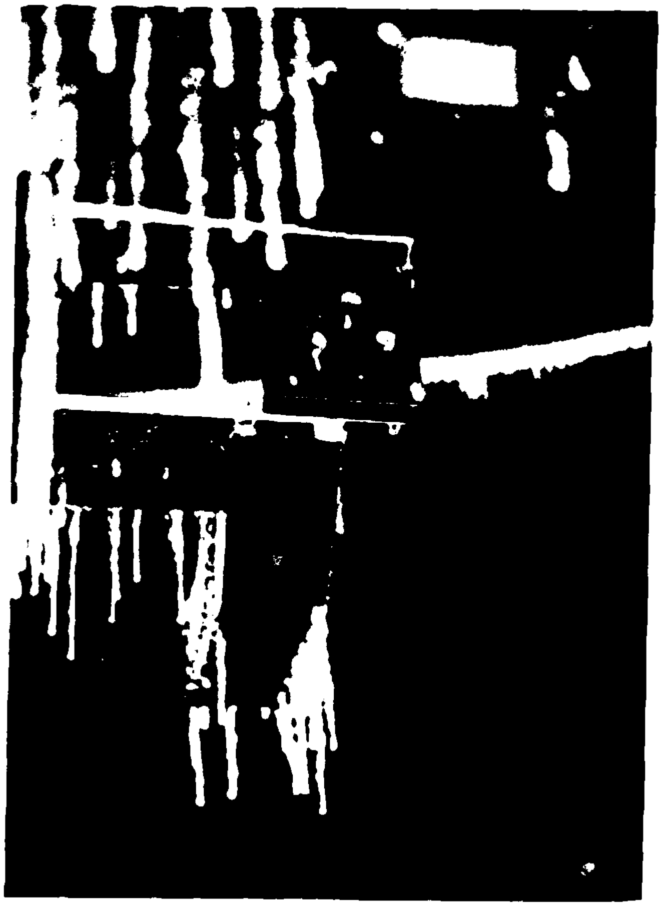
(a)



(b)

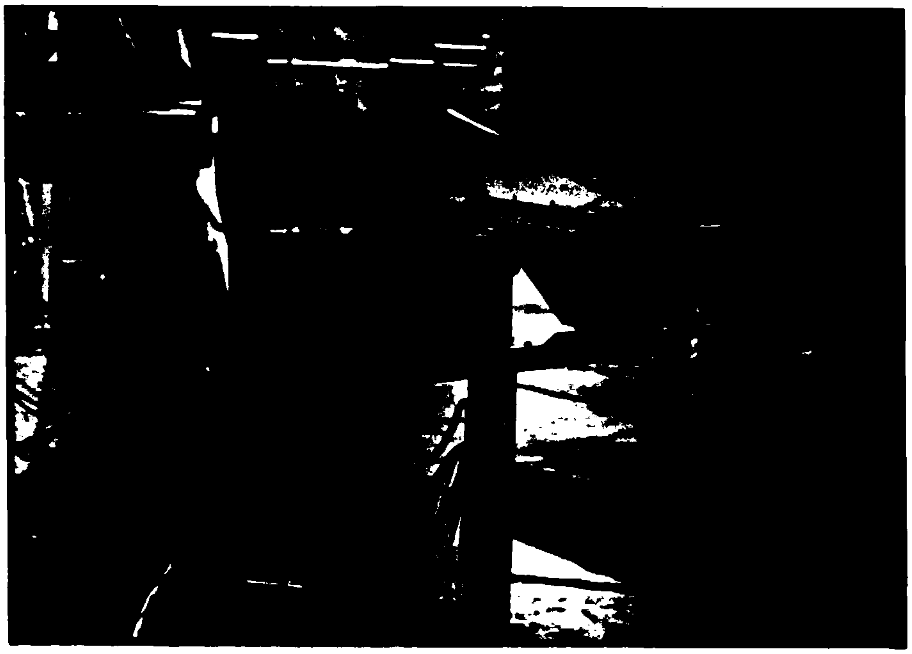
FIGURE 5-10. IMPULSPHYSICS FUMOSENS III FORWARD-SCATTER METER: (c) IN SNOW, (d) IN FREEZING RAIN.

(c)

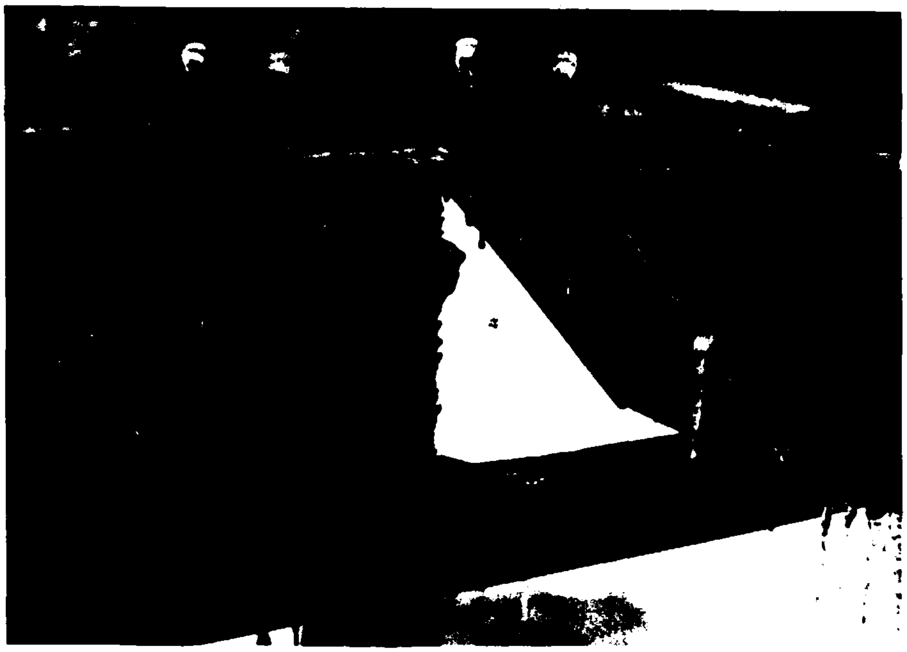


(d)

FIGURE 5-10. (CONCLUDED)



(a)



(b)

FIGURE 5-11. ENERTEC EV-1000 FORWARD-SCATTER METER:
(b) IN FREEZING RAIN.

5.1.3 Human Observations

Five runway edge lights were set up at 50-foot spacings to allow direct visual estimates of RVR. Usually light setting 3 (4.2 A current) was used to give a minimum RVR. The RVR 500 signal data converter was set to the same light setting (night) for comparison. The line of runway lights was located about 20 feet to the side of the calibrator baseline. The closest runway light was located next to the 40-foot receiver tower. The observer adjusted his distance from the last light until he could just barely see one of the runway lights.

5.2 DATA COLLECTION

5.2.1 Recording

The Climatic Laboratory data acquisition system (DAS) was used to record the sensor data on magnetic tape (Table 5-2 lists the channel assignment, signal conditioning, and calibration constants A, B, and C). In addition, the chamber temperature, dew point, and relative humidity were recorded. The data system samples its inputs once per second. It was programmed to record and display sensor data whenever a record gate was turned on. A 1 1/2 second record gate was generated every 15 seconds by the TSC built sensor interface electronics. Thus the data were assured of being sampled at least once every 15 seconds.

Many of the sensors generated signal voltages which could be interfaced directly to the DAS signal conditioning circuitry. One of the FOG-15's generated a frequency output which was fed into a frequency to voltage signal conditioner. The two Impulsphysic sensors and the Enertec EV-1000 generated signal currents which were converted to voltages with a series resistor.

The RVR 500 transmissometer, RVR calibrators, and Marconi MET-1 transmissometer required more complex interfaces. The RVR 500's and RVR calibrators generate a pulse output which was counted for 15 seconds and

TABLE 5-2: ELGINE CLIMATIC CHAMBER DATA CHANNEL ASSIGNMENT

Channel Number	Instrument	Signal Conditioner	A	B	C
1	Reference Temperature	Standard			
2	Temperature	Standard			
3	Dew Point	Standard			
4	Relative Humidity	Standard			
5	Spare (temperature)	Standard			
6	RVR 500 (250 - foot)	0 - 10 VDC	9.766		131.2
7	RVR CAL (250 - foot)	0 - 10 VDC	9.766		131.2
8	RVR 500 (40 - foot)	0 - 10 VDC	9.766		820.2
9	RVR CAL (40 - foot)	0 - 10 VDC	9.766		820.2
10	Marconi	0 - 10 VDC	9.766		1666.7
11	Skopograph	0 - 5 VDC	4.64		728.9
12	Laser Photometer	0 - 20 mVDC	4.5 mV		728.9
16	# 1 EG&G 207	0 - 5 VDC	11.491	0	98.0
17	# 1 EG&G 207	0 - 1 VDC	11.491	0	98.0
18	# 2 EG&G 207	0 - 5 VDC	7.666	0	98.0
19	# 2 EG&G 207	0 - 1 VDC	7.666	0	98.0
20	# 1 FOG-15	0 - 10 VDC	9.57	0	100.0
21	# 1 FOG-15	0 - 1 VDC	9.57	0	100.0
22	# 2 FOG-15	0 - 10 kHz	6.70	25	0.05
23	# 2 FOG-15	0 - 500 Hz	6.70	25	0.05
24	Fumosens-III	0 - 5 VDC		0	43.1
25	HSS	0 - 10 VDC	0.90		624.0
26	HSS	0 - 5 VDC	0.90		78.56
27	Enertec	0 - 5 VDC	4.55		3910.0
28	Repeats 18				
31	Low Gain Switch	0 - 30 VDC			
32	Steady State Switch	0 - 30 VDC			
33	Record Data Switch	0 - 30 VDC			
35	RVR 500 Background	0 - 30 VDC			

then latched into a digital to analog (D/A) converter. The MET-1 generated an 11 bit parallel output which was converted to a voltage with a D/A converter.

The forward-scatter meters have a potential dynamic range that is too great for the data acquisition system and even too great for their own internal electronics. The former problem was addressed by recording some of the sensors on two channels with different sensitivities. The second problem was addressed in different ways for different sensors. The HSS VR-301 comes equipped with two different output levels. The FOG-15's were modified with gain switches to reduce the signal gain by approximately a factor of ten when the fog density was high enough to cause clipping at the normal sensitivity. The sensitivity of the EG&G 207's was reduced by approximately a factor of ten by installing neutral density filters when the fog density was high. Likewise, neutral density filters were installed on the Fumosens III for high fog densities. The EV-1000 generates a logarithmic output. The need for these gain changes was due to the desire of covering both RVR and AWOS visibility ranges with the same test sensor. The dynamic range of the sensors is generally large enough to meet either the RVR or the AWOS coverage requirements without any gain change.

Some difficulties were experienced with the sensor interfaces. Channel 18 was unstable; the same data were recorded on channel 28. Sometimes the D/A converter on channel 7 exhibited a 2 MHz oscillation which produced small dc signal offsets. Adding a capacitor to the output eliminated the oscillation.

5.2.2 Real Time

The conduct of the tests would have been impossible without real-time information about sensor measurements. Two types of real-time data were available:

1) Displays from the data collection computer, and
2) Stripcharts of selected sensor outputs.

The software which controls data collection by the Climatic Laboratory computer is designed to furnish real-time readout of sensor information according to the needs of a particular experiment. Seven special displays were designed specifically for the tests. Standard displays of raw data (digital counts or voltage) were also available.

Three special displays showed the raw digital data every second for channels 1-13, 14-26, and 27-39. The zero signal count (1638) was subtracted to make the display easier to interpret. These displays were useful for calibrating the interface electronics, checking sensor calibrations, and identifying recording problems.

The four other special displays were keyed to the record gate and showed only data being recorded, i.e., one or two measurements every 15 seconds. The first of these displays was intended for controlling the experiment and showed temperature, dew point, and relative humidity, along with calculated extinction coefficient from the 250-foot transmissometer, the two RVR calibrators, the two EG&G 207's, and the two FOG-15's. The three other displays were designed to select appropriate sensors and channels for three ranges of extinction coefficient:

a) $\sigma < 100$
b) $100 < \sigma < 500$
c) $\sigma > 500$

Up to six stripchart channels were used to record signals from selected sensors. Usually the two EG&G 207 units were recorded on a dual-channel recorder which allowed an immediate assessment of fog homogeneity and time variation. The Tasker recorder continually recorded the RVR 500 baseline selected by the signal data converter.

5.3 FOG

The original plan for generating fog called for careful adjustments of cooling, steam injection, and air circulation to produce a uniform stable fog. The fogs resulting from this approach was found to be very inhomogeneous. Subsequent experience indicated that several effects contributed to the inhomogeneity:

1) The steam was injected at a small number of points which were not uniformly distributed.
2) The floors of the chamber were not saturated with water.
3) The large (100-horsepower) circulation fans mounted on the chamber floor depleted the fog by droplet impact on the blades and by air heating.
4) The air passing through the cooling coils loses both droplets and relative humidity.

These problems were overcome in various ways to produce reasonably stable, homogeneous fogs at various densities.

5.3.1 Steam Fog

Very dense fogs could be generated by saturating the chamber with steam so that all surfaces became wet. This type of fog would stabilize and decay slowly if all circulation (both floor fans and external circulating fans) were turned off. As the fog dissipated it would become less uniform. Turning on the floor fans tended to improve the homogeneity while reducing the fog density. Figure 5-12 shows an example of such an event. The fog density measured by all the sensors is plotted against time. The format of the stripchart will be explained in Section 6. The steam was turned on at about 16:11. (NOTE: All times are GMT). The steam and circulation were turned off at 17:23. The slight drop in the curves at 17:49 was caused by turning on the floor fans to homogenize the fog density. As the fog decayed it became patchy as is shown in the differing responses of the various sensors.

FIGURE 5-12. STRIPCHART FOR THE STEAM FOG EVENT ON 6/10/82.

Figure 5-13 compares the extinction coefficient measurements at different locations for this event. Figure 5-13a shows the lateral variation in fog density by comparing the response of the 250-foot and 40-foot RVR 500 baseline (see Figure 5-1). The 250-foot baseline shows only slightly higher readings, thus indicating reasonable lateral homogeneity over the chanber for most of the event. Figure 5-13b shows the vertical variation in fog density by comparing the response of the 40-foot RVR 500 mounted at 14-foot height to that of the 40-foot RVR calibrator mounted at 5-foot height. In this comparison the fog tends to become more dense near the floor as the fog density decays. When the floor fans were turned on for a short period of time the vertial variation was reduced significantly (near σ = 1000) for a time after which the same vertical variation (denser near the floor) developed. Figure 6-13c compares the response of the two EG&G 207 sensors. The two agree reasonably well, again indicating good lateral homogeneity. EGG1 (SN 003) which was located closer to the middle of the chamber, (Figure 5-2) shows somewhat higher density as was also indicated by comparison of the two RVR 500 baselines (Figure 5-13a). Last of all, Figure 5-13d compares the average response of the two EG&G 207 sensors to that of the 40 foot calibrator. The response agrees well except at low fog density where the fog had become patchy. Note that the average EG&G 207 response agrees reasonably well with the RVR calibrator even when the two 207's disagree with each other.

Three other steam fog events are plotted in Figures 5-14 through 5-16 using the same comparisons as Figure 5-13. The results are generally similar. The vertical inhomogeneity was generally greater because no fan mixing was used to improve the homogeneity. One event (Figure 5-15a) showed significantly greater differences between the middle and the end of the chamber.

In conclusion, reasonably uniform (at least over 40 feet) steam fogs can be generated with extinction coefficients between 500 and 5000 by adjusting steam injection and chamber circulation. The fog generally dissipated rapidly or became too inhomogeneous at lower density. A

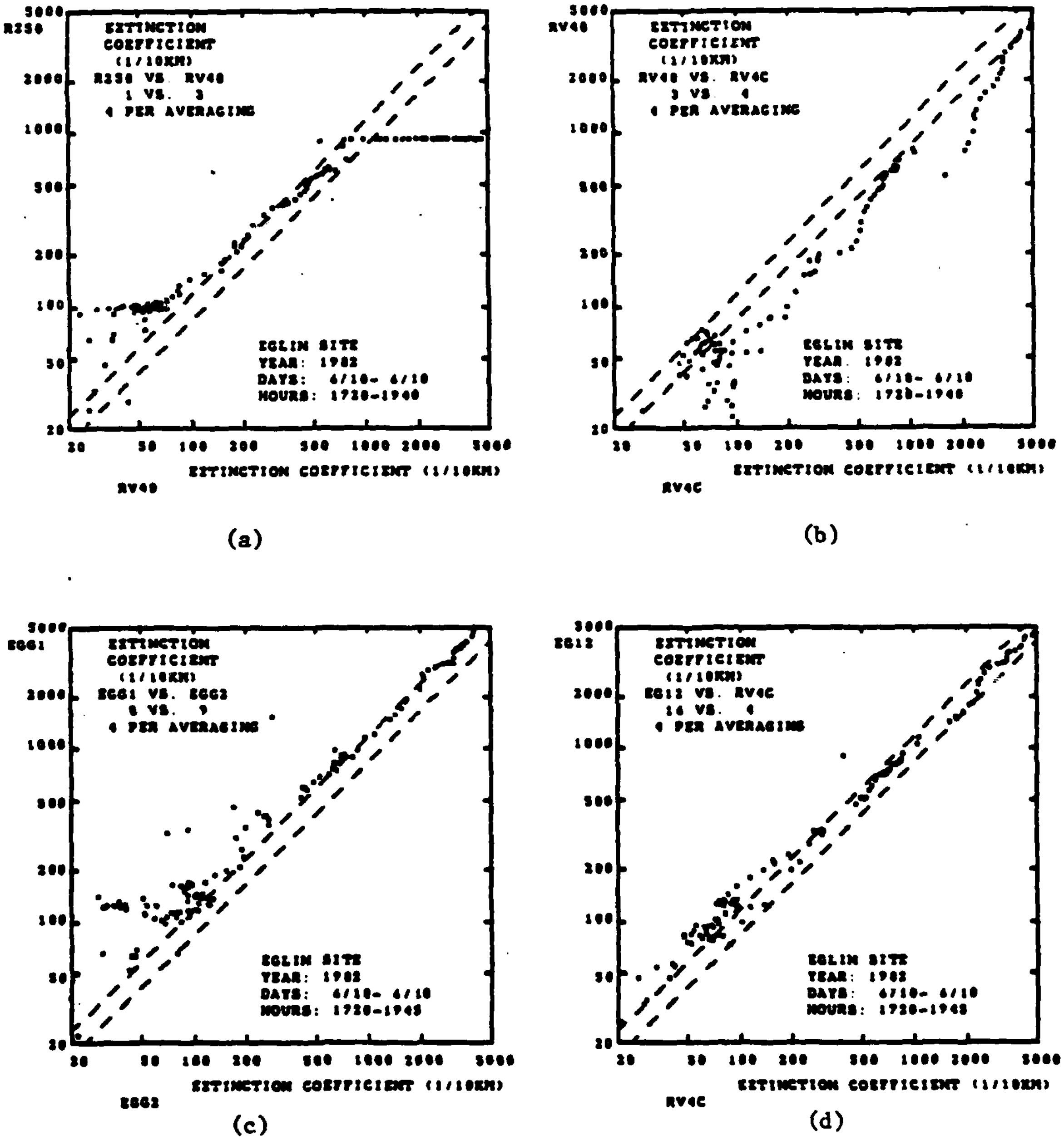


FIGURE 5-13. HOMOGENEITY OF THE STEAM FOG EVENT ON 6/10/82: (a) 250-FOOT RVR 500 VERSUS 40-FOOT RVR 500, (b) 40-FOOT RVR 500 VERSUS 40-FOOT RVR CALIBRATOR, (c) COMPARISON OF TWO EG&G 207's, (d) AVERAGE EG&G 207 VERSUS 40-FOOT RVR CALIBRATOR.

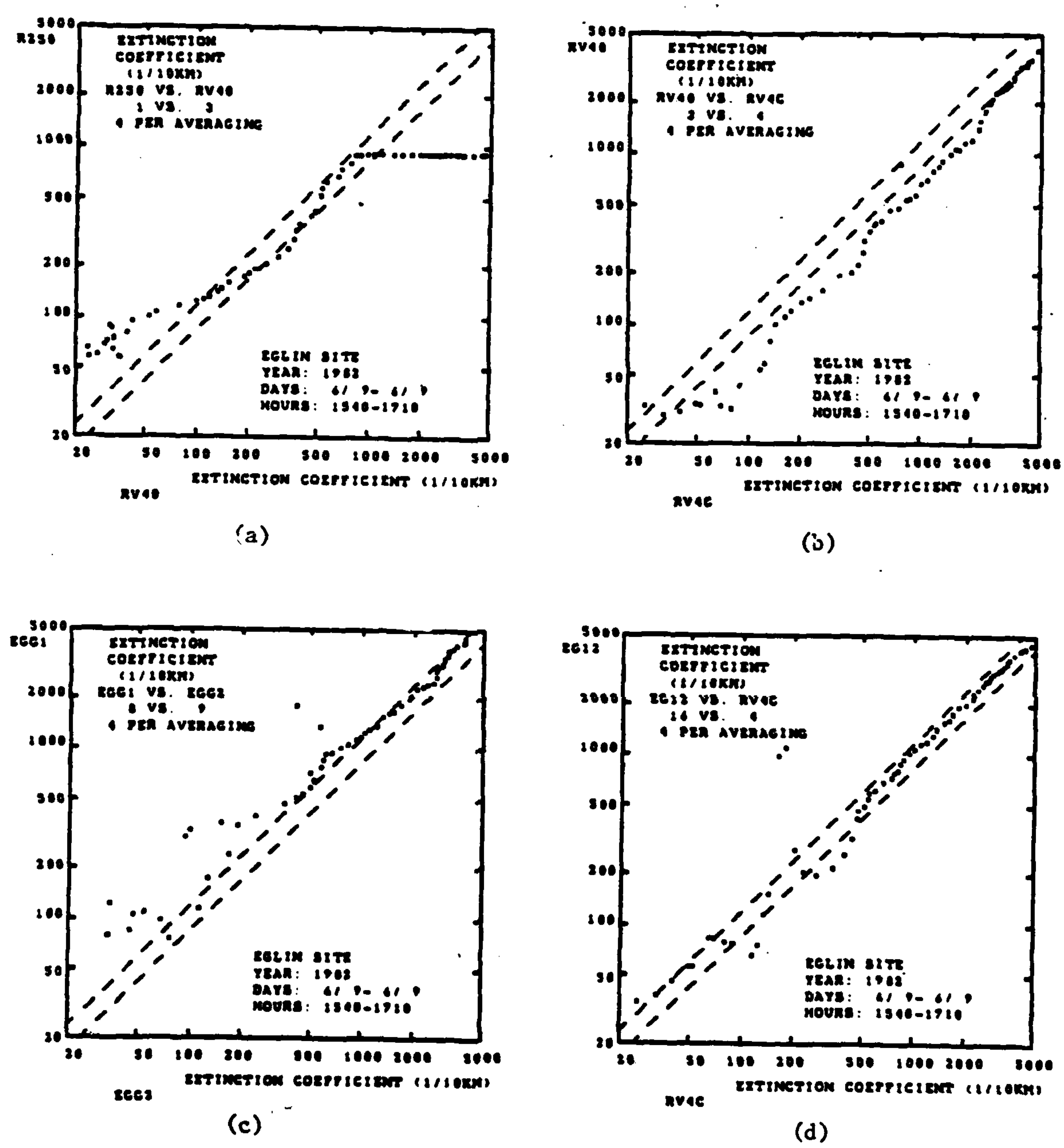
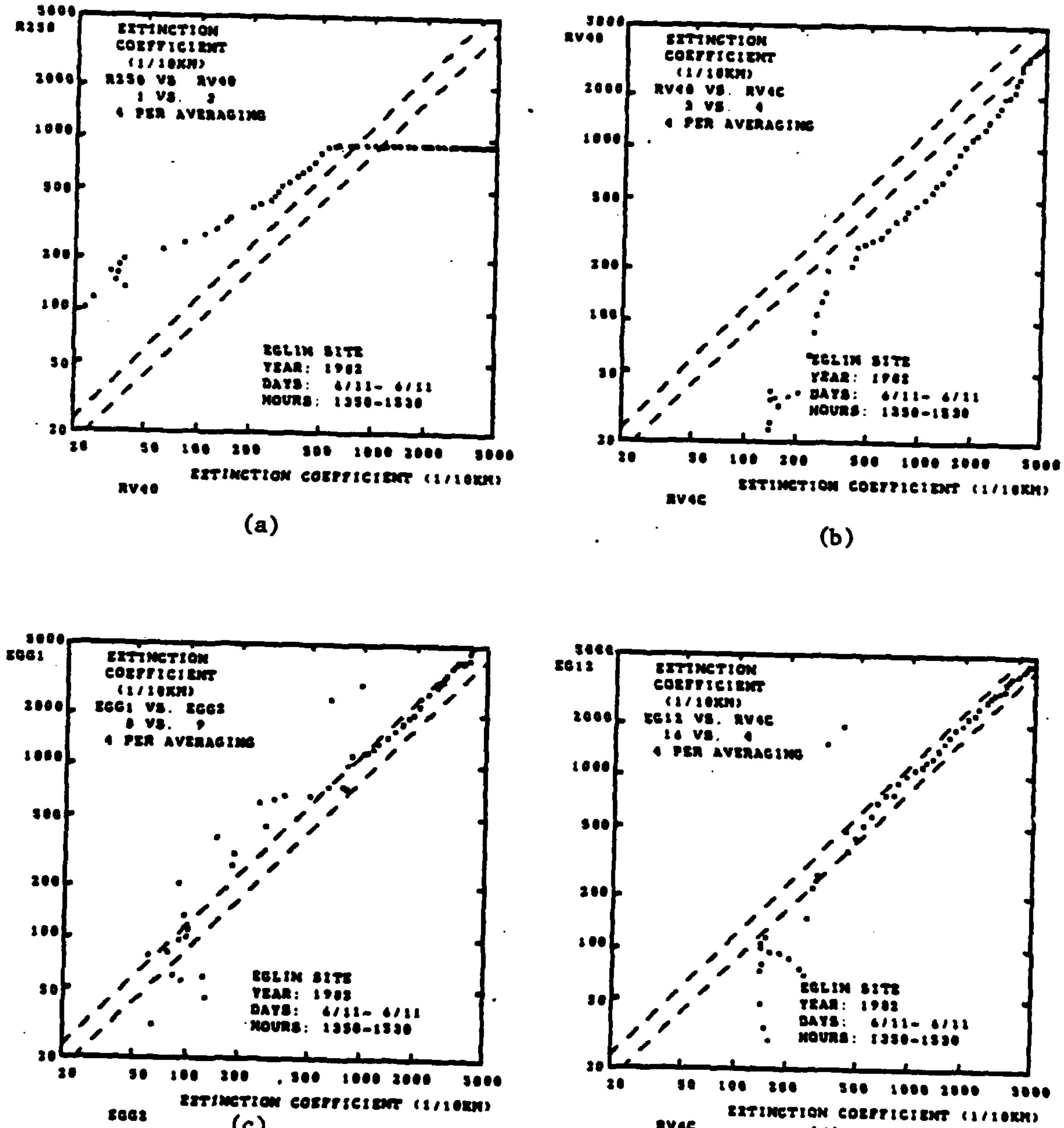


FIGURE 5-14. HOMOGENEITY OF THE STEAM FOG EVENT ON 6/9/82.



(a) (b)

(c) (d)

FIGURE 5-15. HOMOGENEITY OF THE STEAM FOG EVENT ON 6/11/82.

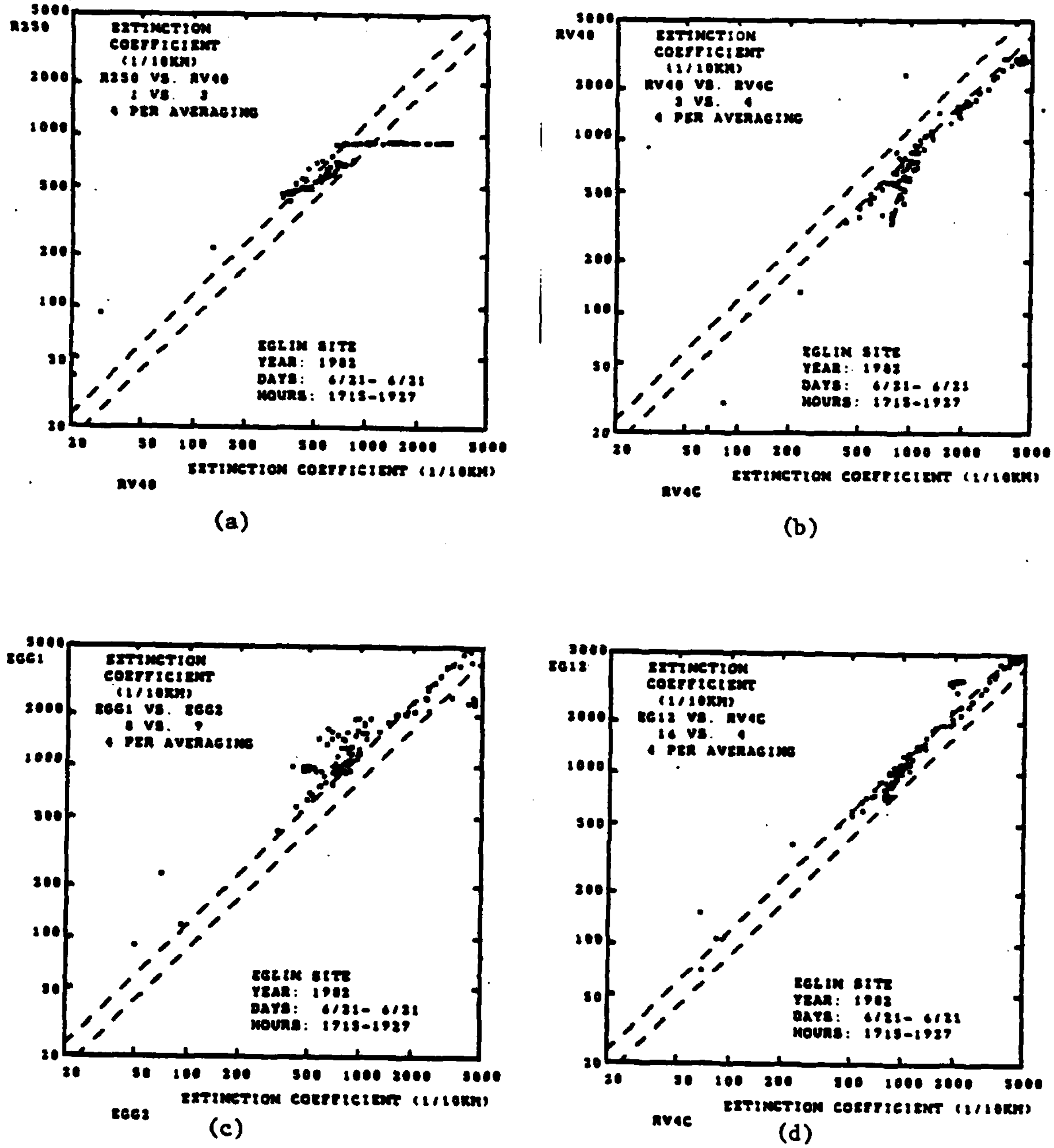


FIGURE 5-16. HOMOGENEITY OF THE STEAM FOG EVENT ON 6/21/82.

method of preserving fog while maintaining circulation was needed to reach lower extinction coefficients.

5.3.2 Cooling Fog

Another method of generating fog was to cool the chamber after it had been saturated with water vapor. Figure 5-17 shows the strip chart for the cooling fog event which immediatley followed the steam fog of Figure 5-12. The cooling was initiated at 20:08. Figure 5-18 shows the variation comparison plots for the event in Figure 5-17, while Figure 5-19 shows the same plots for another cooling fog.

The character of cooling fogs is different from that of steam fogs. Because air is being circulated thorugh the cooling coils, fog patches do not develop. The fog density varies more smoothly in time. On the other hand, the systematic variations in fog density are greater, presumably because of the consistent circulation pattern in the chamber. The final decay of the fog is also much more abrupt for cooling fogs as the cooling finally suceeds in driving the dewpoint below the temperature. It is clear that cooling fogs, while useful for close spaced sensors, are not a satisfactory method for achieving stable, uniform low fog densities.

5.3.3 Snow-Machine Fog/Haze

After the snow and rain tests were completed, the climatic chamber test supervisor decided to try using the snow machines rather than steam injection to generate fog. The resulting fogs appeared to be surprisingly stable and uniform, particularly after the snow machines had been shut off and the extinction coefficient had decayed to about 10 units. The likely explanation for this stability is that the snow machines were actually generating haze by injecting large numbers of condensation nucleii into the chamber. Impurities in the tap water used in the snow machines would form nucleii when the water droplets evaporated. When the snow machines were in use, any lack of fog

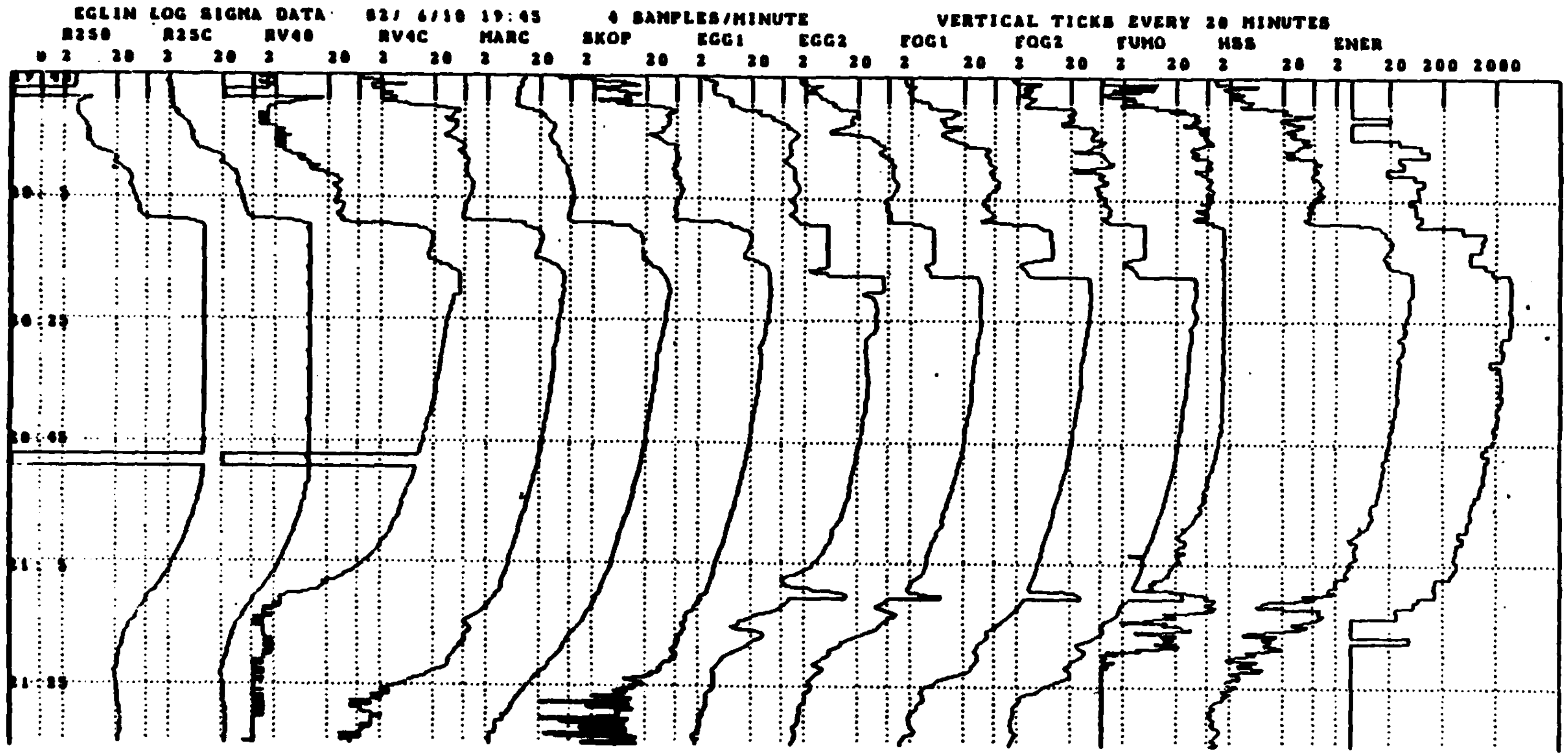


FIGURE 5-17. STRIP CHART OF THE COOLING FOG EVENT ON 6/10/82. The spikes at 20:15 and 21:10 for EGG, FOG, AND FUMO are caused by reducing and increasing the sensor gains.

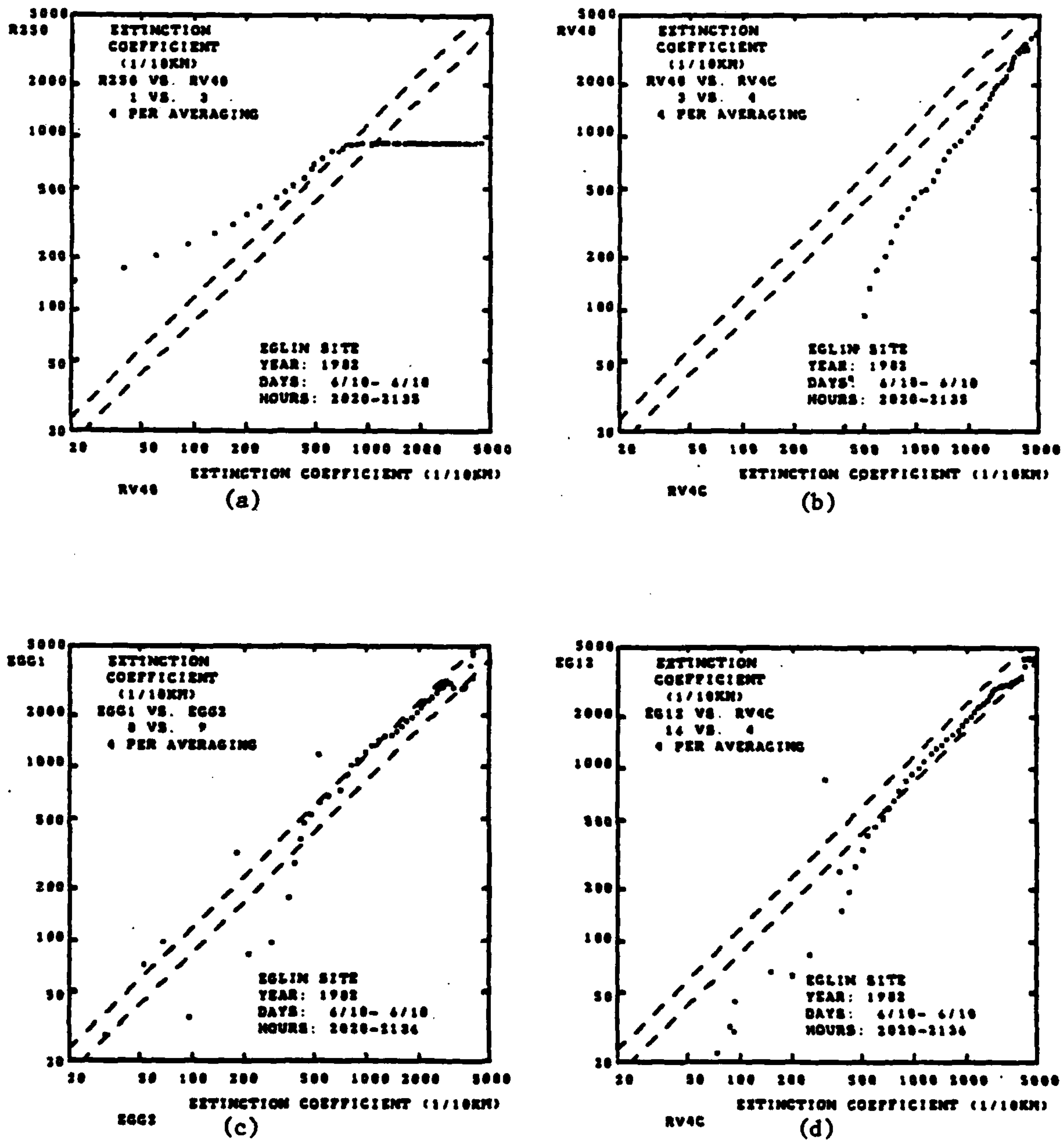


FIGURE 5-18. HOMOGENEITY OF THE COOLING FOG EVENT ON 6/10/82.

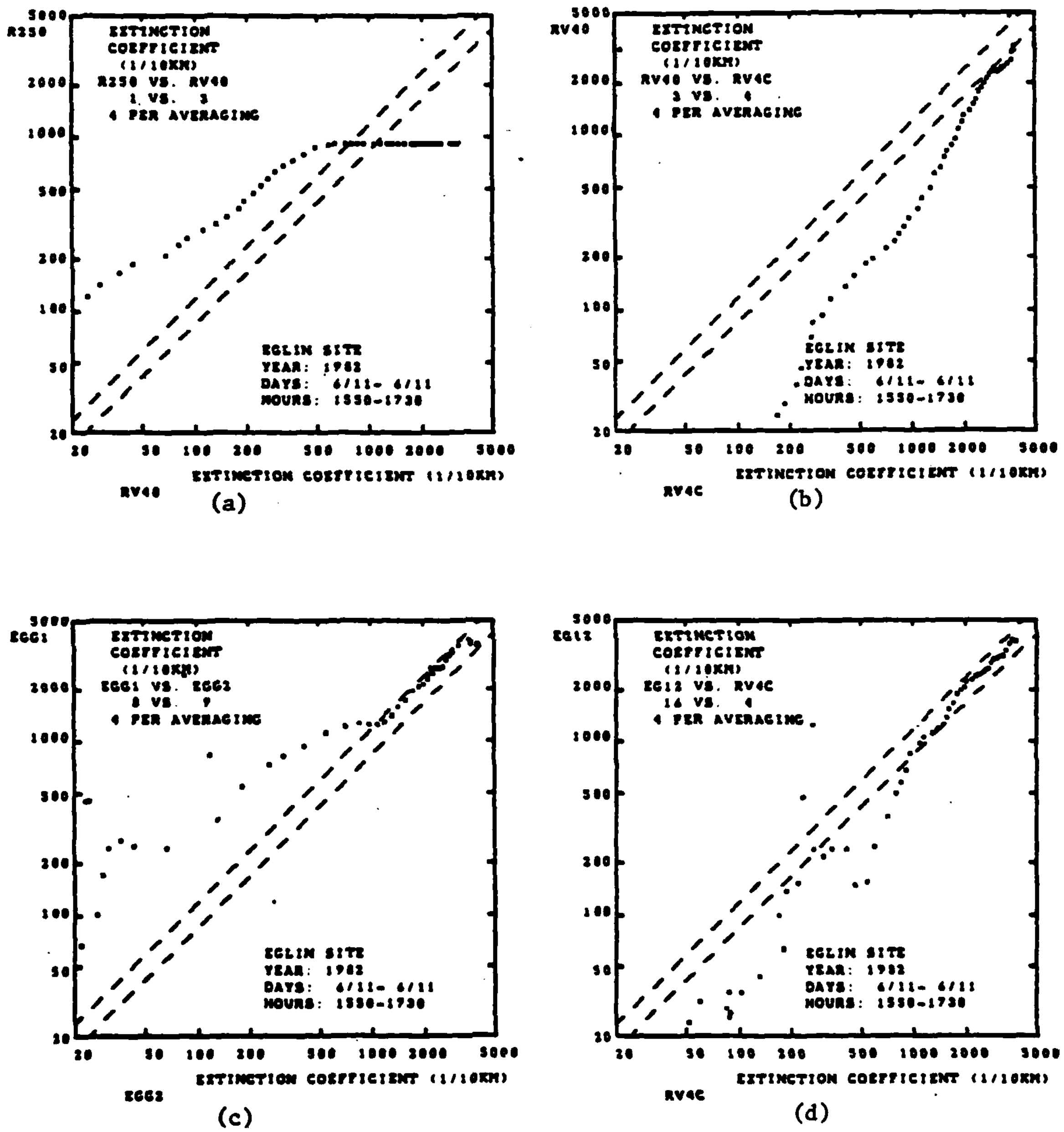


FIGURE 5-19. HOMOGENEITY OF THE COOLING FOG EVENT ON 6/11/82.

homogeneity was correlated with the appearance of large water droplets in the laser beams. Under uniform conditions, individual particles were rare; only a uniform beam scattering (implying very small particles) could be seen. With this insight into the formation of fog with snow machines, uniform hazes up to an extinction coefficient of 50 units and usable fogs to 500 units were achieved. The following procedure was adopted:

1) Aim the snow machines to minimize the large droplet density in the sensor test region.
2) Run the snow machines with relative humidity below 90 percent to generate a maximum number of condensation nucleii.
3) Increase the relative humidity to saturation to increase the size of the droplets formed around the condensation nucleii.
4) Decrease the haze density by circulation losses of nucleii and/or reducing the relative humidity.

The last fog/haze event on 6/22 achieved the highest fog and haze extinction coefficients. Figure 5-20 shows the build-up period for this event. Approximately two hours were spent generating condensation nucleii and increasing the relative humidity. Figure 5-21 shows the decay period for the event. It shows less random variations. The snow machine output was cut back at intervals (17:13, 17:45, 18:22, 18:32) to gradually reduce the extinction coefficient. Figures 5-22 and 5-23 show the variation plots for the build-up and decay portions of the event respectively. The homogeneity is very good over a range of extinction coefficients which cannot be covered with steam or cooling fogs. The biggest variation noted is between the two RVR 500 baselines (Figures 5-22a and 5-23a) which indicate a difference between the two ends of the chamber. The build-up period (Figure 5-22) shows more scatter than the decay period (Figure 5-23).

The decay portions of all the fog-haze events are combined in Figure 5-24. Many of these events reached lower extinction coefficients than

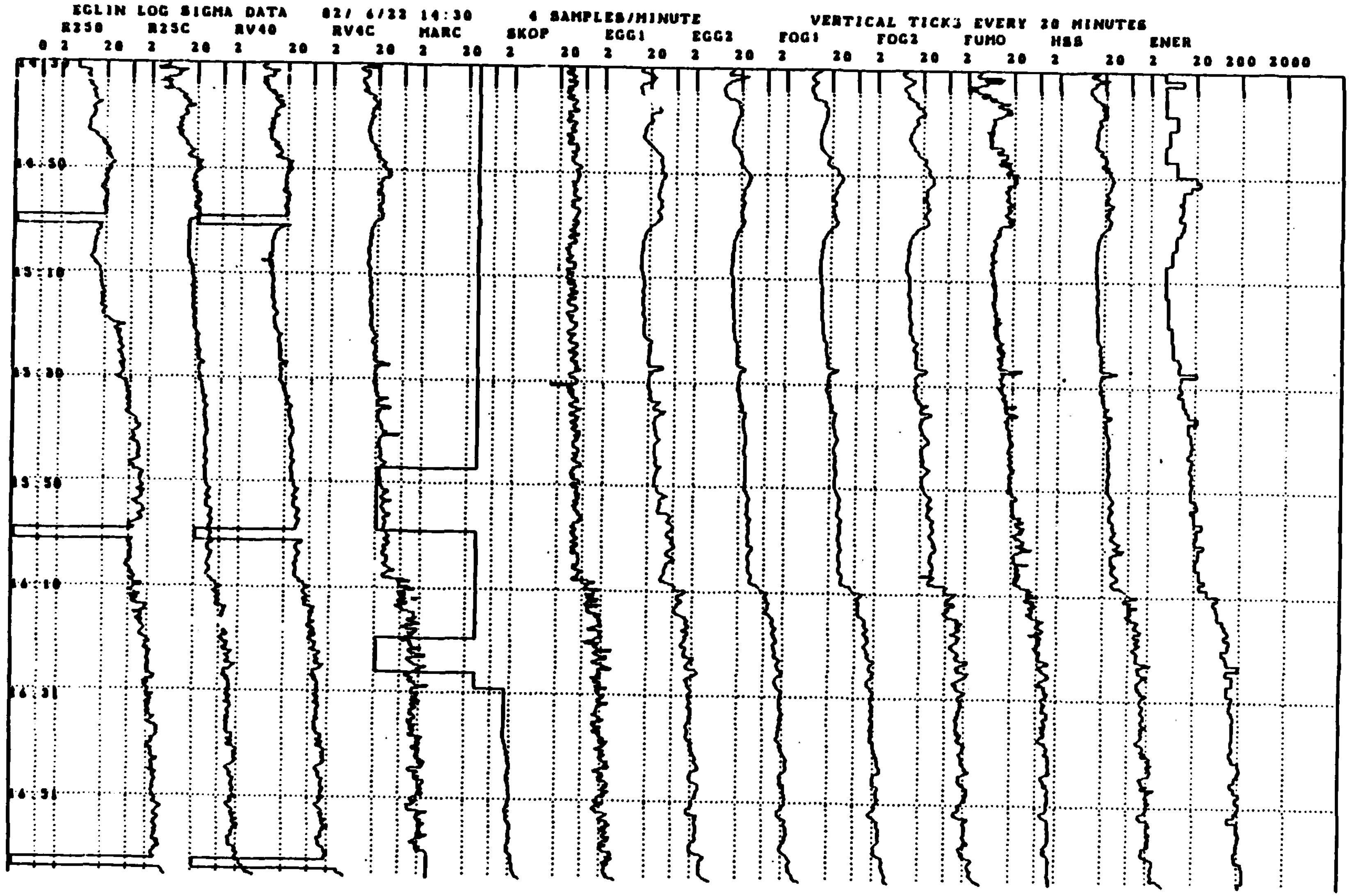


FIGURE 5-20. STRIPCHART OF THE BUILD-UP PERIOD OF THE FOG/HAZE EVENT ON 6/22/82.

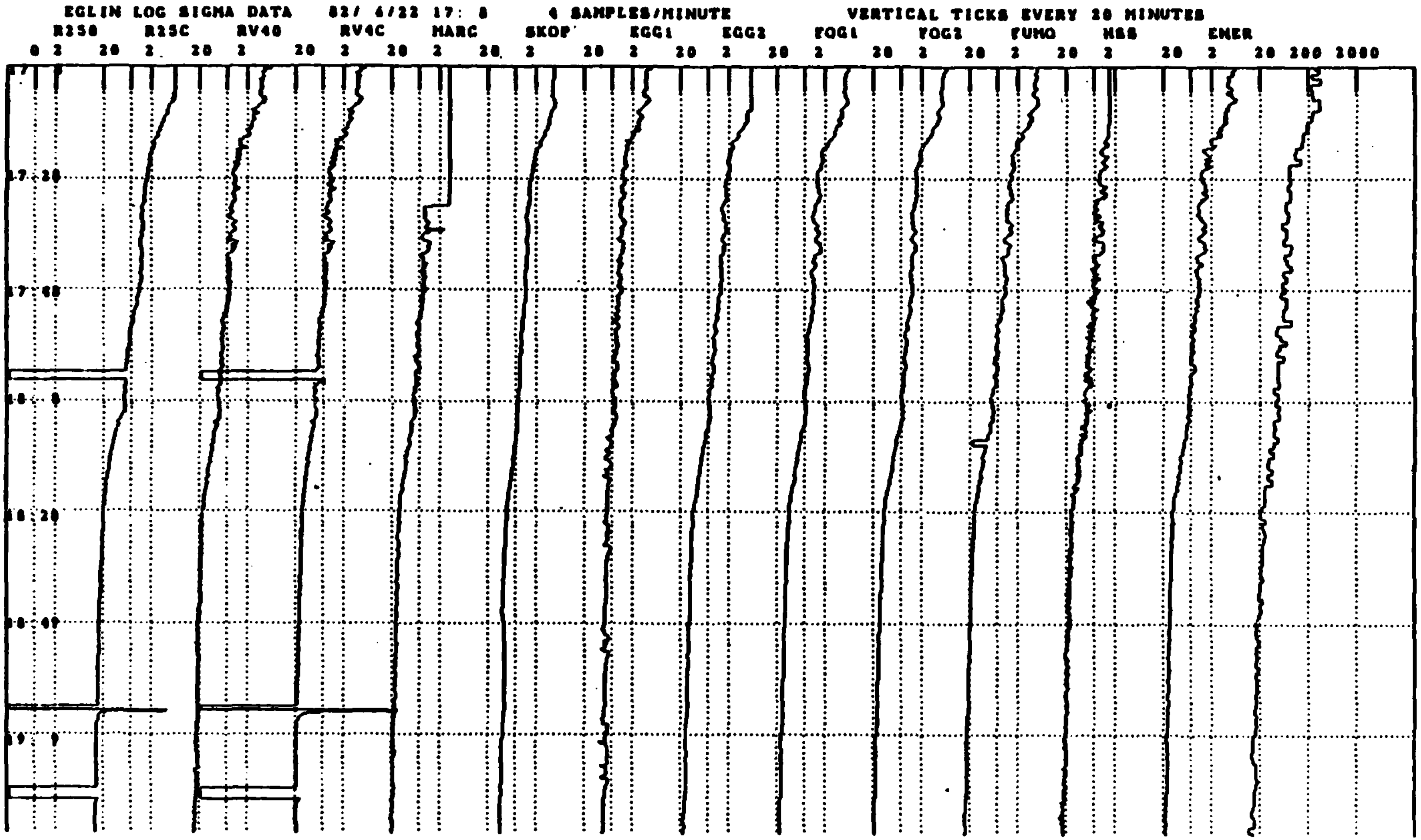


FIGURE 5-21. STRIPCHART OF THE DECAY PERIOD OF THE FOG/HAZE EVENT ON 6/22/82.

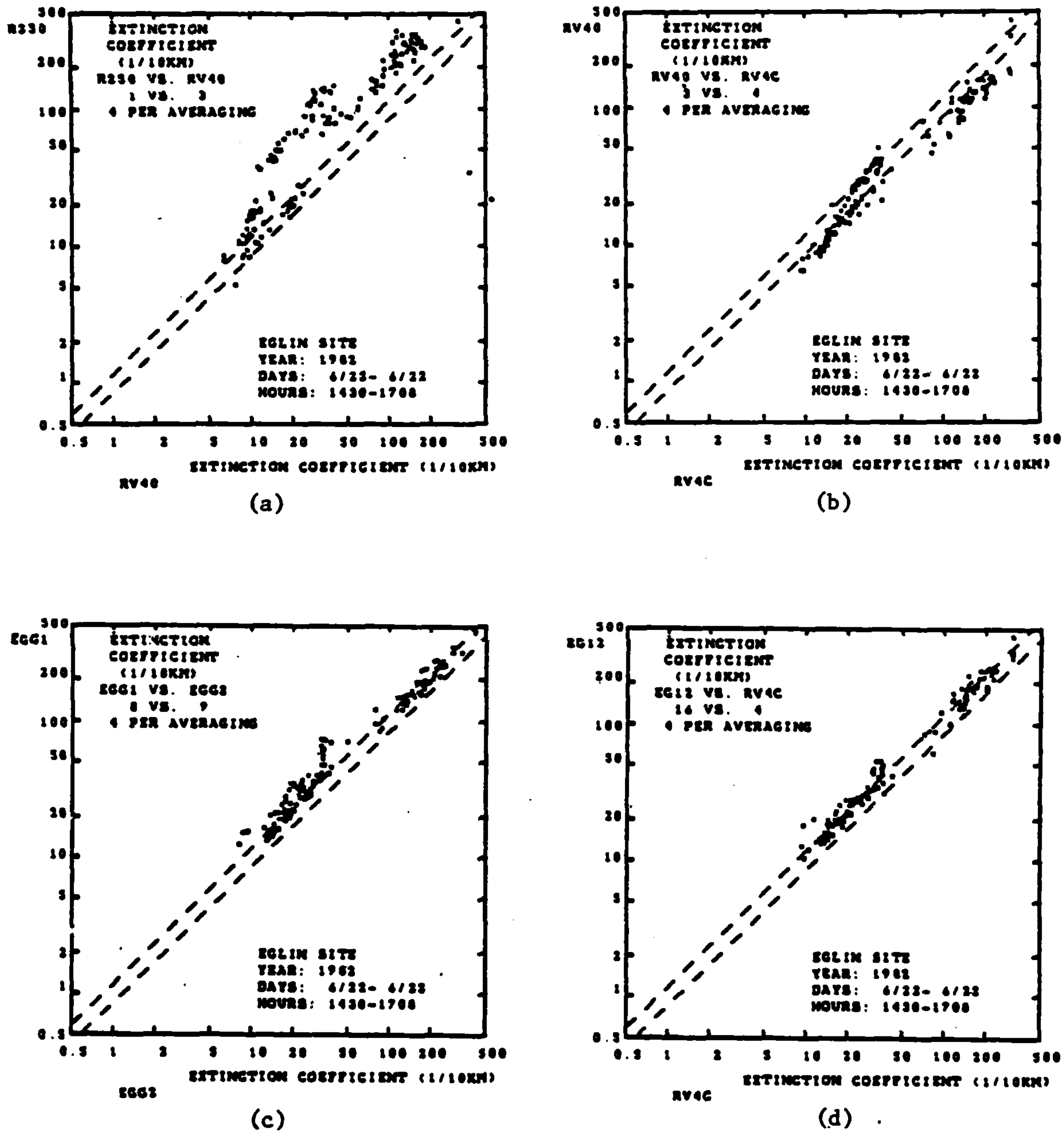


FIGURE 5-22. HOMOGENEITY OF THE FOG/HAZE EVENT ON 6/22/82: BUILD-UP PERIOD.

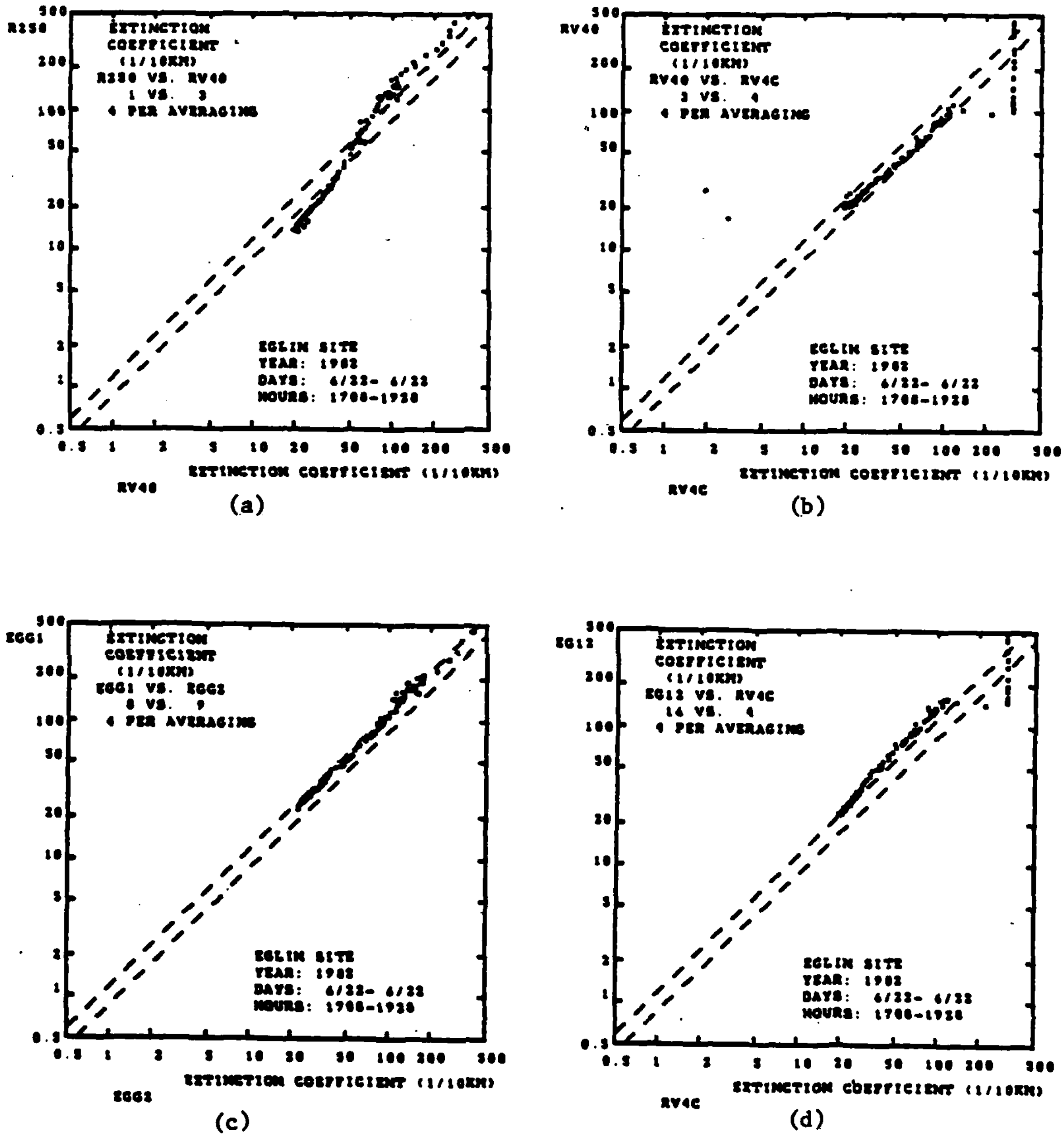


FIGURE 5-23. HOMOGENEITY OF THE FOG/HAZE EVENT ON 6/22/82: DECAY PERIOD. The RVR calibrator failed when the extinction coefficient was above 100 units in (b) and (d).

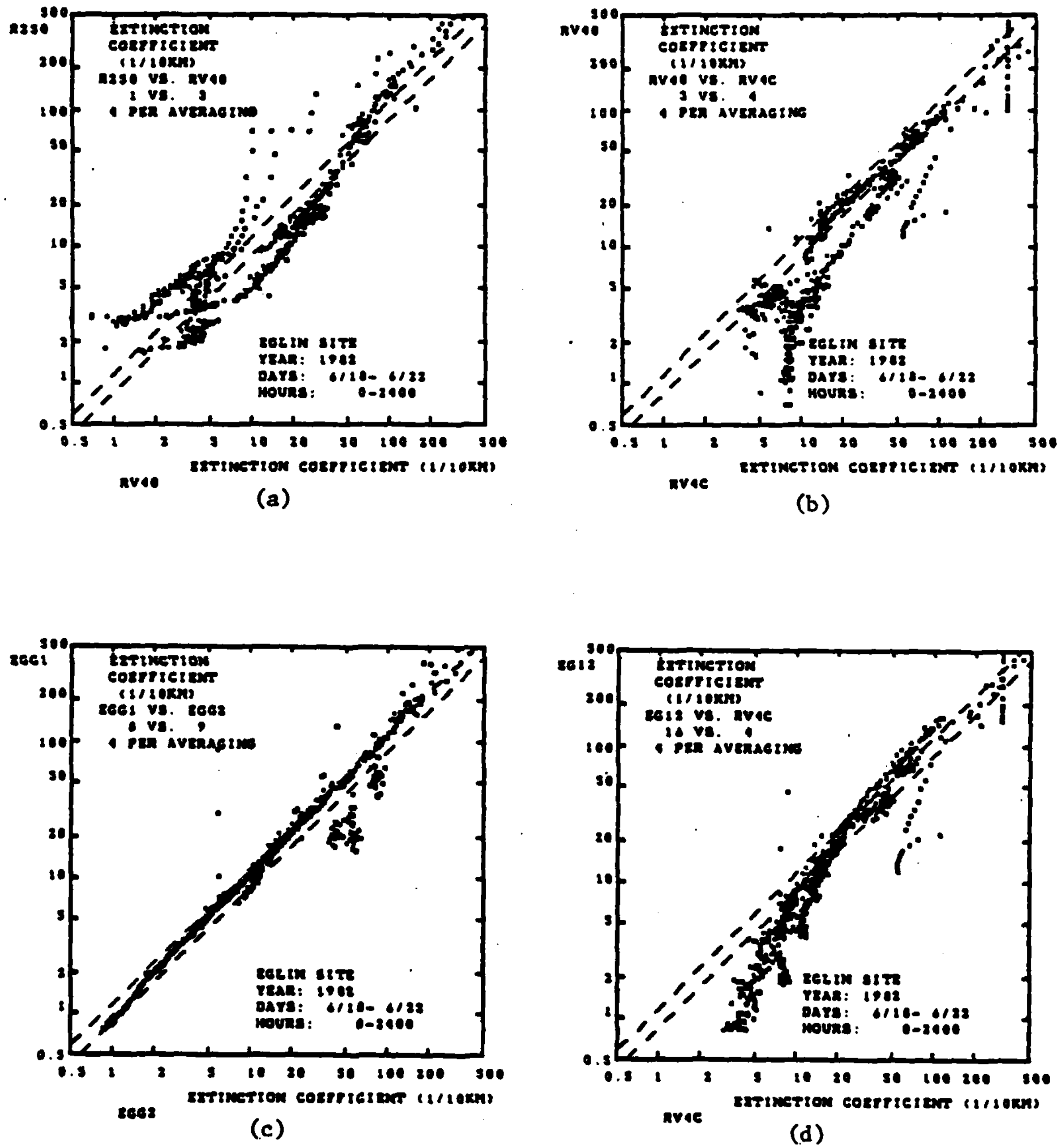


FIGURE 5-24. HOMOGENEITY OF ALL FOG/HAZE EVENTS. Note: the zig zag in (b) and (d) was caused by a transient in the RVR calibrator.

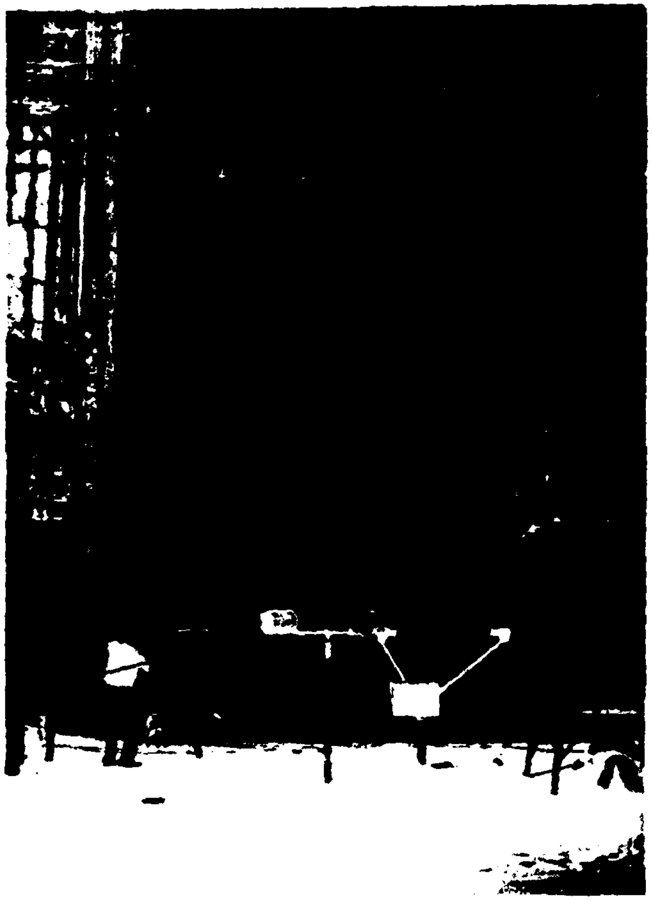
shown in Figure 5-23. At these low values the 40-foot baseline transmissometer become very sensitive to the 100-percent calibration setting and can therefore no longer serve as a standard sensor. The data in Figure 5-22d indicate an extinction coefficient offset of 3 or 4 units which corresponds to a 100-percent setting of about 99.6 percent. This calibration accuracy, which is much better than can be maintained in normal field operation, is a consequence of the clear calibration period which began most test days.

5.4 RAIN

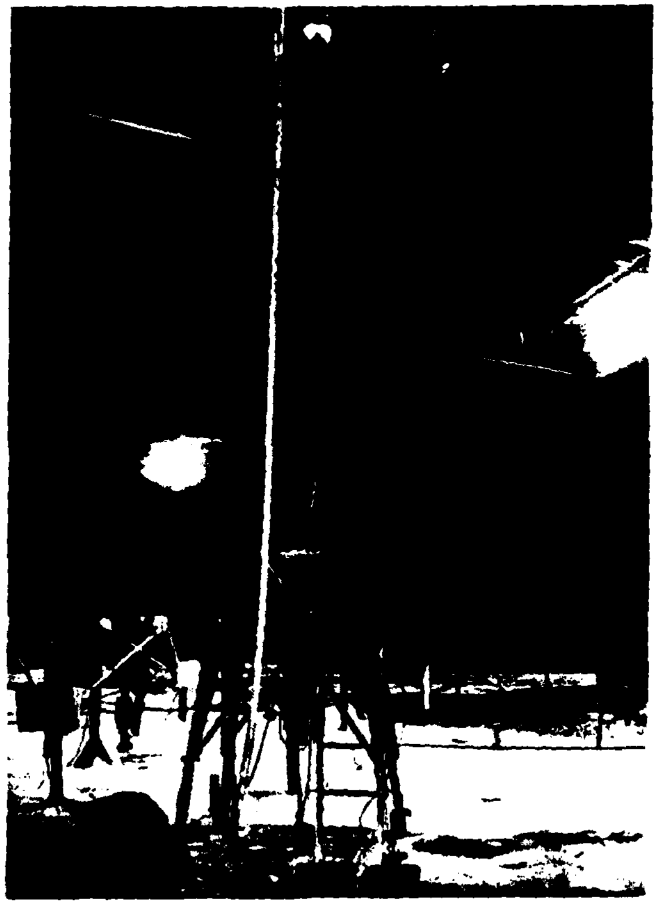
The climatic chamber generates rain by means of rain nozzles installed at periodic spacings along water pipes. Two nozzle configurations were used in the tests: a double pipe running the length of the 250-foot baseline and a rectangular rack of nozzles (about 12 feet by 60 feet) which could be placed near the 40-foot baseline. When it was found that the 250-foot pipes were not very useful because of the narrowness of the rain pattern, they were removed and the rectangular rack (Figure 5-25) was used to cover the sensors clustered around the 40-foot baseline. In order to cover all the sensors the rain rack had to be operated in three separate positions, (Figure 5-2), one for the RVR-500, RVR Calibrator, FOG-15s, and MET-1; one for the EG&G 207's, EV-1000, VR-301, and Fumosens III; and one for the Skopograph.

The rain produced by the nozzles selected was not similar to natural rain. Although the rain rate was that of heavy rain (about two inches per hour), the droplet size was about 0.3 mm, which is characteristic of drizzle. Moreover, the distribution of the rain was not uniform, but had peaks under the nozzles (see Figure 5-25a). An attempt was made to make the rain more uniform by swinging the rain rack on its support wires. The response of the sensors having small sensitive volumes (e.g., HSS) was not noticeably steadier with the swinging.

Freezing rain was generated by cooling the chamber to 25°F while operating the rain frame. The temperature was later reduced to 15°F to increase the rate of ice accumulation.



(a)



(b)

FIGURE 5-25. RAIN TESTS

5.5 SNOW

The Climatic Laboratory had just received delivery of new snow machines (see Figure 5-26a) in time for the snow tests. They operate by spraying water into a rapidly spinning 12-blade propeller which blows the resulting droplets up into the air. The chamber was operated at $0^{o}F$ for the snow tests. The resulting snow particles were fine grains rather than large flakes.

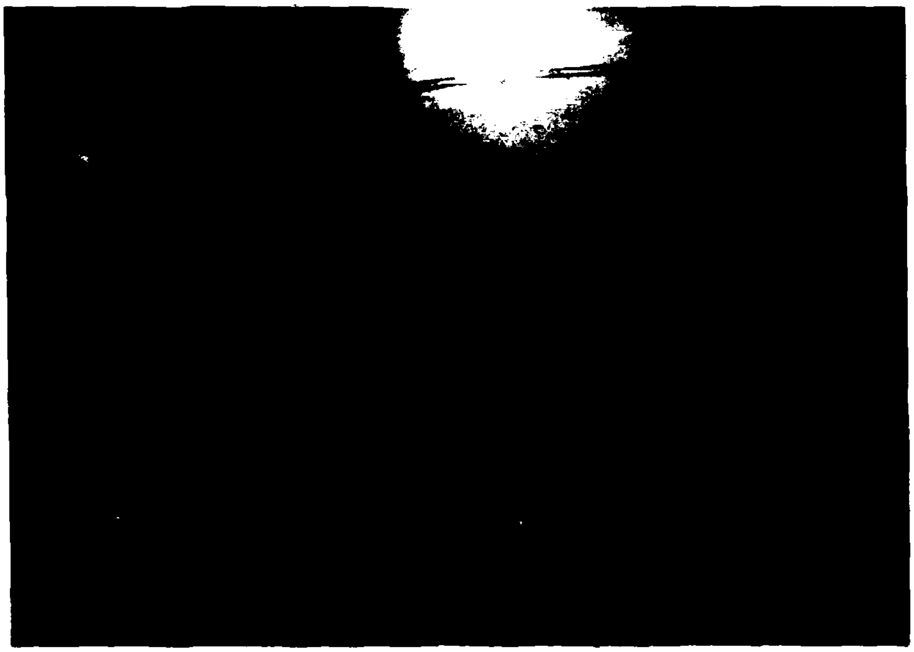
On the first day of snow testing the floor fans were mounted behind the snow machines to drive the snow into the sensors, which were clustered around the 40-foot baseline. The trajectories of the snow particles was horizontal in this case.

The test configuration was rearranged on the second day to achieve a more vertical snow trajectory. The fans were not used and the snow machines were positioned to drop snow into the middle of the cluster of sensors.

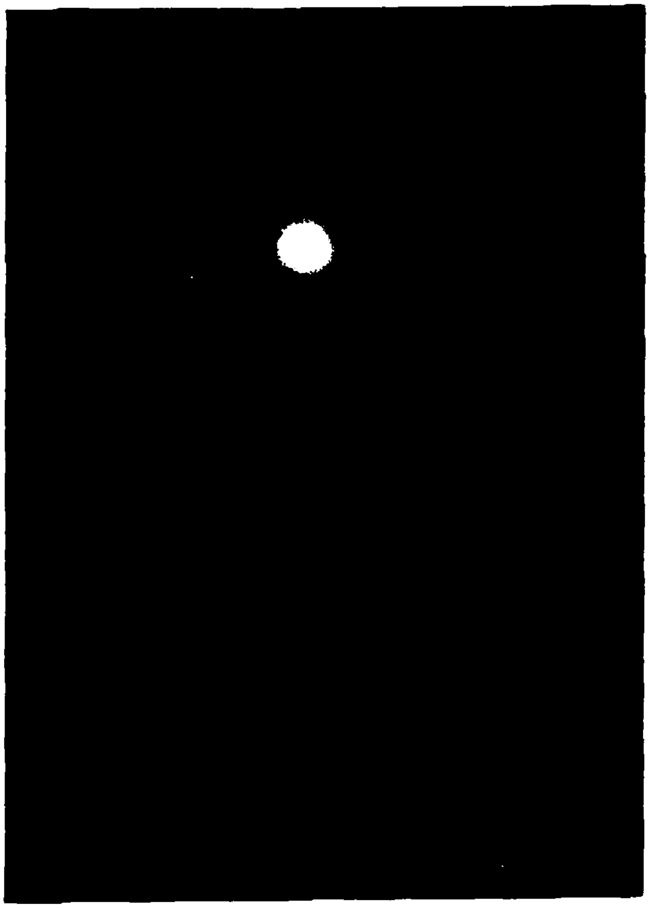
The snow rate was nonuniform over the test area on both days of testing. Some snow fall distributions were taken.

5.6 TEMPERATURE CYCLE

The $\pm$ $50^{o}C$ temperature cycle was accomplished on two successive weekends. The cold cycle preceeded the snow tests. Because of a communication breakdown the calibrators were not installed in the forward-scatter meters as had been intended to check the calibration stability. Nevertheless, the chamber tends to fill with fog when cooled so that signals were present to evaluate the sensors. Periodically during the cool-down the temperature was raised to eliminate the fog. The sensor results showed little reduction in fog density. The high temperature cycle was conducted the following weekend. Calibrated scatterers were installed in some of the FSM's for this cycle. The snow from the snow testing was finally melted during this cycle.



(a)



(b)

FIGURE 5-26. SNOW TESTS: (a) SNOW AND WIND MACHINES, (b) ROW OF FORWARD-SCATTER METERS.

5.7 CALIBRATION

The test schedule for most days incorporated a high visibility, low relative humidity period in the morning when the 100-percent calibrations of the transmissometers were checked and the zero levels of the FSM's were verified. Two calibrations of the forward-scatter meters were carried out, one near the beginning of the test and one near the end.

The constants A, B and C in Table 5-2 were used during the test in calibration equations (Table 5-3) to calculate the extinction coefficient σ from the measured signal voltage V.

TABLE 5-3. CALIBRATION EQUATIONS

Sensor Type	Channels	Equation
Transmissometer	6-12	$\sigma = C \ln(A/V)$
Forward-Scatter Meter	16-24,28	$\sigma = C(V-B)$*
HSS	25,26	$\sigma = CV^A$
Enertec	27	$\sigma = C10^{-(3V/A)}$

*For channels 16-23 multiply σ by A when low gain switch is on.

For the final data analysis many changes were necessary in the constants of Table 5-2 and even in the equations of Table 5-3. These changes were based on calibration checks made during the test period and on measurements made subsequent to the test period. Each forward-scatter sensor requiring a calibration change will be discussed in turn.

5.7.1 EG&G 207

The calibrator used to calibrate the EG&G 207 sensors during the tests was a special unit which could be disassembled for shipping. Its calibration constant relative to the standard AFGL calibrator was checked long before the Eglin tests (ratio = 2.105 on 11/4/81) and immediately after the tests (ratio = 2.152, 2.129 on 7/22/82). The ratio shifted by only two percent in a year and a half. The ratio 2.14 was adopted to transfer the AFGL calibration to the Eglin tests. The exact calibration of the AFGL calibrator was found to be somewhat uncertain. For the analysis of the Eglin data it was assumed that 1.500 volts from the calibrator correspond to a constant C = 100 in the forward-scatter meter calibration of Table 5-3. The two EG&G 207 sensors were checked out after their return to AFGL. The first unit (SN 003) was found to have moisture in the optics and to exhibit some drift in calibration. The second unit (SN 015) exhibited no problems. Cleaning the windows produced no change in calibration.

The Eglin calibrations are listed in Table 5-4. The high temperature cycle appeared to reduce the calibrator signal. The resulting constants are shown in Table 5-5.

Values of sensor zero offset (B in Table 5-3) were taken from times where the chamber was clear and dry (i.e., low relative humidity). These offsets include the effects of light bouncing off the chamber walls as well as any electronic zero offsets. The values adopted are listed in Table 5-6. The reduction in offset on 6/22 for EGG1 and FOG1 was due to black baffles being installed behind the transmitter heads, to reduce the wall-scattered light. The wall-scattering level was sensitive to the direction of pointing the sensor. For some orientations a beat signal was observed between the two EG&G 207 units which operate at almost identical frequencies.

TABLE 5-4. EG&G 207 CALIBRATIONS AT EGLIN

Date	Unit	Attenuator	Zero	Calibrator	Net Signal
6/10	003	out	0.005	3.010	3.005
		in	0.0035	.2676	.2641
6/22		out	0.008	2.809	2.801
6/4	015	out		3.00	
		in		.392	
6/10		out	0.0005	2.996	2.991
		in	0.0049	.3963	.3914
6/22		out	0.010	2.710	2.700

Table 5-5. EG&G 207 CALIBRATION CONSTANTS

UNIT	C (before 6/20)	C (after 6/20)	A
SN 003 (EGG1)	106.6	114.6	11.38
SN 015 (EGG2)	107.1	118.9	7.64

TABLE 5-6. FORWARD-SCATTER METER OFFSETS

DATE	SN 003 (EGG1)	SN 015 (EGG2)	SN 016 (FOG1)	SN 004 (FOG2)
6/9	11 mV	13 mV	11 mV	29 Hz
6/10-19	8 mV	10 mV	11 mV	29 Hz
6/21	14 mV	15 mV	11 mV	47 Hz
6/22	12 mV	15 mV	7 mV	47 Hz

5.7.2 FOG-15

The calibration of the FOG-15 units was more complicated than that of the EG&G 207 because each unit contained its own neutral density (N.D. 3.0) filter to attenuate the light scattered from a 1/4 inch thick white plastic scattering disk. Since the exact attenuation of a filter can vary by as much as a factor of two, there was no way to assign an exact relationship between the calibration signal and the instrument response to fog without comparing each instrument with a transmissometer. This unsatisfactory calibration procedure was rectified after the chamber tests were over by designating a particular filter/disk combination as the standard calibrator which can be used in any FOG-15 unit. The extinction coefficient represented by the standard calibrator must be determined by comparison with a transmissometer. The relative response of a secondary calibrator can be determined by comparing its signal to that of the standard calibrator for the same FOG-15 unit. A secondary calibrator can then be carried into the field to calibrate any other unit.

Table 5-7 shows the calibration measurements made on two FOG-15 units tested. Unfortunately, the relevant measurements were spread out over three months and were not carried out in a consistent fashion. In addition to the data using the available scattering disk (SN 001) and the internal neutral density filters, data are included using the standard disk and filter. The last calibration points for each unit were taken after the nonlinear "soft" clipping cicuit was removed; no dramatic change was noted. The calibration for SN 016 was observed to change significantly between 6/10 and 6/22. The cause for this change was most likely an inadvertant change in the gain potentiometer during the snow tests (6/14-15). The change in calibration on 6/22 when the windows were cleaned indicated window losses of 16 and 13 percent for SN 016 and 003 respectively because of the window contamination built up during the snow, rain and snow-machine fog tests. This contamination reflects the impurities in the tap water used in these tests and probably represents a worse case than most natural environments. The

TABLE 5-7 FOG-15 CALIBRATIONS

DATE	GAIN	ZERO	CALIBRATOR	NET SIGNAL	HIGH/LOW
			SN 016 (FOG 1) (Volts)		
5/7	Low	0.0075	0.0301	0.0226	12.4
	High	0.0075	0.2878	0.280	
6/10	Low	0.0085	0.0295	0.0210	12.6
	High	0.0085	0.2733	0.265	
6/22	High	0.0061	0.1657	.160	
6/22*	High	0.0061	0.1964	.190	
9/1**	High			.211***	11.6
	Low			.018***	
9/1**	High	-.001	.494	.494+	12.1
	Low	-.001	.040	.041+	
			SN 004 (FOG2) (Hz)		
6/7	Low	27.8	126.7	99.1	8.19
	High	25.9	838	812	
6/10	Low	17.2	123.5	106.3	8.15
	High	16.8	883	866	
6/22	High	38.2	942	904	
6/22*	High	38.2	1007	968	
7/9	High	38.1	1148	1110	11.6
	Low	38.1	132	96	
7/9	High	38.1	1256	1218+	11.8
	Low	38.1	141	103+	
8/20**	High	29.5	1205	1175	10.5
	Low	29.5	142	112	

*Clean windows
**Nonlinear clipping circuit removed
***Corrected from a different scattering disk
+Standard FOG-15 calibrator.

FOG-15 windows are totally unbaffled and are therefore susceptible to all the contaminating (and cleaning) processes of the environment.

The calibration of SN 004 exhibited a number of anomalies. (Note that the frequency output from the sensor rather than the voltage output was used). First, there was a general increase in the calibration signals over this course of the tests. Second, the high/low gain ratio was smaller than it should be, based on the resistors being switched (and also the values measured later).

The source of these problems may lie in the converter unit for Climatic Laboratory Laboratory data recording system. Considerable difficulty was experienced in interfacing to the FOG-15's square wave current output. The best results (i.e., no drop out at high frequency) were obtained when a small series resistor was used to generate a relatively low voltage signal at the converter. The reduced value of high/low gain ratio may be due to signal saturation in the converter.

Table 5-8 lists the calibration constants adopted for the FOG-15. SN 016 is observed to give good agreement with transmissometers during the period 6/9 -6/11 with its nominal calibration C = 100. The value C = 166 after 6/20 was based on the 6/22 calibration. Since the calibration was observed to drop by about 10 percent during the heat cycle, the value C = 150 was adopted for the time period before the heat cycle. The SN 004 calibrations present more questions because of the possible nonlinearities in the frequency converter response. It was decided to adopt the high/low gain ratio measured later (11.7) and let any signal saturations, if present, simply appear in the data. The nominal response of SN 004 was set for twice the gain (half the full scale response) of SN 016. The SN 004 value C = 0.05 leads to 500 extinction coefficient units for the full scale signal of 10,000 Hz, whereas the SN 016 value C = 100 leads to 1000 extinction coefficient units for the full scale signal of 10 volts. The FOG-15 voltage to frequency converter outputs 10,000 Hz for 10 volts input. The calibration data in Table 5-7 for 6/10 support the use of these nominal values for C. The

SN 016 calibration signal of 0.280 volts can be converted to a standard calibrator response of 0.657 volts by multiplying by the ratio of the standard response (.495) to the interval calibrator response (.211) on 9/1. Likewise the SN 004 low gain can be converted to a standard signal of 1365 Hz by multiplying by the high/low gain ratio (11.7) and the ratio of the standard response (1218) to the interval calibrator response (1110) on 7/9. Use of the calibration constants C = 100 and 0.05 leads to the effective standard measurements 65.7 and 68.2 respectively for SN 016 and 004, which are in good agreement. Because of the various uncertainties in the SN 004 calibration and the fact that only small changes were noted, its value of C = 0.05 was kept fixed for the tests.

TABLE 5-8 FOG-15 CALIBRATION CONSTANTS

UNIT	C	A
S/N 016	100 (before 6.14)	12.5
(FOG1)	150 (after 6/14, before 6/20)	
	166 (after 6/20)	
S/N 004	0.05	11.7
(FOG2)		

5.7.3 HSS VR-301

The nonlinear (0.9 power law) calibration of the HSS VR-301 shown in Tables 5-2 and 5-3 was based on tests in the Calspan fog chamber. Field tests at Otis ANGB, conducted after the Eglin tests were over, led to the conclusion that a linear calibration was more appropriate. The data in this report therefore reflect this linear calibration (equivalent to A = 1.0). The values of C adopted are 549 for channel 25 and 54.9 for channel 26. In addition to the calibration constant C, the VR-301 developed serious offsets (B) in later portions of the tests, apparently because the signal cable connector was not properly locked into place after the sensor was moved to the new configuration (6/9). The poor connection resulted in contact potentials which disappeared on 6/23 when the connector was properly locked. Measurements by HSS led to the following choices of B: before 6/14: 0.0015 V, 6/14 - 6/15: -0.35V, 6/16-6/20: -0.13 V, after 6/20: 1.86 V. These B values were divided by 10 for channel 25.

5.7.4 Enertec EV-1000

The full scale voltage of the EV-1000 was measured to be slightly different (C = 4.525 volts) than the nominal value listed in Table 5-2. Note: it was assumed that the EV-1000 calibration is based on a 2-percent contrast ratio.

6. TEST RESULTS

As an introduction to the data analysis, Figure 6-1 shows the data selected from the steam fog event on 6/10/82 (Figure 5-10). Appendix C contains stripcharts of all the other events analyzed. The extinction coefficient is plotted on a vertical logarthmic scale while elapsed time is plotted on the horizontal scale. The scale for each sensor is displaced by a factor of 100 on the logarithmic scale. The bottom six plots are for transmissometers and the top seven are forward-scatter meters. A number of salient features of Figure 6-1 should be noted. The 250-foot baseline transmissometers (bottom two traces) saturate at high extinction coefficient. They also show the smoothest variation in time because they average over the longest distance. The forward-scatter meters show extremely variable signals after the fog has decayed. The background check periods for the RVR 500 can be noted in traces one and three as drop outs occurring every hour. The Fumosens III (third trace from the top) saturates at a level of 150 units. The spikes at 18:14 are caused for the EG&G 207's, FOG-15's and Fumosens III by gain changes. The Enertec data is stepped because of the one or three minute averaging times built into the sensor.

6.1 Transmissometers

The RVR calibrators formed the natural comparison standard for the transmissometers being evaluated. The correlation was excellent when a calibrator was located next to a transmissometer. Only data collected from such a configuration will be used for comparison. One should note that the RVR calibrator has a coarser resolution (0.5 percent transmission) than the transmissometers being tested.

The calibrator and transmissometer baselines must be defi~~d carefully to achieve accurate comparisons, expecially for short baselines. The effective baselines of the sensors are different from the nominal window to window spacing because the fog density is reduced inside the instrument hoods. The RVR 500 receiver hood is purged with filtered air and its projector hood is heated. No fog could be seen inside the hoods. The heating inside the

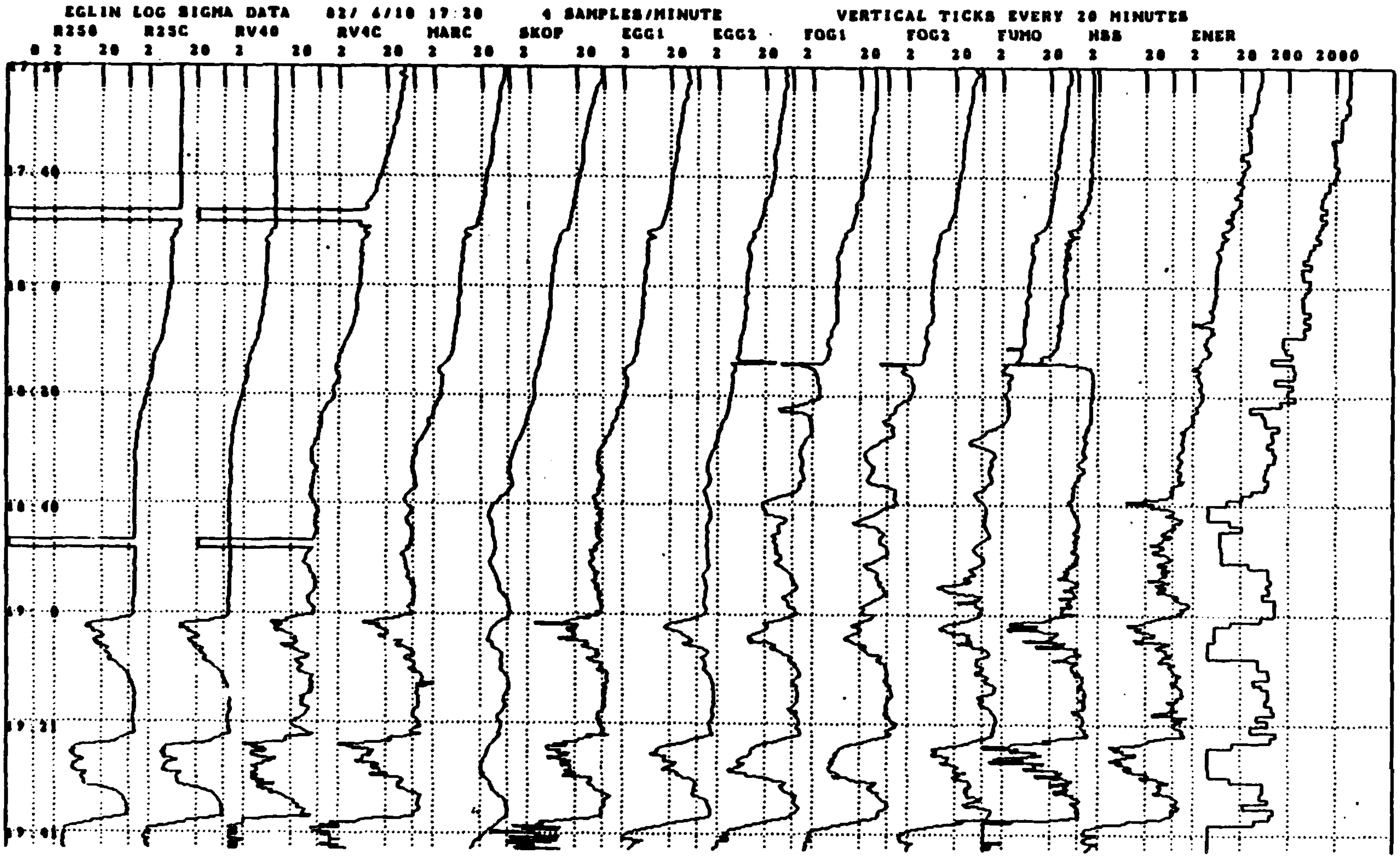


FIGURE 6-1. DATA SELECTED FOR ANALYSIS FROM THE STEAM FOG EVENT ON 6/10/82.

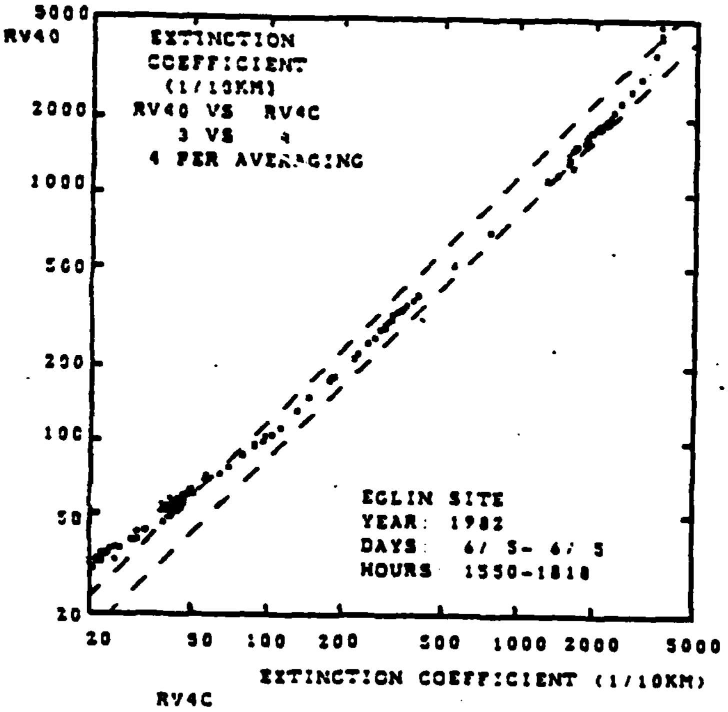
RVR calibrator hoods is less, but the hoods appeared to be free of fog, presumably because the large fog droplets settle out. Thus the baselines adopted for the data analysis, listed in Table 6-1, are the separations between the tips of the hoods. The RVR calibrator (RV4C) had no receiver hood until 6/8/82.

TABLE 6-1 TRANSMISSOMETER BASELINES

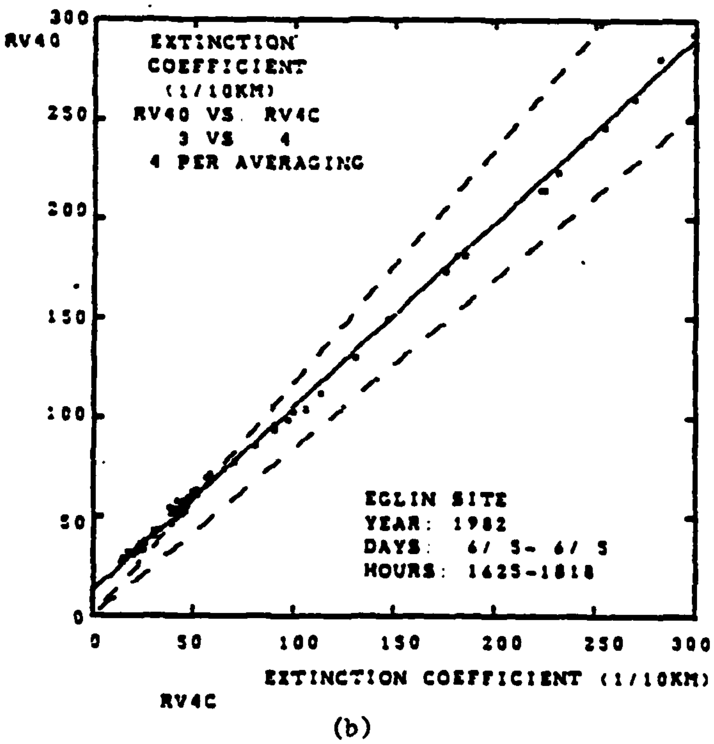
SENSOR	LABEL	DATES	BASELINE (ft)
RVR CALIBRATOR	RV4C	6/5-6/7	40.0
		6/8	37.0
		6/9-6/22	36.2
	R25C	6/5-6/20	250
		6/21-6/22	39.0
RVR 500	RV40	ALL	38.0
	RV25	ALL	250
SKOPOGRAPH	SKOP	ALL	43.0
MARCONI MET-1	MARC	ALL	19.7

6.1.1 TASKER RVR 500

Since the 250-foot baseline RVR 500 is used operationally, its performance is known and is assumed to be satisfactory. Consequently, the critical element for RVR 500 evaluation is the performance of the 40-foot baseline. The projector hood of the dual-baseline RVR 500 contains a 4-inch diameter baffle which is intended to reduce the forward-scatter error which is expected to affect measurements with such a short baseline. Figures 6-2 to 6-6 show scatter plots for all the events where an RVR calibrator was operating next to the 40-foot RVR 500 baseline. The dashed lines in the plots represent disagreements of ±15 percent. For Figures 6-2, 6-3, and 6-6 where the logarithmic plots show

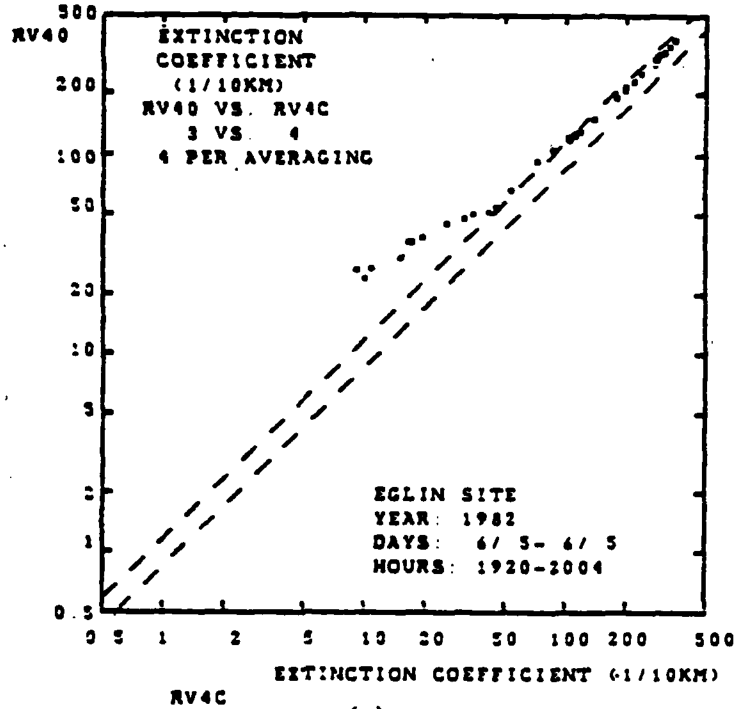


(a)

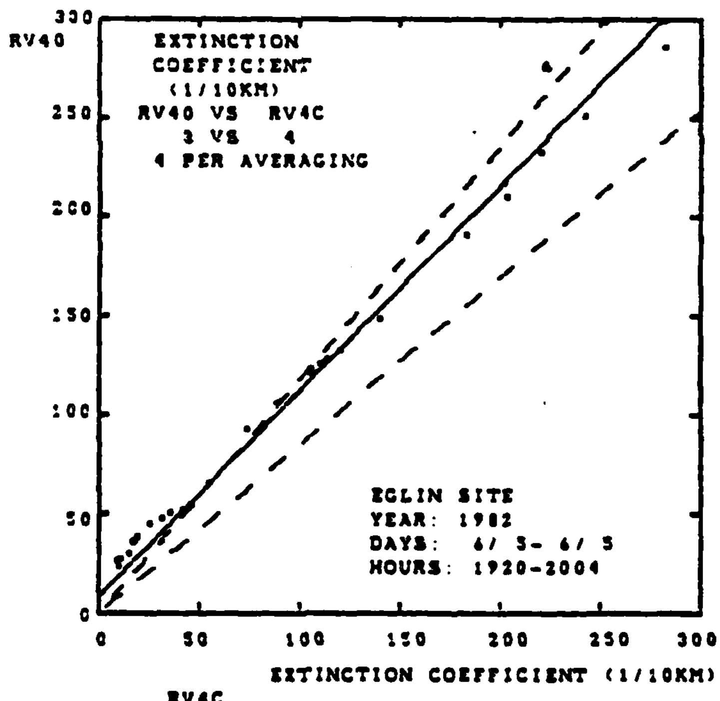


(b)

FIGURE 6-2. 40-FOOT RVR 500 VERSUS RVR CALIBRATOR SCATTER PLOTS FOR A STEAM FOG EVENT ON 6/5/82: (a) LOGARITHMIC, (b) LINEAR (SLOPE = 0.93) OFFSET = 13.2)

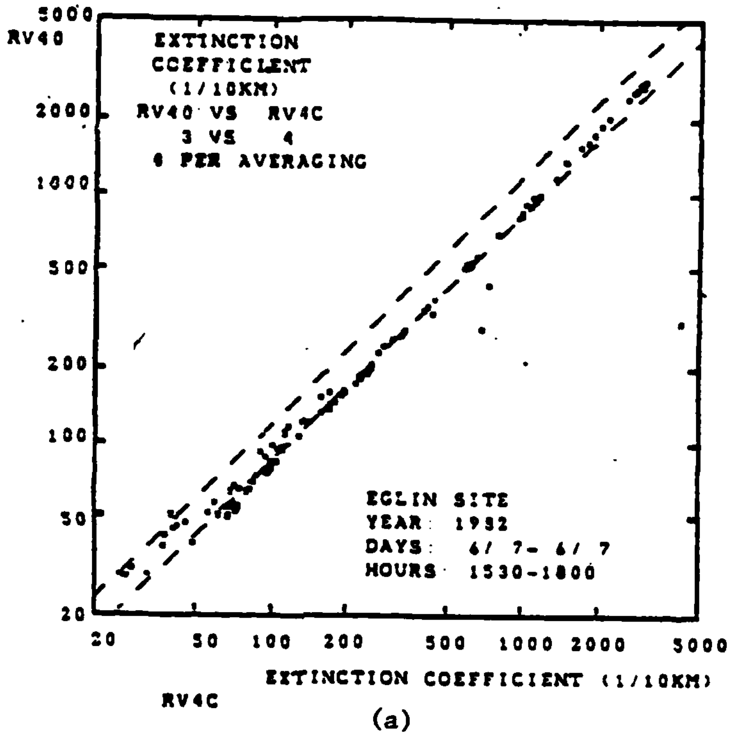


(a)

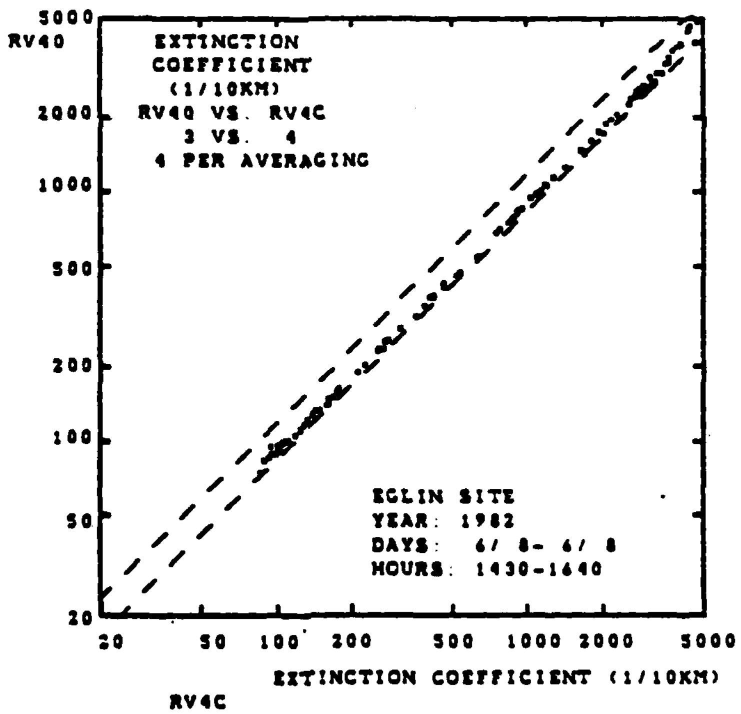


(b)

FIGURE 6-3. 40-FOOT RVR 500 VERSUS RVR CALIBRATOR SCATTER PLOTS FOR A COOLING FOG EVENT ON 6/5/82: (a) LOGARITHMIC, (b) LINEAR (SLOPE = 1.04. OFFSET = 8.5).



(a)



(b)

FIGURE 6-4. 40-FOOT RVR 500 VERSUS RVR CALIBRATOR FOR STEAM FOG EVENTS: (a) 6/7/82, (b) 6/8/82.

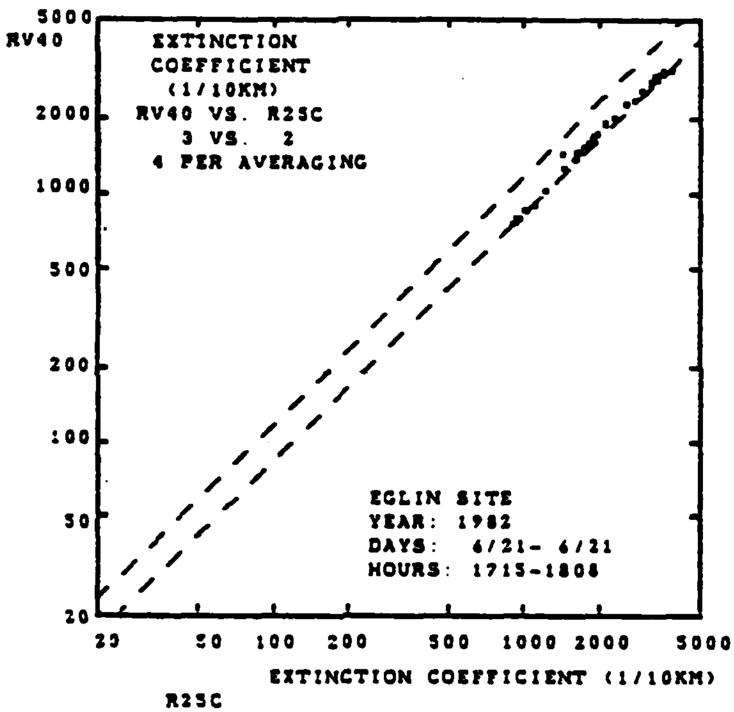
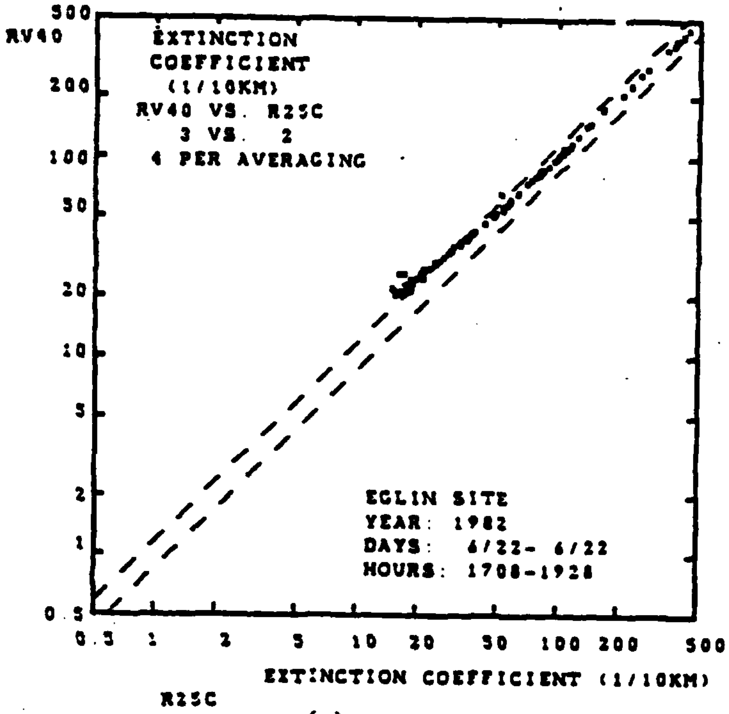
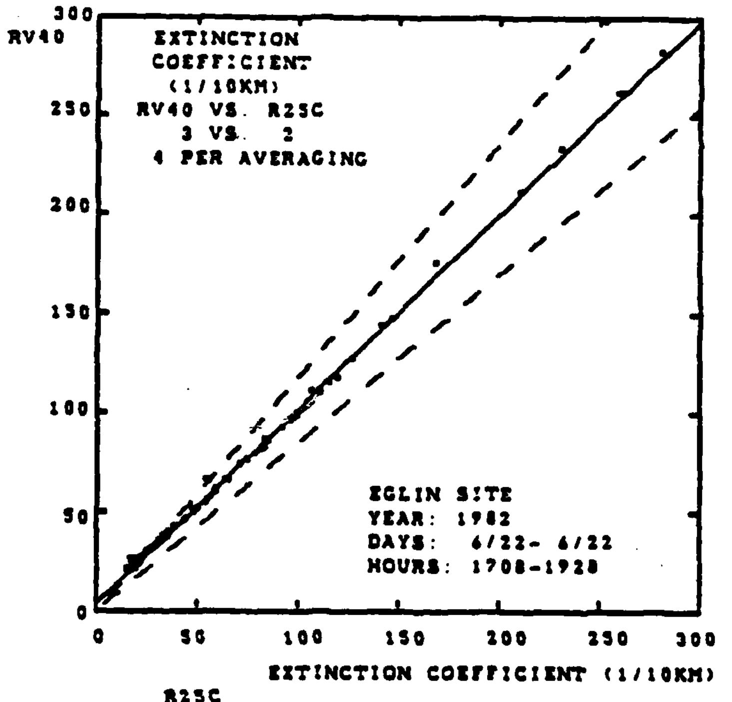


FIGURE 6-5. 40-FOOT RVR 500 VERSUS RVR CALIBRATOR SCATTER PLOT FOR A STEAM FOG EVENT ON 6/21/82.



(a)



(b)

FIGURE 6-6. 40-FOOT RVR VERSUS (b) RVR CALIBRATOR SCATTER PLOTS FOR SNOW MACHINE FOG/HAZE ON 6/22/82: (a) LOGARITHMIC, (b) LINEAR (SLOPE = 0.98, OFFSET = 3.9).

a well defined curvature, a linear plot is also included to show that the curvature is caused by an offset in the extinction coefficient. The solid line in the linear plots is the least-square fit to the data points. The observed offsets of 13.2, 8.5, and 3.9 correspond to errors of 1.6, 1.0, and 0.5 percent respectively in the 100-percent calibration of the transmissometer. These values are consistent with the observed variation in 100-percent setting (see below). The offset could be caused by either or both instruments. The biggest offsets occurred on 6/5/82 which was a trial rather than an actual test day.

The comparisons between the 40-foot RVR 500 and a 40-foot calibrator show excellent agreement. Apart from the offsets discussed above, the measured values agree to better than the 15 percent pass/fail criteria. These are, however, some observed systematic disagreements which can be explained. In general the RVR 500 reads low during the steam fog events by 10 to 15 percent.

During those portions of the events where the circulation fans were operating the agreement is much better (the densest fog in Figures 6-2 and 6-4, and the middle of the event in Figures 6-1, 6-2). Likewise, the snow machine event (Figure 6-6) showed better agreement. The most likely explanation for this observation is the effect of the RVR 500 receiver hood blower on the measurements. When the air is still, the blower clears out a portion of the measurement path so that the measured extinction coefficient is lower. When there is a crosswind, the exhaust from the receiver hood is blown out of the measurement path and more representative value is measured. The analysis of the Arcata data (Appendix A) ascribed the observed low reading of the RVR 500 to forward scattering and proposed a 7 percent correction on the readings. That value still appears to be a reasonable choice to represent the observed disagreements which appear to be the combined result of forward scattering and the blower reduction of the effective baseline. This correction corresponds to installing a nominal 40-foot baseline with an actual hood-to-hood spacing of 42.8 feet. Neither the 40-foot RVR calibrator used as a standard at Eglin nor the 250-foot RVR 500 transmissiometer used at Arcata are expected to have a significant forward-scatter error. See Appendix E of Reference 1 for an analysis of the forward-scatter error.

The agreement between the 250-foot baseline RVR 500 and the parallel RVR calibrator was very good. Figures 6-7 through 6-9 show some selected scatter plots. Some peculiar responses are noted at high extinction coefficients which are near the resolution limit of the RVR calibrator. A transmission of 0.5 percent corresponds to an extinction coefficient of 695 units.

The RVR 500 calibration variation from day to day was 2.5 percent or less, which is consistent with the use of the 40-foot baseline below RVR = 1000 feet and the 250-foot baseline below 6000 feet. No significant cumulative shift in calibration was noted.

6.1.2 Impulsphysics Skopograph

The Skopograph operated without attention throughout the test schedule. The initial calibration (Table 5-2) was based on the nominal 100-percent signal level. A precise 100-percent calibration was set according to the measured clear air signal on 6/10/82 (A = 4.497 volts in Table 5-3). The 100-percent signal exhibited a cyclical variation of about one percent with a period of about 90 seconds. The clear air signal was observed to drop at a rate of approximately one percent per week, presumably because of window contamination. These variations are all within the expected tolerances for the Skopograph.

Figures 6-10 through 6-12 compare the Skopograph to the adjacent RVR calibrator for fog events. The correlation is excellent. There is a consistent offset, however, of about 15 percent toward lower extinction coefficients. A similar error (17 percent) was observed at Arcata on a 164-foot baseline. The observed errors are consistent with a forward-scattering error. Since both the beam size and the baseline were reduced in the Eglin tests, it is not unreasonable to have the same resultant error. If the 15 percent correction is made, the Skopograph

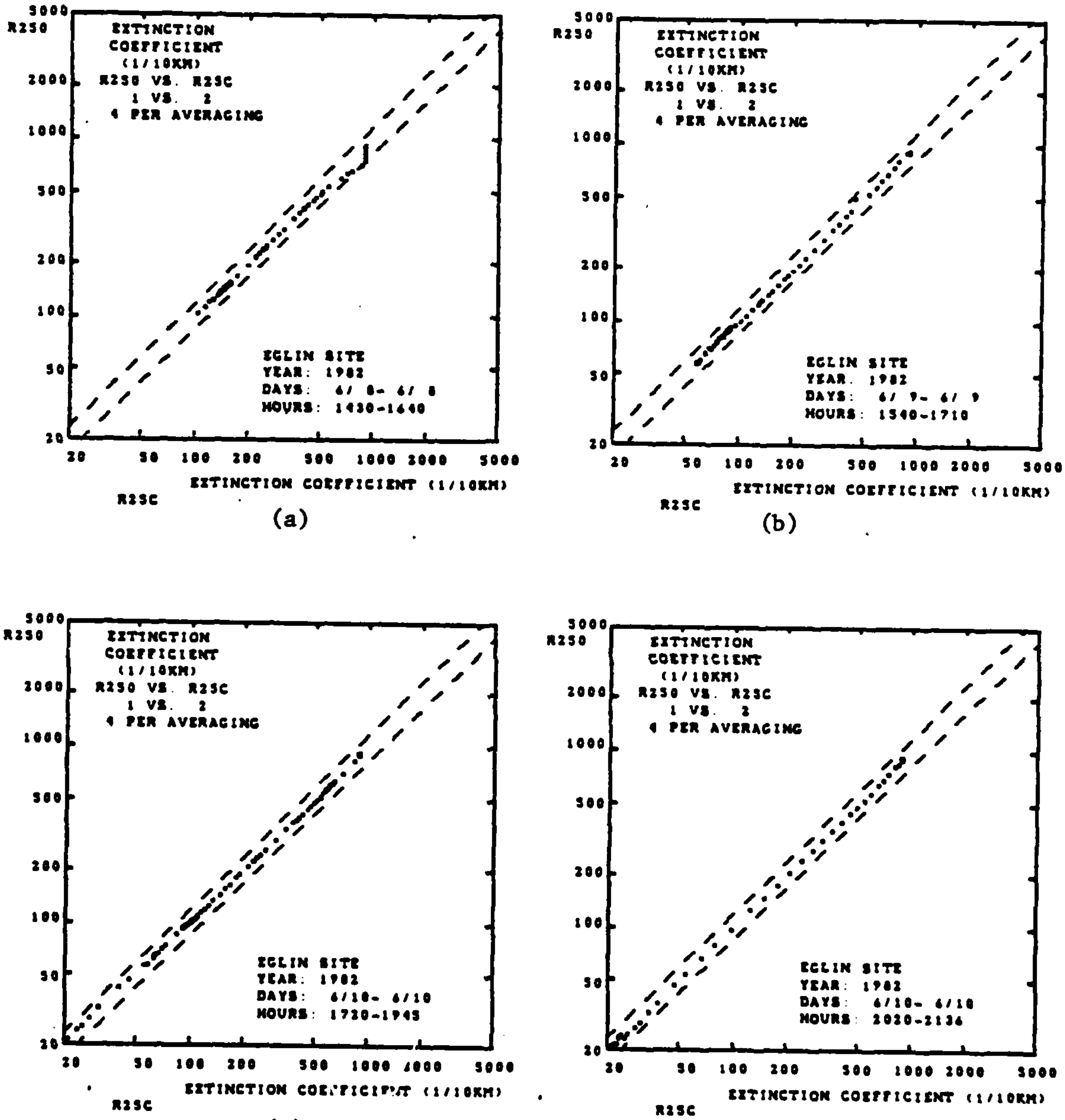


FIGURE 6-7. COMPARISONS OF THE/RVR 500 TO THE RVR CALIBRATOR ON A 250-FOOT BASELINE

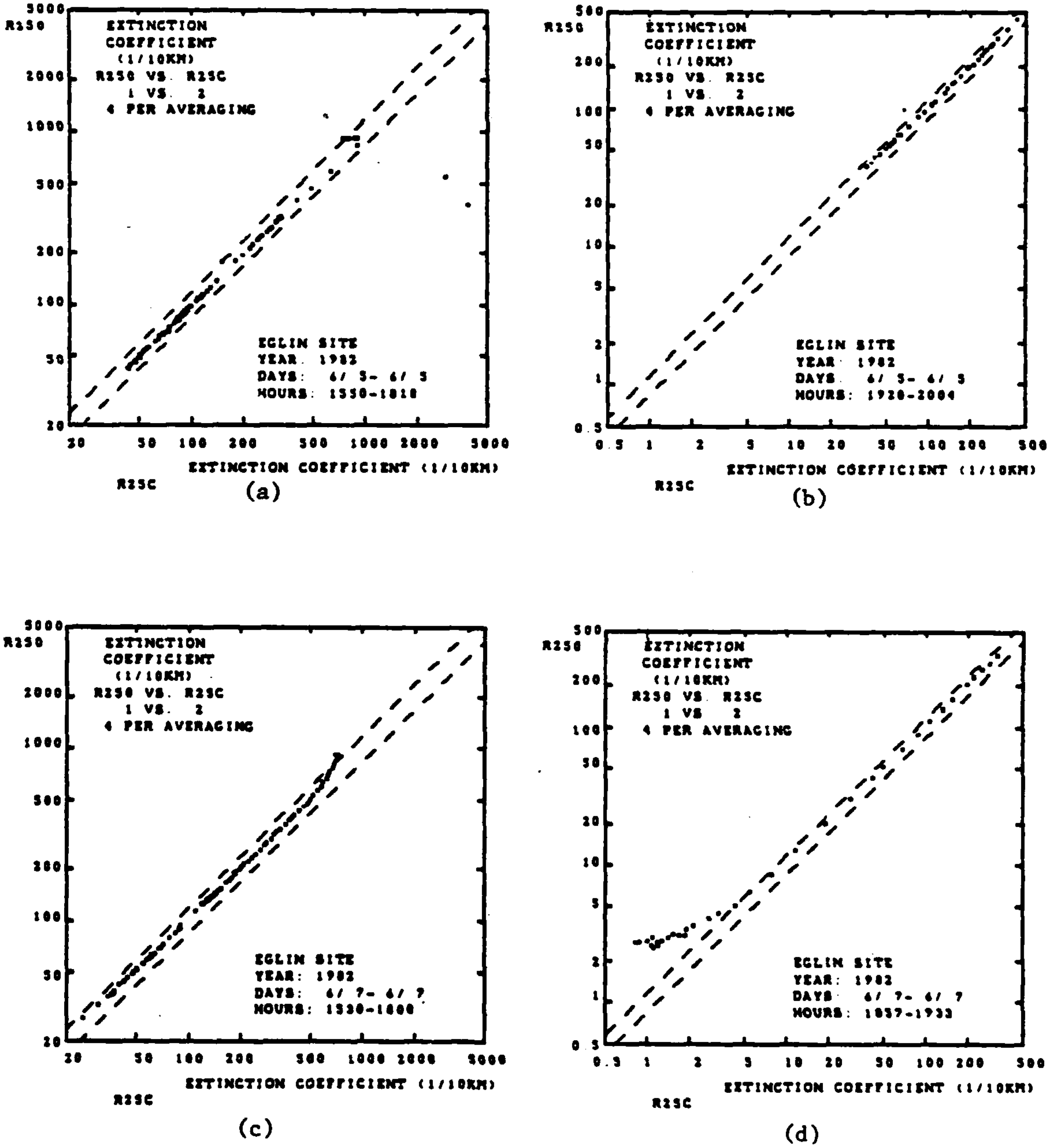
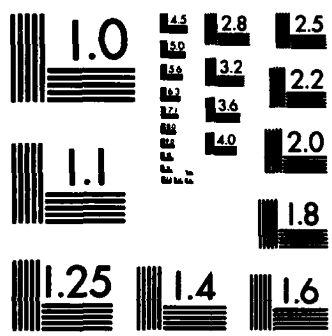


FIGURE 6-8. COMPARISONS OF THE RVR 500 TO THE RVR CALIBRATOR ON A 250-FOOT BASELINE

AD-A135 375 EVALUATION OF VISIBILITY SENSORS AT THE EGLIN AIR FORCE BASE CLIMATIC CHAMBER(U) TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MA D C BURNHAM OCT 83 DOT-TSC-FAA-83-1 2/3

UNCLASSIFIED DOT/FAA/PM-83/29 F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

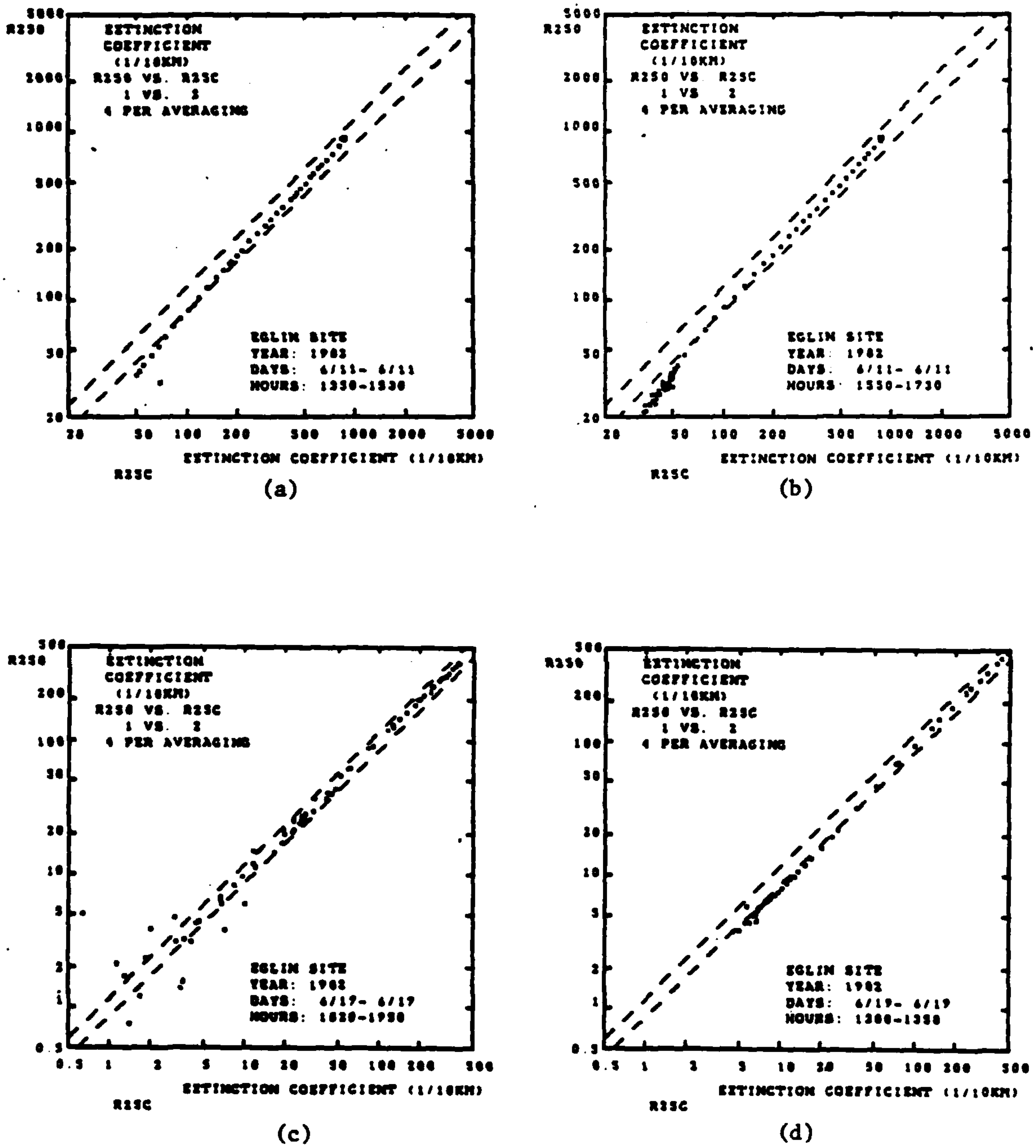
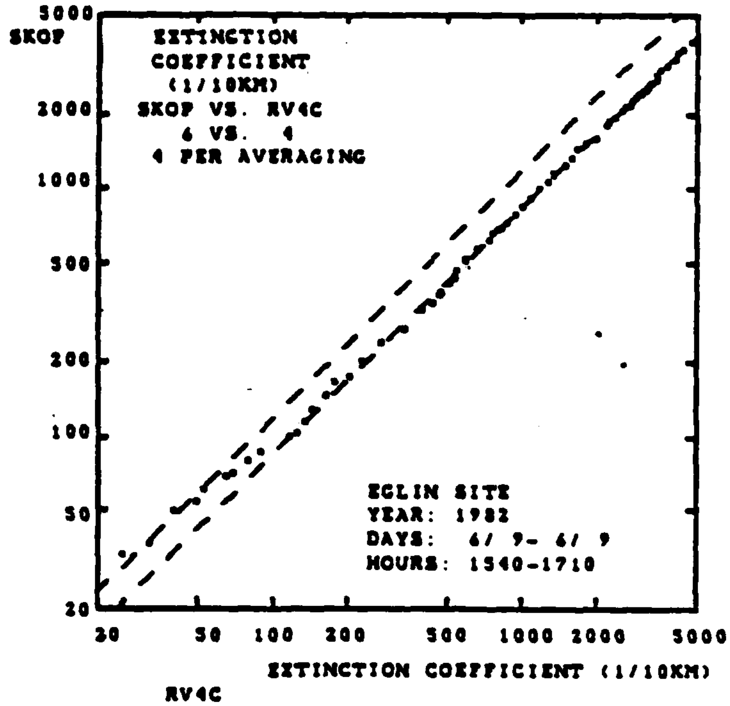
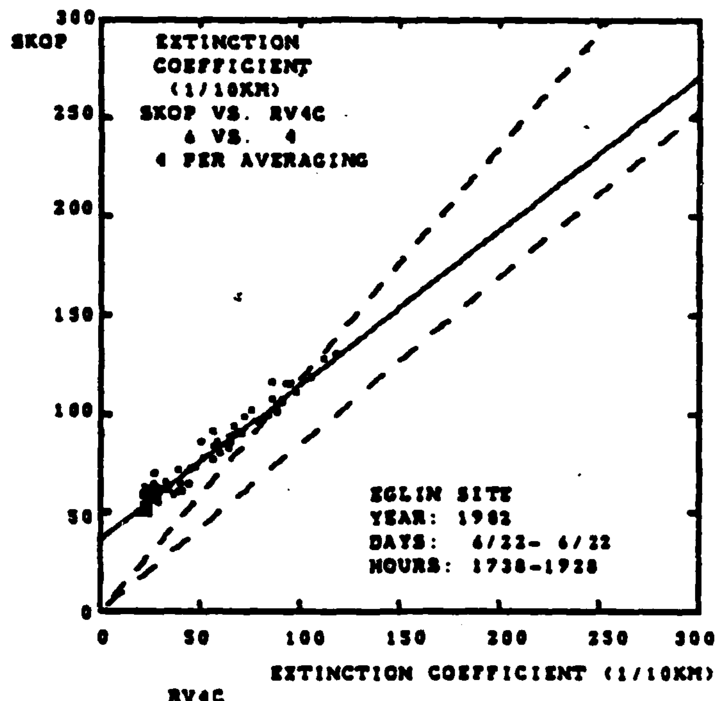


FIGURE 6-9. COMPARISONS OF THE RVR 500 TO THE RVR CALIBRATOR ON A 250-FOOT BASELINE.



(a)



(b)

FIGURE 6-10. SKOPOGRAPH RESPONSE FOR TWO STEAM FOG EVENTS.

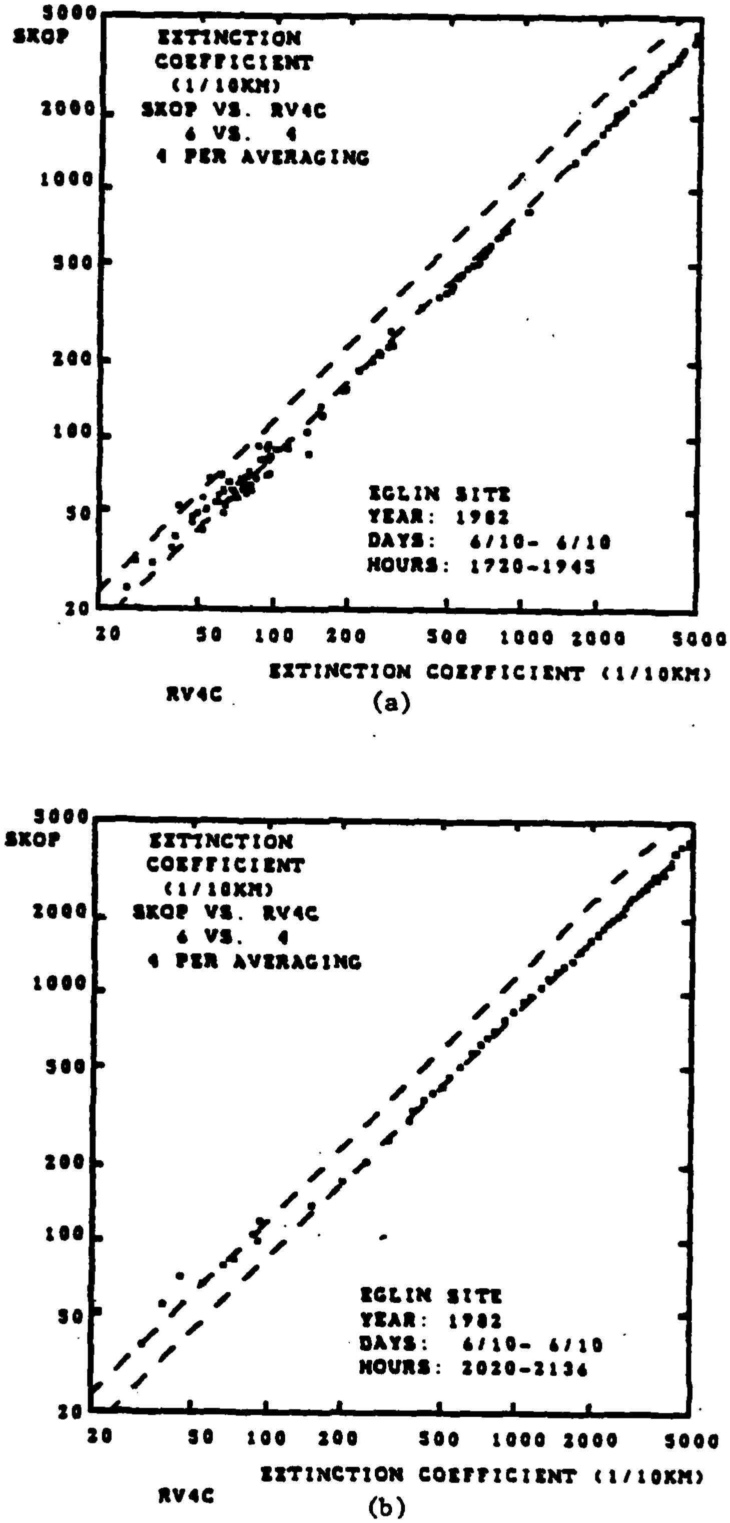
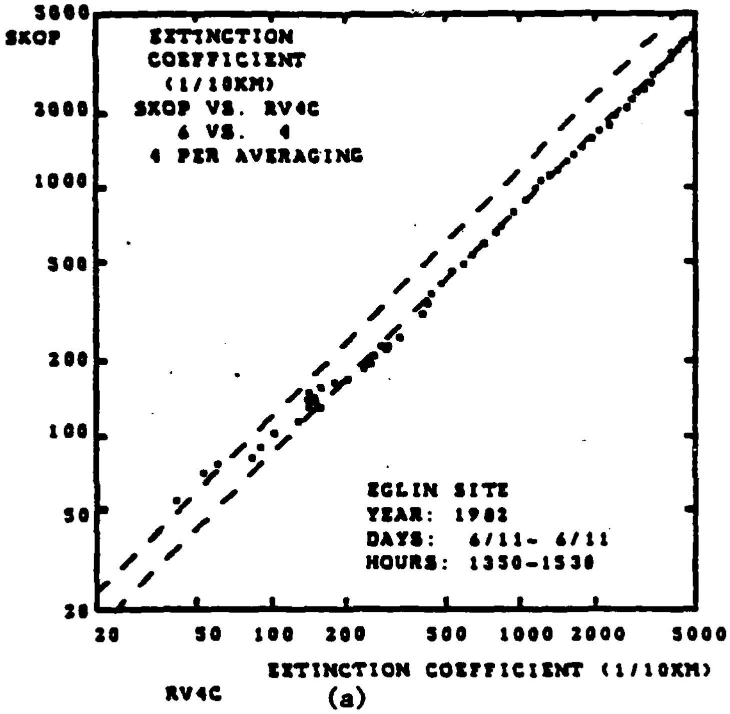
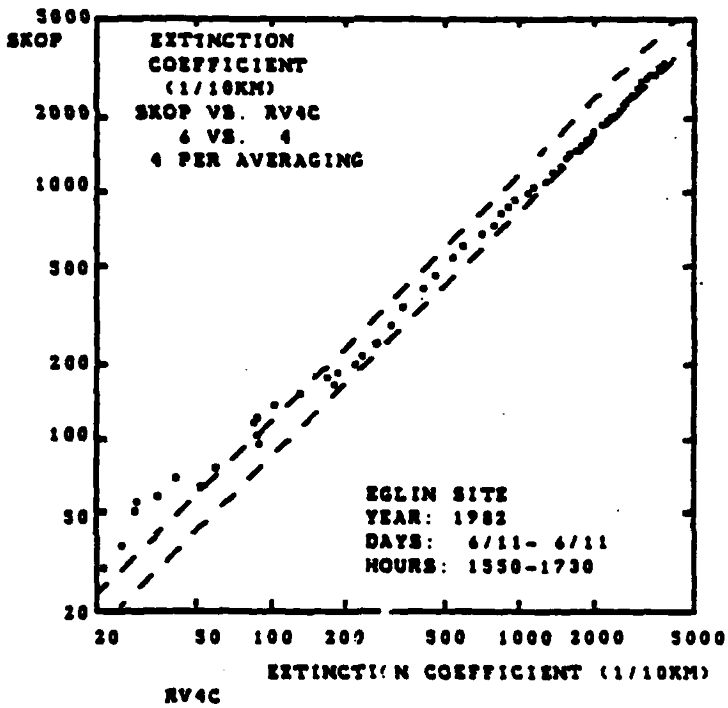


FIGURE 6-11. SKOPOGRAPH RESPONSE FOR TWO FOG EVENTS ON 6/10/82: (a) STEAM, (b) COOLING.



(a)



(b)

FIGURE 6-12. SKOPOGRAPH RESPONSE FOR TWO FOG EVENTS ON 6/11/82: (a) STEAM, (b) COOLING.

meets the pass/fail criteria for the tests and would function satisfactorily on a 45-foot baseline to cover Category IIIb RVR.

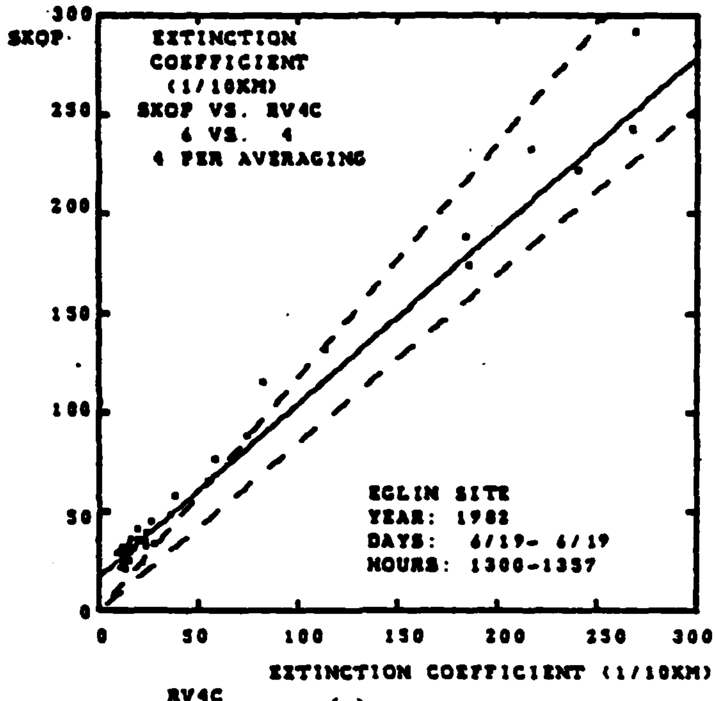
Figure 6-13 shows Skopograph data for two snow-machine fog-haze events. The results are consistent with the 15 percent correction recommended from the fog measurements.

6.1.3 Marconi MET-1

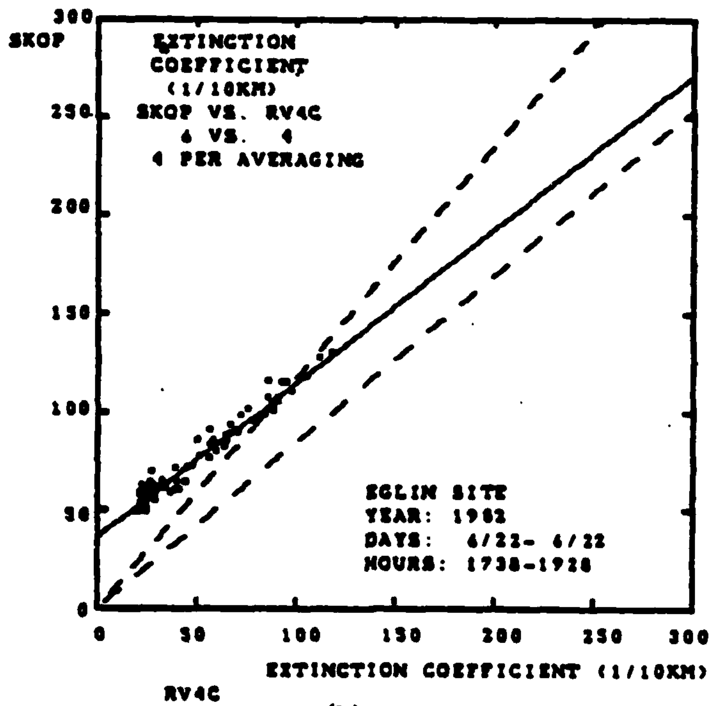
The Marconi MET-1 was not equipped to handle low temperatures. The temperature compensation was changed and/or damaged during the low temperature cycle. After that time the 100-percent calibration did not hold but gave typical offsets of 15 extinction coefficient units. The factory was requested to measure the new temperature compensation "after the fact" so that the data could be corrected if possible. No diagnosis of the effect of low temperatures has been received.

Figures 6-14 through 6-16 compare the MET-1 to the RVR calibrator for fog events. The MET-1 results are generally similar to those of the Skopograph; it indicates an extinction coefficient consistently lower than the RVR calibrator by about 10 percent. Two differences from the Skopograph are noted. 1) The points turn up above an extinction coefficient of about 4000. This rise is undoubtedly caused by saturation in the RVR calibrator (0.5 percent transmission corresponds to 4400 extinction coefficient units). Because of its much shorter baseline, the MET-1 can read to much higher values of extinction coefficient. 2) The shorter baseline of the MET-1 also produces a second difference in the MET-1 data: there is more scatter in the MET-1 data than the Skopograph data because there is less overlap with the measurement baseline of the RVR calibrator. This effect becomes more noticeable as the fog has dissipated.

The MET-1 100-percent calibration was sufficiently stable during the fog testing to satisfy the requirements for Category IIIb visibility measurements. Unfortunately, there were no fogs stable enough to check

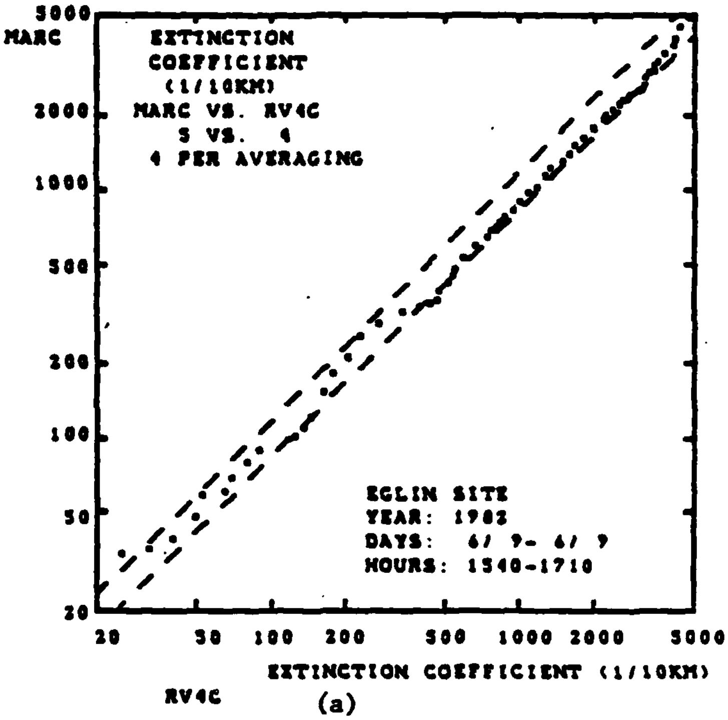


(a)

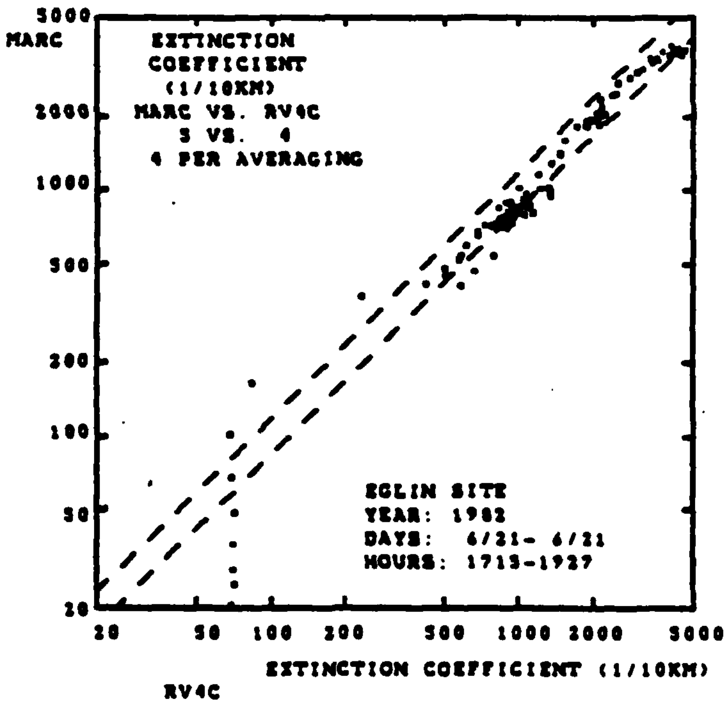


(b)

FIGURE 6-13. SKOPOGRAPH RESPONSE TO TWO FOG-HAZE EVENTS.

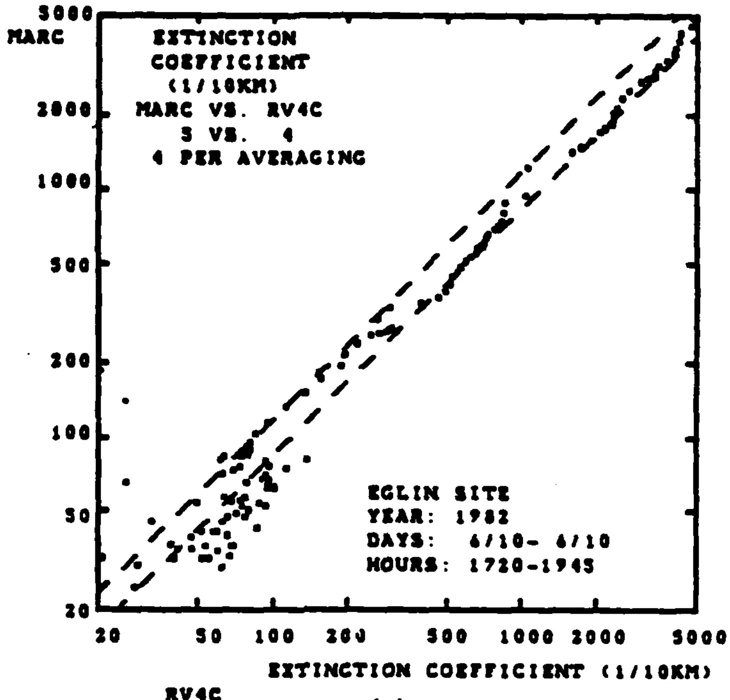


(a)

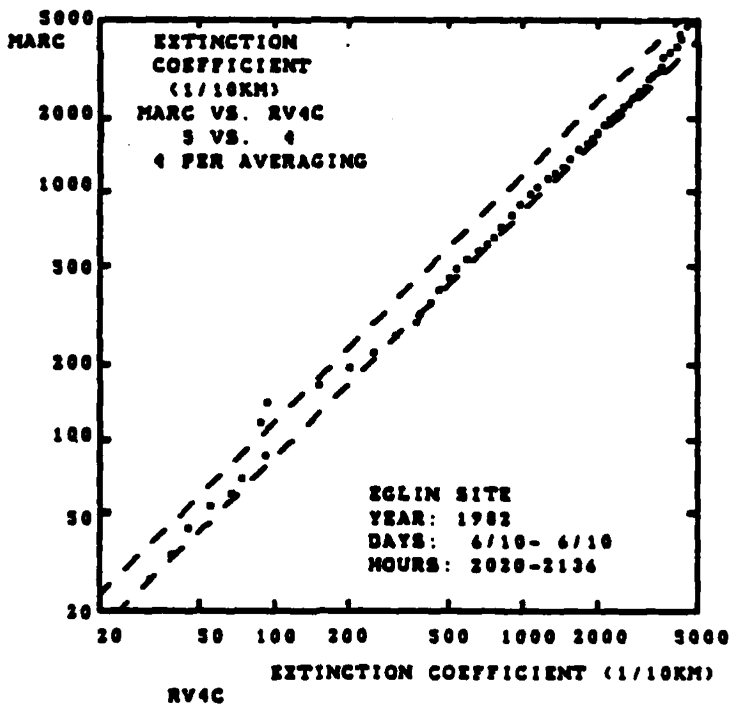


(b)

FIGURE 6-14. MARCONI RESPONSE TO TWO STEAM FOG EVENTS.

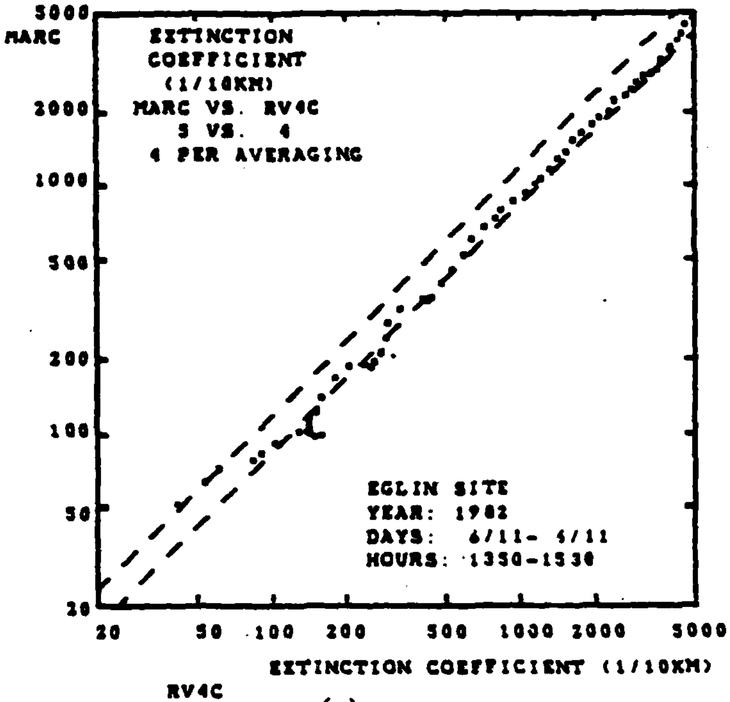


(a)

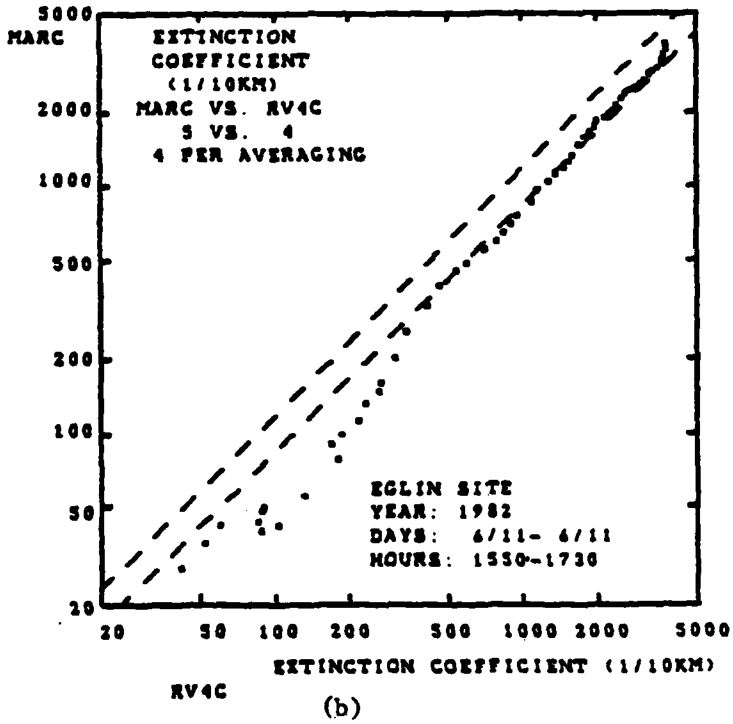


(b)

FIGURE 6-15. MARCONI MET-1 RESPONSE FOR TWO FOG EVENTS ON 6/10/82: (a) STEAM, (b) COOLING.



(a)



(b)

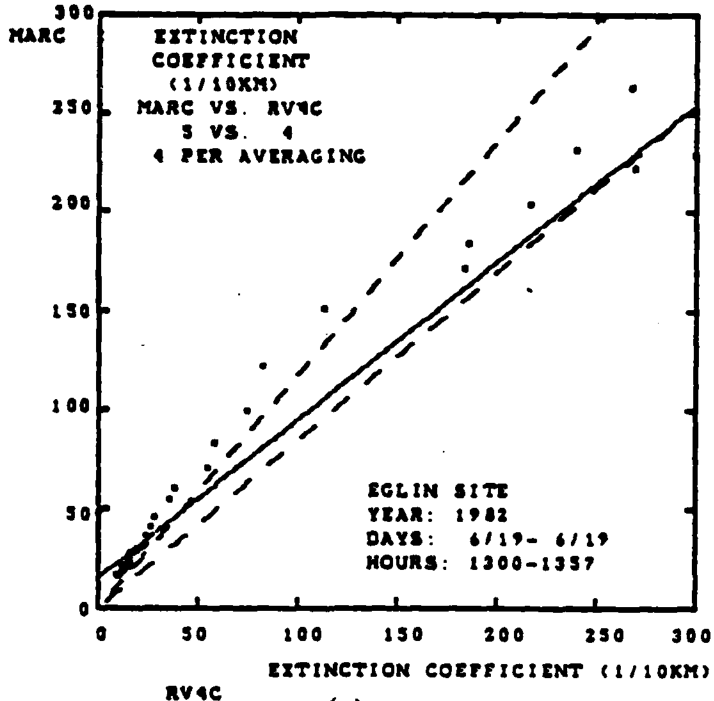
FIGURE 6-16. MARCONI MET-1 RESPONSE FOR TWO FOG EVENTS ON 6/11/82: (a) STEAM, (b) COOLING.

the response out to 6000 foot RVR (σ = 15 in daytime) until after the cold temperature cycle which destroyed the stability of the 100-percent calibration. Offsets as large as σ = 15 were observed after that time. Figure 6-17 compares the Marconi response to the RVR calibrator for two snow machine fog/haze events. The 6/19 event (6-17a) is consistent with the 10 percent correction noted for the fog events but the 6/22 event (6-17b) as well as the low extinction end of the 6/19 event shows a higher slope. Figure 6-18 compares the MET-1 to the average of the two EG&G 207 sensors for all the fog/haze events. The divergence of the various lines is caused by the shifts in 100-percent calibration.

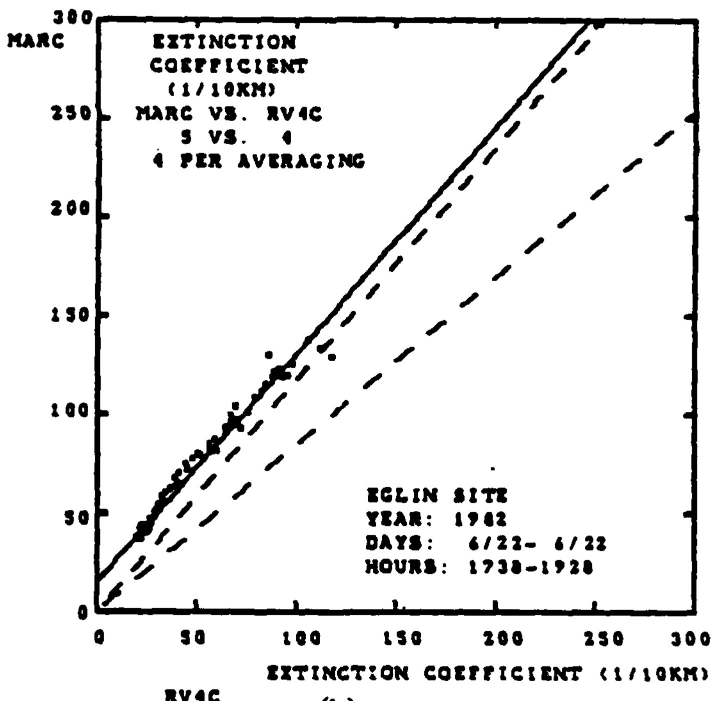
In fog the Marconi measurements appear to require a boost of 10 percent to achieve an accurate calibration. It then easily meets the pass/fail criteria for Category IIIb conditions. This correction may be due to forward-scattering. On the other hand, the haze measurements indicate that a reduction of about 10 percent is needed. The latter effect has been noted in U.K. field testing and has been attributed to haze particles filling the hoods which protect the optical windows. There is no reason to expect such small particles to settle out. Of course, the same argument applies to the RVR calibrator hoods, so that the exact baselines become uncertain during the transition from fog to haze.

6.2 FORWARD-SCATTER METERS

The 40-foot baseline RVR calibrator (Figure 5-4) suffers from two deficiencies as a standard sensor for evaluating forward-scatter meters. First, it does not have the calibration accuracy and resolution to measure small extinction coefficients (99.5 percent transmission corresponds to σ = 4 units). Second, it samples a significantly different portion of the chamber than the forward-scatter meters which sample a very small volume. Because of these two deficiencies, the EG&G 207 forward-scatter meters will also be used as a secondary standard of comparison for the forward-scatter meters. As shown in Figure 5-2, the EG&G 207 sensors were located on either end of a line of forward-scatter meters. The extinction coefficient at each sensor's location is

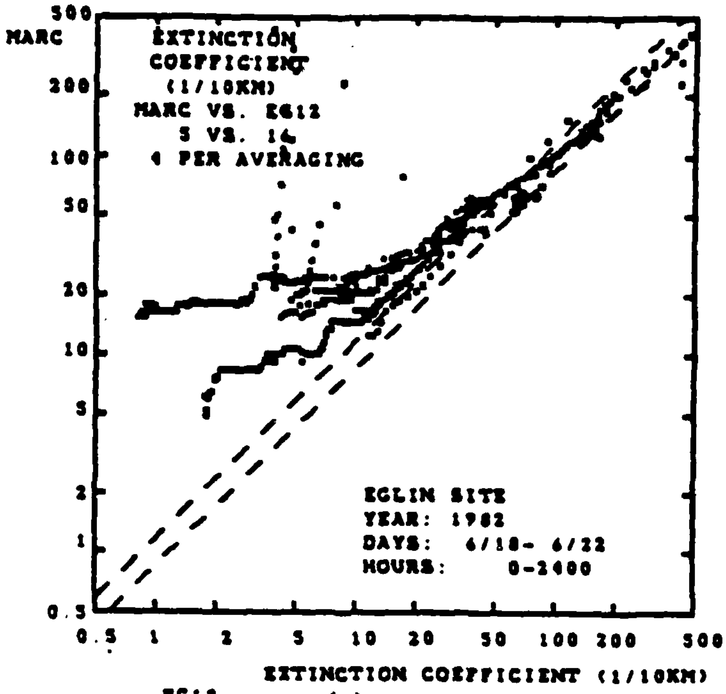


(a)

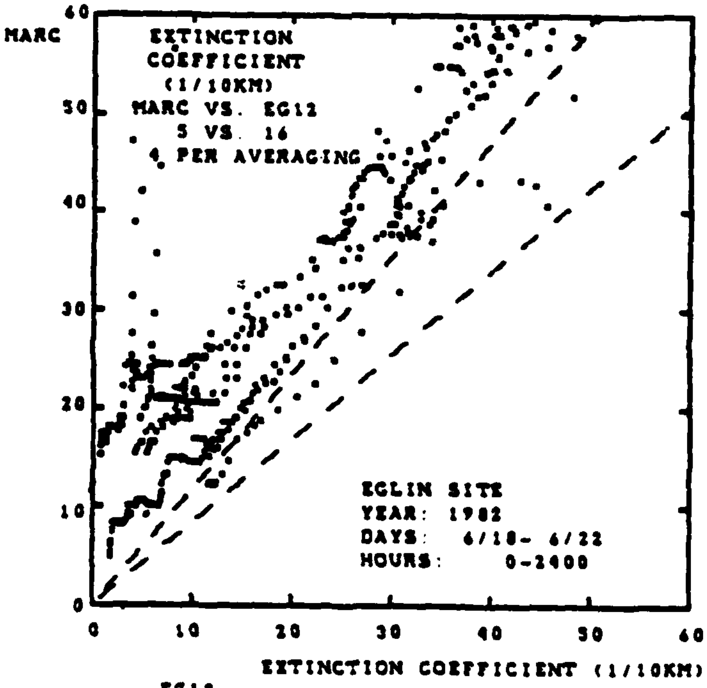


(b)

FIGURE 6-17. MARCONI MET-1 RESPONSE FOR TWO FOG-HAZE EVENTS.



(a)



(b)

FIGURE 6-18. MARCONI MET-1 RESPONSE TO ALL FOG-HAZE EVENTS.

obtained by linear interpolation between the measurements of the two EG&G sensors. These values are termed "EGGE" and "EGGF" for the Enertech EV-1000 and Fumosens III respectively. The average of both sensors "EG12" is used for the HSS VR-301 as well as for comparisons with the transmissometers. The nearest EG&G 207 is compared to each FOG-15 ("EGG1" with "FOG2" and "EGG2" with "FOG1"). Because they were closer to the RVR calibrator baseline the FOG-15 measurements gave better correlation with the RVR calibrator ("RV4C") measurements than those of the other forward-scatter meters. Comparisons of the two EG&G 207's with each other and of their average with the 40-foot RVR calibrator are shown in Figures 5-11 through 5-22.

One of the primary limitations of forward-scatter meters is the stability of the zero response which can be affected by sunlight, radio frequency interference and electronic drift. The chamber test results have little bearing on these practical problems.

6.2.1 EG&G 207

Both EG&G 207 forward-scatters meters showed reasonable agreement with the RVR calibrator during dense fogs which were uniform. Figures 6-19 through 6-21 show how each EG&G 207 unit compared with the 40-foot RVR calibrator for four steam and two cooling fog events. In general both units measure within 15 percent of the RVR calibrator above 500 extinction units for the steam fogs, which tend to be more uniform. The one exception (Figure 6-19c) is for EGG2 (S/N 003) which read somewhat higher. Figure 5-16c shows that this steam fog event showed more difference between the two EG&G sensors than the other steam fog events (Figures 5-13c through 5-15c). Figures 5-13d through 5-16d and 5-18d through 5-19d also compare the average of the two EG&G 207 sensors (EG12) with the RVR calibrator. Averaging the two sensors improves the agreement with the calibrator.

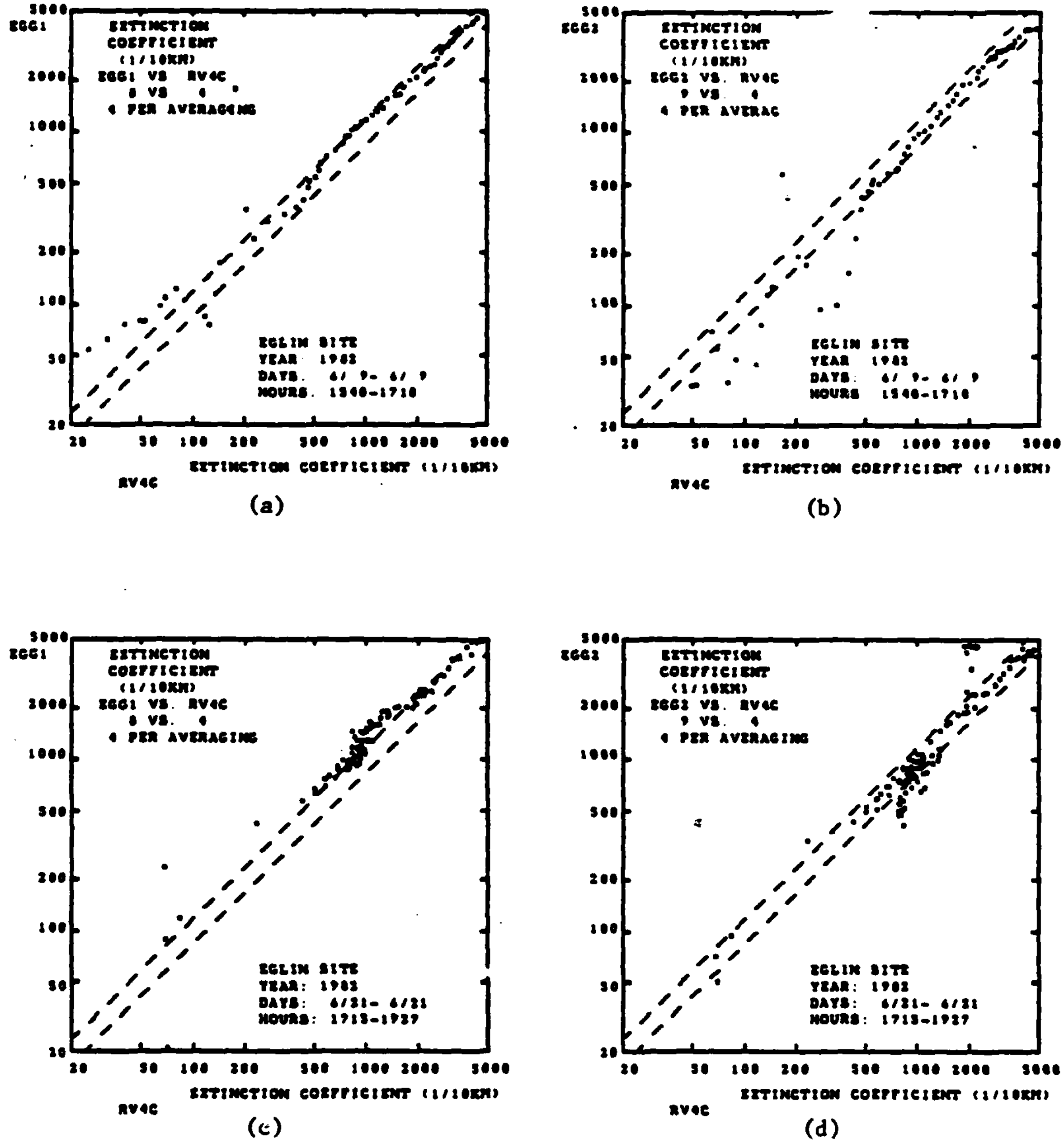


FIGURE 6-19. EG&G 207 RESPONSE FOR TWO STEAM FOG EVENTS.

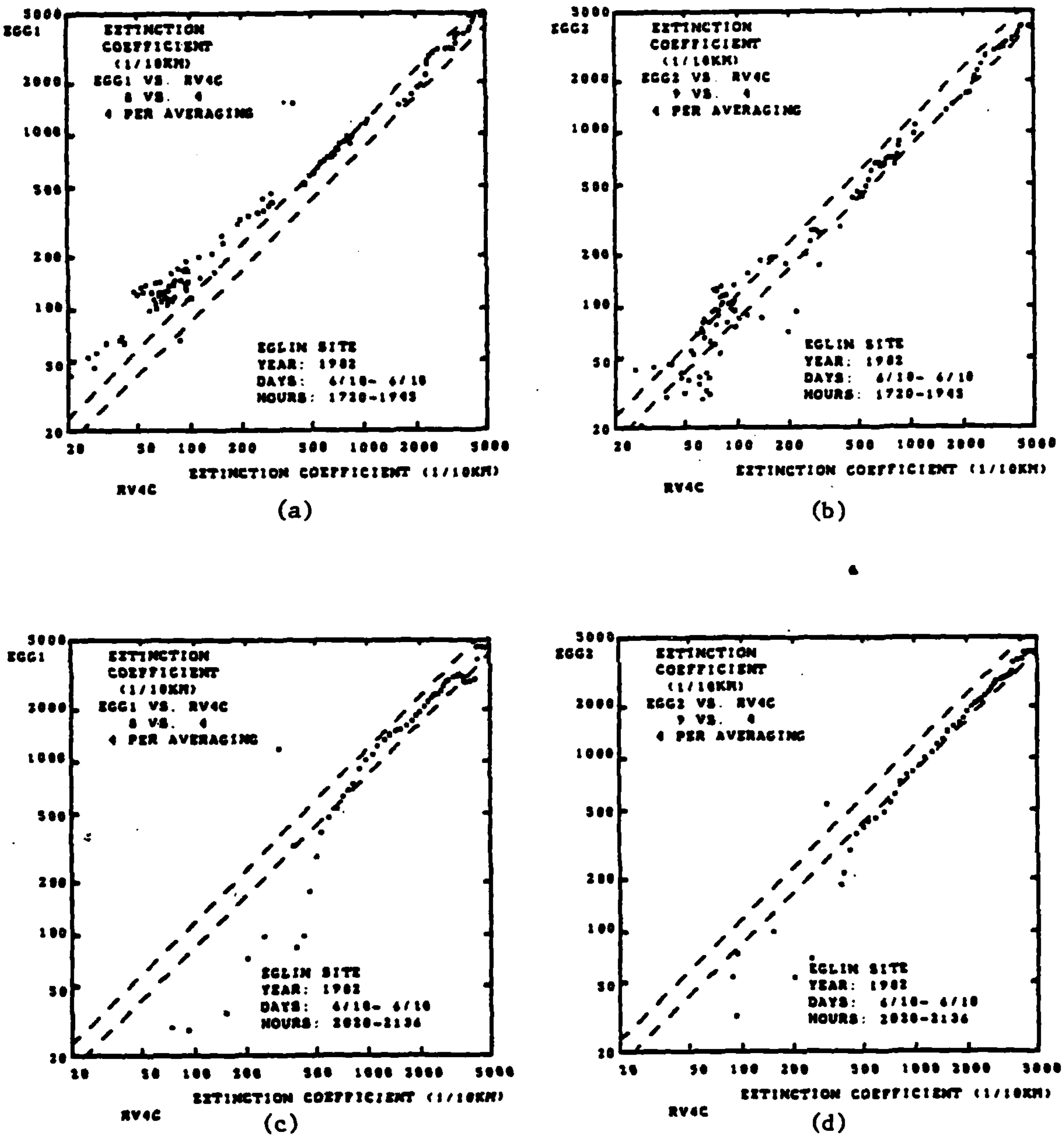


FIGURE 6-20. EG&G 207 RESPONSE FOR TWO FOG EVENTS ON 6/10/82: (a),(b) STEAM: (c), (d) COOLING.

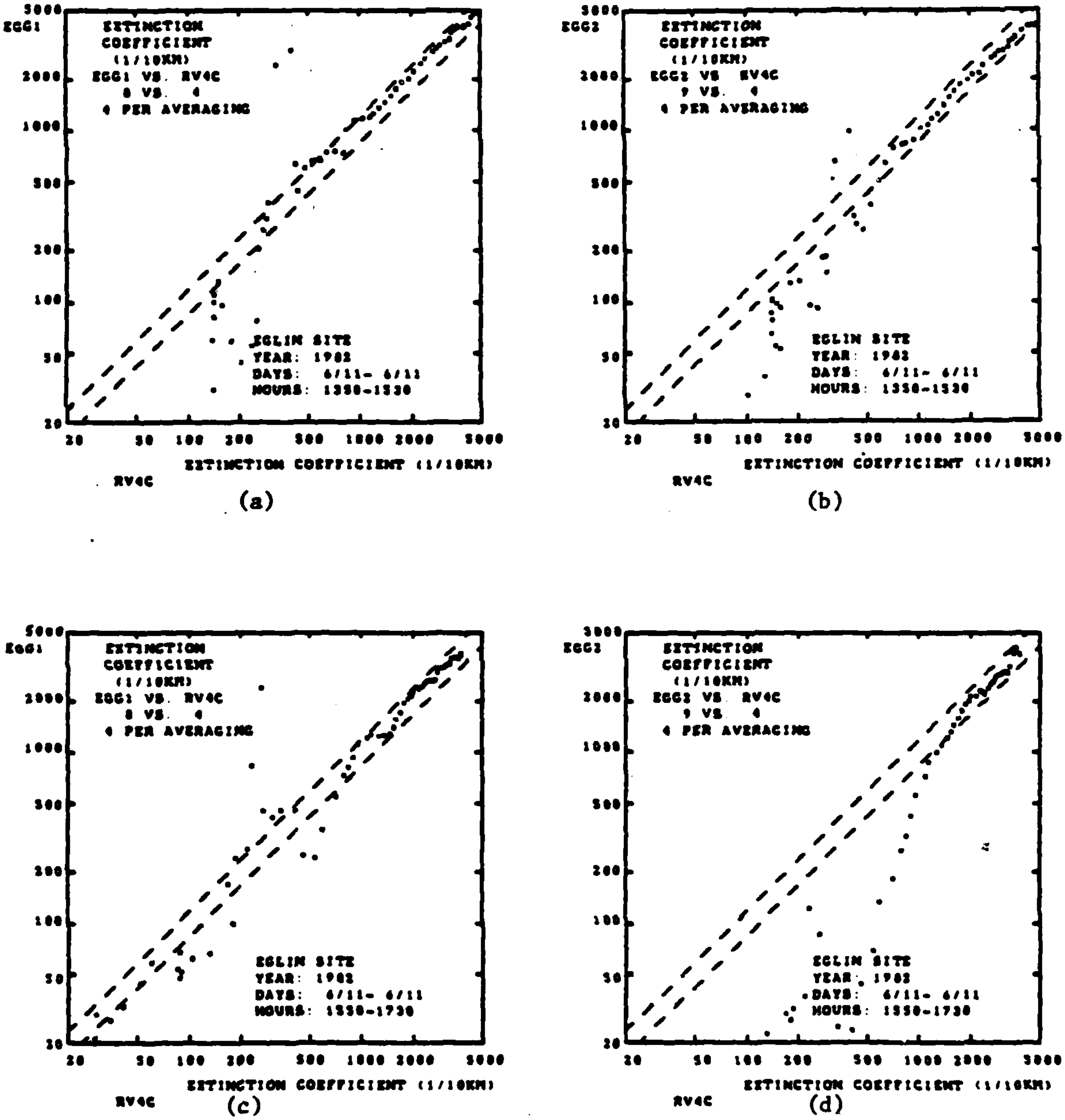


FIGURE 6-21. EG&G 207 RESPONSE FOR TWO FOG EVENTS ON 6/11/82: (a), (b) STEAM: (c), (d) COOLING.

The agreement of the EG&G 207 sensors with the RVR calibrator was less accurate during the snow-machine fog/haze events. Figure 5-23d shows a 30 percent higher measurement (σ = 40 to 100) for the average of the two EG&G 207 sensors than for the calibrator. The two EG&G units agreed with each other to better than 20 percent. This systematic disagreement was much larger during the decay period (Figure 5-23d) then during the build up (Figure 5-22d) even though the systematic disagreement between the two units is comparable for both time periods. Two effects probably contribute to the haze discrepancy. First, in haze the calibrator hoods will be filled with haze particles so that the resulting extinction coefficient measurements are about 10 percent higher. This effect would be smaller during build up since large droplets were present at that time. Second, the EG&G 207 sensor has been observed in field tests to have a higher response to haze than to fog. This effect results in a nonlinear response to extinction coefficient in comparisons with a transmissometer. This nonlinear response must be kept in mind when the EG&G 207 is used as a standard of comparison for the other forward-scatter meters in the following sections. If the EG&G 207 haze response relative to the calibrator is taken as 1.30, then the haze response of the other sensors relative to the EG&G 207 must be divided by 1.30 to give the absolute haze calibration.

The EG&G 207 sensor shows good correlations with long-baseline transmissometers in field tests but has proved to be difficult to maintain as a operational sensor. It thus can play a role in the test environment but cannot be considered as an operational sensor.

6.2.2 FOG-15

Figures 6-22 through 6-27 show the FOG-15 response for four steam and two cooling fog events. In general the FOG-15 measurements correlate better with the RVR calibrator than with the nearest EG&G 207 sensor, presumably because they were located very close to the calibrator baseline (Figure 5-2). The agreement with the calibrator is generally

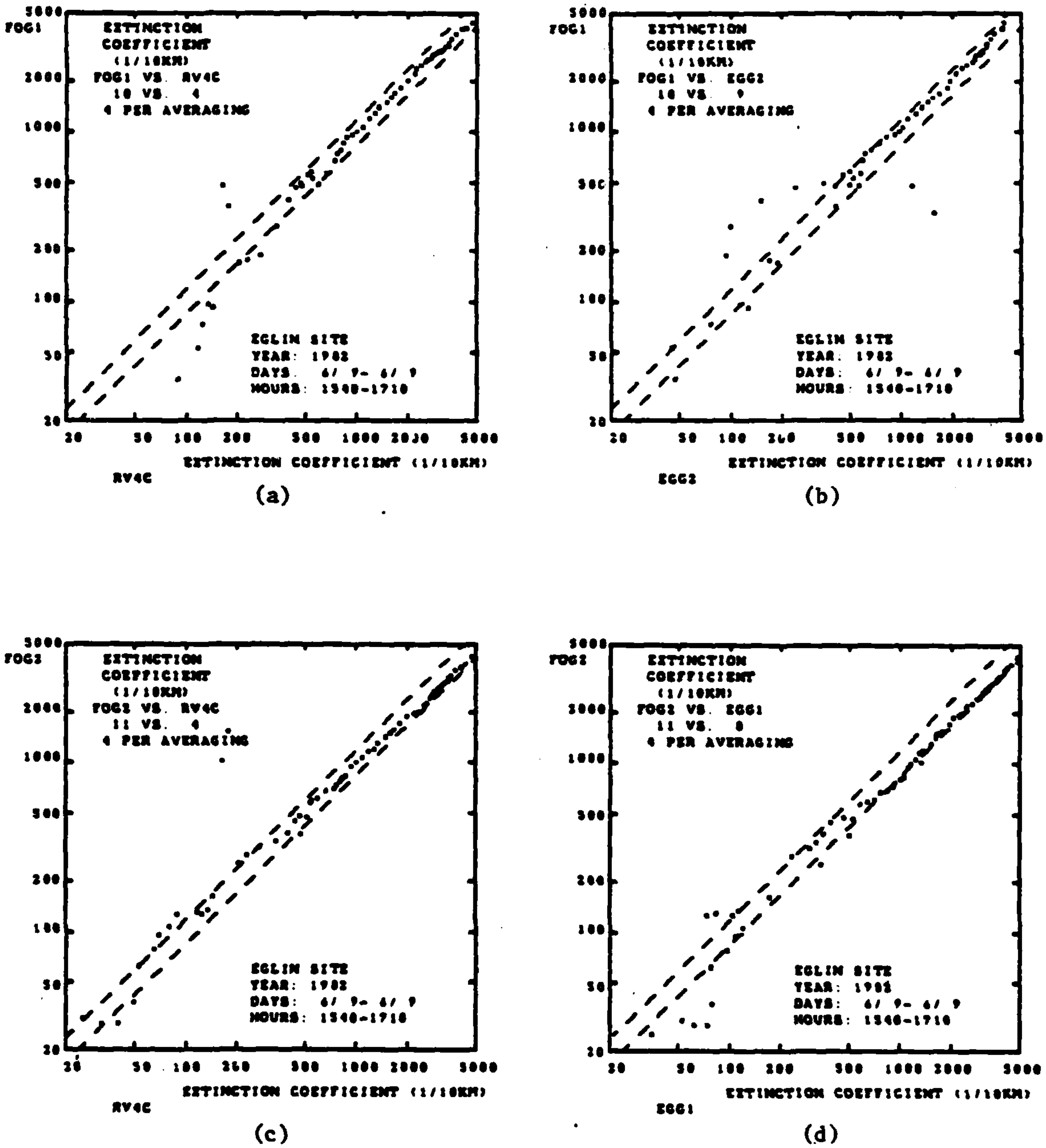


FIGURE 6-22. FOG-15 RESPONSE FOR THE STEAM FOG EVENT ON 6/9/82.

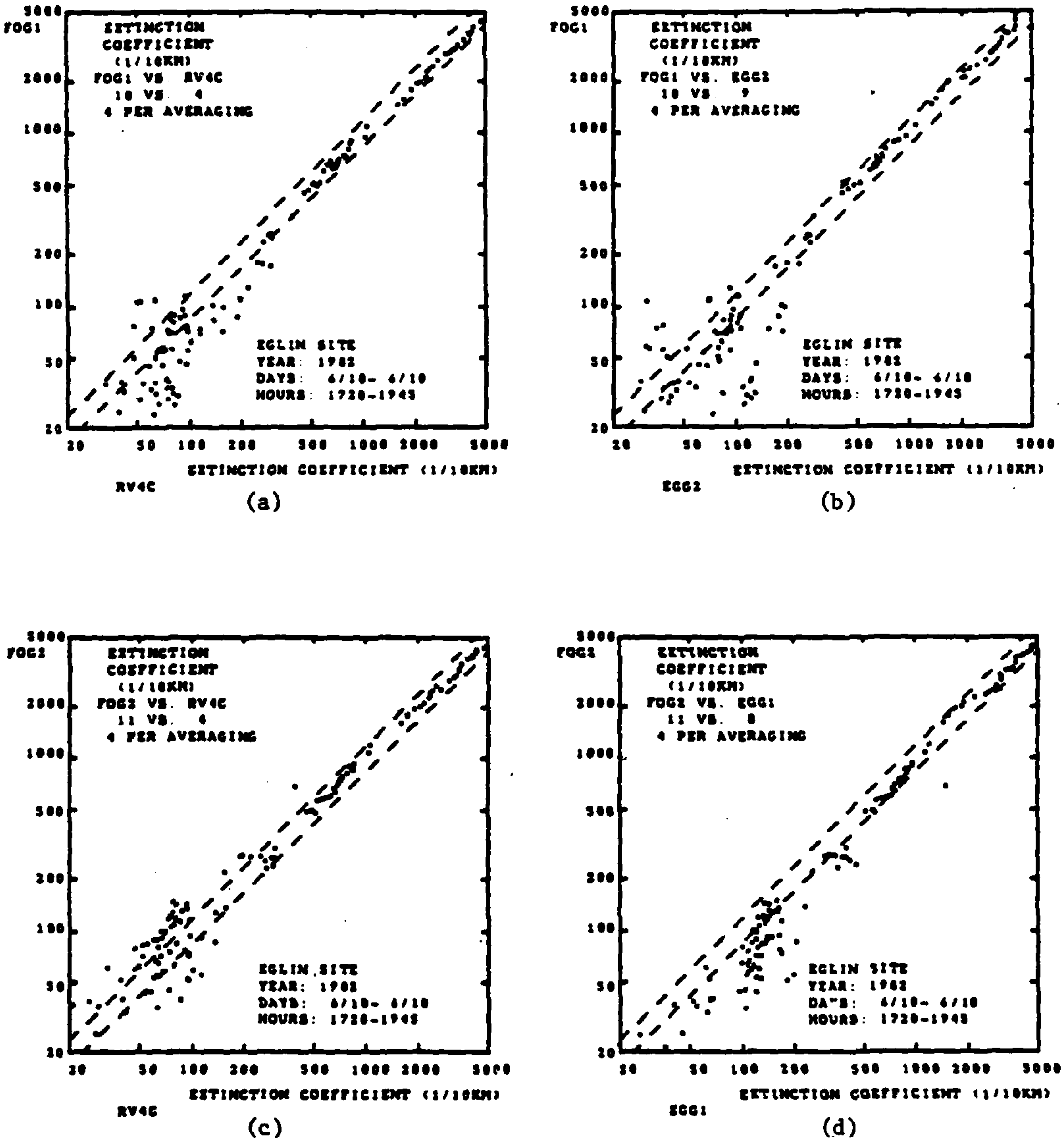


FIGURE 6-23. FOG-15 RESPONSE FOR THE STEAM FOG EVENT ON 6/10/82.

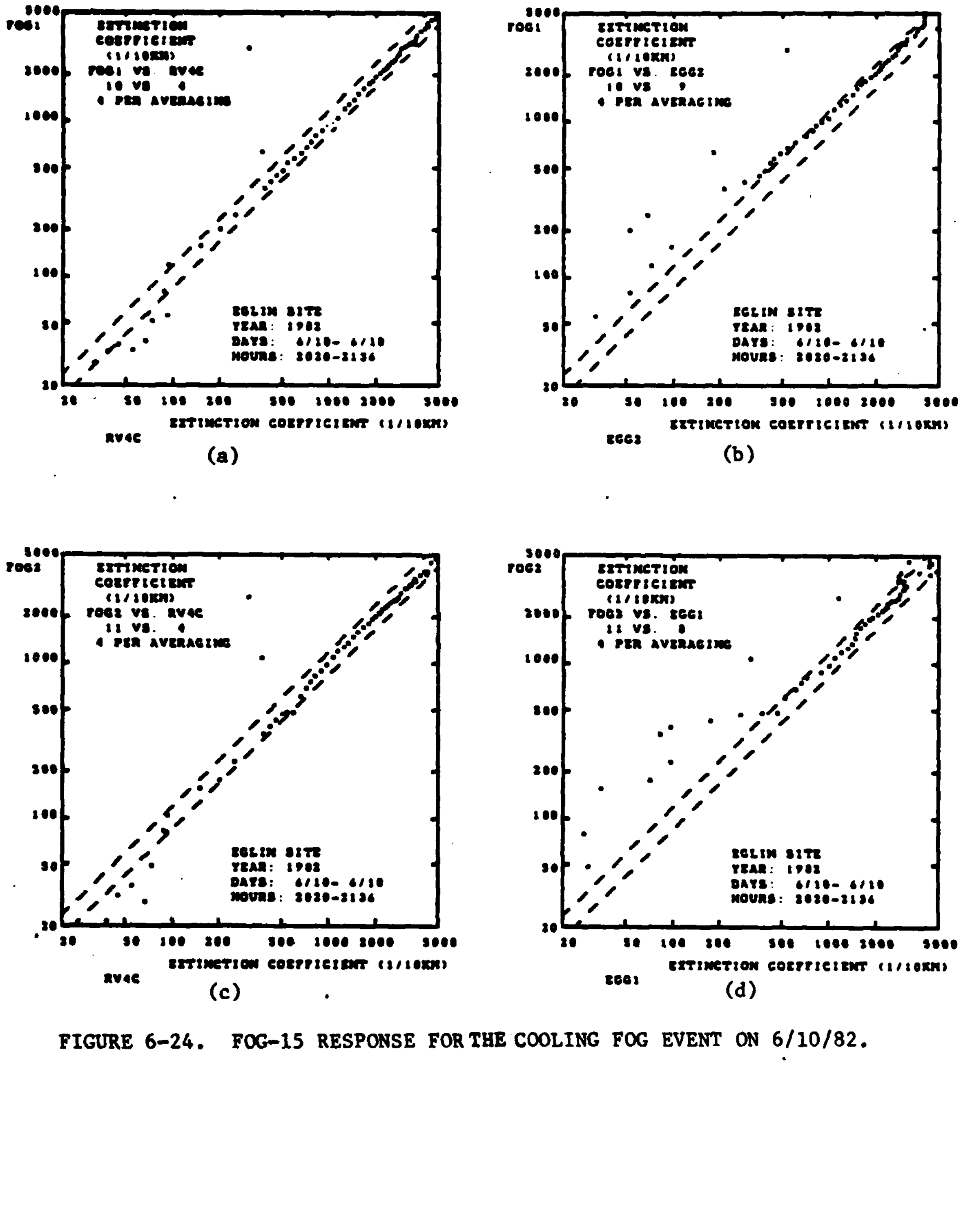
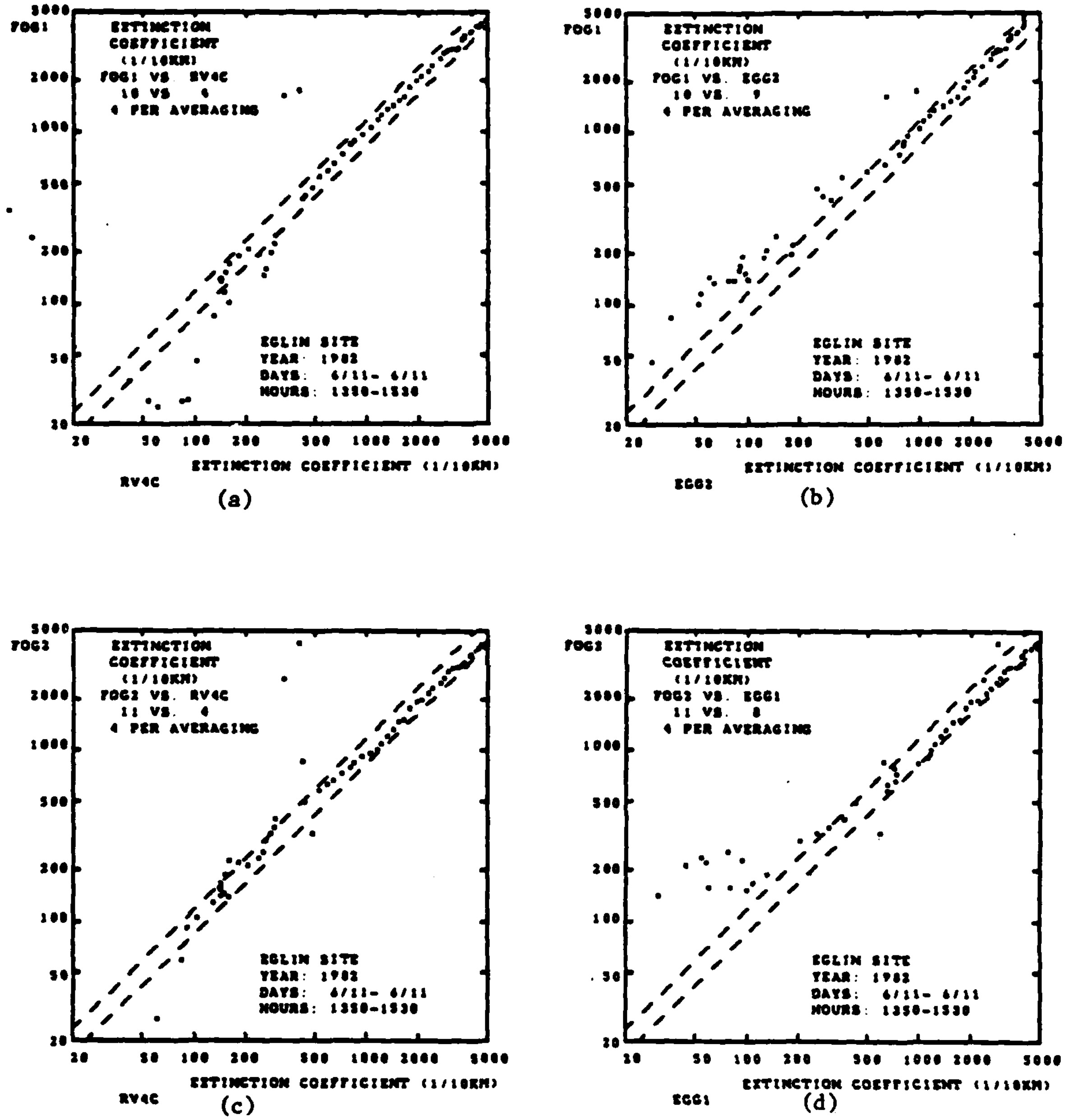


FIGURE 6-24. FOG-15 RESPONSE FOR THE COOLING FOG EVENT ON 6/10/82.



(a)

(b)

(c)

(d)

FIGURE 6-25. FOG-15 RESPONSE FOR THE STEAM FOG EVENT ON 6/11/82.

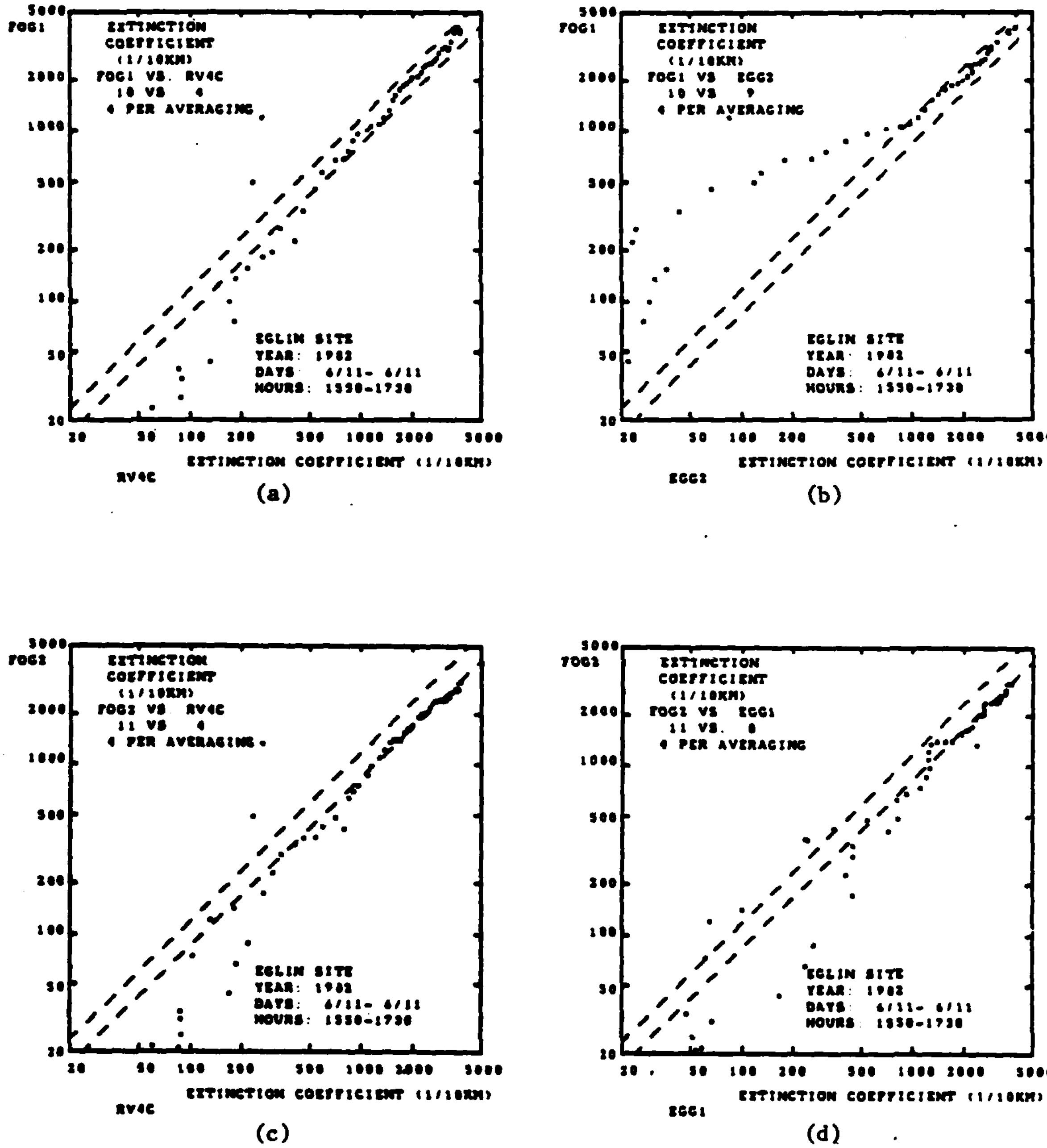


FIGURE 6-26. FOG-15 RESPONSE FOR THE COOLING FOG EVENT ON 6/10/82.

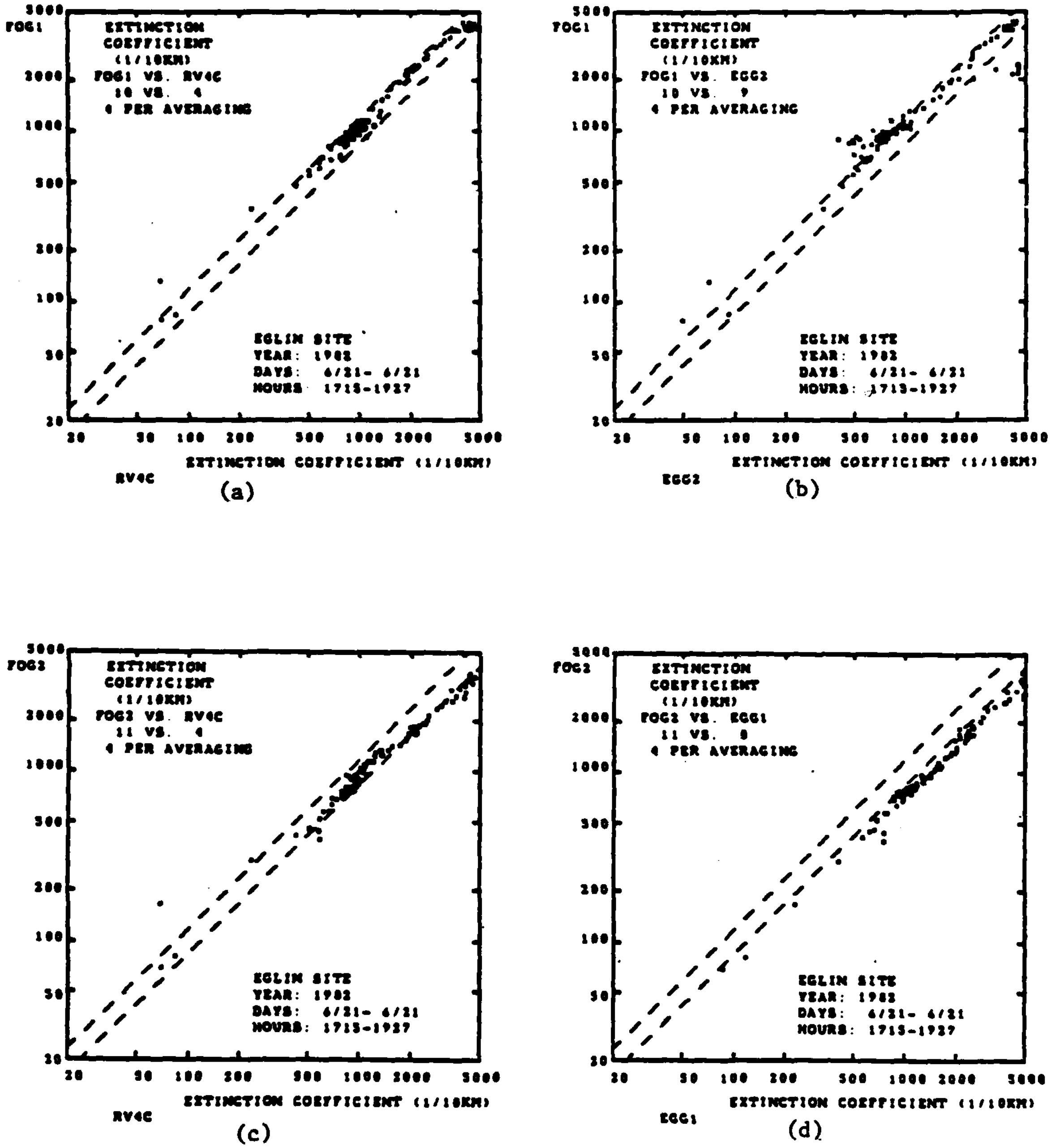


FIGURE 6-27. FOG-15 RESPONSE FOR THE STEAM FOG EVENT ON 6/21/82.

within the 15 percent limits of the pass/fail criterion above σ = 500. The possible saturation for FOG2 at high extinction coefficients, mentioned in Section 5.7.2, may be indicated in some of the plots (6-22c, 6-25c, 6-26c, and 6-27c). In these same Figures FOG2 also reads low compared to EGG1.

The response of the FOG-15 to snow-machine fog-haze events is shown in Figure 6-28. Again there is a tendancy for FOG2 to read low at high extinction coefficients, expecially after the heat cycle. The observed correlation between the FOG-15 and the EG&G 207 sensors is remarkably good even down to very low extinction coefficients, where there is evidence for small errors in the assigned zero offsets of the sensors.

The FOG-15 thus appears to be a promising candidate sensor. However, the climatic chamber measurements were plagued with calibration problems and were performed with units having the nonlinear "soft" clipping circuit; therefore, they do not constitute a definitive evaluation of the sensors' true performance capabilities.

6.2.3 HSS VR-301

Figures 6-29 through 6-31 show the VR-301 response for the four steam and two cooling fog events. The VR-301 response is consistent with 15-percent accuracy above σ = 500 but the calibration constant appears to be low by about 10 percent.

Figure 6-32 shows the VR-301 response to the snow-machine fog-haze events. The data in Figure 6-32a show considerable spread below σ =10, presumably because of the contact potential offsets which developed at this period of the tests. The other three plots in Figure 6-32 show linear plots for different portions of the data combined in 6-32a. Each event shows up as a straight line segment on these plots with an offset corresponding to the exact contact potential at the time of the event. Because of these offsets a determination of the VR-103

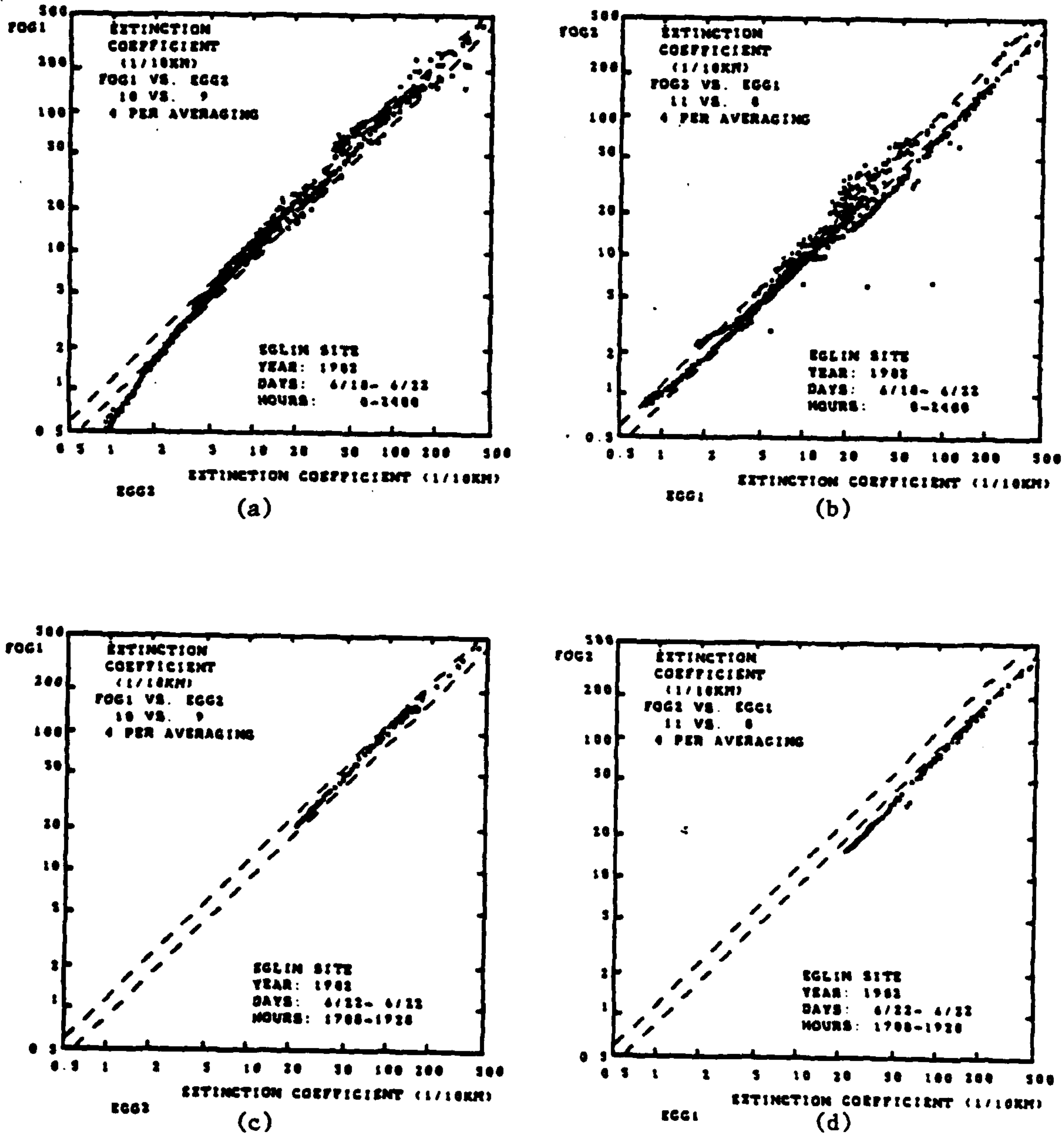


FIGURE 6-28. FOG-15 RESPONSE TO FOG/HAZE EVENTS: (a), (b) ALL EVENTS: (c),(d) 6/22 EVENT.

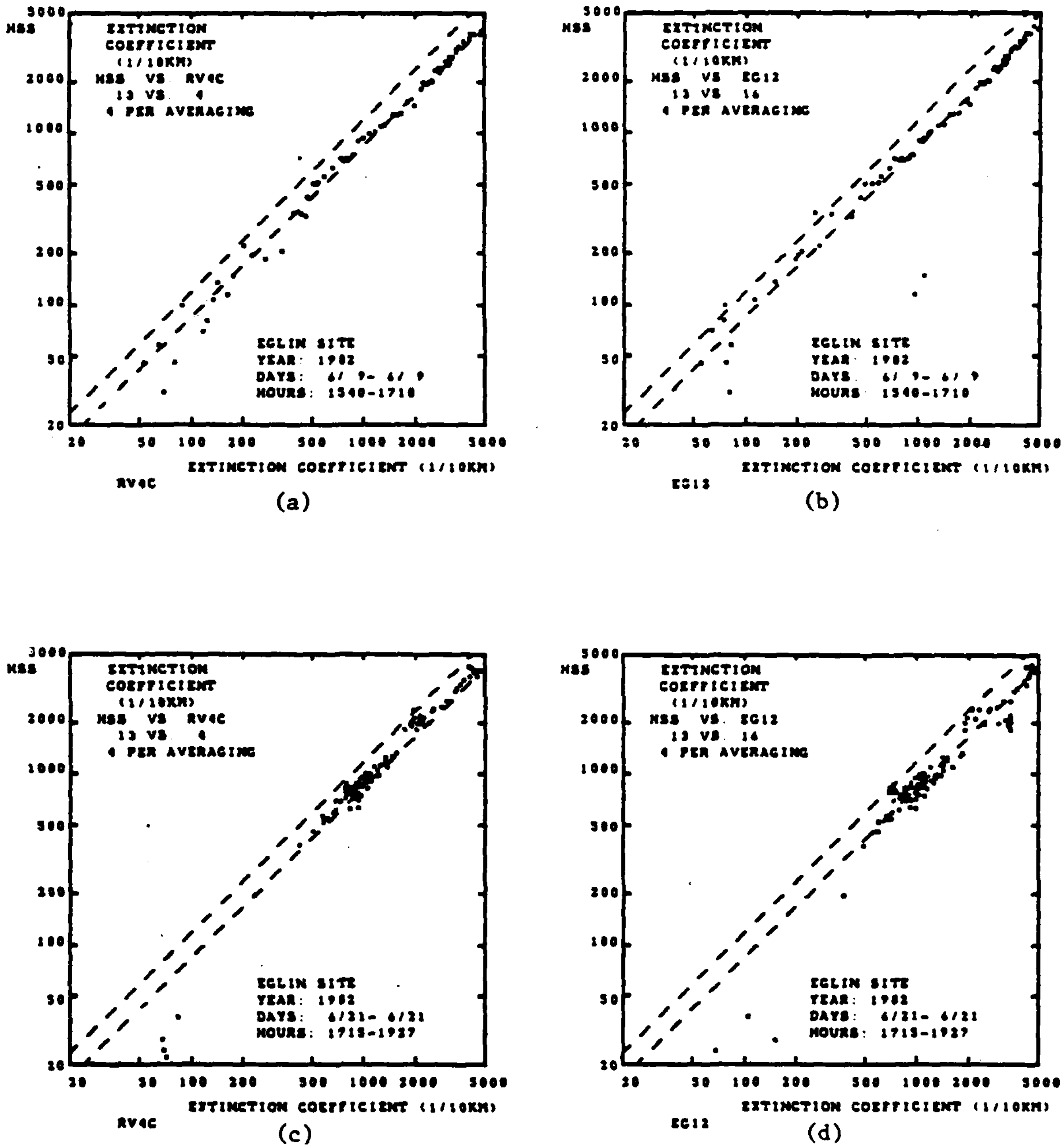


FIGURE 6-29. HSS VR-301 RESPONSE FOR TWO STEAM FOG EVENTS.

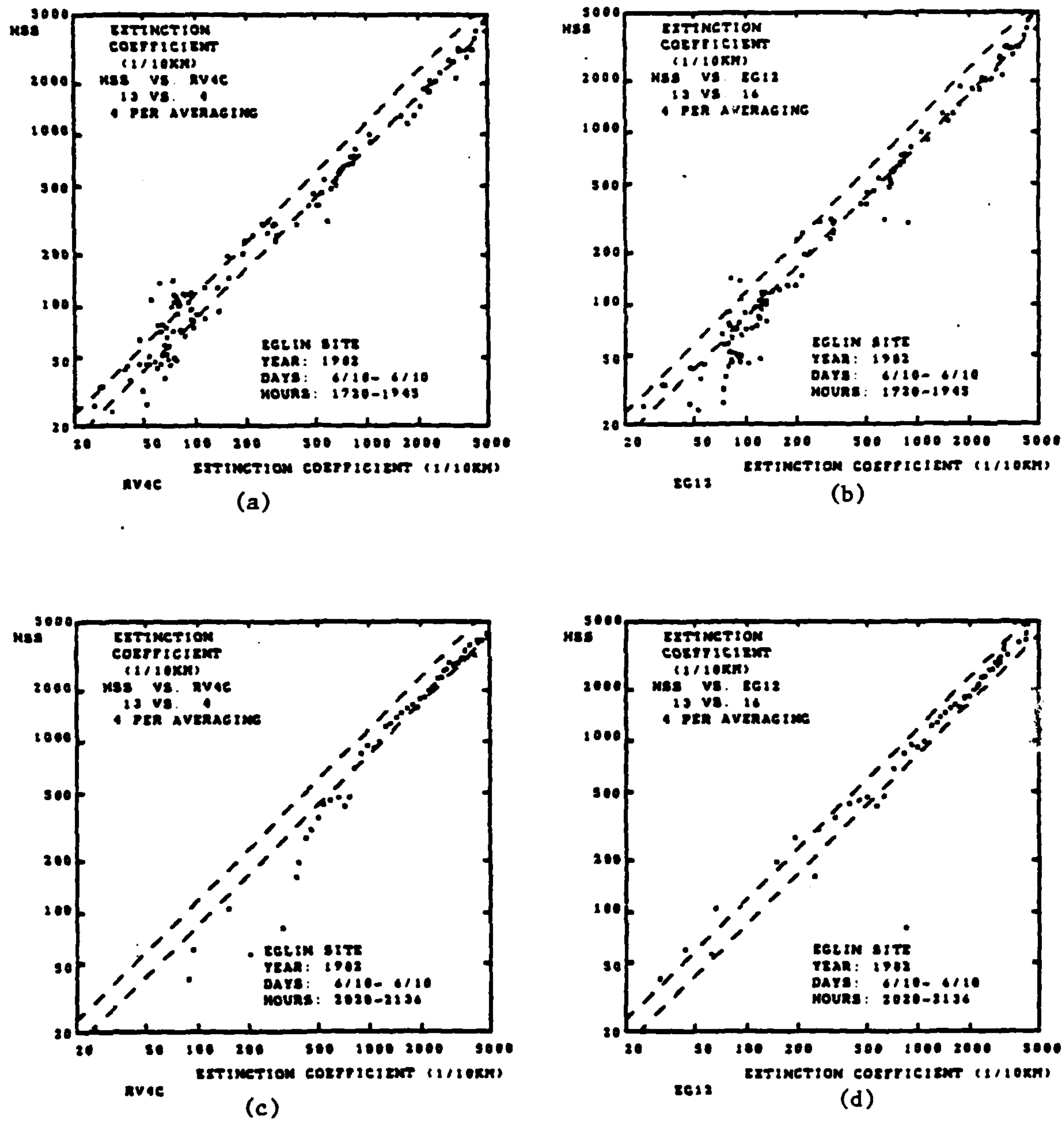
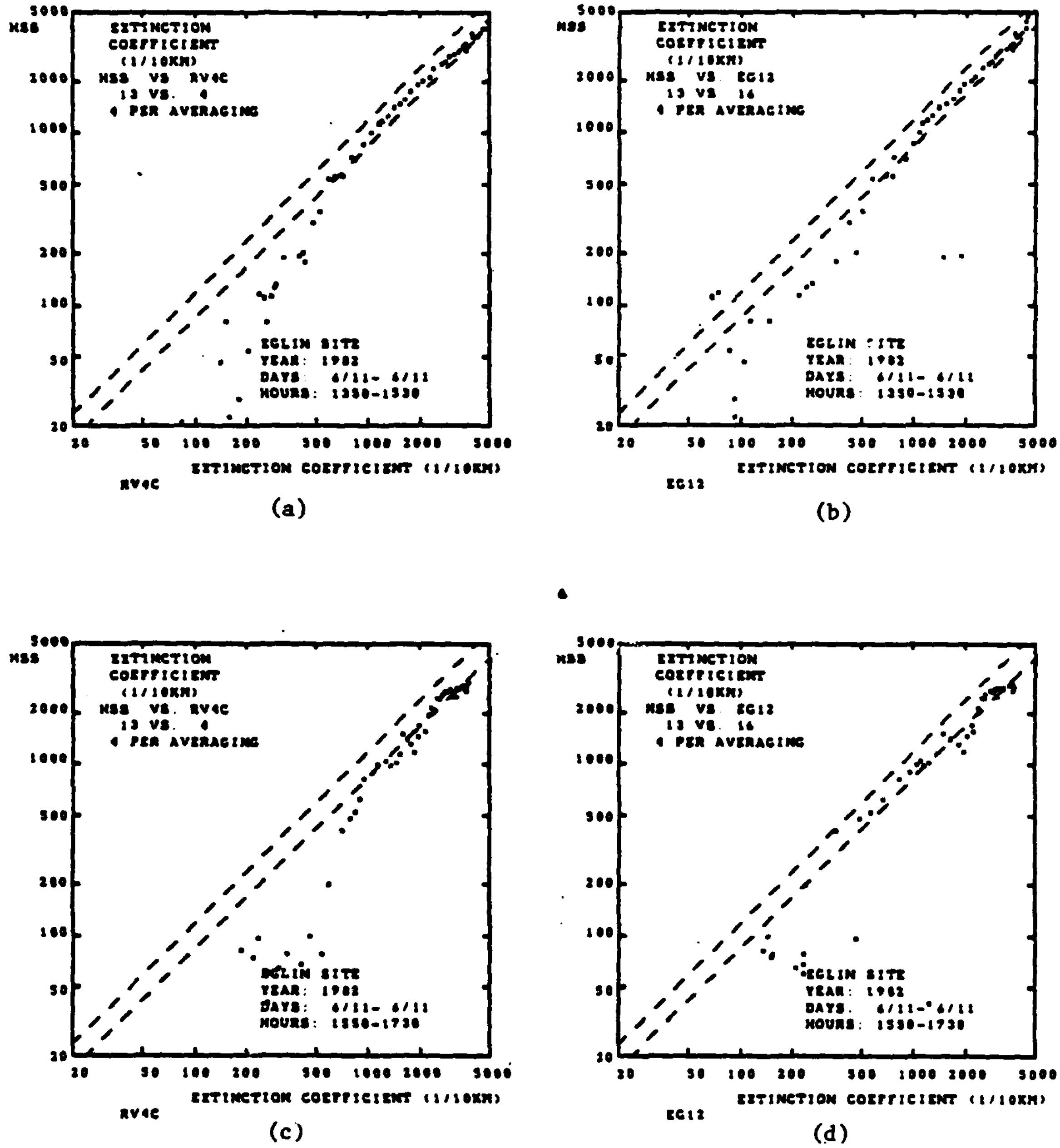


FIGURE 6-30. HSS VR-301 RESPONSE FOR THE TWO FOG EVENTS ON 6/10/82: (a), (b) STEAM: (c), (d) COOLING.



(a) (b) (c) (d)

FIGURE 6-31. HSS VR-301 RESPONSE FOR THE TWO FOG EVENTS ON 6/11/82: (a), (b) STEAM: (c), (d) COOLING.

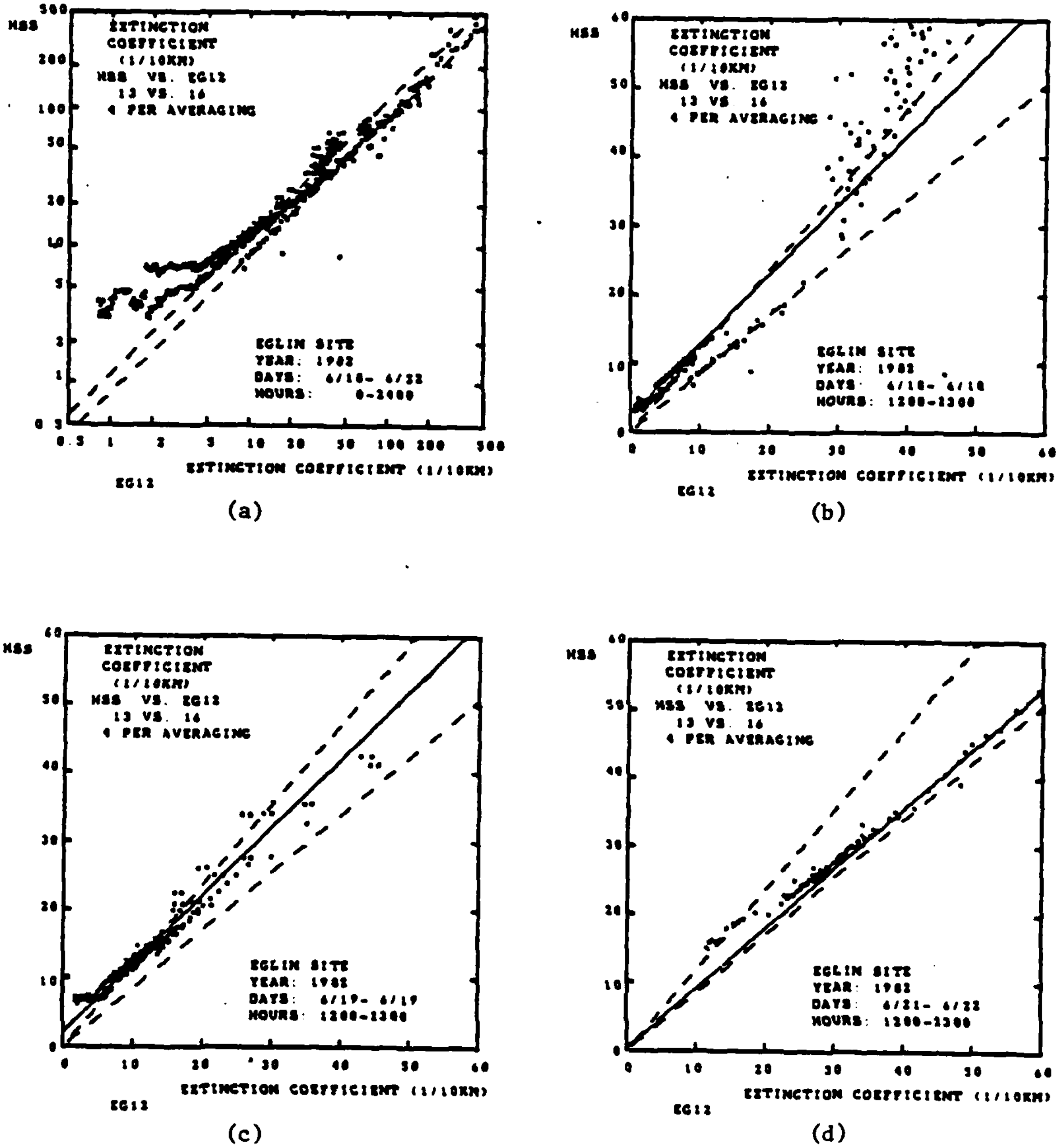


FIGURE 6-32. HSS VR-301 RESPONSE TO FOG/HAZE EVENTS: (a) ALL EVENTS, (b), (c), (d) SELECTED TIME PERIODS.

performance at high visibility cannot be made. The correlation with the EG&G 207 sensors is good for each event, thus indicating that the sensor may have satisfactory performance. The slope response of the VR-301 appears to be about 10 percent low compared to the EG&G 207 for the best haze event on 6/22.

6.2.4 Fumosens III

The Fumosens III saturated at about 1.5 mA output current (σ = 150 according to the nominal calibration). The range was increased to about σ = 3000 by covering the receiver with neutral density filters (approximately N.D. = 1.3). The measurements with the filters present were multiplied by a factor of 20.

Figures 6-33 through 6-35 show the Fumosens III response for the four steam and two cooling fog events. The saturation at σ = 3000 is evident in the plots. For two of the steam fog events (6/10, 6/11) the filters were removed in the middle of the event (a vertical line separates the two regions) and the sensor again saturates at σ = 150 until the fog density decays to a lower value. The Fumosens III would give acceptable response between σ = 500 and σ = 2000 with the filters in place and a 10 percent reduction in the calibration constant C.

Figure 6-36 shows the Fumosens III respone to the snow-machine fog-haze events. The calibration constant (without filters) appears to be about 30 percent low relative to the EG&G 207. The Fumosens III would thus be expected to agree well with the RVR calibrator in haze. The sensor response is noisier than the FOG-15 and the VR-301. The curvature in Figure 6-36a is due to a small offset error (about σ =1.5) in the Fumosens III measurements. Figure 6-36b shows that the relationship between the Fumosens III response and the EG&G 207 response is linear at low extinction coefficients.

The lack of a reference calibrator makes the Fumosens III unusable as an operational instrument. The interpretation of the chamber test results is only qualitative because of this lack.

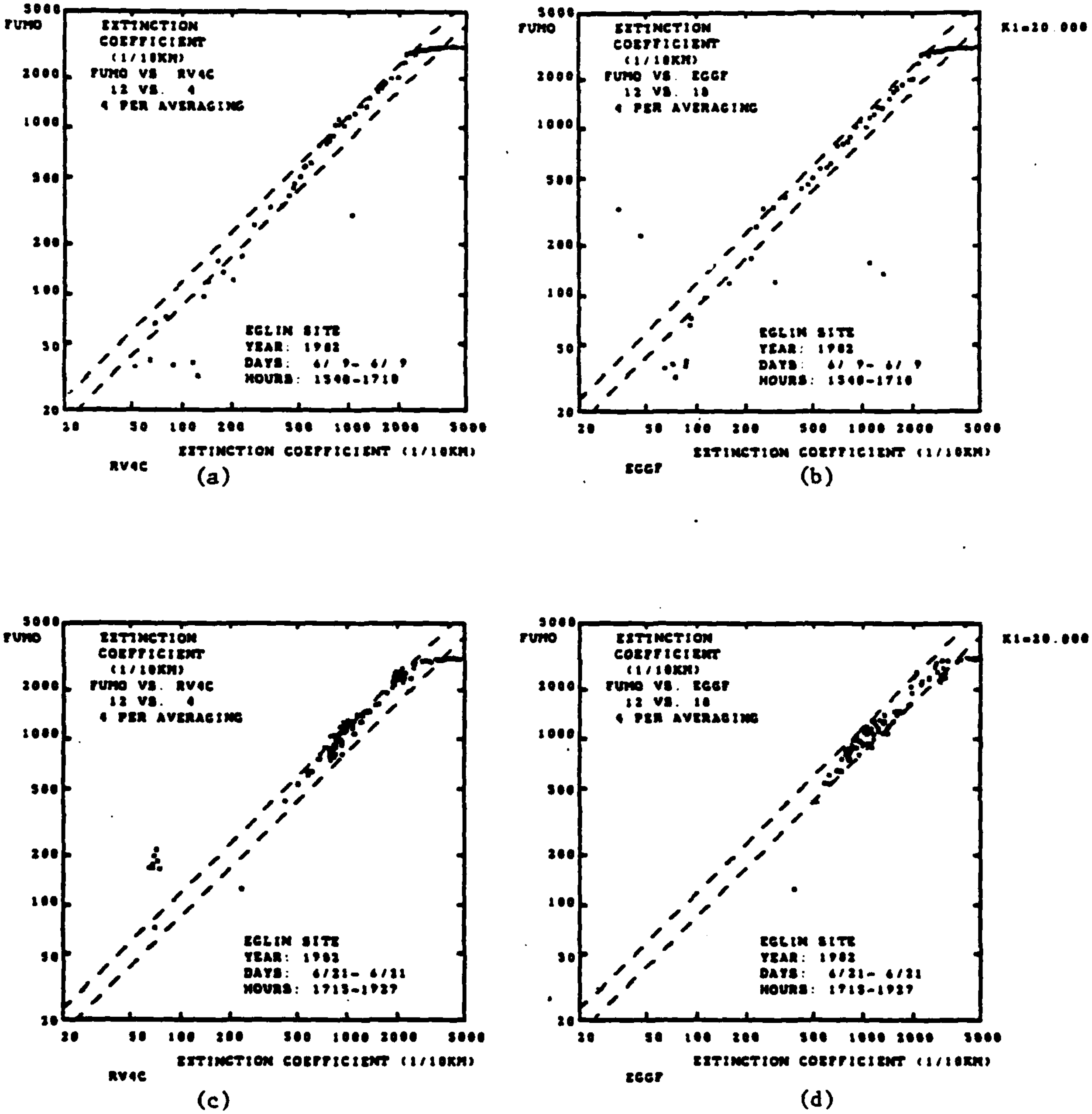


FIGURE 6-33. FUMOSENS III RESPONSE FOR TWO STEAM FOG EVENTS.

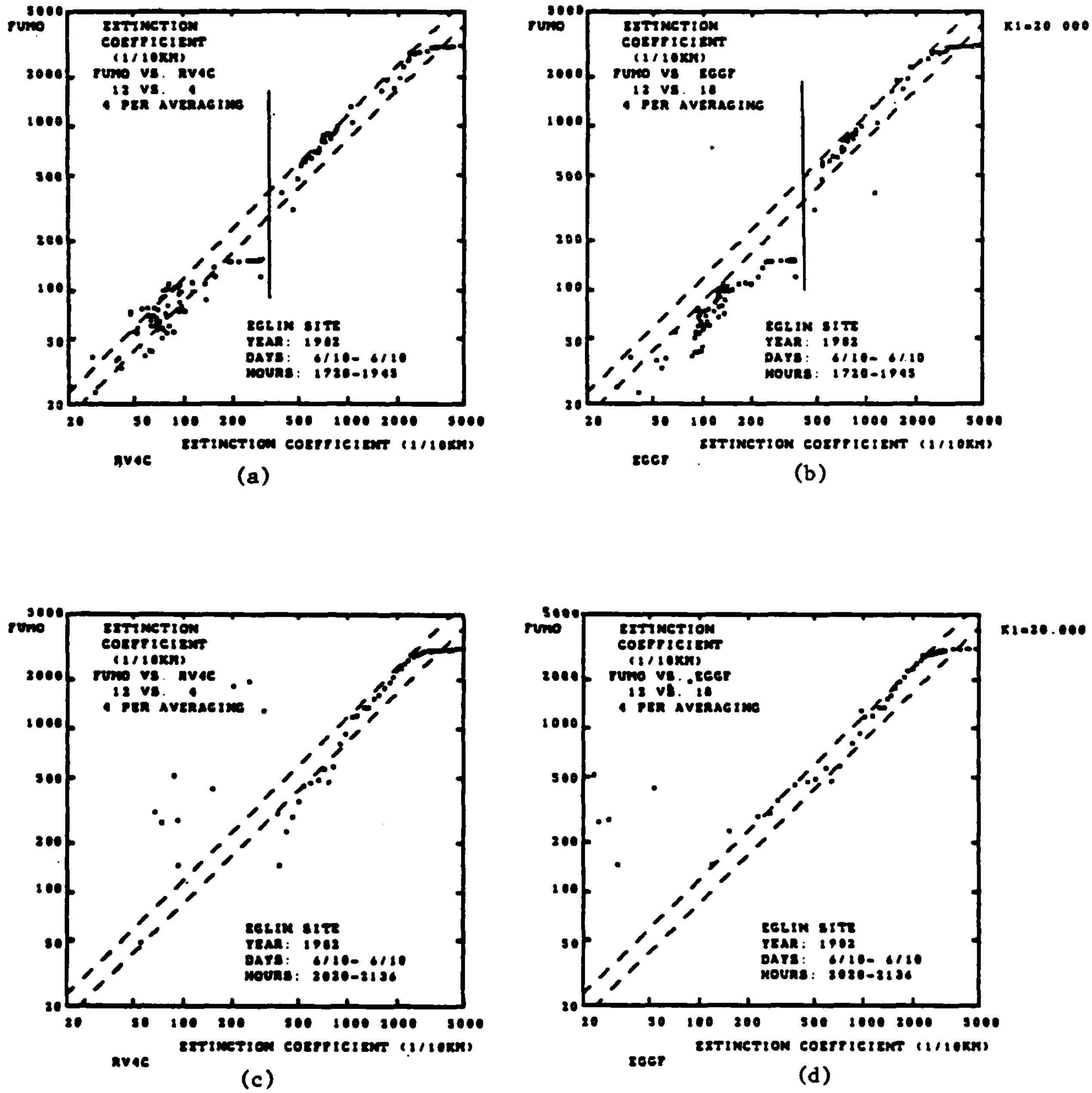


FIGURE 6-34. FUMOSENS III RESPONSE FOR THE TWO FOG EVENTS ON 6/10/82: (a), (b) STEAM: (c), (d) COOLING.

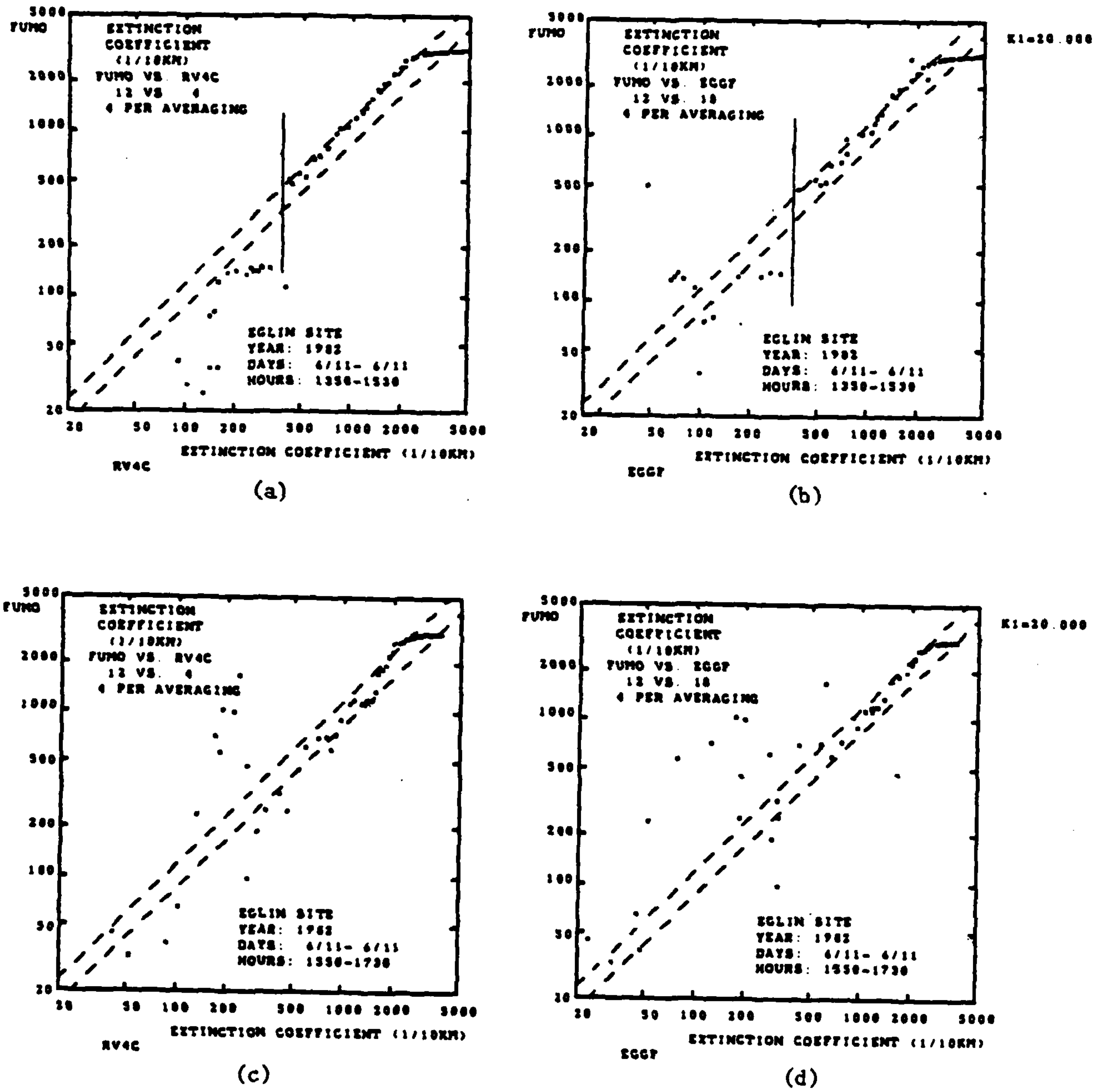


FIGURE 6-35. FUMOSENS III RESPONSE FOR THE TWO FOG EVENTS ON 6/11/82: (a), (b) STEAM: (c), (d) COOLING.

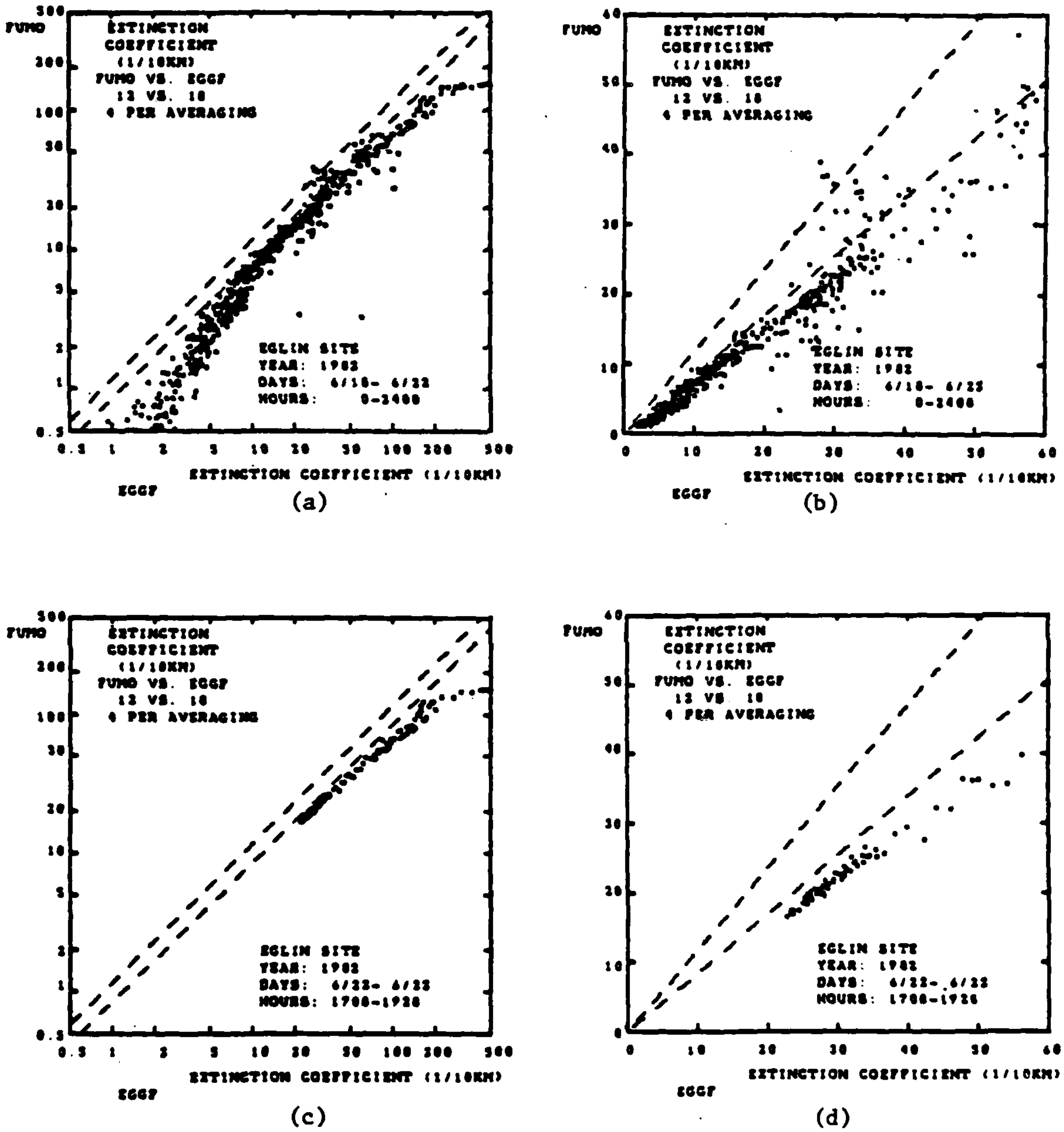


FIGURE 6-36. FUMOSENS III RESPONSE TO FOG/HAZE EVENTS: (a), (b) ALL EVENTS: (c), (d) 6/22 EVENT.

6.2.5 Enertec EV-1000

Figures 6-37 through 6-39 show the response of the EV-1000 for the four steam and two cooling fog events. The scatter in the data above σ = 500 is much greater than for any other sensor. The calibration constant for the sensor appears to be approximately 20 percent low. With this correction the sensor would probably just marginally pass the 15 percent pass/fail criteria for the tests.

Figure 6-40 shows the snow machine fog-haze data for the tests. A large amount of scatter is again observed. The calibration relative to the EG&G 207 units is about 40 percent low. The EV-1000 would thus be expected to read extinction coefficients about 10 percent low in haze relative to the RVR calibrator.

As with the Fumosens III, the lack of a calibrator makes the sensor useless for operational use and allows only qualitative interpretation of the chamber results.

Some of the scatter in the EV-100 results is due to the long averaging time (3 minutes) used for low extinction coefficients. The rest may be caused by the low flash rate and the small scatter volume. The method of reporting the measurement also tends to produce apparent errors. The measurement for one measurement period (1 or 3 minutes) is held during the next measurement period (See Figure 6-1). No attempt was made to compensate for this delay in the data analysis. Since only decaying events were used in the analysis, the delay would lead to higher EV-1000 measurements than for the other sensors. The observed differences were, in fact, in the opposite direction.

6.3 HUMAN OBSERVATIONS

Table 6-2 compares the human observations described in Section 5.1.3 with sensor measured values of RVR. The 40-foot RVR calibrator located at about 5-foot height was used to calculate the sensor RVR. The line of runway

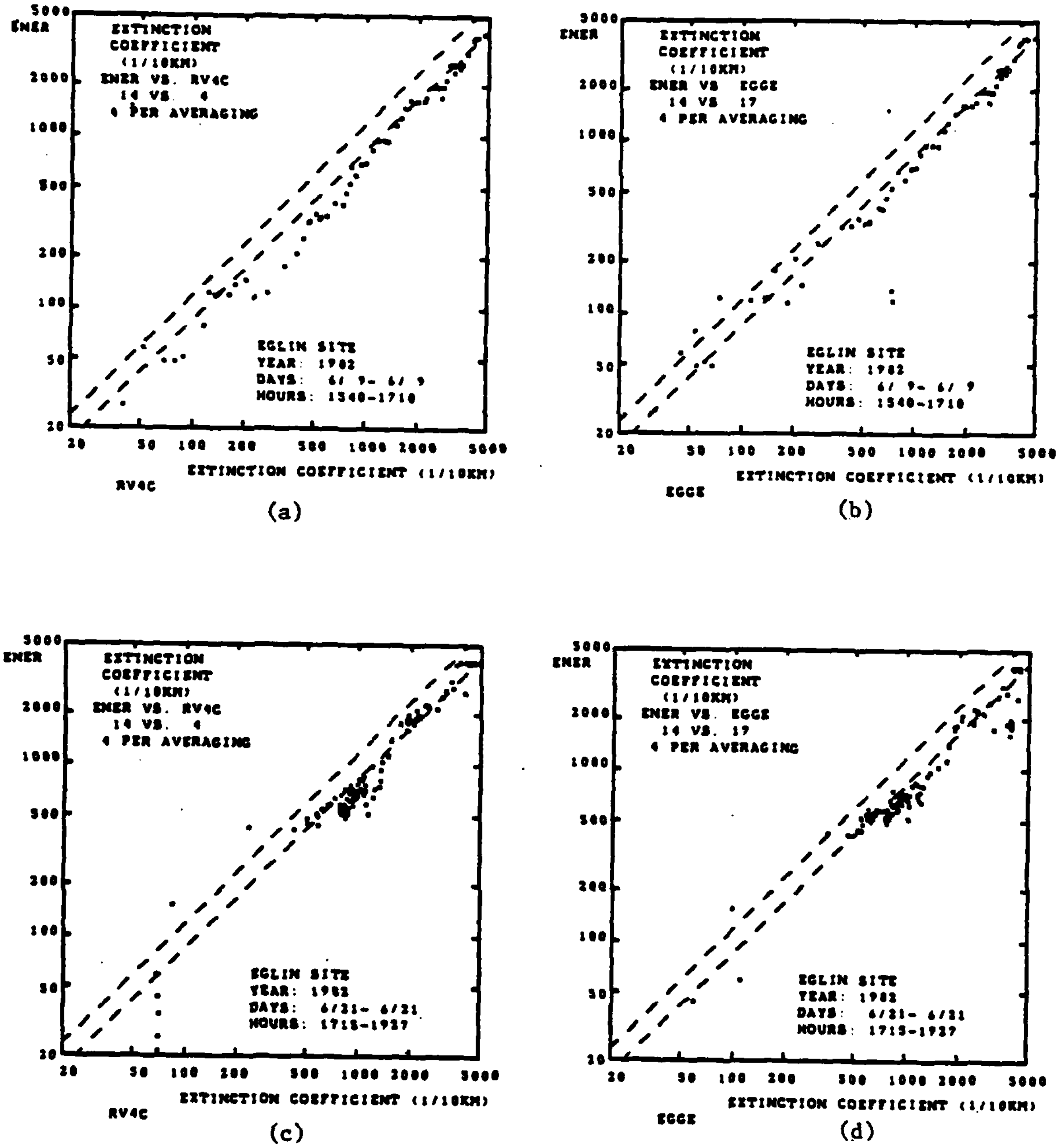


FIGURE 6-37. ENERTECH EV-1000 RESPONSE FOR TWO STEAM FOG EVENTS.

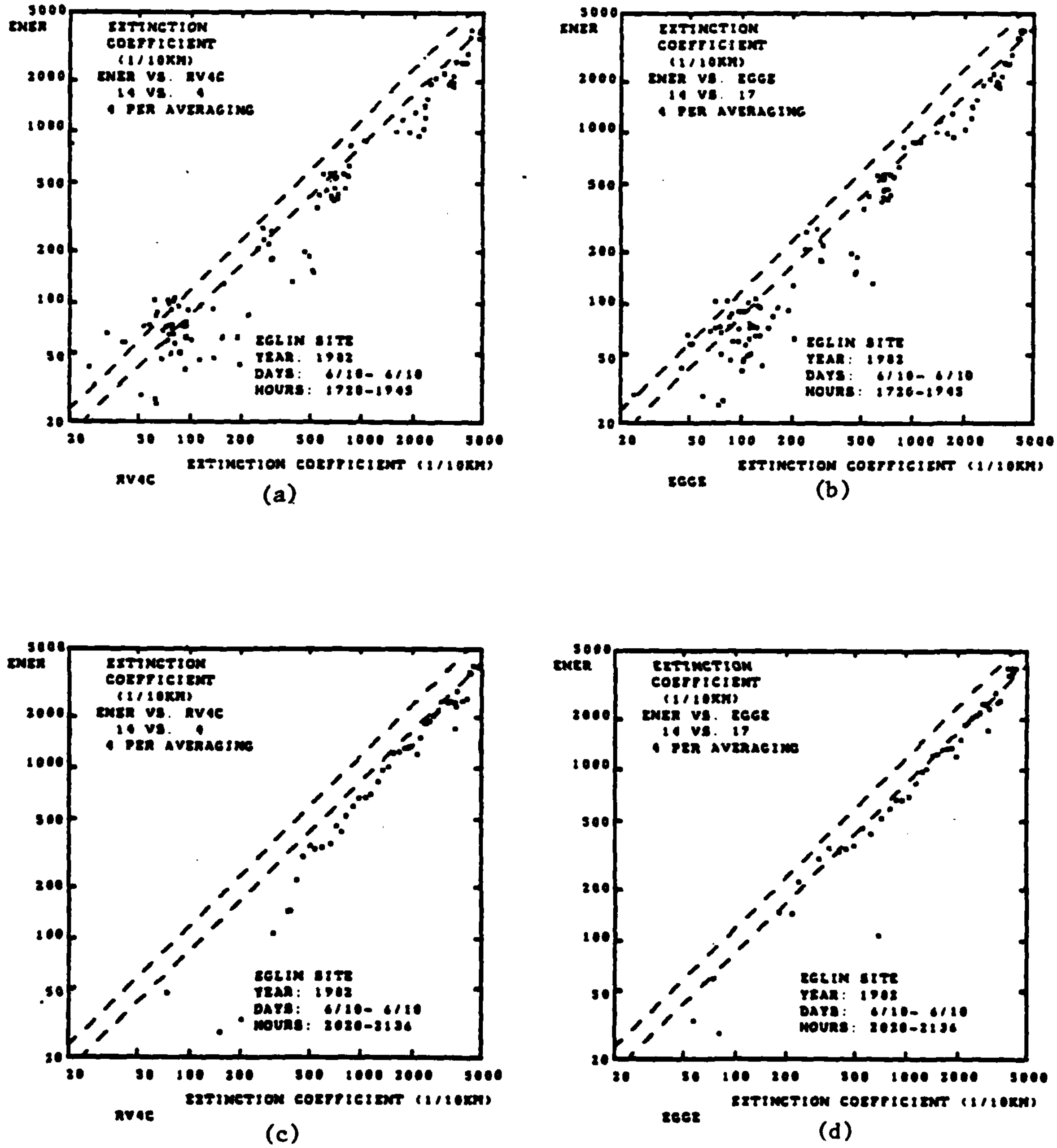


FIGURE 6-38. ENERTEC EV-1000 RESPONSE FOR TWO FOG EVENTS ON 6/10/82; (a), (b) STEAM: (c), (d) COOLING.

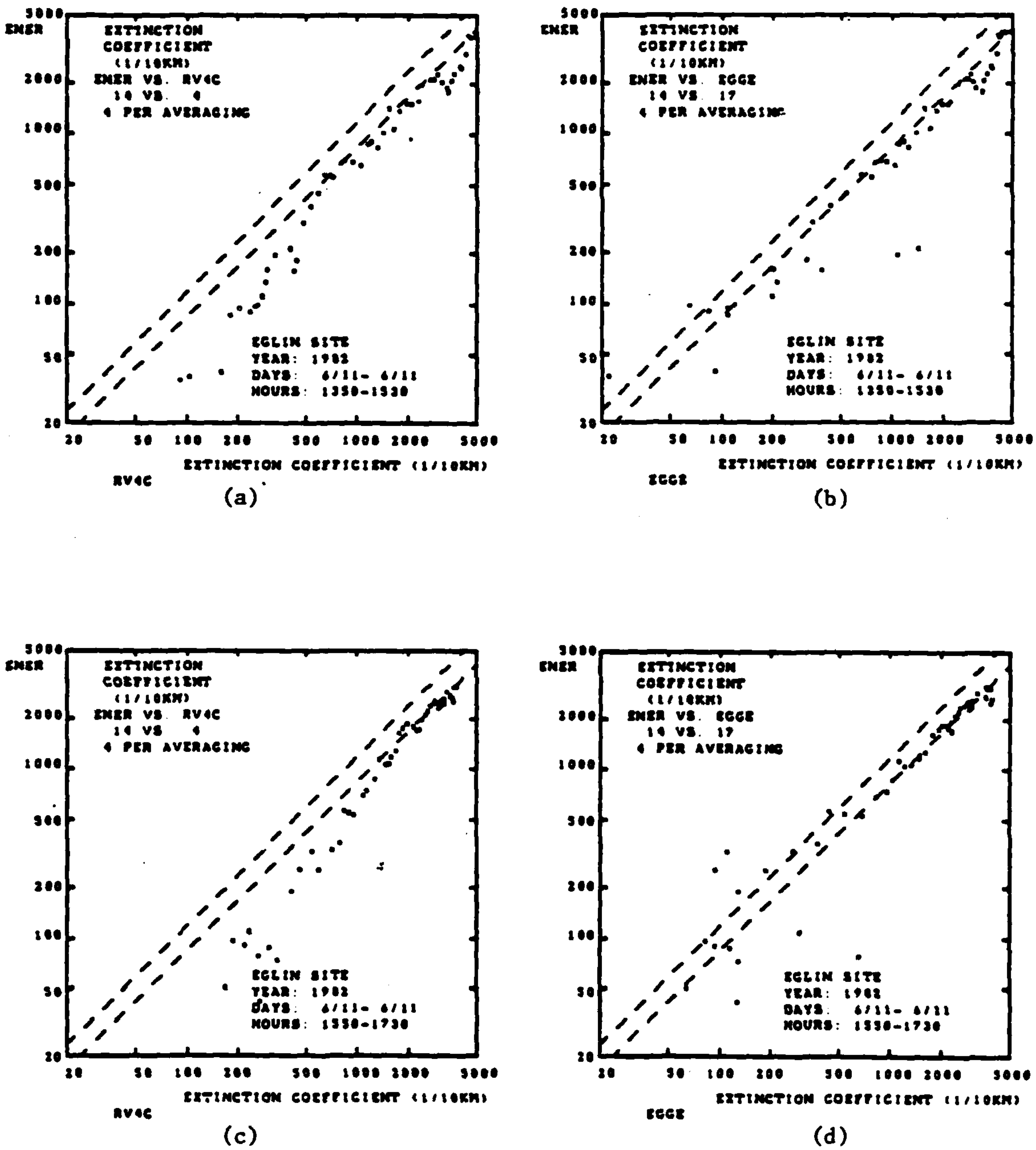


FIGURE 6-39. ENERTECH RESPONSE TO FOG EVENTS ON 6/11/82; (a), (b) STEAM, (c), (d) COOLING.

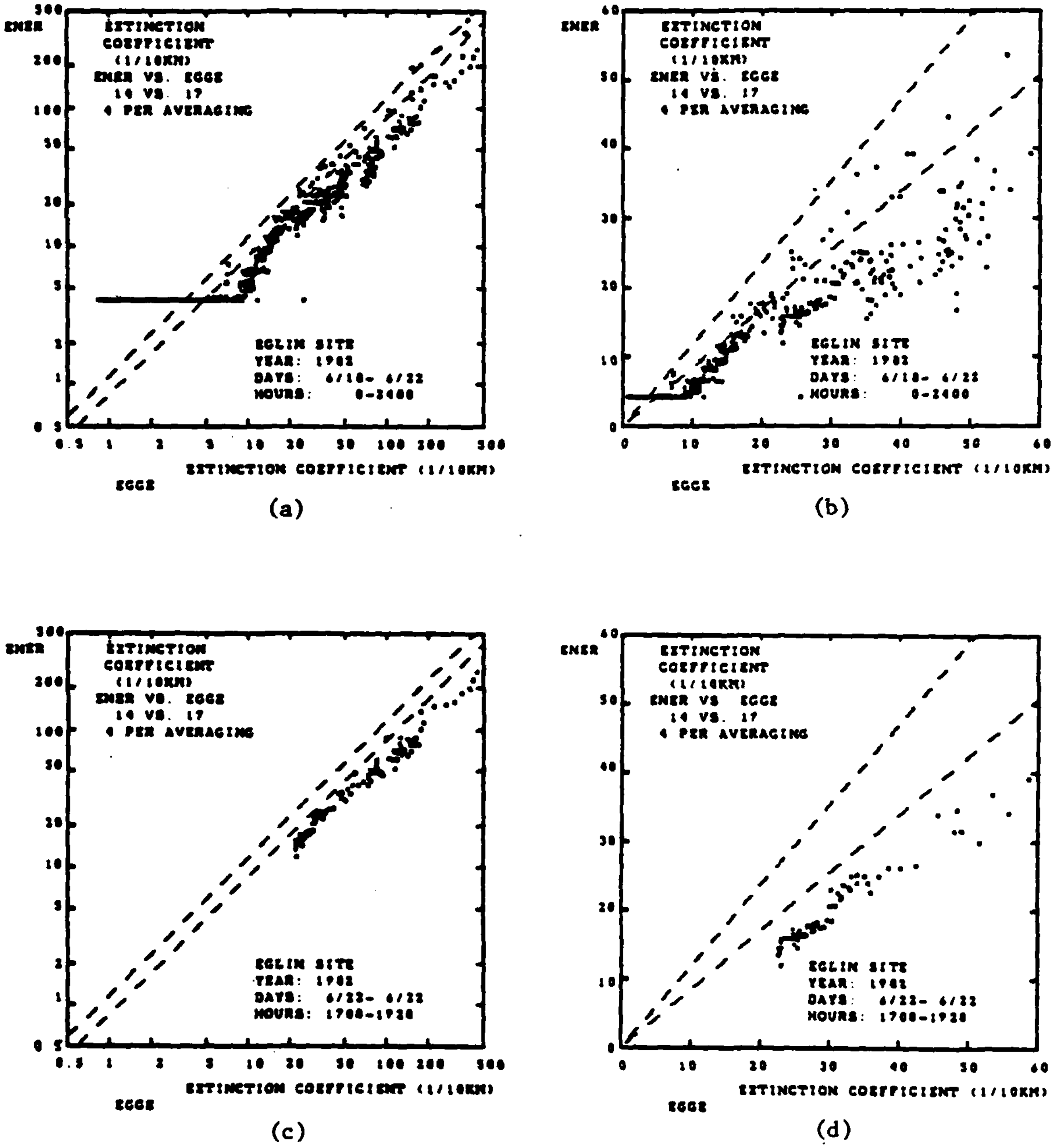


FIGURE 6-40. ENERTEC EV-1000 RESPONSE TO FOG/HAZE EVENTS; (a), (b) ALL EVENTS: (c), (d) 6/22 EVENT.

TABLE 6-2. COMPARISON OF SENSOR MEASUREMENTS WITH HUMAN OBSERVATIONS ON 6/11/82

TIME (GMT)	HUMAN RVR (feet)	SENSOR RVR (feet)
1340	55	70
1355	53	67
1401	65	70
1419	107	103
1427	145	150
1440	220	305
1548	93	79
1556	100	116

lights was located about 20 feet to the side of the calibrator baseline. The closest runway light was located next to the 40-foot receiver tower. The observer adjusted his distance from the last light until he could just barely see one of the runway lights. The sensor and human results in Table 6-2 agree reasonably well, although not nearly as well as two sensors can agree. The disagreements are caused by spatial variation of the fog and the nonrepeatability of human observations.

6.4 RAIN

Section 5.4 describes the rain generation. Three different rain rack positions were needed to cover all the sensors. Consequently simultaneous rain measurements for all sensors were not possible.

Table 6-3 shows the responses of the sensors for the rain events on 6/16/82 and 6/17/82. The number in parentheses after the relative response is the fractional standard deviation (one-minute averaging), which indicates the variability of the measurement. The nominal rain rate was the same for all the rain tests. The response data have been normalized to the response of the 40-foot RVR 500 which was located in the middle of the rain frame for the first test position. The RVR 500 data show some variation in the extinction coefficient, especially for the second event of 6/16/82 which was of short duration (as short as 7 minutes). The test segments on the second day, when the rain was freezing, lasted for about one hour in each position. The data in Table 6-3 show a number of irregular readings (underlined) which are characterized by an abnormally large standard deviation. In most cases the cause of the irregular reading is unknown; the following discussion will be based on the consistent readings.

Many of the observed differences between sensors in Table 6-3 appear to be related to inhomogeneities in the rain distribution rather than the sensor response. Consequently, the data may not accurately characterize the rain response of the sensors. The reduced response of the RVR

TABLE 6-3. RELATIVE RAIN RESPONSE OF VISIBILITY SENSORS

SENSOR	6/16/82 FIRST EVENT	6/16/82 SECOND EVENT	6/17/82 FIRST EVENT	6/17/82 SECOND EVENT
RVR 500 (40-foot)	1.00 (.10)	1.00 (.18)	1.00 (.07)	1.00 (.10)
RVR CALIBRATOR (40-foot)	0.62 (.26)	0.80 (.08)	0.61 (.15)	0.66 (.13)
MET-1	0.91 (.06)	0.64 (.35)	0.90 (.04)	1.05 (.15)
FOG-15 #1	2.58 (.44)	3.12 (.21)	1.22 (.32)	1.70 (.22)
FOG-15 #2	0.75 (.57)	2.22 (.14)	1.32 (.18)	1.65 (.20)
SKOPOGRAPH		1.01 (.06)		
EG&G 207 #1		1.97 (.27)	2.07 (.21)	2.41 (.12)
EG&G 207 #2		1.47 (.17)	1.50 (.13)	1.60 (.11)
VR-301		0.94 (.56)	0.71 (.46)	0.89 (.42)
FUMOSENS III		0.90 (.25)	0.29 (.95)	0.68 (.36)
EV-1000		1.24 (.24)	0.88 (.18)	______
NOMINAL EXTINCTION COEFFICIENT (1/10 KM)	156	191	161	154

calibrator is probably due to its location near the edge of the rain frame (Figure 5-25b). It was mounted on the sides of the transmissometer towers. The MET-1 and Skopograph gave reasonable agreement with the RVR 500, which is understandable since they both average over a large volume of the rain. The forward-scatter meters were significantly affected by the fine structure in the rain (Figure 5-25a). Each rain nozzle generated a spray of fine droplets which drifted slowly down to the sensors. The nozzle spacing was great enough that the spray from each nozzle remained separate; thus, the fine scale inhomogeneities were substantial. The position of the spray from each nozzle moved around in response to slight air movements. The fine-scale inhomogenieties should have the biggest effect on the three forward-scatter meters with the smallest scattering values: VR-301, Fumosens III, and EV-1000. The VR-301 showed an extremely variable response to rain, apparently because of its short time constant (15 seconds). The smaller variations of the Fumosens III and EV-1000 are presumably due to longer averaging times. The Fumosens III data were taken with a factor of 20 optical attenuation which puts the readings near the bottom of the sensor's dynamic range. Unfortunately the extinction coefficient for the rain was near the sensor's saturation level. The Fumosens III has by far the smallest dynamic range of all the forward-scatter meters. As a group the small-volume forward-scatter meter showed a response equal to or smaller than the transmissometer. On the other hand the large-volume forward-scatter meters (EG&G 207 and FOG-15) showed a substantially larger response to rain. An enhanced response to rain by a factor of 1.7 has been observed for the EG&G 207 in field tests. The Table 6-3 measurement are generally consistent with the 1.7 factor but with significant variations. The two EG&G 207 units had different responses, perhaps because of different average rain density at the two locations. The two FOG-15 units often agreed well with each other but showed significant differences from event to event. These variations probably reflect the fine-scale inhomegenities of the rain which are still signficant over the scatter volume of the large-volume sensors.

The effect of freezing rain or sensor performance was generally not as severe as that of snow (section 6.5). Only three sensors were affected. The EV-1000 was most severely affected. An icicle formed in the scattering volume and saturated the sensor. An icicle on the MET-1 (Figure 5-5b) also came close to penetrating the measurement volume. The MET-1 was not equipped with the heaters which would normally be installed in freezing environments. The FOG-15 light blocks (Figure 5-8b) also built up ice. The heaters may have been turned off to avoid the fog which rose from them during the rain tests.

6.5 SNOW

The generation of snow was described in Section 5.5. Figure 5-26 shows the accumulation of snow on the forward-scatter meters. Although the snow distribution was nonuniform, no attempt will be made to relate the sensor measurements to the observed depth of snow accumulation for an event.

The relative response to four snow events is shown in Table 6-4 which uses the same data format used in Table 6-3 for rain. In this case the 40-foot RVR calibrator is used as the reference sensor to which the other sensors are compared. The observed agreement between all the transmissometers (top four sensors) was good on 6/15/82 when there was little wind. On 6/14/82 the two transmissometers away from the RVR calibrator (Skopograph to the side and RVR 500 9 feet above) showed significant differences. The forward-scatter meters gave reasonable agreement with the RVR calibrator considering the likely variations in snow distribution. Comparisons between the two EG&G 207s showed considerable differences between the two ends of the line of forward-scatter meters. The fractional standard deviation for forward-scatter meters was smaller in snow than in rain. The VR-301 variation was substantially less. The FOG-15 #2 was disabled during the snow tests.

Snow degraded the performance of some sensors, especially on 6/14/82 when it was driven by wind. On 6/14/82 the projector grid of the RVR 500

TABLE 6-4. RELATIVE SNOW RESPONSE OF VISIBILITY SENSORS

SENSOR	6/16/82 1825-1930	6/16/82 1410-1445	6/17/82 1524-1551	6/17/82 1840-1945
RVR 500 (40-foot)	1.49 (.07)	0.99 (.05)	0.94 (.19)	1.07 (.16)
RVR CALIBRATOR (40-foot)	1.00 (.10)	1.00 (.06)	1.00 (.03)	1.00 (.22)
MET-1	0.96 (.09)			1.04 (.16)
SKOPOGRAPH	0.77 (.10)	0.95 (.05)	0.91 (.03)	0.86 (.22)
EG&G 207 #1	1.24 (.13)	1.08 (.04)	1.38 (.11)	0.81 (.39)
EG&G 207 #2	1.11 (.10)	0.91 (.03)	0.85 (.08)	1.29 (.15)
FOG-15 #1	1.24 (.30)	1.13 (.04)	0.97 (.03)	1.55 (.10)
FUMOSENS III		1.41 (.07)	1.39 (.21)	1.09 (.32)
VR-301	0.76 (.15)	0.74 (.10)	0.91 (.06)	1.32 (.10)
EV-1000	0.37 (.23)	0.56 (.26)	1.49 (.16)	1.16 (.15)
RVR CALIBRATOR EXTINCTION COEFFICIENT (1/10 KM)	650	1382	1122	884

(Figure 5-3d) accumulated some snow. A heater should be installed near the grid assembly. The Skopograph and MET-1 exhibited no particular snow problems. The lack of problems may be fortuitous since the wind direction did not blow snow into the enclosed hoods. Of all the forward-scatter meters, only the VR-301 had no snow problems. The light blocks on the EG&G 207 (Figure 5-7b) and the Fumosens III (Figure 5-10c) iced up at times. The FOG-15 windows and light blocks iced up (Figure 508a). Insulating the FOG-15 covers eliminated the window icing. The EV-1000 exhibited snow accumulation on its light baffle.

6.6 TEMPERATURE CYCLES

The interpretation of the low temperature data is complicated by the existence of fog which became dense enough to saturate the sensors that were set for high gain. Because of the lack of a standard sensor (the RVR calibrators were removed and the EG&G 207's saturated), the data analysis will be qualitative rather than quantitative. Apart from the MET-1 all the sensors appeared to function down to -58°F. The MET-1 started to lose 100-percent calibration at 50°F and ceased functioning at -5°F. Apart from saturation problems, all sensors but the EV-1000 gave a similar measurement of extinction coefficient over the cycle. The fog density reached saturation for the Fumosens III, FOG-15 #2, EG&G 207 and FOG-15 #1 at temperatures of -25°, -30°, -35°, and -40°F respectively. The RVR 500, Skopograph, VR-301, and EV-1000 measured through the cold cycle. The EV-1000 exhibited an occasional instability in its output (a factor of five drop in extinction coefficient) which started at -40°F and terminated when the temperature rose above -30°F. During the warm-up the fog density was less and all sensors were observed to function above -40°F. The VR-301 had a severe zero shift during warm- up.

The high temperature cycle provided information on the stability of the transmissometers and the three forward-scatter meters with calibrators installed (EG&G 207 #2, FOG 15 #1, and VR-301). The RVR 500 and Skopograph were observed to have a shift in the 100-percent calibration at 127° F which disappeared when the temeprature was returned to normal. The shifts for the 250-foot RVR 500, the 40-foot RVR 500, and the Skopograph were -4%, -2%, and +2% respectively. These shifts could have been caused by alignment or by temperature effects on the lamp intensity or receiver sensitivity. The MET-1 put out a fixed value during most of the temperature cycle. A fixed reading indicated a sensor failure during the cold test and may also indicate a failure here. Normally the sensor output shows some variation. Both the EG&G 207 and the FOG-15 showed a drop in calibration during the hot cycle. The EG&G 207 changed gradually over the cycle and lost 9 percent of its response. On the other hand, the FOG-15 first gained in response by 13% as the temperature reached 118° F and then had a net loss of 9 percent in response as the temperature reached 127° F. The total loss of the FOG-15 at the end of the cycle was 13 percent. The VR-301 showed an increase in response of about 15 percent at 127° F. Subsequently during the long soak at 120° F it suffered a large abrupt shift in response, presumably because of a zero shift.

7. EPILOGUE

Recommendation a) of Section 3 called for the operational testing of the Tasker dual-baseline transmissometer. The results of implementing this recommendation proved to be unsatisfactory. A number of important conclusions and recommendations can be drawn from this failure and have been incorporated in the planning for a FY84 comprehensive visibility sensor test program.

7.1 ATLANTA INSTALLATION

In January 1983 the three existing RVR 500 250-foot transmissometers on Runway 9R-27L at Atlanta were converted to dual-baseline operation by adding 40-foot baseline receivers and by adding the 4-inch diameter baffles to the common projector lamp. When the FAA field technicians attempted to certify the installation, they discovered a number of problems which eventually resulted in abandoning the concept of using a common projector for a dual-baseline transmissometer.

The basic problem encountered was that the projector beam could not simultaneously be centered on two different receivers spaced one degree apart. The lamp profile is so narrow that at least one receiver will be looking at the sloping edge of the lamp profile where a small shift in alignment can produce a proportional shift in indicated transmittance. If the shift produces an increase in transmittance, the reported RVR will be higher than the actual RVR. This possibility was considered to be unacceptable because it is inconsistent with current practices where measurement errors are conservative, i.e., leading to lower RVR. In the normal transmissometer installation, virtually all sources of instrumental error lead to an RVR reading lower than actual.

The narrow lamp profile that makes the common projector undersirable was exacerbated by the 4-inch baffle which resulted in close-spaced, multiple peaks in the projector beam profile. Data collected with the baffle removed showed an unacceptable forward-scatter error (20 percent) which was two or three times larger than observed at

Arcata and Eglin and is considered to be unacceptable. Tasker confirmed that the field stop used in the Atlanta units was twice as large as that used in Arcata. The field stop size used at Eglin is unknown. It should be noted that, the forward-scatter error is proportional to the field stop diameter, which must be proportional to the projector diameter (see Appendix E of Reference 1).

7.2 ADDITIONAL CONCLUSIONS AND RECOMMENDATIONS

a) The model number is not an adequate specification of a visibility sensor for the purposes of evaluation. Detailed optical, mechanical, and electronic schematics must be supplied to define the configuration of the sensor being tested. Control of the sensor configuration should be maintained between the time of testing and the ultimate procurement and operational use of a sensor.

b) An adequate evaluation of a visibility sensor for operational use must include an examination of all relevant sensor characteristics. It would be highly desirable to include FAA field technicians in all future evaluations of visibility sensors.

c) A satisfactory 40-foot baseline transmissometer must have the following features: 1) its own projector and 2) a projector lamp diameter no longer than 4 inches and preferably smaller.

REFERENCES

1. Burnham, David C. and Collins, Dennis F. Jr, "AWOS Sensor Evaluation," DOT/FAA/PM-83/20, September 1982, DOT Transportation Systems Center, Cambirdge, MA.

APPENDIX A

PRELIMINARY SENSOR EVALUATION REPORT

This Appendix constitutes material originally issued as an internal report, DOT-TSC-FA269-PM-81-64, by TSC in December 1981, under the title Preliminary Evaluation of Visibility Sensors for Category 3b, and authored by David C. Burnham.

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LIST OF ILLUSTRATIONS

1. SUMMARY

The Category 3b Runway Visual Range (RVR) requirements were examined to develop acceptance criteria. Four visibility sensors which were tested from June through November 1981 in Arcata, CA were evaluated for their suitability for measuring Category 3b conditions. On the basis of a preliminary examination of the data, two of them, one transmissometer and one forward-scatter meter, are recommended for further evaluation in an operational environment. A least-squares-fit method was used to compare the measurements from different sensors and thereby determine their systematic and random disagreements. The random variations between sensors can also be used to assess the spatial representativeness of the measurements and the optimum averaging time. Recommendations are made for expediting the operational sensor testing so that a Category 3b RVR system can be certified by the end of FY82.

2. CONCLUSIONS

Two of the sensors tested, the Tasker RVR 500 40-foot transmissometer and the Wright and Wright FOG-15 forward-scatter meter are recommended for additional testing in an operational environment. Both exhibited some problems which need to be resolved by their respective manufacturers before operational testing. The RVR 500, being a much more mature instrument than the FOG-15, has fewer unanswered questions. The FOG-15 is still worthy of further consideration since it would be much less expensive to procure and install.

A first examination of the data indicates that a forward-scatter meter making a point measurement of visibility represents a one-minute average visibility equally as well as a transmissometer averaging over a 40-foot baseline. It also appears to represent the visibility equally as well as a 250-foot transmissometer at distances several baselines away from the sensors.

3. REQUIREMENTS

Category 3 involves values of Runway Visual Range (RVR) below 1200 feet. Category 3a requires an RVR of 700 feet or greater. Category 3b requires an RVR of 150 feet or greater. Category 3c has no lower RVR limit. RVR is measured at 14-foot height and is reported in multiples of 100 feet (200 feet above 800 feet). The current RVR processor averages for one minute. The reference lights for viewing are the runway edge lights for RVR of 600 feet or greater and the runway centerline lights (which are only half as bright) for RVR below 600 feet. The 150 foot RVR at the lower end of Category 3b is required to allow visual taxiing of the aircraft. There is another RVR limit of approximately 400 feet which is required to allow the pilot to keep the aircraft on the runway visually in case the auto-land system decouples.

The current RVR sensor is a 250-foot-baseline transmissometer which is certified for measuring RVR down to 600 feet. This certification is reasonable and possibly conservative in the daytime. For daytime RVR the transmission is 4.5 percent for RVR = 550 feet at the brightest light setting (L.S.5) For RVR=450 feet the transmission drops to 2.7 percent which could probably still be resolved if the background light were not too troublesome. At night the RVR = 550 transmission is only 0.27 percent which is also resolvable because of the low night background. A 40-foot-baseline transmissometer can just measure down to 100-foot RVR where the transmission for L.S.5 is 3.2% in daytime and 0.14% at night. A 60-foot baseline would actually be adequate to reach the 150-feet lower RVR limit of Category 3b.

The dependence of RVR on light setting and day/night is the result of the fact that visibility sensors actually measure the atmospheric extinction coefficient rather than the visibility. The visibility is then calculated from the measured extinction coefficient and the other operational conditions. The use of RVR values to compare the measurements from different sensors is inconvenient because the actual RVR values depend upon factors unrelated to the sensors. Likewise, sensor intercomparisons using extinction coefficient are inconvenient because the values are not easily related to visibility. As a compromise, this report will use measurements of 5-percent-contrast visibility to compare instruments. This visibility is inversely proportional to the extinction coefficient and represents the daytime visibility for viewing objects (rather than lights). Because the runway lights are very bright, they can be much more visible than objects, even in the daytime. Figure 1 shows the ratio of RVR (L.S.5) to 5-percent-contrast visiblilty for the Category 3 range of RVR. The ratio is typically four at night and two in the daytime. These factors can be used to convert 5-percent-contrast visibility plots (shown later) to RVR. The break at 600 feet in Figure 1 is caused by the change from edge to centerline lights.

The rare occurrence of Category 3b conditions complicates the sensor evaluation. At Arcata the minimum 5-percent-contrast visibility observed is about 200 feet, which corresponds to 400-foot day RVR and 800-foot night RVR. Perhaps the best method for certifying a sensor down to 150-foot RVR is to identify sources of sensor error and calculate their effects for RVR's below those readily observed. Fog chamber testing may also be an option.

A realistic definition of visibility sensor accuracy requirements is difficult and has been avoided whenever possible. The transmissometer was certified on the basis that it represented a tremendous improvement over human observations. A Category 3b transmissometer could be certified on the same basis; by definition, a properly functioning transmissometer is acceptable. Such an approach leads to difficulties in certifying a different sort of sensor, such as a forward-scatter meter, which has different characteristics than the transmissometer's.

The simplest approach to defining sensor accuracy is to require an accuracy consistent with the reporting resolution (100 or 200 feet in the case of RVR). Although this approach is reasonable for measuring temperature or pressure, it may fail for visibility for two reasons. First, the intrinsic sensor accuracy may not be this good for the higher values of RVR. Second, even if the sensor were perfectly accurate, its measurement is not necessarily representative of the actual visibility seen by the pilot at a different location.

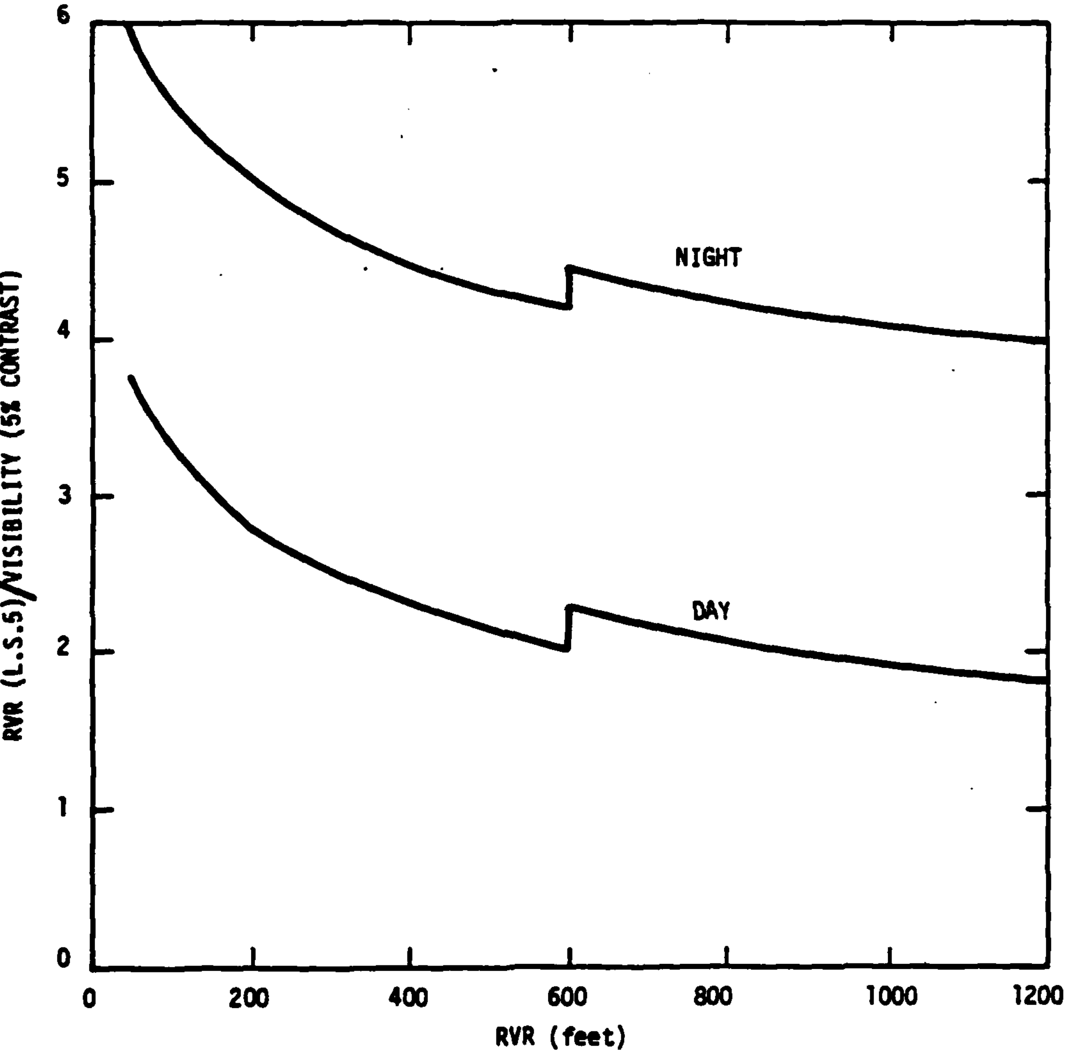


FIGURE 1. RATIO OF RVR (L.S.5) TO 5-PERCENT-CONTRAST VISIBILITY VERSUS RVR.

The most natural method of specifying visibility sensor accuracy is in terms of a percent accuracy. If a particular visibility is required for a particular operation, a pilot will be able to tell a difference in his viewing only when the visibility changes by a significant fraction (perhaps 20%). Likewise, the visibility is likely to vary from one place to another by a given percent. An ideal sensor should have random errors which make little contribution to the variation between sensor and pilot locations. Likewise, any systematic errors should either be a small fraction of sensor-pilot variation, or be in a direction to assure safety.

4. SENSORS

The visibility sensors listed in Tables 1 and 2 were tested at the FAA Visibility Test Site in Arcata, CA. Four sensors are candidates for use under category 3b conditions: two transmissometers and two forward-scatter meters. The third forward-scatter meter tested, the Impulsphysics FS-3, is excluded because of its unstable operation. Three longer baseline transmissometers, two of them forming dual-baseline systems with the candidate sensors, are used for comparison.

The Tasker RVR 500 40-foot baseline transmissometer used a modified transmitter and receiver in order to reduce the forward-scatter error. The transmitter was apertured and baffled and the receiver field of view reduced in order to minimize the scattered light collected. An unmodified Tasker system was tested a few years ago and apparently exhibited an unacceptable forward-scatter error. The selection of a 40-foot baseline was based on the need to measure RVR down to 100 feet.

The Skopograph transmissometer differs from the conventional United States transmissometer in having a pulsed spark light source. This pulsed source is claimed to substantially reduce the background-light problems encountered with steady light sources. The Skopograph also differs from all U.S. visibility sensors in that it measures mostly with visible light. The U.S. sensors use incandescent lamps with silicon photodetectors and thus

TABLE 1. CANDIDATE CATEGORY 3b SENSORS

MODEL	MANUFACTURER	BASELINE (feet)
RVR 500	Tasker	40
Skopograph	Impulsphysics	164
207	EG&G	*
FOG-15	Wright & Wright	*

* Forward-Scatter Meter

TABLE 2. COMPARISON SENSORS

MODEL	MANUFACTURER	BASELINE (feet)
RVR 500	Tasker	250**
RVR 500	Tasker	720
Skopograph	Impulsphysics	720**

** Part of a dual-baseline system with a common light source.

have more than half their response in the infrared. This factor is unimportant for the present study since, for the dense fogs characteristic of Category 3 conditions, infrared and visible light are expected to suffer equal attenuation. The 164-foot (50-meter baseline) was erroneously selected by Impulsphysics because of the European use of Meteorological Optical Range (MOR) (equivalent to 5-percent contrast visibility) instead of RVR. The 50-meter baseline can measure to MOR = 150 feet. Unfortunately, the MOR is only one fifth of the RVR for RVR = 150 feet at night.

Forward-scatter meters (FSM) differ from transmissometers in that they detect the light scattered out of a beam rather than the light remaining in a beam. The range of scattering angles collected (20 to 50 degrees) was selected to make the instrument calibration independent of the obstruction to vision. Comparisons of forward-scatter meters to transmissometers have shown little dependence of the calibration upon the cause for reduced visibility with the exception of rain with no fog. An FSM calibrated for fog will underestimate the visibility by a factor of 1.7 in fogless rain. This rain error should have no impact on the Category 3 evaluation since rain alone cannot reduce the RVR below 1200 feet.

The difference in measurement method produces a number of relative advantages and disadvantages between a transmissometer and an FSM:

(1) An FSM provides a point measurement of the visibility rather than the line average measured by a transmissometer. A point measurement may require a longer time average to produce a representative measurement than does a line-averaged measurement. Several FSM's might be required to provide an output equivalent to that from one transmissometer.

(2) An FSM has a much greater dynamic range than a transmissometer. A transmissometer is limited on the high visibility end by calibration errors and window losses and on the low visibility and by background light and noise. The FSM's use a chopped light source to discriminate against background light and are thus limited only by noise and background signal saturation on the

high visibility end. On the low visibility end they are limited by possible clipping of the very large signals generated. In particular, an FSM is much less sensitive to window losses and lamp dimming than a transmissometer; the FSM visibility measurement is in error by the same percentage as the loss or dimming. In summary, the operational RVR range is only a factor of 10 for a single baseline transmissometer while a factor of 50 or more is readily achieved by an FSM.

(3) The installation of a transmissometer is more complicated and inherently more expensive than that of an FSM. Two towers, rather than one, are required. The receiver tower must be very rigid to maintain alignment while the instrument is being serviced. Deep footings are required to maintain alignment under freezing conditions.

(4) Because the FSM is less sensitive to lamp drift and window losses, the frequency of calibration/maintenance required could be much lower than that required for a transmissometer.

The EG&G 207 forward-scatter meter has been used successfully for ten years by the Air Force for scientific studies. The Air Force experience indicates that the sensor requires considerable maintenance and suffers from poor quality control at the factory because of limited production.

The Wright & Wright FOG-15 sensor is essentially an improved version of the EG&G 207, designed to overcome the operational difficulties experienced by the Air Force. The optics and housings are simplified to reduce costs and facilitate maintenance.

5. SYSTEMATIC ERRORS

This section examines in more detail the sensor systematic errors mentioned in the last section. Because the sensors actually measure extinction coefficient, most errors assume a simpler form when related to extinction coefficient rather than to visibility. In particular, one can relate the measured extinction coefficient σ_1 for sensor 1 to the actual extinction coefficient by the equation

$$\sigma_1 = K_1\sigma + D_1 \qquad (1)$$

where K_1 not equal to unity is a slope or gain error and D_1 not equal to zero is an offset error.

A forward-scatter meter (FSM) generates an output signal proportional to the extinction coefficient. The constant of proportionality depends upon the lamp intensity, the geometry of the optics, the receiver sensitivity, and, to some extent (e.g. in rain), the obstruction to vision. The primary question concerning FSM's is how well the constant K_1 in Equation 1 can be kept at unity. The offset D_1 is normally very small for a forward-scatter meter which uses a chopped light source. Only if the background light fluctuations are large enough to cause clipping in the electronics will a significant value of D be generated. Such clipping generally occurs only under sunny conditions. It is usually of short duration (a few minutes) and can be minimized by proper sensor siting.

The transmissometer is subject to errors in both slope (K) and offset (D). The slope errors, in contrast to the FSM, are not likely to be large. The first potential source of slope error is the use of light outside the visible range.[3] The extensive use of infrared light in U. S. sensors, both FSM's and transmissometers, could conceivably introduce errors under haze conditions, but it is unlikely to cause any important error in Category 3 measurements. A second potential source of slope error in transmissometers is due to forward-scattered light being collected by the receiver. This error leads to an overestimate of the visibility. Forward-scatter errors are most troublesome for very short baselines where the receiver field of view must be large to include the full transmitted beam. One can show that the forward-scatter error introduces a fixed percentage error in slope K if one considers only single scattering and a fixed droplet size. For high visibilities the most important transmissometer error involves the light setting corresponding to 100-percent transmission. Errors in 100-percent setting produce an offset D in measured extinction coefficient. Contributing to the 100-percent error are (1) window contamination, (2) calibration error, (3) lamp drift, and (4) receiver drift. In state-of-the-art transmissometers the drifts are relatively unimportant in producing offsets. The calibration error can be important for long baselines but should have litle effect for very short baselines. Window contamination thus remains the dominant source of offset error. The one remaining transmissometer error is background light, the effect of which is not simply an offset or a slope error. Background light produces an offset error for high transmissions but the error increases for smaller transmissions.

The fact that most sensor systematic errors can be described by Equation 1 means that a linear-least-squares fit to the measurements of two sensors can be used to identify relative systematic errors. In this case the extinction coefficient measurements of the two sensors, 1 and 2, are fitted to the equation:

$$\sigma_1 = K_{12}\,\sigma_2 + D_{12} \qquad (2)$$

where K_{12} will be the ratio of K_1 to K_2 and D_{12} will be approximately D_1-D_2 for K_1 and K_2 near unity. This method yields an additional bonus that the residual error in σ_1 can be used as a measurement of the sensor disagreement.

Figure 2 shows some examples of linear-least-squares fits betwen sensors. The 40-foot transmissometer and the FOG-15 FSM are compared to the 250-foot transmissometers for averaging times of one and six minutes for a 9-hour fog event (Event 1) where the variations in extinction coefficient were relatively slow. Each data point in a scatter plot represents simultaneous measurements made by the two sensors. The dashed line with 45° slope represents exact agreement between the two sensors. The solid line through the points represents the least-squares fitted line. Table 3 contains the parameters of the fit. Figure 3 shows the corresponding 5-percent-contrast visibility scatter plots with dashed lines representing $\pm$ 15 percent error.

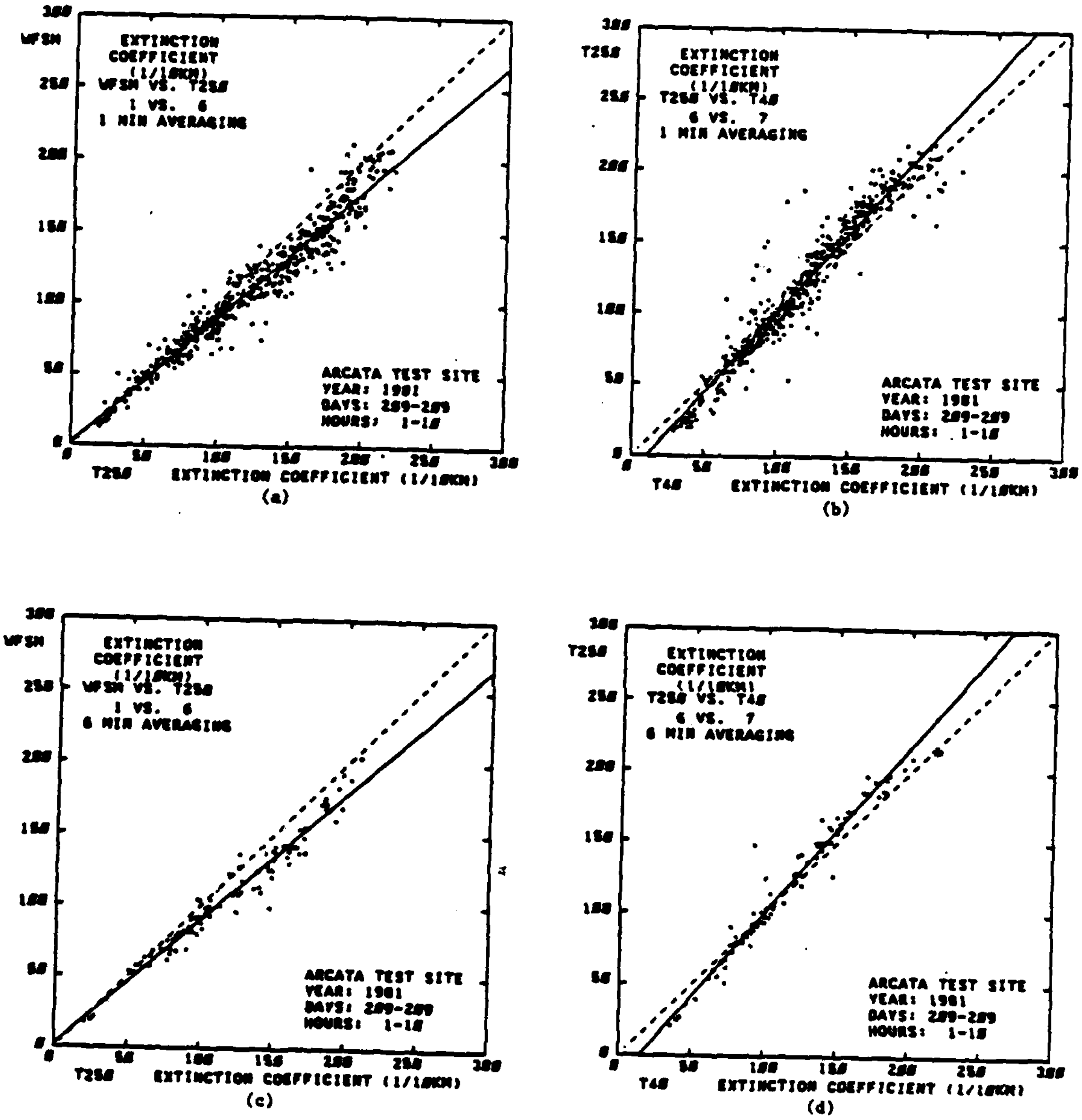


FIGURE 2. EXTINCTION COEFFICIENT SCATTER PLOTS FOR EVENT 1: (a), (c) FOG-15 VERSUS 250-FOOT TRANSMISSOMETER: (b), (d) 250-FOOT TRANSMISSOMETER VERSUS 40-FOOT TRANSMISSOMETER; AVERAGING TIME = 1 MINUTE FOR (a), (b), 6 MINUTES FOR (c), (d).

TABLE 3. LEAST-SQUARES FIT: EVENT 1

SENSOR* PAIR	AVERAGING TIME (MIN)	SLOPE K	OFFSET D	RMS ERROR	FRACTION RMS ERROR
1,6	1	0.88	2	10.5	0.098
1,6	6	0.88	2	8.8	0.082
6,7	1	1.13	-12	12.6	0.105
6,7	6	1.17	-17	9.6	0.081
1,7	1	1.05	-14	8.4	0.078
1,7	6	1.07	-17	5.9	0.055

* 1 = Wright & Wright FOG-15.

6 = Tasker RVR 500 250-foot baseline.

7 = Tasker RVR 500 40-foot baseline.

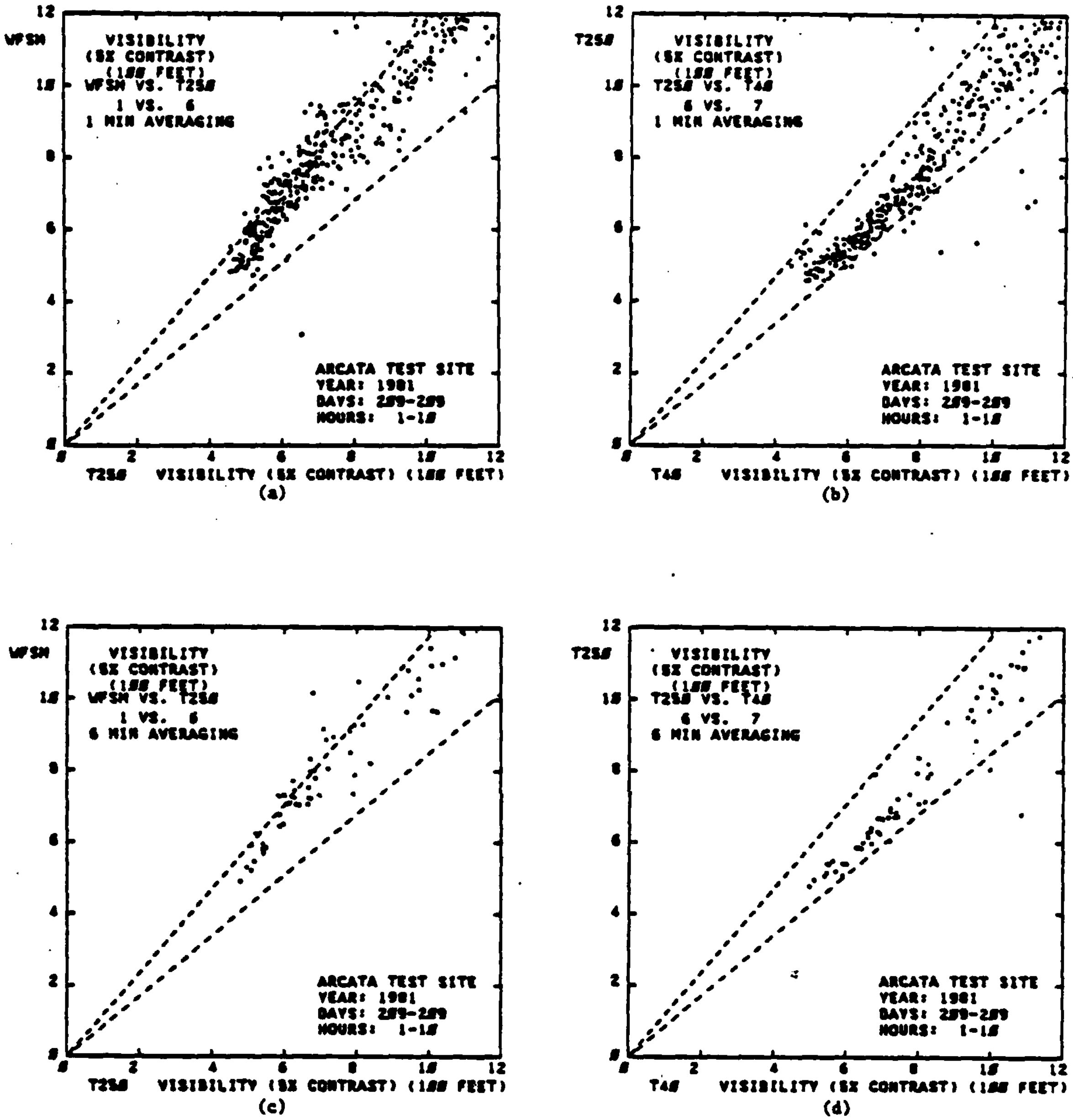


FIGURE 3. VISIBILITY SCATTER PLOTS FOR EVENT 1: (a), (c) FOG-15 VERSUS 250-FOOT TRANSMISSOMETER; (b), (d) 250-FOOT TRANSMISSOMETER VERSUS 40-FOOT TRANSMISSOMETER: AVERAGING TIME = 1 MINUTE FOR (a), (b), 6 MINUTES FOR (c), (d).

The examples in Figure 2 illustrate how the fitted values of K and D in Equation 2 can be used to evaluate the sensor systematic errors. First, one can assume that the offset error is zero for the FSM and that the slope is unity for the 250-foot transmissometer because of the small forward-scatter error for such a long baseline. Thus, the combination of an FSM with a transmissometer constitutes a valid "standard" for determining systematic errors in visibility sensors. The offset error is seen to be small ($D_{16}=2$) for the 250-foot transmissometer by its comparison with the FSM. The FMS is observed to have a significant slope error ($K_{16}=0.88$) in its comparison with the 250-foot transmissometer. Since the 250-foot transmissometer exhibits no significant errors for this event, the offset ($D_{67}=12$, 17) and slope ($K_{67}=1.13$, 1.17) of the comparison between the two transmissometer baselines can be ascribed to the 40-foot transmissometer. The offset is not surprising; it corresponds to a window loss of 2 percent. The slope error of 13 or 17 percent is due to two effects. The first is that, the actual separation between the ends of the receiver and transmitter baffles is actually 36.6 feet rather than the nominal 40 feet used to calculate the extinction coefficient. This error would lead to $K_{67} = 40/36.6 = 1.09$, i.e. a 9 percent error. The remaining slope error of 4 or 8 percent can be ascribed to forward-scatter error and random error. Note, the forward-scatter error causes the 40-foot baseline sensor to read low extinction as is observed.

6. RANDOM ERRORS

Random errors in visibility measurements can arise from a number of sources. The first is the intrinsic noise of the sensor. The second is the statistical fluctuations which occur when there are few particles within the sample volume sensed (relevant to rain and snow). The third is spatial variations in the extinction coefficient. All random errors can be reduced by averaging for a longer period of time. The second and third source of error can also be reduced by averaging over a larger volume of space.

The existence of long-baseline transmissometers at Arcata offers the opportunity of correlating the short-baseline and point sensors with what a pilot would see. The pilot's view averages over a distance equal to the RVR, while the sensors all measure over a distance much shorter than the measured RVR. Comparisons with the long-baseline transmissometers thus gives some indication of how representative the sensor measurements can be. Because of the greater stability of the long-baseline measurements, most of the variation in such comparisons can be ascribed to the short-baseline measurement.

The least-squares fit method described in the last section can be used to measure the random variation between two sensors. The root-mean-square (rms) errors listed in Table 3 represent the variation in σ_1 which is not explained by Equation 2. Because the variation tends to be a fraction of the extinction coefficient, it is useful to divide the rms error of σ_1 by the mean value of σ_1. The resulting fractional rms errors are listed in the last column of Table 3. This normalization also allows the comparisons of rms errors for different sensors to be independent of slope (K) errors.

The evaluation of Event 1 in Table 3 provides an example of the sorts of information that can be derived from the variation analysis.The FOG-15 FSM was mounted on the tower supporting the 40-foot receiver of the dual-baseline transmissometer. The fractional rms errors for the 40-foot transmissometer and the FSM with the 250-foot baseline transmissometer are the same (although the scatter plots show a different distribution of errors). The FSM and the 40-foot transmissometer, because of their proximity, agree better with each other than with the 250-foot transmissometer. Comparisons for the same event of the three sensors in Table 3 with the 720-foot transmissometer (all transmitters at the same location) illustrate the representativeness of the measurements. The one-minute average fractional rms errors are 0.168, 0.178, and 0.115 for the FOG-15 FSM, 40-foot transmissometer, and 250-foot transmissometer, respectively. For comparison, the equivalent value for the parallel 720-foot Skopograph is 0.036; thus two adjacent transmissometers are observed to agree very well. The results show that the 250-foot transmissometer gives a significantly better prediction (one third less rms variation) of the 720-foot averaged exinction coefficient than the 40-foot transmissometer or the FSM, which have similar correlations. The sensor displacement probably has more effect than spatial averaging on this result. The EG&G 207 FSM, mounted on the 250-foot receiver tower near the middle of the 720-foot baseline, showed an even lower fractional rms error of 0.107.

Event 1, evaluated in Figures 2 and 3 and Table 3, had slowly varying extinction coefficients. The most rapidly varying events have fractional rms errors larger by factors of 3.5 and 2.0 for one and six minute averaging, respectively. As would be expected, longer time averaging is more effective in reducing the rms errors for the rapidly varying events, compared to the modest reductions in Table 3. In fact, increasing the averaging time from one to six minutes is observed to reduce the rms error by almost the full factor, $\sqrt{6}$, expected for random time variation.

7. SENSOR EVALUATION

The basic measurement characteristics of the candidate sensors of Table 1 are illustrated in Figures 4 and 5 and Table 4 for another slowly varying fog event (Event 2). This event reaches lower visibilities than Event 1 shown in Figures 2 and 3 and Table 3. Consequently, the 720-foot baseline transmissometers clip (see Figure 6) and cannot be used in least-square fits. The 250-foot transmissometer therefore serves as the primary standard sensor. Figure 4 shows the extinction coefficient scatter plots for six minute averaging. Figure 5 shows visibility scatter plots for one minute averages. The dashed line correspond to $\pm$ 15 percent errors, which approximately represents the outer error limit for one minute averaging. Table 4 which contains the results of the least-squares fits for both one and six minute averages. The offsets D are less well defined for this event because the extinction coefficient never falls below 100 units. Figure 7 shows the visibility time history of the first part of Event 2.

The characteristics of each candidate sensor will be discussed in turn. The sensors are listed in order of decreasing usefulness.

TABLE 4. LEAST-SQUARES FIT: EVENT 2

SENSOR* PAIR	AVERAGING TIME (Min)	SLOPE K	OFFSET D	FRACTION RMS ERROR
1,6	1	0.99	-1	0.098
1,6	6	0.99	-2	0.073
3,6	1	1.09	12	0.072
3,6	6	1.10	9	0.043
7,6	1	0.83**	9	0.081
7,6	6	0.83**	11	0.053
12,6	1	0.83	-14	0.058
12,6	6	0.83	-14	0.031

*1 Wright & Wright FOG-15 FSM
3 EG&G 207 FSM
6 250-foot RVR 500 Transmissometer
7 40-foot RVR 500 Transmissometer
12 164-foot Skopograph Transmissometer

**Correcting for the baseline error yields a slope of 0.90.

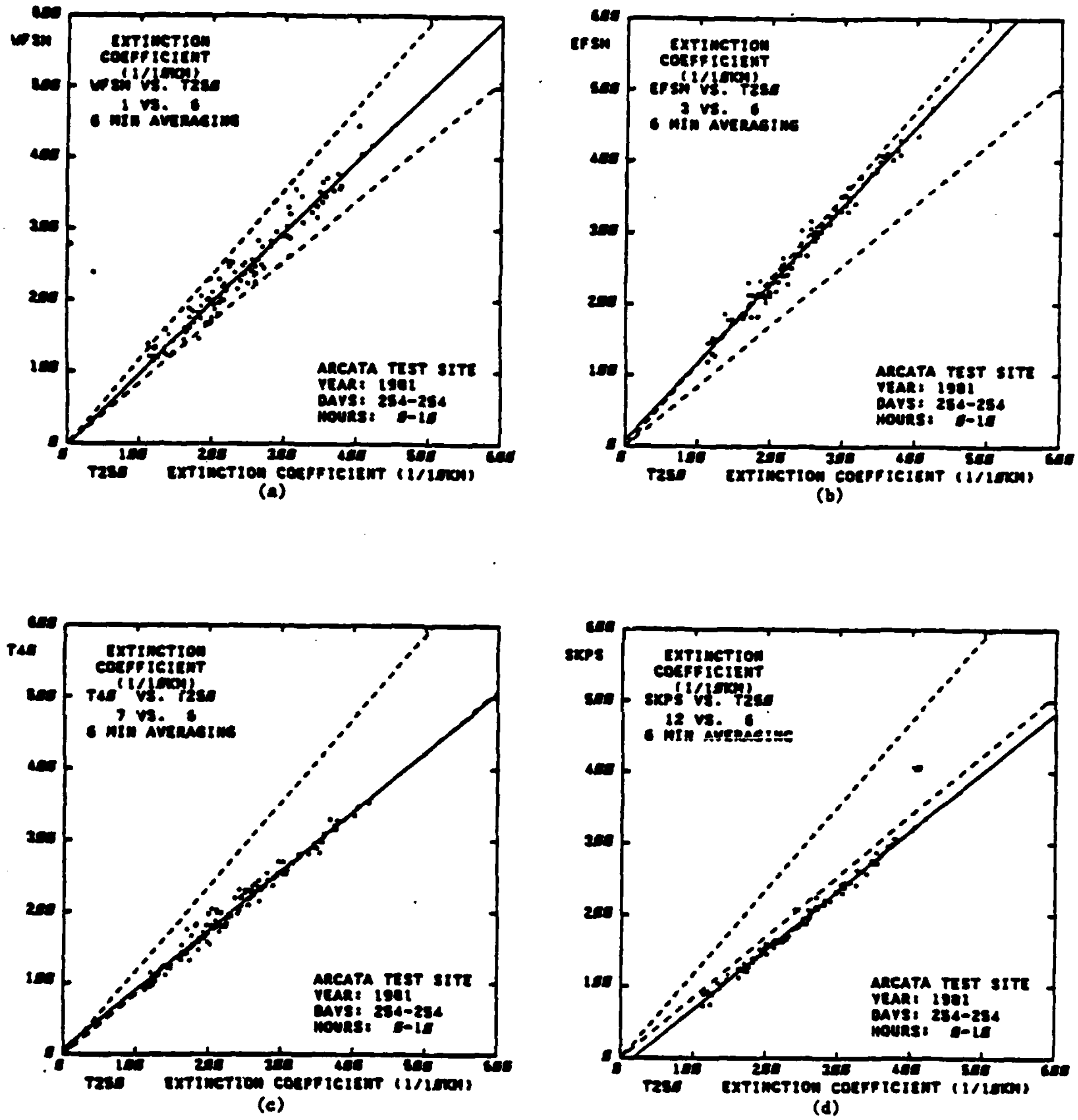


FIGURE 4. EXTINCTION COEFFICIENT SCATTER PLOTS FOR EVENT 2 FOR FOUR SENSORS VERSUS THE 250-FOOT TRANSMISSOMETER: (a) FOG-15, (b) 207, (c) 40-FOOT TRANSMISSOMETER, (d) 164-FOOT SKOPOGRAPH

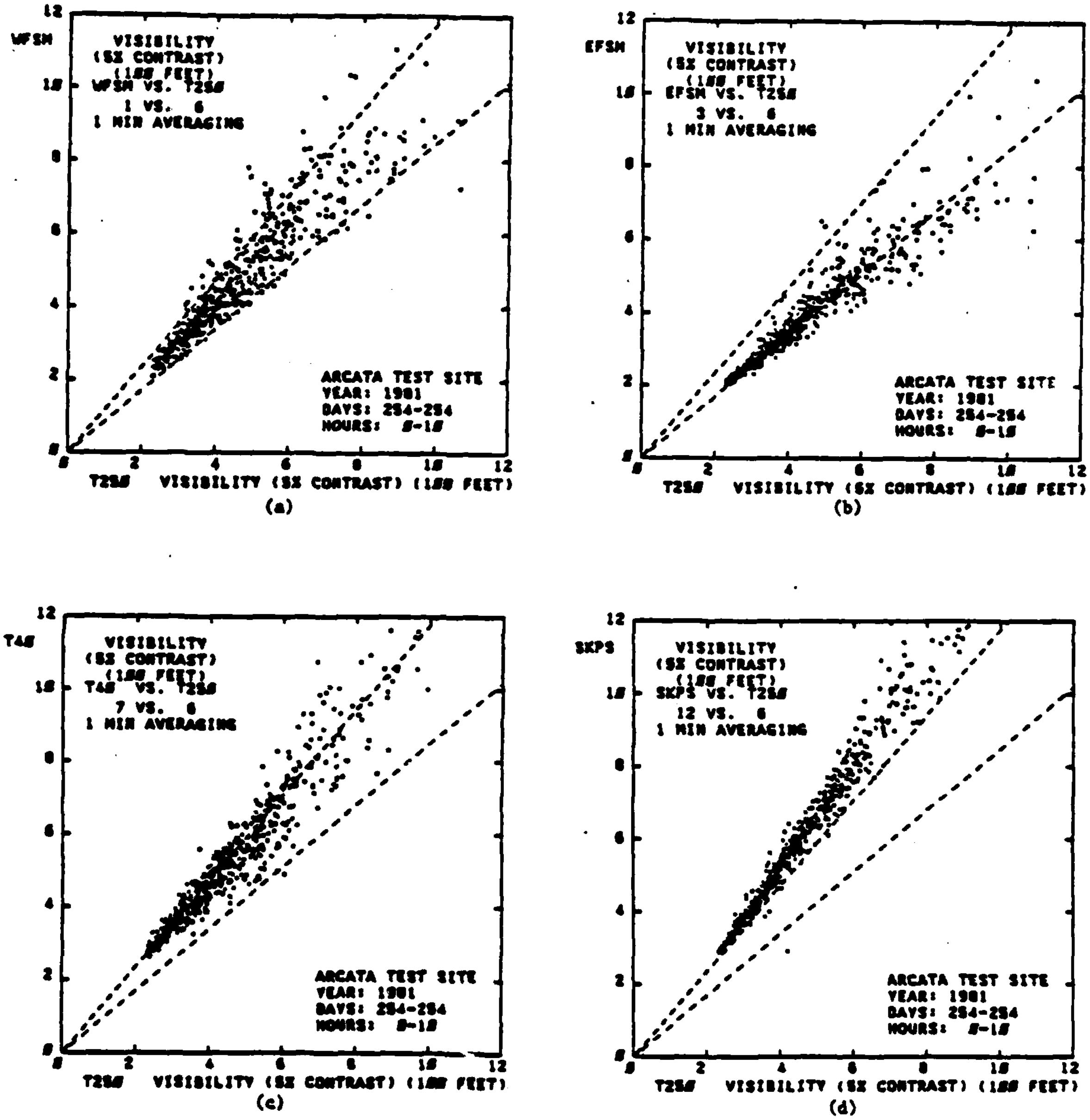


FIGURE 5. VISIBILITY SCATTER PLOTS FOR EVENT 2 FOR FOUR SENSORS VERSUS THE 250-FOOT TRANSMISSOMETER: (a) FOG-15, (b) 207, (c) 40-FOOT TRANSMISSOMETER, (d) 164-FOOT SKOPOGRAPH.

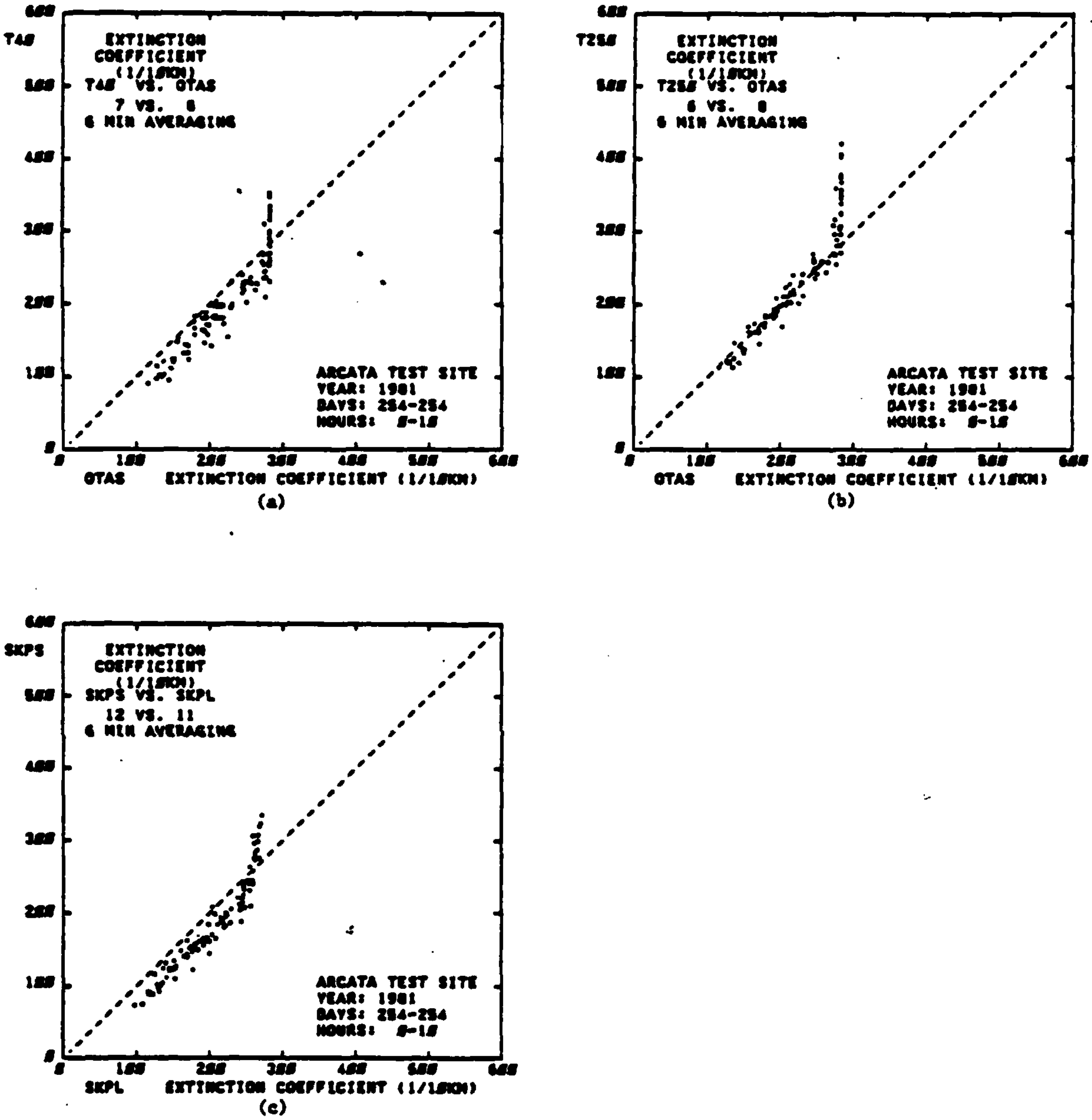


FIGURE 6. EVENT 2 EXTINCTION COEFFICIENT SCATTER PLOTS FOR SHORT-BASELINE TRANSMISSOMETERS VERSUS 720-FOOT BASELINE TRANSMISSOMETERS OF THE SAME TYPE: (a) 40-FOOT RVR 500, (b) 250-FOOT RVR 500, (c) 164-FOOT SKOPOGRAPH.

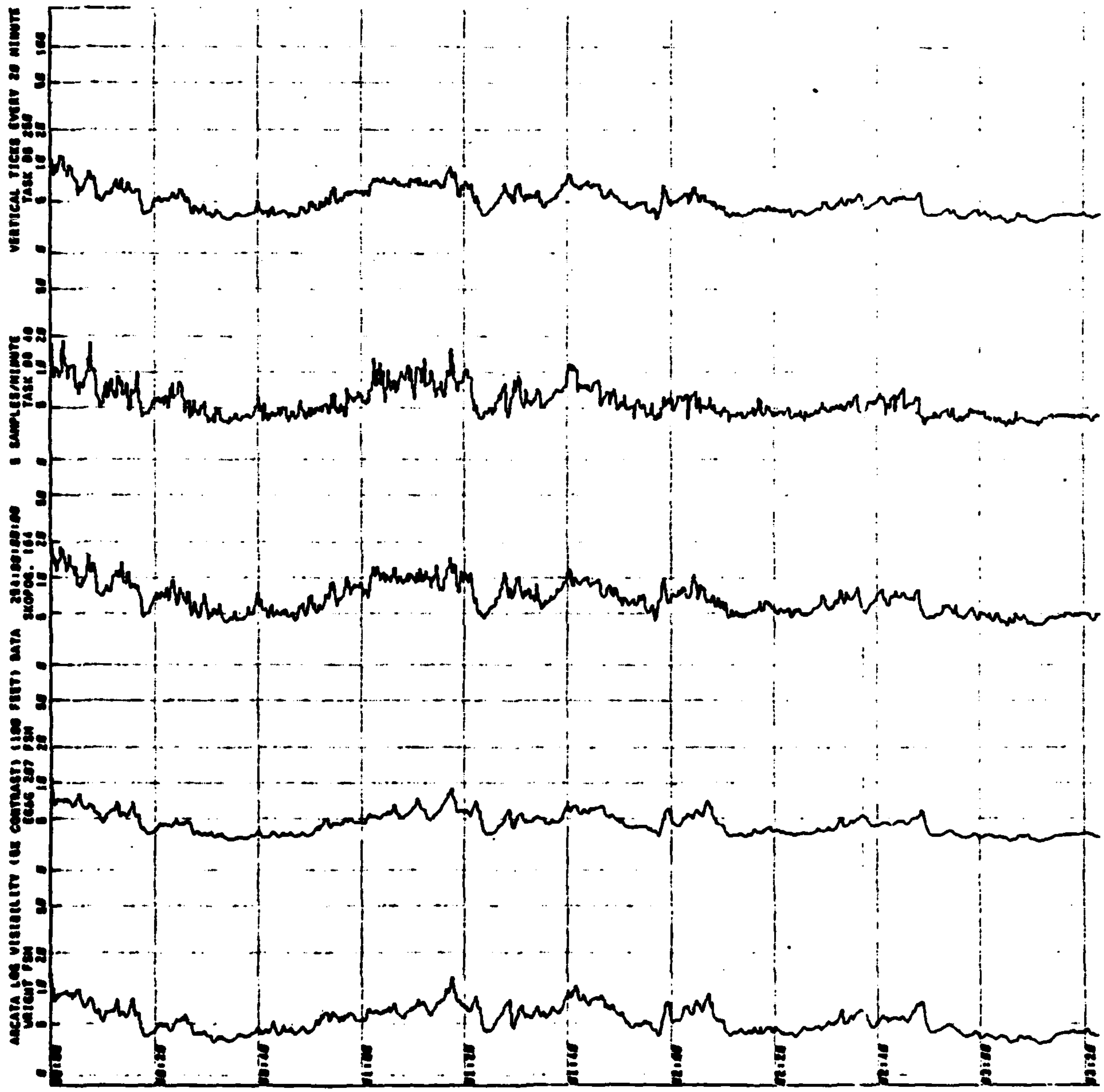


FIGURE 7. VISIBILITY TIME HISTORY FOR THE FIRST PART OF EVENT 2.

7.1 RVR 500 40-FOOT TRANSMISSOMETER

Comparisons of the 40-foot transmissometer with the 250-foot transmissometer indicate a forward-scatter error of 5 to 10 percent. This value is small enough that a calibration correction of perhaps 7 percent would probably result in systematic errors negligible compared to random variations. The 100-percent calibration of the 40-foot transmissometer appears to be more stable than that of conventional transmissometers, presumably because the elaborate hood over the transmitter has drastically reduced the rate of window contamination. This stability appears in both the data analysis and the observations of the site operator. Figure 6a,b shows that the RVR 500 receiver can measure transmission to below 0.2 percent which was set as a software clipping level in the data analysis. The 40-foot transmissometer thus appears to have no fundamental limitations on use for RVR down to 100 feet.

Several problems requiring further study were observed in the course of the Arcata tests. During the last portion of the tests (September 1981 and after) the 40-foot transmissometer sometimes acquired a large offset at the beginning of night fog event. The offset would then last until noon of the following day. The 40-foot transmissometer also showed greater diurnal variations in offset than one would expect from the normal background light level.

7.2 FOG-15 FSM

The FOG-15 sensor appears to have a stable calibration. During the early part of its testing the calibration was checked periodically using a translucent plastic disk as scatterer and was found to be unchanged. The difference in calibration between Event 1 (slope = 0.88) and Event 2 (slope = 0.99) is due to a gain reduction by about a factor of three, (assumed to be exactly three in the analysis), which was intended to allow measurements at lower visibilities without saturation. At the standard gain the sensor response becomes nonlinear for 5-percent-contrast visibility below about 160 feet, according to the manufacturer. The factor of three gain reduction reduces the saturation level to about 50 feet, which corresponds to a night

RVR of about 250 feet, according to Figure 1. Extending the range down to 100-foot night RVR would require an additional range reduction by a factor of 2.5 (a 5-percent-contrast visibility limit of 20 feet). These gain reductions should have no significant effect on measurements at the high RVR limit (1200 feet) of Category 3. The gain reduction should also totally eliminate any effects of daylight.

The FOG-15 data at Arcata were affected by transmission line problems which are difficult to disentangle from actual sensor problems. The data under clear conditions show a variety of dc offsets, fluctuation and spikes, which do not correlate with the other visibility sensors. The data from this sensor, as well as the EG&G 207, were transmitted as voltage levels requiring resolution of a few millivolts. Some form of modulated data transmission must be used to make the sensor acceptable for airport use. An examination of FOG-15 data from Otis AFB, which used short, new data lines, could answer some of the questions concerning the FOG-15 performance.

During the latter portion of the tests the FOG-15 showed greater sensor noise than the EG&G 207, next to which it was mounted. This difference appears in Table 4 as larger rms errors for the FOG-15 than the 207 when both are compared to the same sensor. Since this effect did not appear until some time after the two FSM's were mounted together on the 250-foot receiver tower, it could conceivably represent either a sensor or a cable malfunction.

The analysis of Event 1 indicated that the FOG-15 and the 40-foot transmissometer are equally successful in predicting the measurements on a 250-foot or a 720-foot baseline for a one-minute average. Thus, it appears that spatially averaging over a 40-foot baseline offers no advantage over the point measurement of an FSM.

The FOG-15 has shown no fundamental problems which would preclude it from being used for RVR measurements below 600 feet. The observed technical problems must be resolved before the sensor can be recommended for extensive operational testing. The FOG-15 is by no means as mature a sensor as the RVR 500 but its potential for much lower cost makes further examination worthwhile.

7.3 Model 207 FSM

The Model 207 FSM is expensive in both design and required maintenance. The manufacturer, EG&G, has indicated no interest in making sensor improvments without a development contract. Consequently, even though its performance is generally satisfactory, it is not an attractive option for operational deployment.

The slope of 1.10 shown in Table 4 for the 207 versus the 250-foot transmissometer has been consistently maintained over many months and apparently reflects a slight miscalibration of the instrument.

The 207 FMS was installed at Arcata without modification as it came from the factory. It has often exhibited a drastic loss in sensitivity between 1100 and 1600 hours, which has never been corrected. Midway through the test period an Air Force technician overhauled the sensor (as they normally do upon receipt of a new unit from the factory). Even though he found a number of problems, the daytime loss of sensitivity persisted. This problem has never appeared before in the many 207 FSM sensors used by the Air Force. Perhaps it is due to a diurnal problem with the Arcata cables; the same signal cable was used throughout the tests.

7.4 SKOPOGRAPH

The Skopograph is as expensive as the RVR 500 and incompatible with it. Thus, it is an unlikely candidate for extending current RVR measurements to Category 3b, since much of the existing equipment would have to be duplicated.

The Skopograph testing was compromised by two installation decisions made by the manufacturer. First, the short-baseline was set at 164 feet which is too long to cover the full category 3b range. Second, the sensor height was set at 8 feet rather than the 16 feet of all the RVR 500 equipment and the FSM's. Vertical variations in fog density can thus affect the sensor intercomparisons. This would not be so much a problem if there were no other differences between the sensors. Unfortunately, the wavelength of the radiation is also different for the two groups of sensors. The measured slope between the long-baseline Skopogaph and the long-baseline RVR 500 was observed to vary from event to event. Sometimes it was near unity. Sometimes the Skopograph read lower extinction. This variation could be due to lower fog density near the ground or a wavelength effect for the events showing disagreement.

The 17 percent slope error shown in Table 4 for the short-baseline skopograph compared to the 250-foot RVR 500 is typical of the apparant forward-scatter error observed for the Skopograph. Figure 6 shows a similar error in comparisons of the short and long Skopograph baselines. The slope error is thus not due to the height and wavelength effects mentioned before, which are identical for both Skopographs, but apparently to forward scattering. The light source and receiver field of view are significantly larger for the Skopograph than the RVR 500, so that 17 percent forward-scatter is conceivable. The forward-scatter error would become even larger if the baseline were reduced to cover the full Category 3b range. Consequently, the systematic errors of the Skopograph appear to be too large to consider further testing without some modification.

The Skopograph pulsed light source exhibited a two-percent oscillation with a period of 25 minutes. This problem was traced to an unstable temperature control system which was fixed by moving the temperature sensor closer to the heater.

8. LIMITATIONS OF ARCATA DATA

The Arcata tests had a number of limitations which reduce the usefulness of the data collected there. (1) Although the site is blessed with an abundance of fog in the summer and fall and rain in the winter, it rarely experiences below-freezing conditions. (2) Only one sensor of each type was installed. Consequently, it was not possible to determine whether a problem was due to sensor design or a random failure. (3) Calibration and maintenance were often haphazard and were not recorded consistently. (4) The site operator was not able to diagnose some important equipment problems such as the 207 FSM daytime dropouts and the pulse/dc converter glitches.

The remoteness of the test site precluded frequent trouble shooting by the manufacturers or by TSC personnel. (5) The data lines were old and contributed errors to voltage signals (United States FMS's) and probably also to current loop signals (all Impulsphysics sensors).

The pulse/dc converter counts transmissometer pulses for 15 seconds and then converts the count to a dc voltage for measurement by the data acquisition system. The glitch problem has been traced to shortened count periods which result in an apparent reduced transmission. The glitches are of two types: (1) occasional large spikes as large as 10 percent transmission and (2) small continual variations of 1 percent or less.

The pulse/dc converter glitches have the biggest effect on the shortest baseline (40 feet). They contribute to the high frequency variation for the 40-foot sensor in Figure 7. An analysis of the glitches indicates that they make only minor contributions to the one-minute variations of the 40-foot transmissometer in Table 3. In the comparison with the 250-foot transmissometer isolated glitches greater than 2 percent transmission contribute only 10 percent of total mean-square error, while glitches smaller than 2 percent transmission contribute only 1 percent of the mean-square error.

9. RECOMMENDATIONS

The FOG-15 and 40-foot RVR 500 sensors, along with the data recording equipment at Arcata, should be installed as soon as possible at an airport for an operational test. The sensors should be returned to their manufacturers for checkout and updating before installation. Likewise the recording equipment should be returned to TSC for checkout. A quick installation is important in order to make use of the winter fog season at the test airport. Additional sensors should be procured to upgrade the test site to the anticipated operational configuration.

If the FOG-15 continues to be viewed as a viable candidate sensor, the manufacturer should be requested to develop a pulse output which emulates a 40-foot transmissometer, so that it can be interfaced to the existing RVR processor.

Additional analytic work is needed to substantiate the conclusions of this preliminary report. In addition to addressing the problems discussed in this report, a more detailed analysis is needed concerning how well the sensor measurements will represent runway visibility. This question bears directly on the number of sensors required along a runway.

APPENDIX B

ORIGINAL TEST PLAN

PROPOSED

SCHEDULE OF EVENTS, EGLIN AFB

1.	INVENTORY, ASSEMBLY, FABRICATION, ETC.	5/24-6/1
2.	EQUIPMENT ALIGNMENT IN CHAMBER, CALIBRATION, INTERFERENCE TESTS, POWER AND DATA ACQUISITION.	6/1-6/4
3.	START FOG TESTS (100'-6000')	6/7-6/15
4.	REMAINDER OF FOG TESTS (REPEATS)	6/15-6/18
5.	RAIN	6/21
6.	FREEZING RAIN	6/22
7.	SNOW	6/23
8.	LOW TO HIGH TEMPERATURE EXTREMES.	6/24-6/25
9.	DISASSEMBLE, PACK AND SHIP.	6/28-7/2

CLIMATIC CHAMBER, EGLIN AFB.

MR. RICHARD TOLIVER

904-882-5411

FAA VISIBILITY TEST

FEDERAL AVIATION ADMINISTRATION
VISIBILITY SENSOR (S) TEST
McKINLEY CLIMATIC LABORATORY
EGLIN AIR FORCE BASE, FLORIDA

1.0 **Purpose:**

Describe the performance and evaluate the accuracy of various visibility instruments in controlled environments of;

- Fog
- Precipitation (light and heavy rain)
- Freezing rain
- Snow
- Temperature extremes of -50C to +50C

2.0 **Location:**

Visibility instruments will be installed and tested in the main environment chamber of the McKinley climatic laboratory, Eglin AFB, Florida.

3.0 **Date and Duration:**

Tests will be conducted during the month of June 1982.

The climatic chamber is only available for these tests during the four (4) weeks of June 1982.

A preliminary analysis of the data will be available thirty days after completion of the test.

A final report will be available ninety days after completion of the test.

4.0 **Objectives:**

Describe the performance and evaluate the accuracy of various type visibility sensors under low visibility conditions.

Collect, analyze and summarize the test data, and prepare a final report with conclusions and recommendations.

5.0 Test Facility:

Installation of visibility sensors and collection of test data will be accomplished at the McKinley Climatic Laboratory, Eglin AFB, Florida. This environmental test chamber is the only known facility that can provide low visibility conditions down to less than 100-feet RVR, and accomodate a full RVR transmissometer system with a baseline of 250 feet. The climatic laboratory is a technical facility operated by and for the USAF, and other Department of Defense organizations. The facility can also be made available to other government agencies, on an as available basis, through the Directorate of Range Operations (ADTC).

The tests will be under the direction of the Federal Aviation Administration (FAA) at Washington, DC. Chamber environment conditions will be coordinated with, but under the direct control of, the climatic chamber assigned engineering personnel. The FAA coordinator is Jack Dorman of Systems Research and Development Service (ARD-410), telephone number 202-426-8427. Mr. Dave Burnham of the Transportation Systems Center (TSC), Boston, Massachusetts, telephone number 617-837-2470, will provide technical support, data analysis, and personnel to install and monitor all subsequent activities.

6.0 Equipment Installation/Calibration:

Equipment will be transported to the Eglin AFB climatic chamber designated staging area. FAA and TSC personnel will assemble install, test and calibrate all sensors and associated equipment to insure satisfactory operation prior to commencing the environmental tests. Assistance of ADTC personnel will be required to insure that space, power and data collection capabilities are available to optimize the evaluation effort. Signal and power cables will be installed and connected to all sensors and to the data logging facility.

6.1 Equipment Operation:

Once installed, calibrated and made operable, the sensors are expected to operate for the full period of the test in a continuous mode. It is expected that no corrective maintenance will be required. Corrective maintenance may be performed during periods when tests are not being conducted. Maintenance and calibration functions and results will be recorded in the daily log of test activities by the FAA test representative.

6.2 Daily Log:

A record will be maintained on a daily basis. Information to be included shall consist of;

a.) Existing meteorological condition.

B.) Time and duration of each measurement.

c.) Frequency of measurements.

d.) Manual observations of incoming data.

e.) Manual observation of environment (if appropriate).

f.) Any repairs, modifications, corrections, calibrations, etc..

6.3 Data recording:

ADTC will provide digital data logging capability, provide data tapes for subsequent analysis and a computer print-out of all data collected the previous day.

7.0 **Data Processing and Analysis:**

The data tapes will be processed using the TSC computer facility at Cambridge, Massachusetts. All data will be correlated and compared to observations contained in the daily log and to the measured volume of atmosphere as indicated by the calibrated laser Photometer. Achieving compatibility of data for evaluation from the diverse group of instruments will require careful attention to details of the interface.

Data tapes will be forwarded to TSC at Cambridge, Massachusetts for analysis and preparation of test reports. TSC will provide a weekly analysis of the recorded data. Upon completion of the chamber test TSC will provide a preliminary report within thirty days. A final report describing equipment performance and accuracy, and a summary of test results with conclusions and a complete analysis of the data, will be provided to the program manager for review within ninety days after completion of the test. Distribution of the test results will be accomplished by the FAA program manager.

7.1 **Data Presentation:**

Data samples from the sensors will be recorded every fifteen seconds. These samples will be processed to provide a one (1) minute and a three (3) minute average for generating scatter plots and least square fits to the data. Plots of extinction coefficient with linear regression will be prepared. These plots should indicate sensor performance as follows;

7.1 **Data Presentation** (Cont.)

a.) RVR range of 0-- 1200 feet RVR.

b.) RVR range of 600 -6000 feet RVR.

c.) Visibility range of 0 - 1 mile.

d.) Visibility range of 0 - 5 miles.

e.) Extinction coefficient, sensors vs standard.

8.0 **Visibility Sensors to be Tested**:

Instrument	Type	Path Length
Transmissometer	Skop-O-Graph	(64')
Transmissometer	MET-1	(9' folded path)
Transmissometer	RVR-500	(250',40')
Forward Scatter	EG&G-207	(4')
Forward Scatter	FS-3	(2')
Forward Scatter	FOG-15	(4')
Forward Scatter	HSS	(3')

Support instruments will include;

Calibrated laser photometer (chamber standard).

RVR laser calibrator (FAA).

Visibility markers.

Camera equipment.

9.0 **Chamber Test Conditions**:

Fog - Fog densities will be generated to provide visibilities from less than 100 feet to approximately 5 miles.

Approximately thirty levels of stable fog conditions will be generated, monitor and recorded. Each level will be monitored and recorded for fifteen minutes to provide sixty (60) data points. Stable fog density levels will be established within ± 25% of the range factors indicated below;

Stable fog density levels will be generated to cover a range of extinction coefficients by a factor of 2 . Range factors are; 3.5,5,7,10,15,20,35,50,70,100,140,200,350,500,700,1000,1400, 2000,3500,5000. (1/10 Km = units). This range of factors will include visibilities from 100 feet to 5 miles.

Additional specific reporting values may be added if time permits. It is anticipated that approximately 10% of the recorded levels may require re-examination to resolve anomalies.

Rain. - The sensors will be tested with two levels of generated rain rates.

Condition	Intensity	Visibility
Light	0.05-0.10 in./hr.	5/8 miles or more
Heavy	more than 0.30 in./hr.	5/16 miles or less

Freezing Rain. - The chamber temperature will be reduced with a light rain condition to generate freezing rain. Visibility data will collected for a minimum of sixty minutes during this condition.

Snow. - Snow will be generated with a standard snow generating machine. Data will be sampled from sensors within an area approximately 40' X 60'. Data samples will be recorded for approximately two hours.

Temperature.- The chamber temperature will be cycled between temperature extremes of -50C through +50C. Continuous samples of data from all visibility sensors will be recorded.

Calibration filters will be installed on all forward scatter instruments to provide signal levels for monitoring.

A comparison of outputs from the visibility sensors will be made to provide the best possible determination of atmospheric transmittance or extinction coefficient.

All sensor outputs will be compared to the chamber standard calibrated laser photometer.

Sensors will also be compared to each other;

Transmissometer to transmissometer.

Transmissometer to forward scatter meter.

10.2 Random Errors - Random errors in visibility measurements can result from a number of factors, these include but are not limited to;

Intrinsic noise in the instrument.

Statistical fluctuations when the sample volume particles are limited, ie snow/rain.

Spatial variations in extinction coefficient.

Random disagreement between sensors and the standard laser photometer, or as a result of the test data ------

Random disagreement (standard deviation) between sensors will be measured and displayed as a one minute average.

10.3 Systematic Errors - Systematic error in visibility measurements can be attributed to other sources;

Lamp intensity.

Geometry of optics.

Receiver sensitivity.

Forward Scattered light.

10.0 Visibility Sensor Performance/Accuracy:

A comparison of the outputs of visibility sensors will be provided to indicate the measured atmospheric transmittance or extinction coefficient.

Assigned weather observers will be used to make detailed observations of the environment.

Data will be obtained under all of the indicated meteorological conditions contained in item 9 "Chamber Test Conditions".

Information to be obtained from the proposed tests include;

Determine low visibility limits of the transmissometer.

Evaluate the performance of the short baseline transmissometer.

Determine dynamic range and accuracy of all visibility instruments.

Relate measurements of the forward scatter and transmissometer visibility instruments.

Evaluate variations of system instrument performance.

Compare performance of all sensors to the laser calibrated standard and to each other.

10.1 Pass/Fail:

Accuracy and or pass/fail criteria encompasses a number of different factors, even when a recognized standard is available and the units being tested are identical. In this case the only similarity is that all instruments have been developed to sense atmospheric change. Since different methods are used to sense a change, and in some cases the sensor output data is processed to correct sensing irregularities, the sensor raw data and total instrument data will be recorded for analysis.

10.3 Systematic Errors. (Cont.)

- # Lamp spectrum.
- # Window contamination.
- # Lamp/receiver drift.
- # Calibration error.
- # Background light.

Systematic errors will be identified (to the maximum extent possible) to determine whether corrective action or modification may improve performance.

10.4 Expected Sensor Accuracy.

Analysis of visibility instrument data, collected during the stable fog density levels indicated in paragraph 9.0, shall demonstrate that sensor performance does not deviate by more than ± 15% of the established standard.

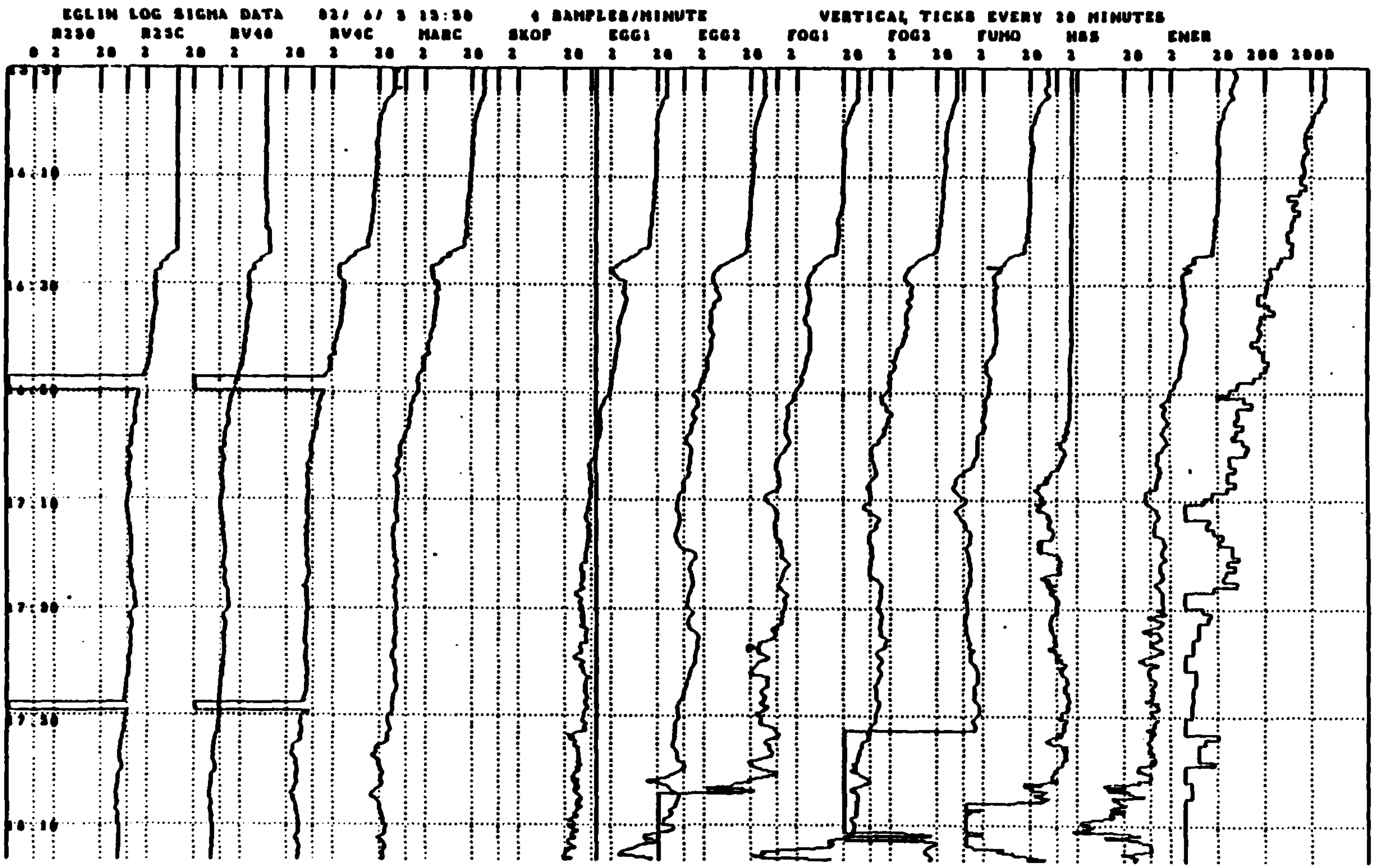
Rain, snow and temperature tests will not be conducted in a fog environment.

68 % of all sampled data points shall fall within ± 15% of the standard.

APPENDIX C

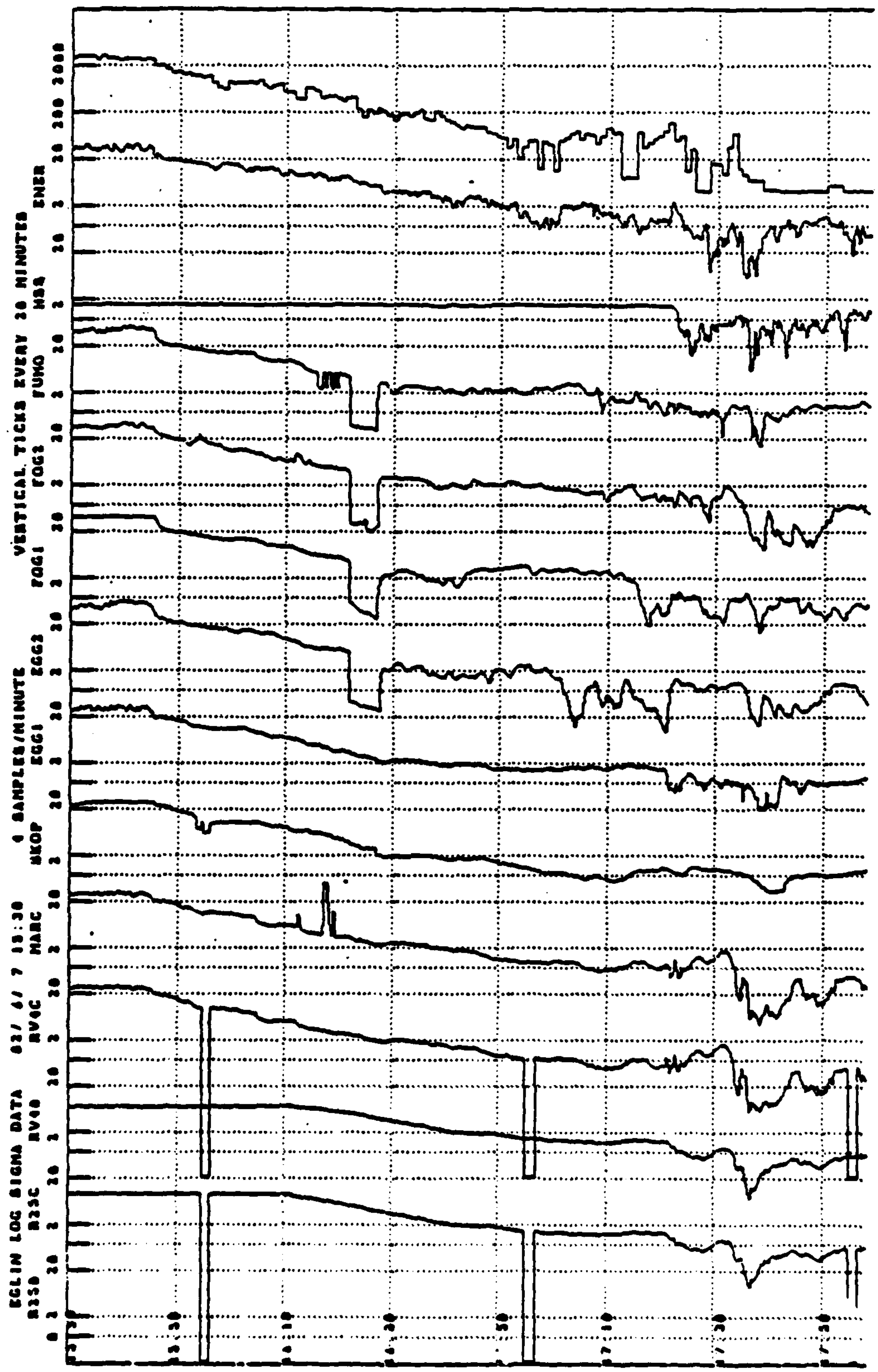
EVENT STRIPCHARTS

This appendix contains stripcharts for all events not included in the body of the report. Figure C-1 contains the steam fog events (see also Figure 6-1). Figure C-2 contains cooling fog events. The nature of the event in Figure C-2a is uncertain since no log was kept of trial fogs. Figure C-3 contains snow-machine fog/haze events (see also Figure 5-19).



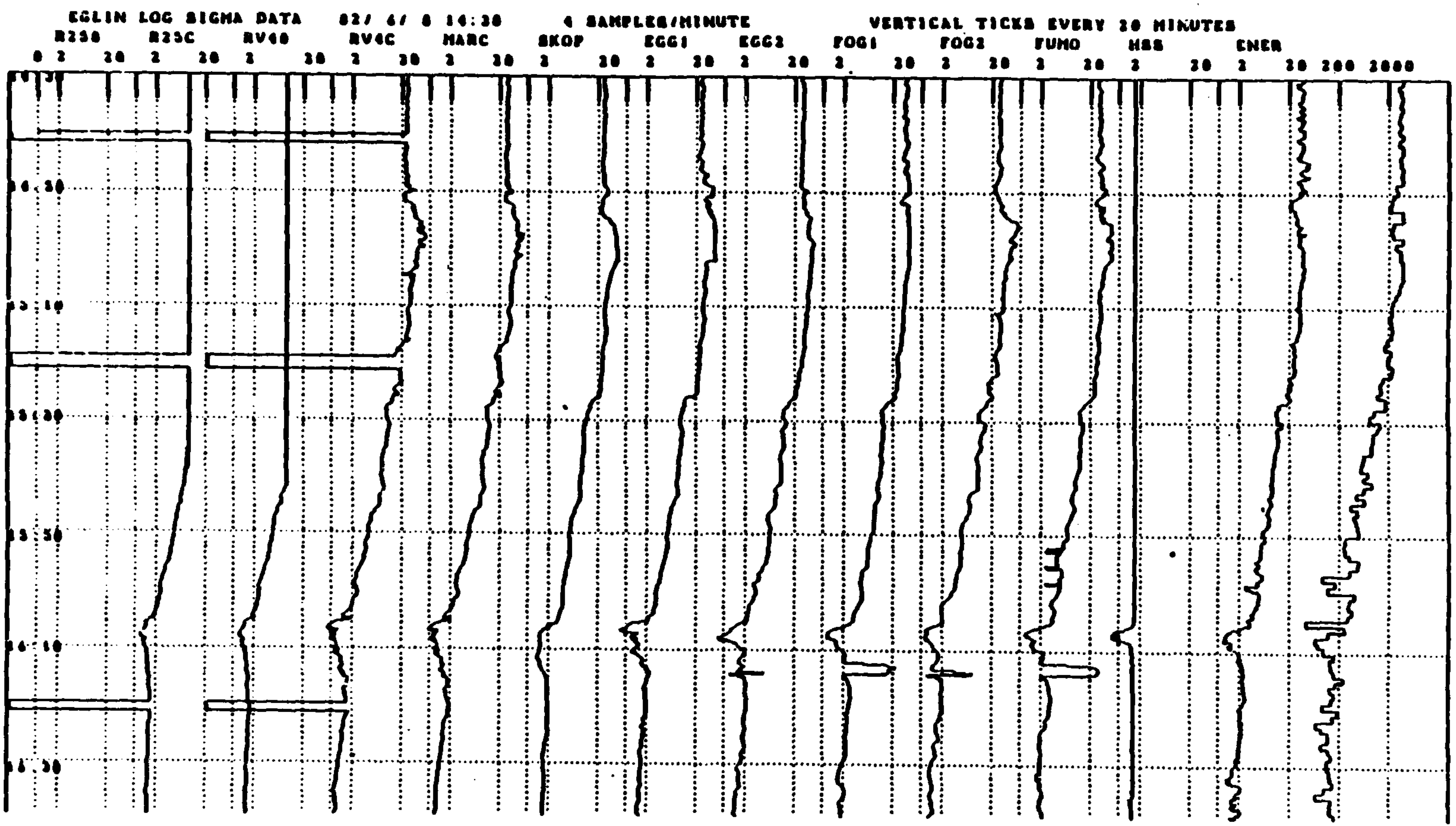
(a)

FIGURE C-1. STEAM FOG EVENTS.



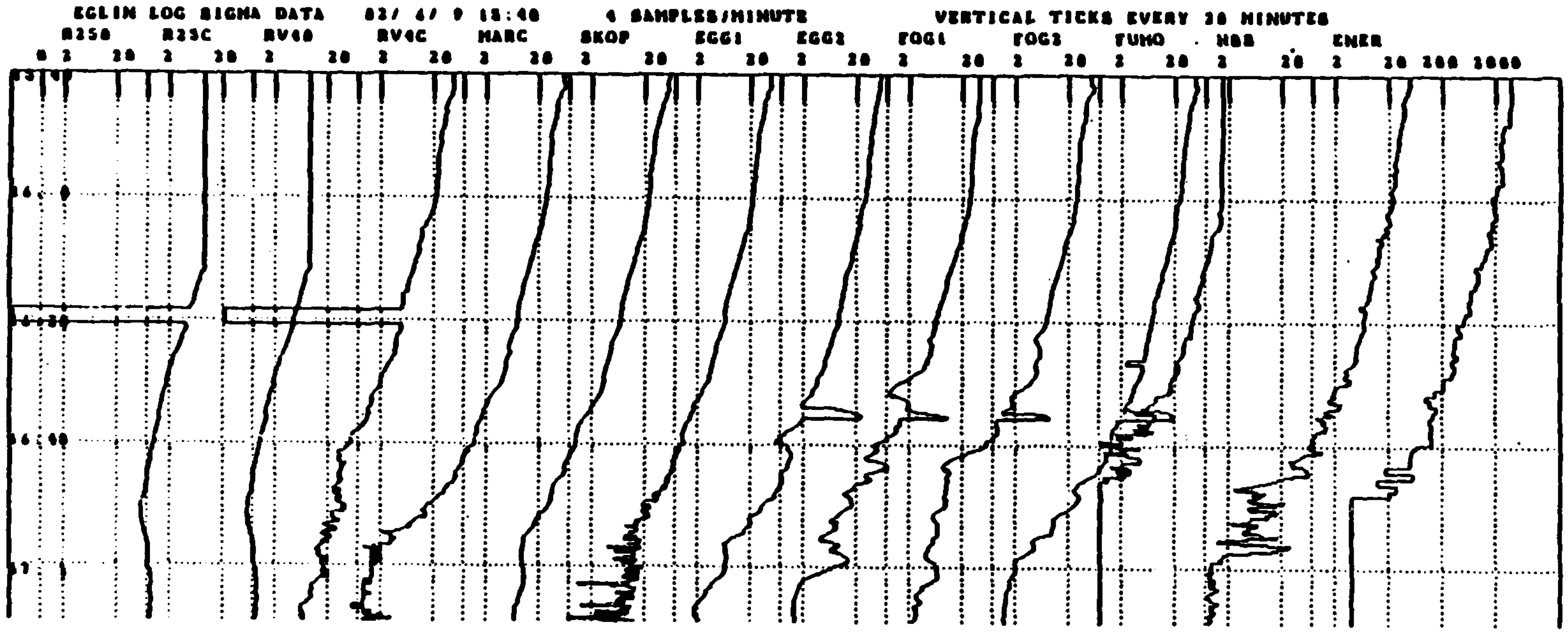
(b)

FIGURE C-1. (CONTINUED)



(c)

FIGURE C-1. (CONTINUED)



(d)

FIGURE C-1. (CONTINUED)

AD-A135 375 EVALUATION OF VISIBILITY SENSORS AT THE EGLIN AIR FORCE BASE CLIMATIC CHAMBER(U) TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MA D C BURNHAM OCT 83 DOT-TSC-FAA-83-1 3/3

UNCLASSIFIED DOT/FAA/PM-83/29 F/G 4/2 NL

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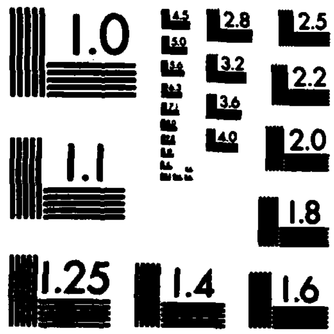
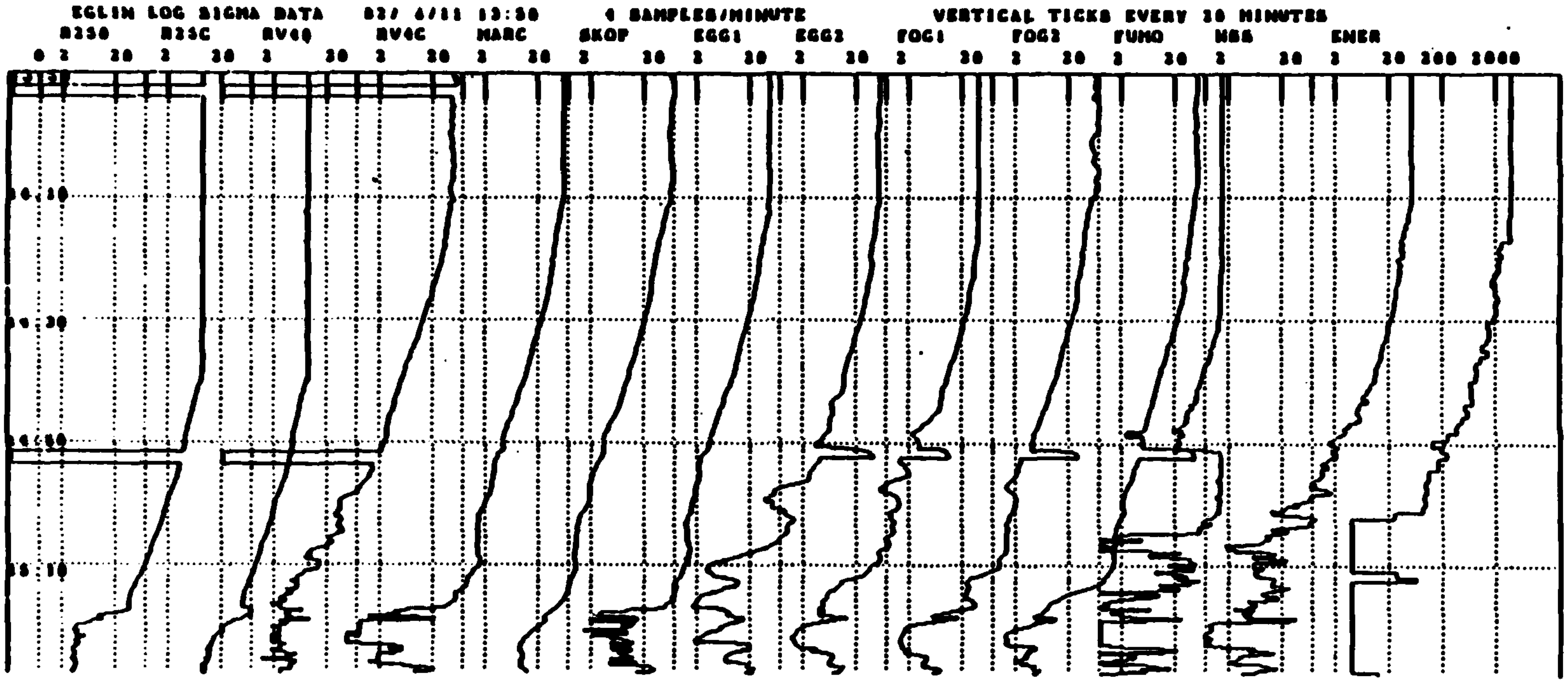
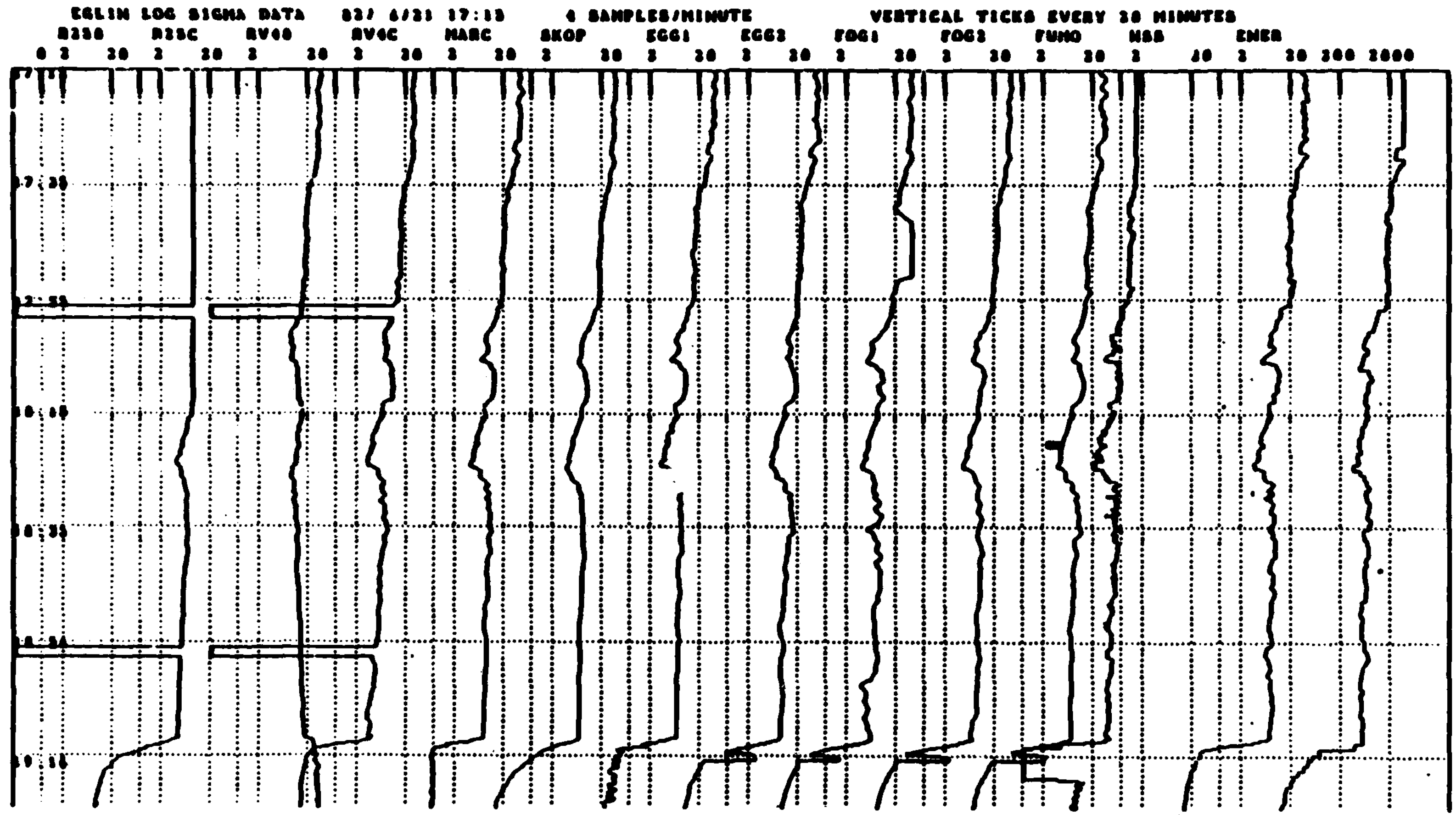


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



(e)

FIGURE C-1. (CONTINUED)



(f)

FIGURE C-1. (CONCLUDED).

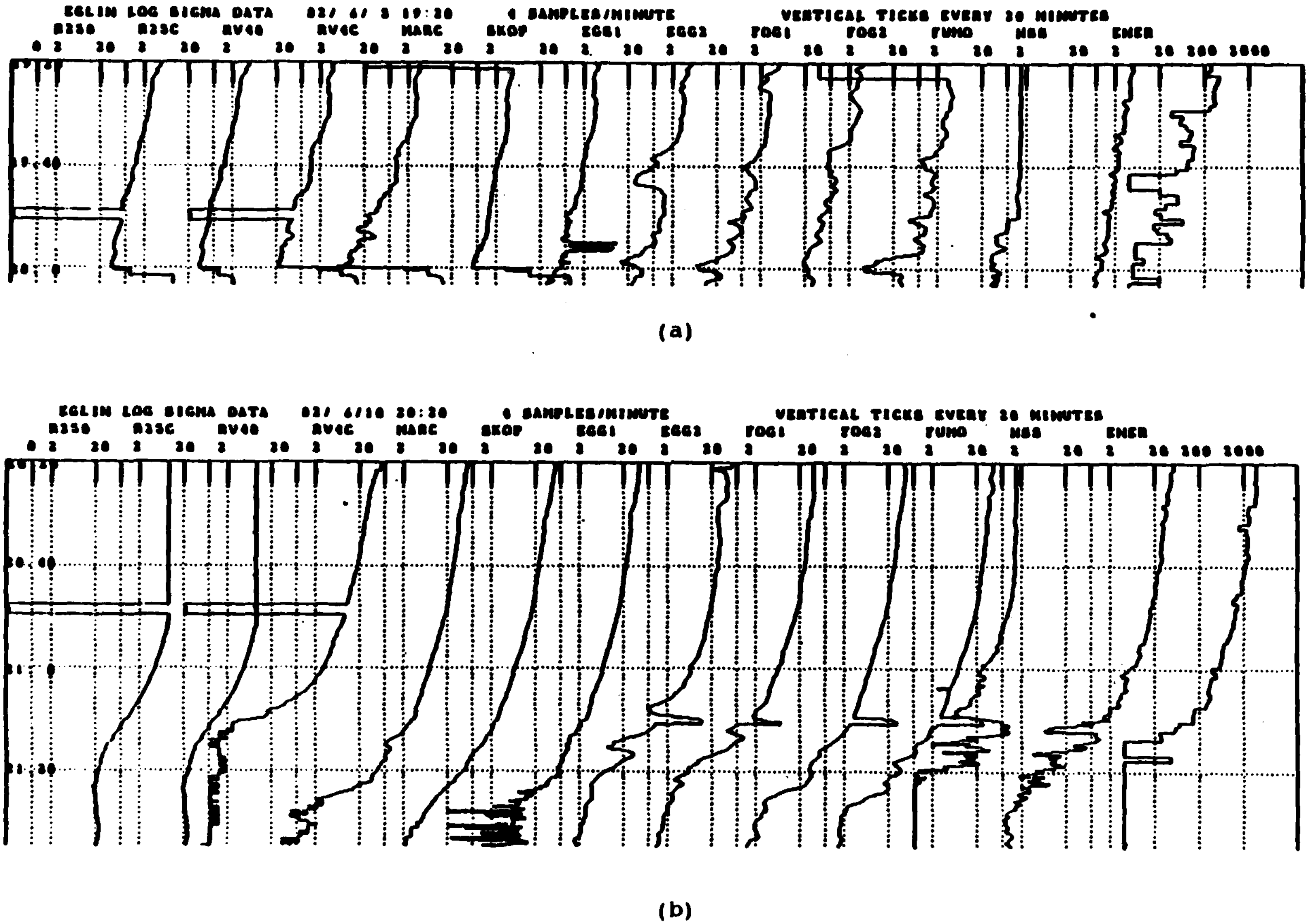
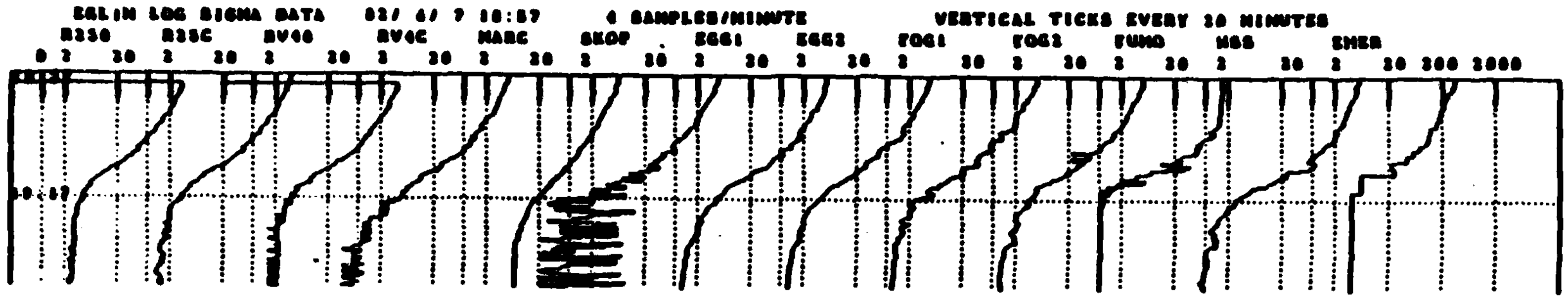
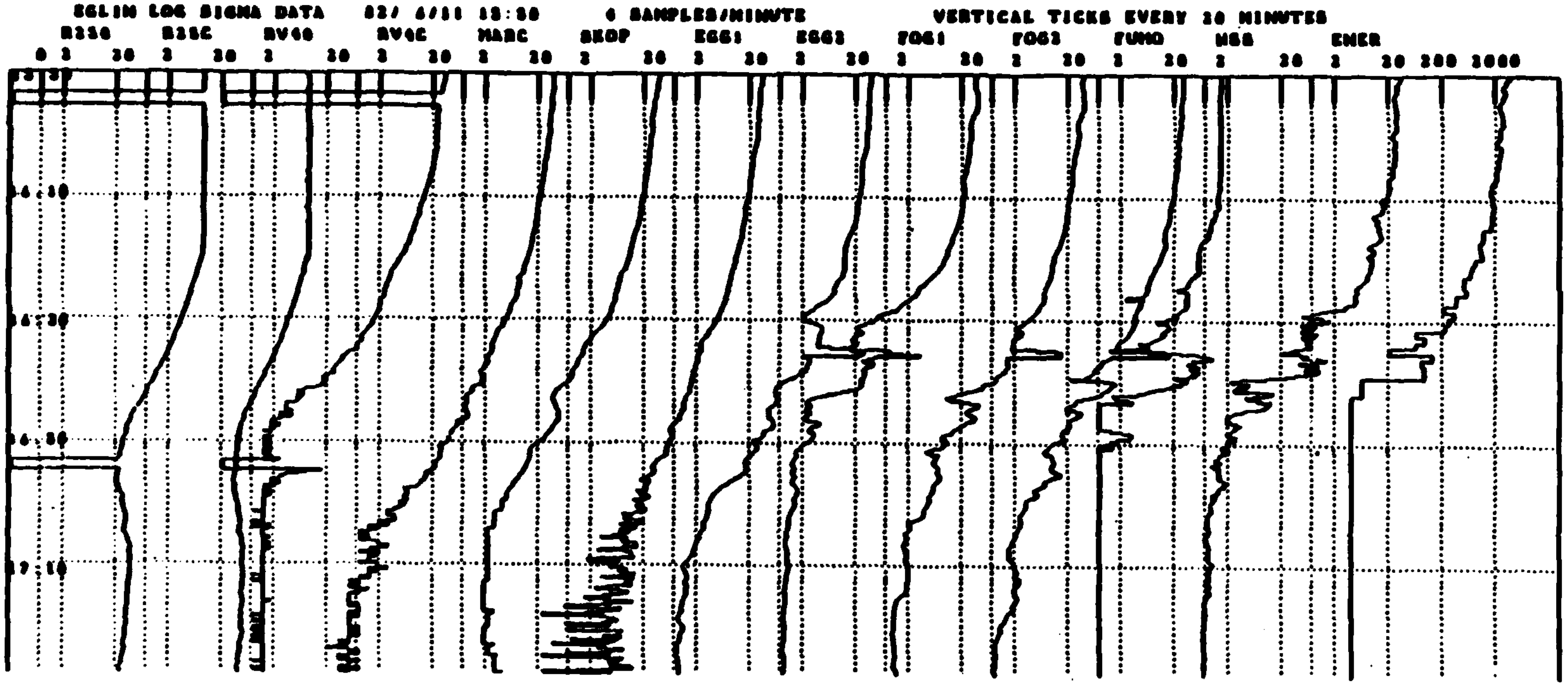


FIGURE C-2. COOLING FOG EVENTS

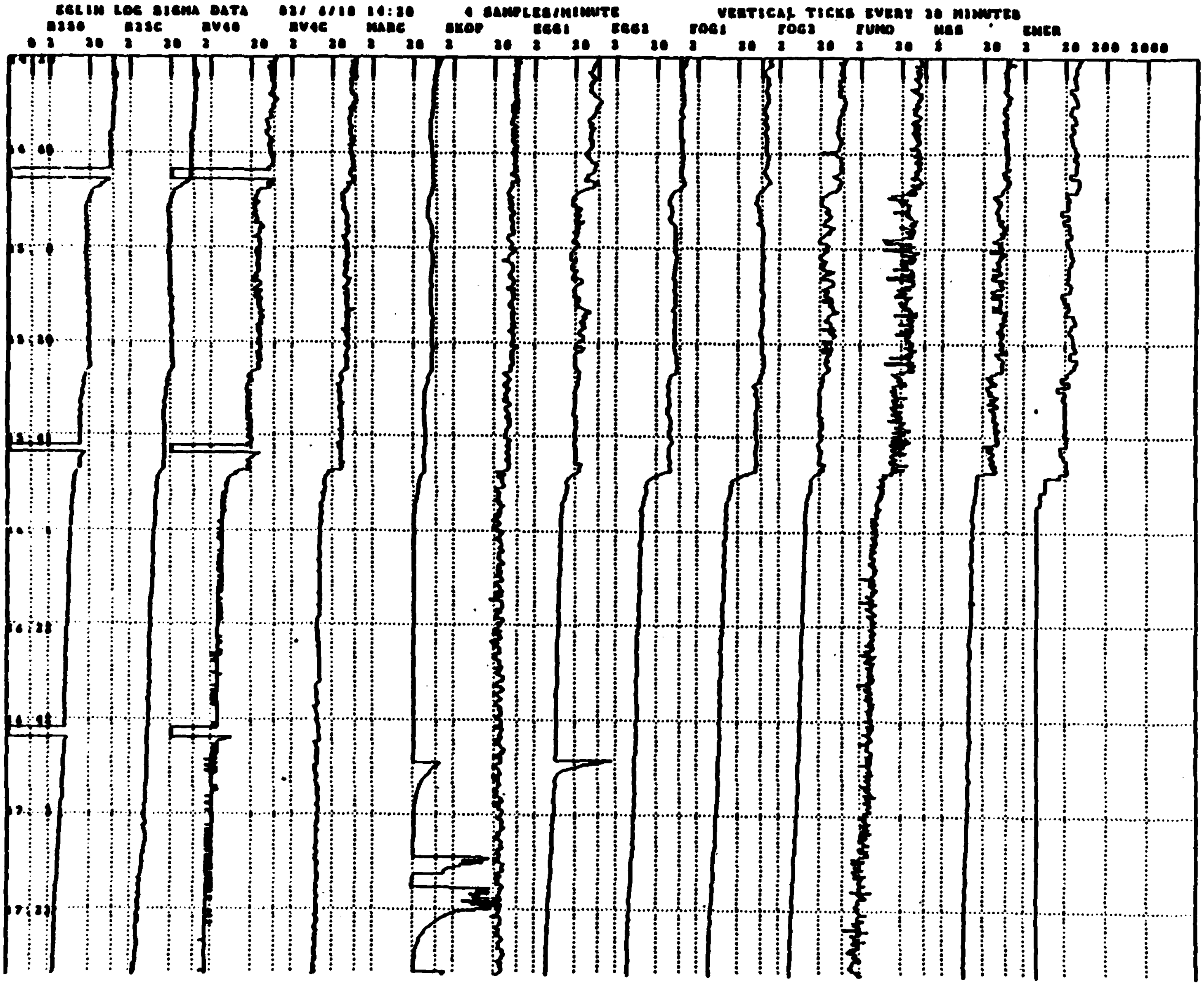


(c)



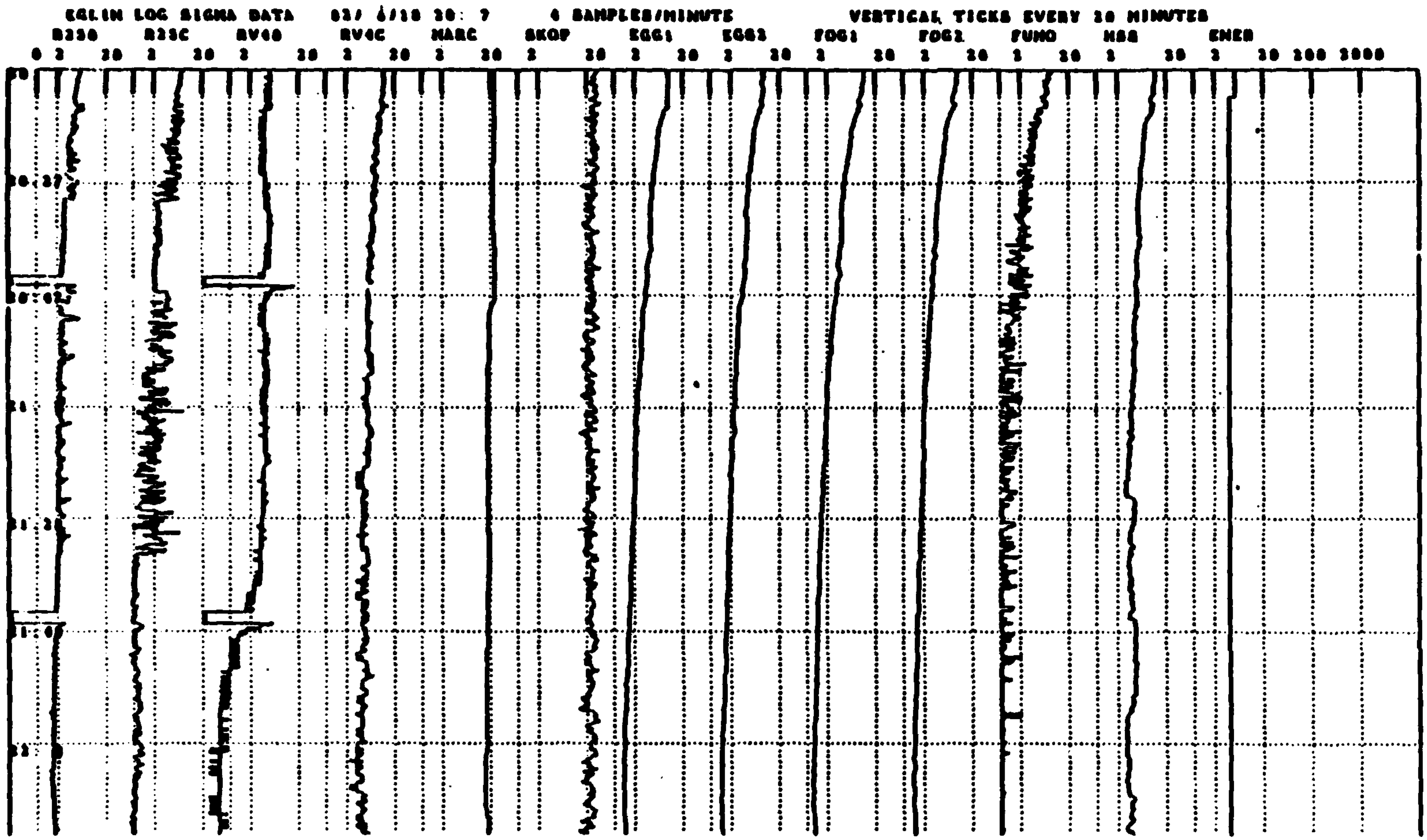
(d)

FIGURE C-2. (CONCLUDED)



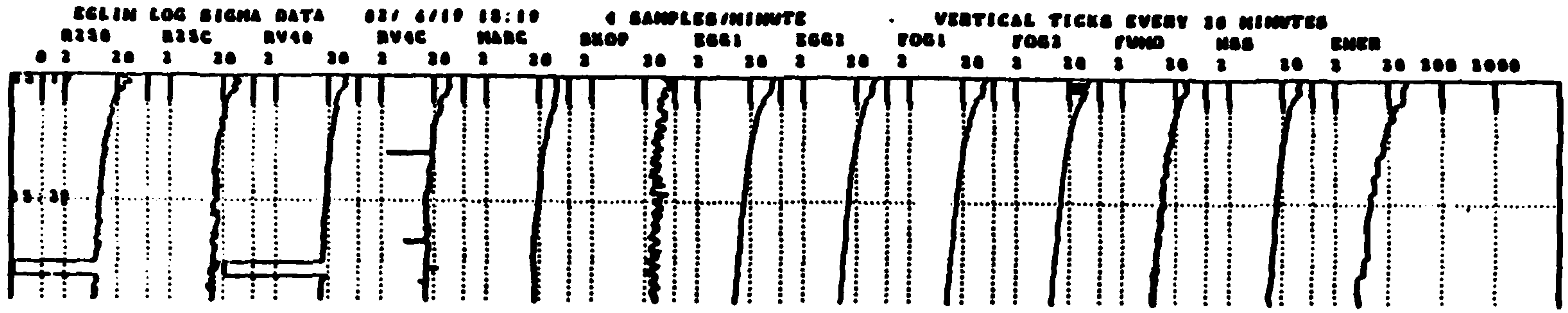
(a)

FIGURE C-3. FOG/HAZE EVENTS .

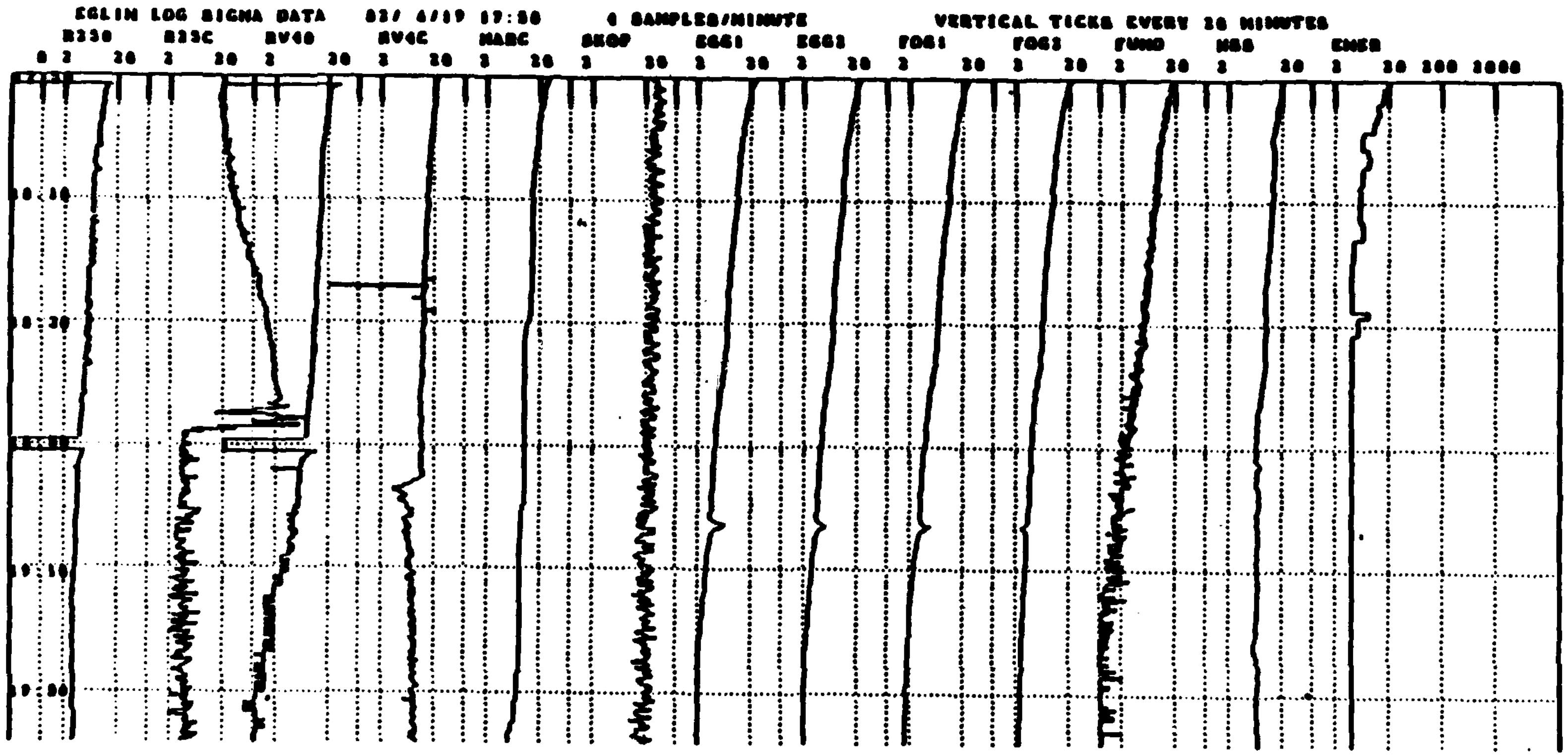


(b)

FIGURE C-3. (CONTINUED)

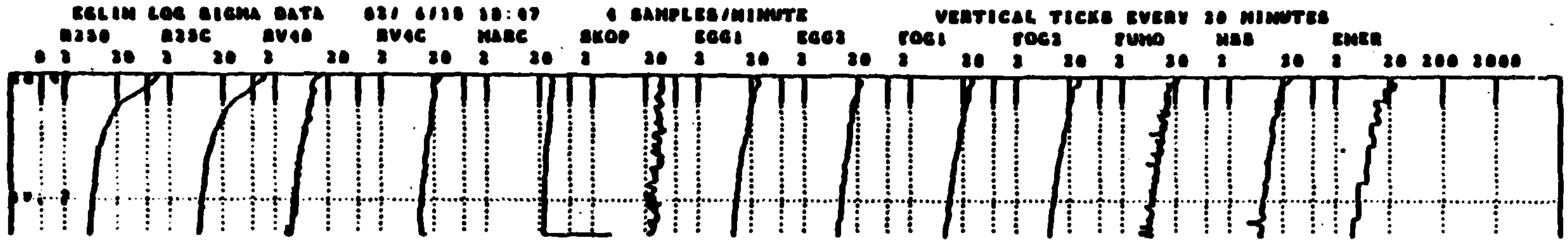


(c)

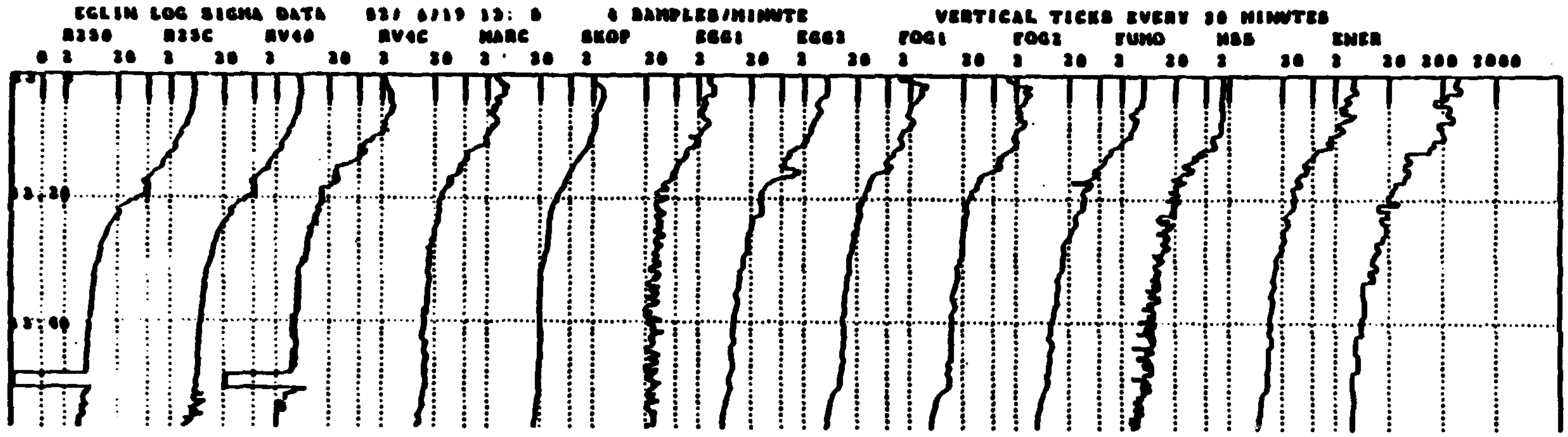


(d)

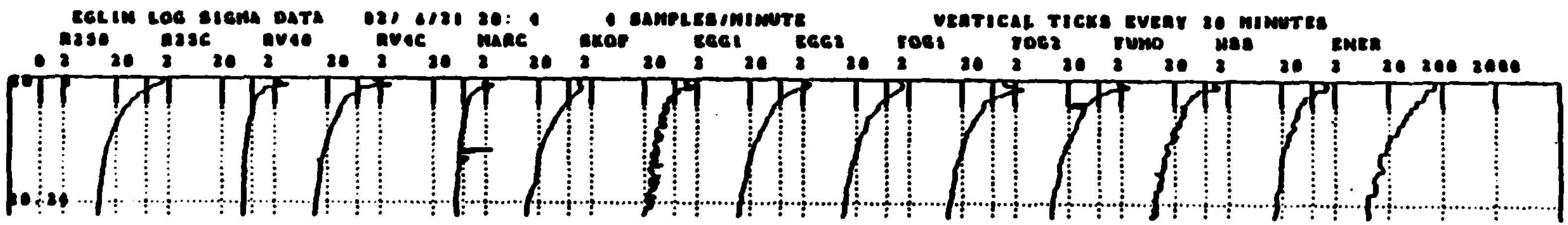
FIGURE C-3. (CONDINUED)



(e)



(f)



(g)

FIGURE C-3. (CONCLUDED)

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