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Investigation of Sensors and Techniques to Automate Weather Observations

EUGENE Y. MOROZ

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FOR THE COMMANDER

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Chief Scientist

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Several sensors and techniques currently being investigated at the Air Force Geophysics Laboratory as part of its program to automate the observation of weather parameters are described. Included are a lidar cloud-height measuring system, a laser weather identifier, a decision tree approach for determination of present weather, a lidar slant visual range measuring system, and a tower mounted visibility meter approach for determination of slant visual range.

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1. INTRODUCTION

The Air Force Geophysics Laboratory (AFGL) has an ongoing program whose objective is to automate the observation of weather parameters for Air Force aviation and forecasting purposes. This involves the automation of existing equipment, the evaluation of promising new surface weather instruments, and, where necessary, the development of observing techniques and sensors. The effort is being brought together into what is called the Modular Automated Weather System (MAWS). The major feature of MAWS is its modular concept. Microprocessor components are used at each sensor and as the central processor. This permits, as necessary, the addition or substitution of sensors, processing, or display units.

The program is being conducted at Hanscom AFB, MA and at the AFGL Weather Test Facility, Otis AFB, MA. The general configuration of the Weather Test Facility is shown in Figure 1. The central test area is a simulated approach zone in which weather observations are made at the surface and on three towers, 5 m, 35 m, and 50 m in height. There are also two instrumented 35-m towers located 500 m to either side of the simulated approach zone. This report will describe some of the new sensors and techniques that are being considered for inclusion in MAWS.

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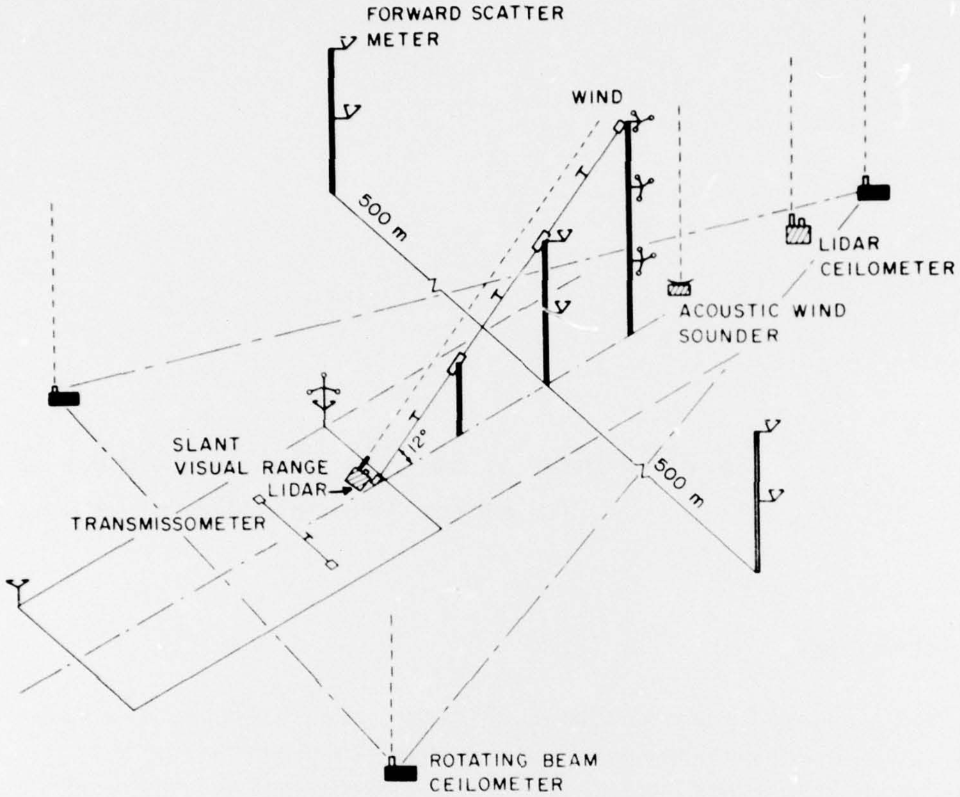

Figure 1. Configuration of the AFGL Weather Test Facility, Otis AFB, MA

2. SENSORS AND TECHNIQUES

2.1 Lidar Cloud Height Measuring System

In the past, AFGL investigated the application of lasers for determination of cloud height. Comparison evaluations[1, 2] of various lidar systems were made with the standard Rotating Beam Ceilometer (RBC). Lidars evaluated were (1) a ruby laser system fabricated by ASEA, Sweden, (2) a gallium arsenide laser system which was developed by Sperry Gyroscope Division, NY, for the AF Avionics Laboratory, and (3) an erbium laser system developed by American Optical Corp.,

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1. Moroz, E.Y., Lawrance, C.L., and Travers, G.A. (1973) Laser Ceilometers, AFCRL-TR-73-0751.
2. Moroz, E.Y., and Travers, G.A. (1975) Measurement of Cloud Height, AFCRL-TR-75-0306.

MA. An example of the oscilloscope display of comparative measurements is shown in Figure 2. Results of the evaluation tests were as follows:

(1) Simultaneous indications of cloud heights determined from RBC and lidar cloud return signals are highly correlated.

(2) Differences in cloud heights as indicated by the two techniques were attributed to the RBC. The RBC is biased toward higher cloud heights by its geometry and multiple scatter. However, the difference in cloud heights is not operationally significant.

(3) Lidar was shown conclusively to have excellent potential as a cloud height measuring device.

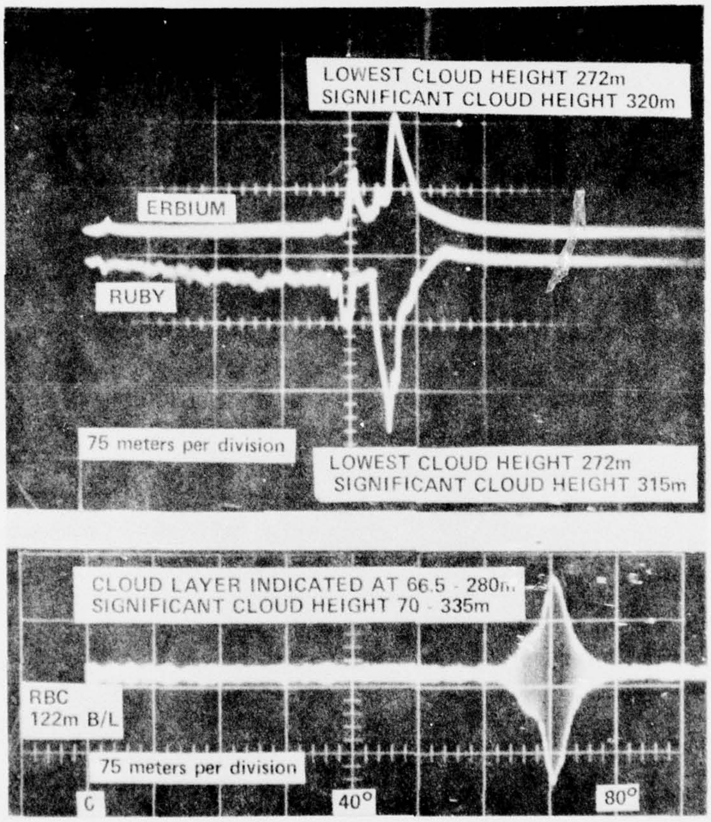

Figure 2. Lidar and RBC Oscilloscope Traces

None of the tested lidars were acceptable as operational systems. The ASEA lidar, though an excellent instrument, cannot be operated in an unattended mode at U.S. airfields, since its ruby laser is not considered eye-safe. (It is, however, being used operationally in Sweden.) The other two systems were feasibility instruments. In order to obtain an operational instrument, AFGL went out on a competitive procurement to have an eye-safe lidar cloud-height measuring system developed.

American Optical Corporation, the successful bidder, has recently fabricated and delivered a system consisting of a transmitter/receiver/processor unit and a control/display unit. These are shown in Figures 3 and 4, respectively. The transmitter is an erbium laser; the laser energy outside the transmitter housing is below prescribed eye-safe levels. The received signal is range-corrected and digitized for processing. Peak detection is used to determine the range to the lowest cloud layer and the range to the most significant layer. Table 1 lists the specific features of the lidar system.

Table 1. Lidar Cloud-Height Measuring System

Erbium-Doped Glass Laser-
- Wavelength: 1.54 μm
- Output Energy/Pulse: 30-35 mJ
- Acousto-Optical Q-Switch
- Pulse Width: 30-35 ns
- Pulse Repetition Rate: 1 Pulse/Min
- Beam Expanded 8 Times
- Output Beam Diameter: 30 mm
- Output Beam Divergence: 0.4 mrad

Receiver
- Germanium Photodiode Detector
- 25 cm, F 1.8 Parabolic Reflector
- 1/R Time Variable Gain

Processing/Display
- A/D Converter
- Peak Cloud Detection
- Display
  - Range/Lowest Cloud Layer, Range/Most Significant Cloud Layer

Rain/Snow/Fog Discriminator
- Auxiliary Optical Components
- Processing
- Display

Preliminary tests of the lidar are being carried out at Hanscom AFB prior to being installed at the Weather Test Facility. Some initial test results are as follows:

(1) Lidar ranged to a cloud layer at 5 km.

(2) Peak detection technique used to process signal provided excellent results.

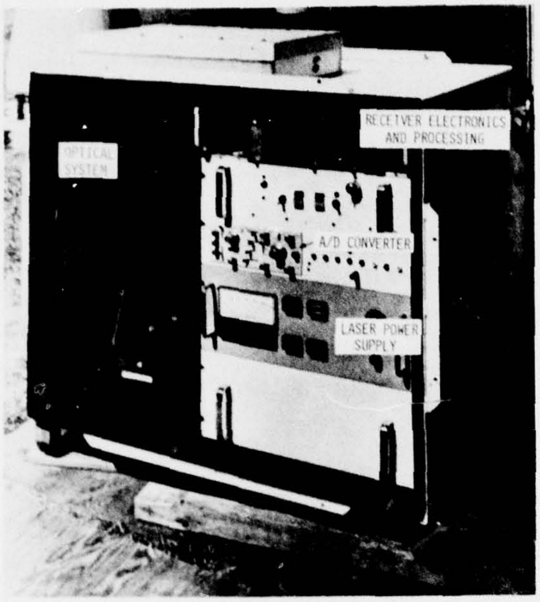

Figure 3. Transmitter/Receiver/Processor Unit of Erbium Lidar Cloud-Height Measuring System With Side Panel Removed

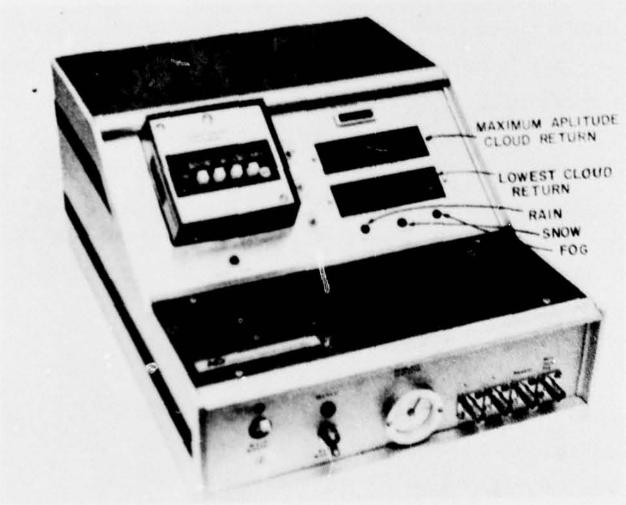

Figure 4. Lidar Control/Display Unit

(3) $1/R$ - and $1/R^2$ - range corrections applied equally well to the empirical data. As a result, a $1/R$ compensation factor was incorporated in the receiver. Electronically, it is simpler to implement and it provides a greater dynamic range.

(4) The acousto-optical modulator worked well as a Q-switch at the erbium wavelength.

(5) The laser has an alignment problem. A new laser rod holder is being fabricated which should improve the stability of the optical alignment.

The lidar should be an excellent candidate for MAWS as a cloud-height measuring device. And, because of its ranging capability, it should also provide better information than the RBC for automating sky cover.

2.2 Present Weather

A variety of instruments and techniques are being considered as candidates for the automation of present weather parameters.

It has been noted for years that the RBC provides distinct characteristic returns during conditions of rain, snow, and fog. These characteristics are even more singular in lidar atmospheric returns.[3] The erbium lidar system has been provided with a near field detector system. The amplitude and frequency content of the signal from this detector will be monitored in order to determine whether a condition of rain, snow, or fog can be determined unambiguously.

Of special interest in this area is the Laser Weather Identifier developed by the Wave Propagation Laboratory, NOAA. A diagram of the system is shown in Figure 5. It uses a 3-mW helium-neon laser and four photomultiplier detectors, two on-axis and two at different forward angles from the laser beam. The form and the character of precipitation/fog will be identified from fall velocity, frequency content, transmission, and forward scatter. A prototype model of the instrument will be installed early in 1977 for field evaluation at Otis AFB.

Another technique that is being implemented is a decision tree approach. A decision on present weather conditions will be made from the outputs of the following instruments:

(1) AN/GMQ-10, transmissometer

(2) EG&G forward scatter visibility meter

(3) Impulsphysics Videograph, backscatter visibility meter

(4) MRI nephelometer

(5) EG&G temperature/dewpoint sensor

(6) Climatronic wind set

(7) Standard rain gauge

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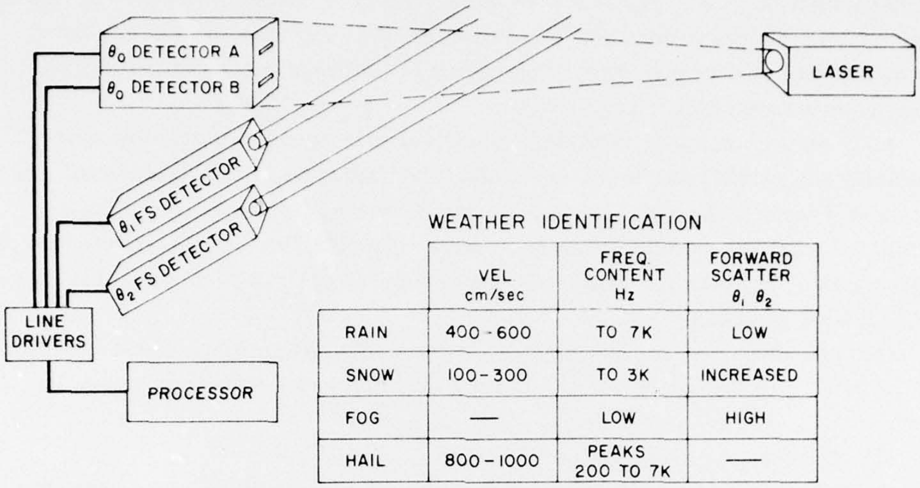
[3] Derr, V.E., Post, M.J., Schwiesow, R.L., Calfee, R.F., and McNice, G.T. (1974) A Theoretical Analysis of the Information Content of Lidar Atmospheric Returns, NOAA TR ERL 296-WPL 29.



WEATHER IDENTIFICATION

	VEL cm/sec	FREQ CONTENT Hz	FORWARD SCATTER θ_1 θ_2
RAIN	400 - 600	TO 7K	LOW
SNOW	100 - 300	TO 3K	INCREASED
FOG	—	LOW	HIGH
HAIL	800 - 1000	PEAKS 200 TO 7K	—

Figure 5. Laser Weather Identifier

2.3 Slant Visual Range

An aviation meteorological parameter for which no operational sensor or observing technique exists is slant visual range (SVR).

In September 1969, Stanford Research Institute undertook an investigation for AFGL (supported in part with FAA funds) to determine the practical and theoretical aspects of measuring atmospheric extinction using lidar. The first approach was to solve the single scatter lidar equation by obtaining empirically a relationship between the volume backscatter coefficient and the extinction coefficient — the equation's two unknowns. Data were gathered during periods of fog at Pillar Point and Arcata, CA. Although considerable effort was made, it was not possible to consistently achieve accurate solutions to the equation using this method.[4]

Using the same data, an alternative approach was considered which involved an analysis of a range-average value of the variation of the lidar return signal with range; that is, the range-averaged slope and its relation to the extinction. The slope method gave reasonable results, particularly in the case of moderate-to-dense fog.

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4. Collis, R.T.H., Viezee, W., Uthe, E.E., and Oblanas, J. (1970) Visibility Measurement for Aircraft Landing Operations, AFCRL-70-0598.

The slope method[5, 6] was explored further in tests at Pillar Point and Vandenburg AFB, CA. The test data had a high correlation coefficient to independent visibility information which demonstrated the feasibility of the technique. However, the tests revealed the importance of obtaining more representative comparative measurements.

As a result, an experiment was specifically designed to determine more precisely the validity and accuracy of the lidar technique. The experiment[7] was set up at Travis AFB, CA, and was conducted during January 1973. It was concluded from the results of the experiment that lidar had excellent potential as a practical instrument for measurement of slant visual range provided that it meet the following conditions:

(1) The effects of multiple scatter in the highly attenuating situation be minimized by optical design or accounted for in the analysis technique, or by both.

(2) The laser be eye-safe.

(3) The lidar have sufficient range penetration capability to determine the extinction up to decision height.

(4) The system be capable of identifying patchy fog conditions and the tops of fog layers that occur below decision height.

An experimental lidar SVR system, designed to meet the capabilities stated above, has been fabricated by Raytheon Company, Sudbury, MA (McManus[8]). The system is housed in a mobile van and can be operated from its own generators or from local power. The lidar has a frequency-doubled ruby laser and two photomultiplier (PM) detectors. Measurements can be made in a plane, from the vertical to the horizontal by manually orienting the lidar telescope. Major features of the SVR lidar are listed in Table 2.

The technique was conceived by HSS Incorporated,[9] Bedford, MA, who, as subcontractor to Raytheon, designed and fabricated the optical system. A schematic drawing of the lidar is shown in Figure 6. The design of the telescope is such that the PM currents are proportional to the product of the scattered light

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5. Viezee, W., Oblanas, J., and Collis, R.T.H. (1972) Slant Range Visibility Measurement for Aircraft Landing Operations, AFCRL-72-0154.

6. Viezee, W. (1973) Lidar Observations of Slant Range Visibility for Aircraft Landing Operations, AFCRL-TR-73-0146.

7. Viezee, W. (1973) Evaluation of the Lidar Technique of Determining Slant Range Visibility for Aircraft Landing Operations, AFCRL-TR-73-0708.

8. McManus, R.G., Chabot, A.A., Young, R.M., and Novick, L.R. (1976) Slant Range Visibility Measuring Lidar, AFGL-TR-76-0262.

9. Stewart, H., Brower, W., and Shuler, M. (1976) Design principles of a slant transmissometer for airport use, TuC6-1 Proceedings of Atmospheric Aerosols Conference, NASA CP-2004.

Table 2. Lidar Transmissometer Features

- Frequency Doubled Ruby Laser -
  - Wavelength: 347.1 nm
  - Output Energy/Pulse: 5 mJ
  - Pockel Cell Q-Switch
  - Pulse Width: 20 ns
  - Pulse Repetition Rate: 10 Pulses/Min
  - Beam Expanded 50 Times
  - Output Beam Diameter: 20 cm
  - Output Beam Divergence: 0.08 mrad
- Receiver
  - Two Photomultiplier Tubes
  - Pinhole Aperture
- Common Laser/Receiver Telescope
  - 30 cm Diameter Lens
  - Focused at 1000 m
- Processing/Display
  - Integrators, Divider and Square Rooter
  - Transmission Over Preselected Range
- Auxiliary Equipment
  - A/D Converter
  - Magnetic Tape Recorder
- Mobile Van
  - Self-Contained Generators With Provisions to Operate From Commercial Power
  - Work Area
  - Heating/Air Conditioning

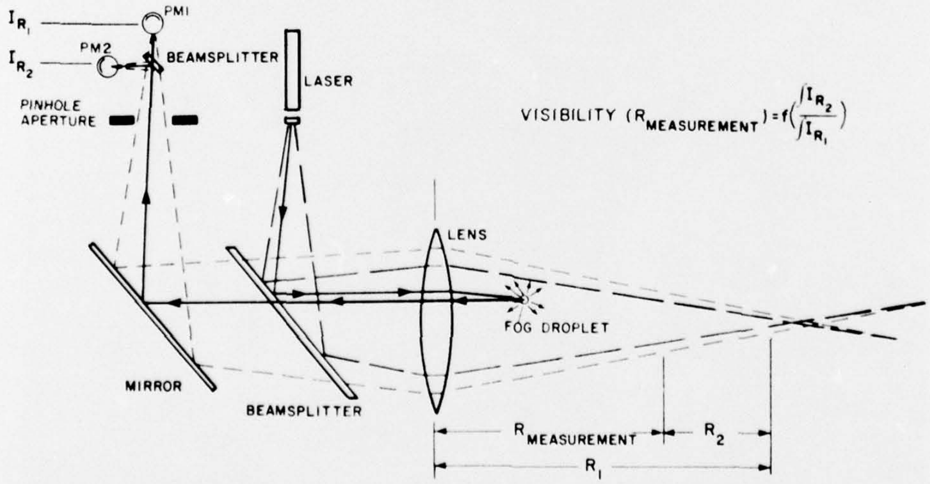

Figure 6. Lidar Slant Visual Range Measuring System

received at the aperture of the telescope and the square of the distance to the scattering point. The atmospheric transmission over the range, $R_{measurement}$, is equal to the square root of the ratio of the two integrated PM currents. The measurement range begins at the telescope, and extends out to a distance of 30 to 500 m from the lidar. The extent of the measurement range is determined by the preselected turn on time of PM_2. The laser is currently being modified because it did not perform satisfactorily during acceptance testing. Upon successful completion of the modification and preliminary testing at Hanscom AFB, the system will be moved to Otis AFB for comparison testing with tower-mounted visibility meters.

Another technique for determining SVR which uses tower-mounted forward scatter measuring visibility meters (FSM), shown in Figure 7, is being evaluated at the Weather Test Facility. The experiment is designed to find out whether slant visual range in the approach zone can be determined adequately from discrete vertical measurements of visibility obtained some distance from the approach zone.

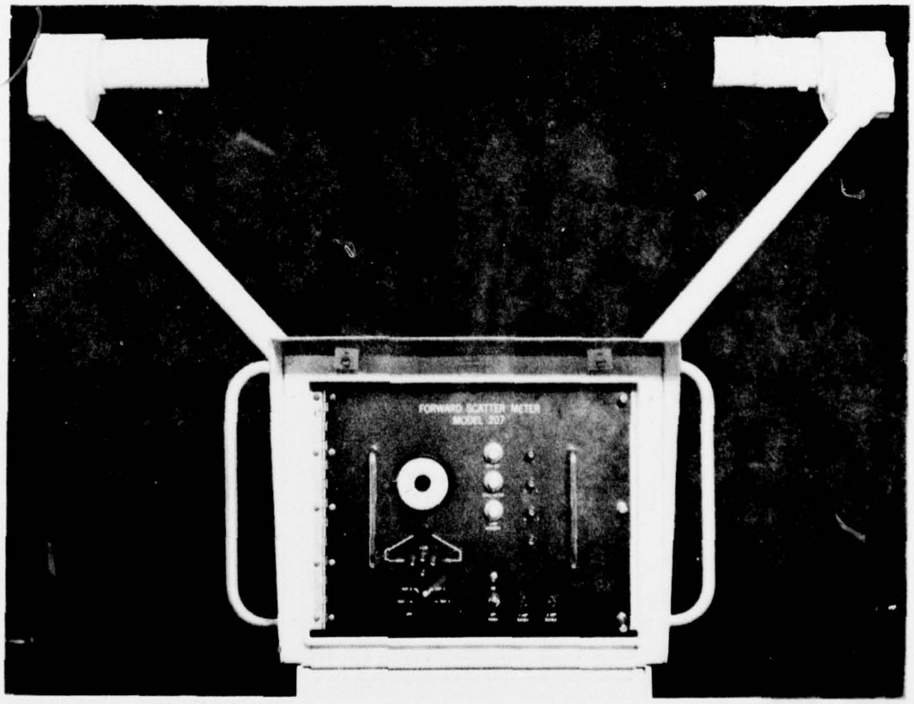

Figure 7. EG&G Forward Scatter Measuring Visibility Meter (FSM)

Preliminary results, which were obtained exclusively in advection fog situations at the Weather Test Facility site, lend support to the visibility meter/tower approach for determining SVR. The horizontal variability of advection fog at Otis AFB tends to be uniformly low. Figure 8 shows an example of the horizontal homogeneity of the fog as indicated by the extinction coefficient observations over a horizontal distance of 1 km at the 17-m level of the two remote towers and two of the central towers (see Figure 1). Data at the 3-m and 33-m levels show the same remarkable horizontal homogeneity. Figure 9 shows the extinction coefficient at the 3-m, 17-m, and 33-m levels of the central 50-m tower during the same fog episode. While the vertical correlation of the two time series shown in Figure 7 and Figure 8 is high, a systematic vertical gradient is stubbornly maintained.

It should be reiterated that these data relate only to advection fog conditions as observed in a coastal environment. A larger data base, including observations in radiation fogs and from other geographical areas, is required before a definitive assessment can be made on the adequacy of the tower approach for SVR measurements.

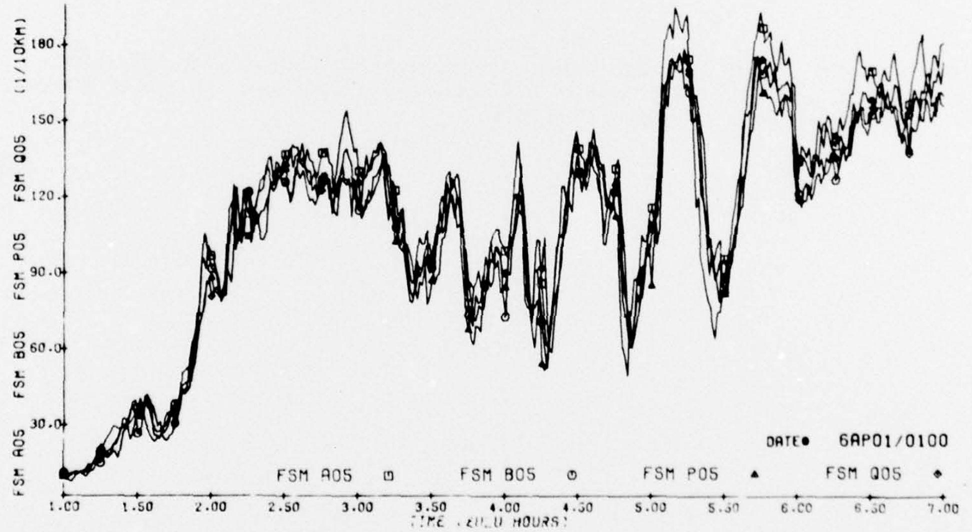

Figure 8. One Minute Average Values of Atmospheric Extinction Coefficient Measured at Four Locations Over a 1 km Range at a Height of 17 m. For reference, an extinction coefficient of 150 × 10^{-4} m^{-1} corresponds to a visibility (V_5) of 200 m

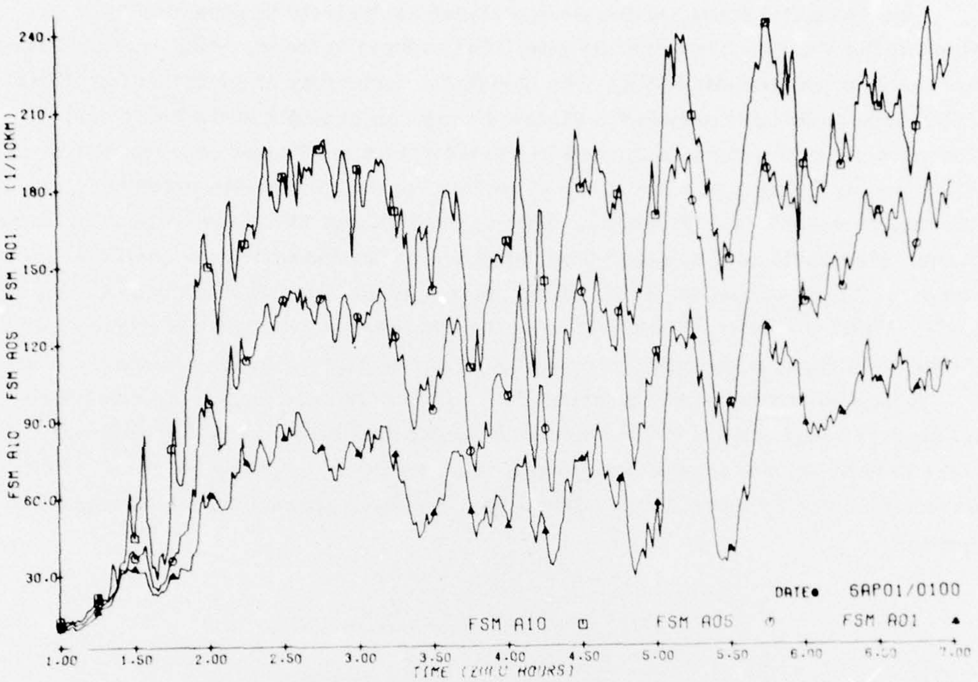

Figure 9. One Minute Average Values of Atmospheric Extinction Coefficients Measured at the 3-m, 17-m, and 33-m Levels of the Central 50-m Tower During the Same Fog Episode as shown in Figure 7

References

1. Moroz, E.Y., Lawrance, C.L., and Travers, G.A. (1973) *Laser Ceilometers*, AFCRL-TR-73-0751.
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6. Viezee, W. (1973) *Lidar Observations of Slant Range Visibility for Aircraft Landing Operations*, AFCRL-TR-73-0146.
7. Viezee, W. (1973) *Evaluation of the Lidar Technique of Determining Slant Range Visibility for Aircraft Landing Operations*, AFCRL-TR-73-0708.
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9. Stewart, H., Brower, W., and Shuler, M. (1976) Design principles of a slant transmissometer for airport use, *TuC6-1 Proceedings of Atmospheric Aerosols Conference*, NASA CP-2004.