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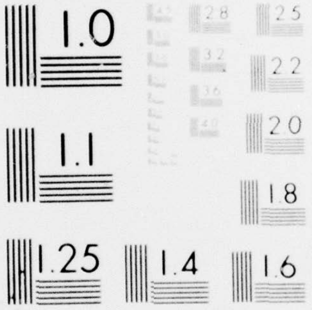

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13. ABSTRACT

A prototype model of a new Modular Automated Weather System(MAWS) will be installed at Scott AFB IL for direct demonstration of its utility in support of fixed base military airfield operations. Remote microprocessor data units provide the flexibility to substitute or add sensor, processing and display components as needed to satisfy local base requirements. The demonstration model emplys off-the-shelf commercial sensors and standard equipment inventory including automated versions of the conventional transmissometer and rotating beam ceilometer instruments. The system has an instrumented tower which provides vertical profiles of visibility, wind and temperature near the approach zone.

The demonstration model of MAWS serves as the baseline for evaluation of the performance characteristics of new candidate sensors for automated airfield observations. Direct intercomparison tests of new instruments and observing techniques are being carried out at Otis National Guard Base on Cap Cod. Sensing techniques now under continuing evaluation include new lidar systems for the discrimination of ceiling, runway visual range, and obstructions to visibility as well as improved sensors for wind, temperature, humidity, sky cover, and altimeter setting. This report summarizes the status and progress of the development and evaluation program and identifies problem areas where additional sensor development is urgently required.

KEYWORDS: Weather instrumentation, Airfield observations, Automated obsering, Visibility

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AIRFIELD WEATHER OBSERVING SYSTEMS

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1. INTRODUCTION

The Air Force Geophysics Laboratory (AFGL) has undertaken the development of a Modular Automated Weather System (MAWS) as part of a continuing program of research into aviation weather observing and forecasting techniques. The MAWS development has progressed rapidly during the past year leading to the installation of an experimental model of the system at Scott AFB IL in September 1976. The objective of the field demonstration is to explore in more detail the utility of MAWS for direct support of fixed-base military operations. The modular design of MAWS offers many options in the selection of system components. Sensors, processing, and display units may be added or substituted as necessary to satisfy specific local base requirements. The demonstration model employs both off-the-shelf commercial sensors as well as automated versions of in-place inventory instruments such as the rotating beam ceilometer and transmissometer.

In addition, the initial components of MAWS serve as a base line for the evaluation of new candidate sensors for automated observing systems. Intercomparison tests of new instruments and observing techniques are being carried out at Hanscom AFB and the AFGL Weather Test Facility established at Otis National Guard Base, Massachusetts. Instruments and techniques under development and evaluation include laser systems for the measurement of ceiling, slant visual range, and runway visual range as well as techniques for observing sky cover and obstructions to vision. This paper summarizes recent progress in the development of MAWS and associated sensors for automated airfield weather observations.

2. MAWS DEMONSTRATION MODEL

The versatility of MAWS results from the use of solid-state microprocessor components. Remote and supervisory data sets composed of central processing units, read-write and programmable memory plus suitable control logic are easily adaptable to aviation weather input/output requirements. The microprocessors can be programmed to interface with a wide variety of sensing elements each having specific requirements with respect to raw data conversion, sampling rate and range of measurement. Similar flexibility exists with respect to selection of output devices, so that the configuration of the system can be personalized through custom-written software packages to satisfy specific local requirements at each operational location.

In addition to having broad flexibility in terms of sensors and peripherals, the MAWS will have several features which greatly extend its reliability in a remote environment. It is planned that the system components will eventually have built-in redundancy which might take the following form: Stand-by modules within the system will periodically test the working hardware and if the hardware is not performing within certain limits, the stand-by hardware will take over the operation and set a flag, thereby alerting the technician of a failure. The software will contain routines for continually editing the data by comparing processed variables against prescribed limits and setting an error flag when suspicious data are encountered, indicating a faulty sensor. Finally, short programs will reside in the microprocessors so that diagnostic tests can be applied to the entire system. Such tests will be activated in two ways: A technician, using a small test module developed with the system, would plug in to the microprocessor and check out the hardware and software; Software diagnostics would be activated at specified intervals to examine the processing routines contained in the system. A distinct advantage in all of these features is that the technician needs no training in computer technology in order to make these tests or to replace faulty components.

2.1 Surface Weather Sensors

The configuration of the Scott AFB demonstration model of MAWS is shown in Figure 1. Since one of the experimental objectives is to help determine the basic requirements for the number and spacing of airfield observing sites and frequency of observations, the array of weather instruments to be installed is anticipated to be more extensive than required to support most fixed base operations. At each observing site continuous measurements will be made of wind speed, wind direction, temperature, dew point and scatter coefficient (visibility). Three observing sites are located adjacent to Runway 15/33, coinciding with the locations of in-place weather instruments near the end points and the mid-point of the runway. In addition, observing sites are located at two levels (25 m and 50 M) of an instrumented tower that is offset 600 m from the touchdown point of Runway 15. The demonstration model instruments are of the same type as those used successfully in the Hanscom

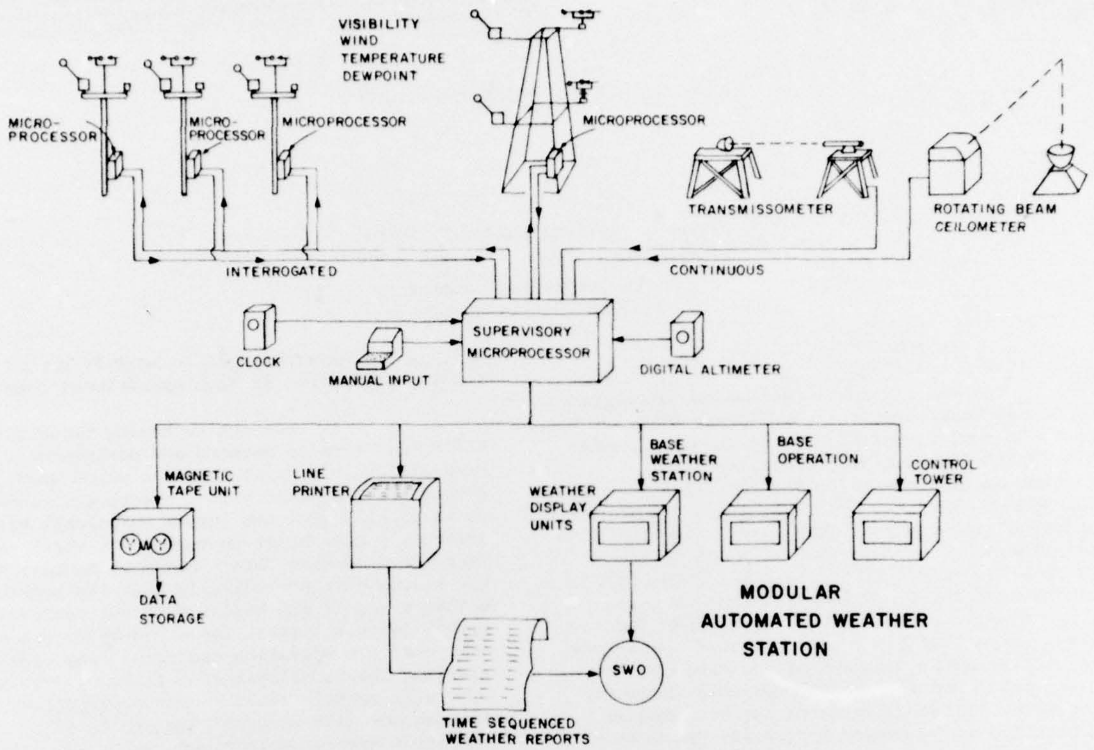

Figure 1. Functional diagram of the Modular Automated Weather System

mesoscale network (Hering, Muench and Brown, 1972) over the past few years. They are the Climatronics wind set, the EG&G temperature/dew point set, and the EG&G forward scatter meter. Altimeter setting and surface pressure measurements are made with a Sperry digital altimeter. Provision is made for manual key-board entry of information on weather elements or conditions not observed automatically in the present MAWS.

Fully automated measurements of cloud-base height are obtained from 2 AN/GMQ-13 Rotating Beam Ceilometers (RBCs) already in place near the approach zones of Runway 15/33. By far the most complex interface problems encountered thus far were associated with the integration of the RBC with MAWS. The resultant processing system successfully establishes a background level from each 90 degree scan of the source lamp, filters out spurious and unwanted returns, identifies primary and secondary peaks representative of cloud structure, and analyzes the sequence of data over the past minute to yield the best estimate of cloud base height over the observing site. Determinations will be made both from a single RBC and from a combination of returns from the 2 RBC instruments located on the airfield. The vertical resolution of cloud base height corresponds to an elevation scan angle resolution of .25 degrees.

During the course of the field demonstration the output of additional Air Weather Service inventory instruments will be integrated with MAWS for the purpose of direct field intercomparisons of the relative performance characteristics with the new instruments. Inventory instruments to be interfaced with the automated system include the AN/GMQ-20 wind set, AN/TMQ-11 temperature/dewpoint set and the AN/GMQ-11 transmissometer.

2.2 Recording and Display Compoents

The various devices used in the MAWS demonstration model for real-time display and storage of processed weather observations and forecasts are shown in Figure 1. The continuous flow of surface weather information will be archived on magnetic tape in a form suitable for convenient recall for climatological or technique development purposes. An on-line printer provides hard-copy output of current weather data. The printer can be programmed to serve as required to display sequential observations from selected sensor combinations or processed information such as objective forecasts or derived quantities in support of "metwatch" advisors and weather warnings. In particular, the printout capability will be used during the course of the field demonstration to monitor and intercompare measurements in relation to the type, spacing and elevation of the instruments.

The primary output device is the Burroughs TD 700. Fresh observations, updated each minute for most elements, are displayed in alphanumeric form. The message format need not be the same for all display units so it may be adjusted to conform closely with the real-time information requirements of the traffic control center, the operations center, the staff weather office, etc.

Each alphanumeric display unit of the demonstration model has 4 pages. The following information updated each minute will appear on the first 2 pages:

Ceiling, visibility, temperature, dewpoint and altimeter setting - latest observation, t, and observations for t-5, t-10, t-15 and t-30 minutes.

Wind direction, wind speed and peak wind gusts - latest observations at the surface, and 25 m and 50 m tower levels.

Visual range - latest average and the highest and lowest values over the past 10 minutes for Runway 15, Runway 13, and the 25 m and 50 m tower levels.

Temperature maximum and minimum - past 24 hours.

Relative Humidity, sea level pressure, 1-hour pressure change (updated each hour).

The third display page is devoted to automated forecasts of runway visual range that are updated each minute as new observations are acquired and processed. Based on a conditional probability model that was developed and tested as part of the Hanscom mesoscale forecasting experiments (Hering and Quick, 1974), the forecasts give the probabilities that the visual range will be less than threshold values of 800 m and 400 m at selected verification times up to 3 hours. Experimental probability forecasts of ceiling will be added to MAWS later on this year using a stochastic model similar to that developed for visual range.

The latest observations of special weather elements that require dissemination of alerts or warnings when critical values are expected or reached are displayed on the fourth and last page of the Burroughs units. For the Scott AFB demonstration these automated "metwatch" parameters are runway cross-wind component, wind chill temperature and wind gust spread.

3. NEW INSTRUMENTATION DEVELOPMENT AND EVALUATION

Meanwhile, the search continues for promising surface weather instruments which offer improved accuracy, representativeness and reliability at reasonable operating costs. Several observing techniques and instruments having good potential for use in fully automated systems are under development and evaluation at the Air Force Geophysics Laboratory. For rigorous evaluation of instrument performance, a Weather Test Facility has been installed at Otis AFB MA, which is located in an area having a relatively high frequency of critically low ceiling and visibility conditions.

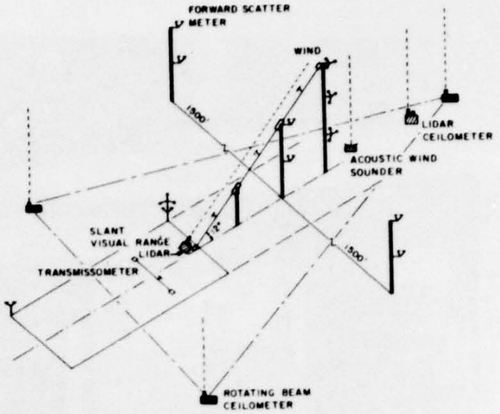

Figure 2. Schematic diagram illustrating the general configuration of the Weather Test Facility installed at Otis National Guard Base, Massachusetts.

TABLE 1

LIDAR CEILOMETER FEATURES

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 mr

RECEIVER
- GERMANIUM PHOTODIODE DETECTOR
- 10 INCH, 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

3.1 Weather Test Facility

The general configuration of surface and tower mounted instrumentation at the Weather Test Facility is shown in Figure 2. In the test area, that is far removed from the operational runways at Otis AFB, continuous weather observations are made in a simulated approach zone by means of 3 towers with heights of 5 m, 35 m, and 50 m. Two additional 35 m-towers are offset 500m on opposite sides of the approach zone complex. Measurements of wind, temperature, dew point, and atmospheric extinction coefficient (visibility) are made at each of the 3m- , 17m- , 33 m- and 50 m levels on the instrumented towers and at several additional surface observing sites. The raw output of those instruments as well as the

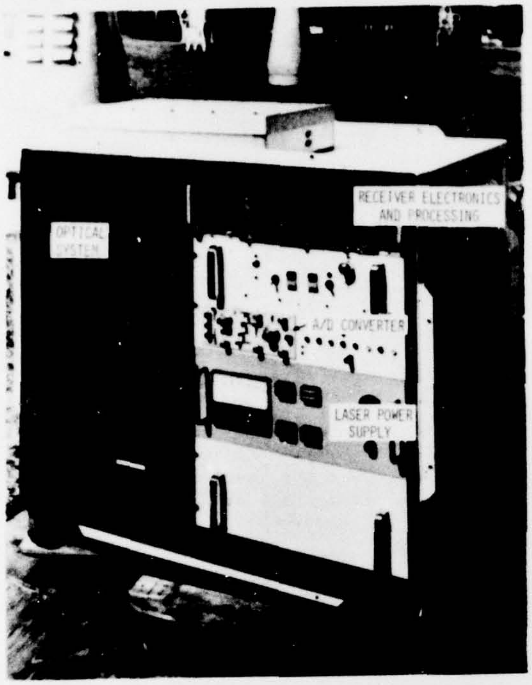

Figure 3. Transmitter/receiver/processor unit of erbium lidar ceilometer with side panel removed.

output from many new sensors installed for test purposes are recorded continuously on magnetic tape and then converted to digital form for rapid processing and analysis.

Prominent among the new instruments which will undergo extensive evaluation during the coming year are 2 lidar systems that have been built as part of the AFGL program to investigate the applicability of lidar for determining ceiling and slant visual range (SVR). The status and progress of these systems are reviewed in the following paragraphs.

3.2 Lidar Ceilometer

The lidar ceilometer system was fabricated by American Optical Corp., Southbridge, MA. It consists of a transmitter/receiver/processor unit and a control/display unit which are shown in Figures 3 and 4 respectively. The transmitter is an erbium doped glass laser; the laser energy outside of the transmitter housing is well 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.

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

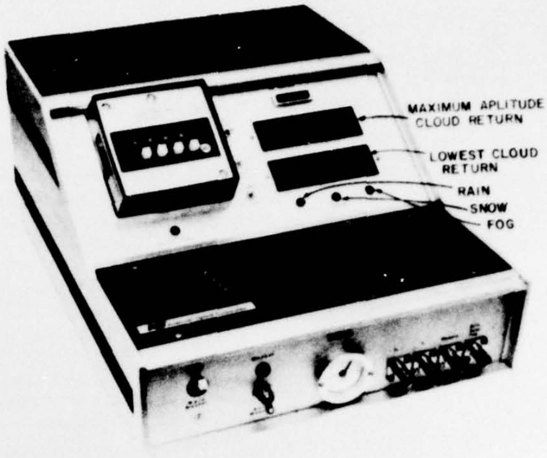

Figure 4. Lidar ceilometer control/display unit.

1. Lidar ranged to a cloud layer at 5 km
2. Peak detection technique used to process signal provided excellent results.
3. $1/R$ - and $1/R^2$ - range corrections applied equally well to the empirical data. As a result, a $1/R$ compensation factor is used 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.

The lidar clearly has excellent potential for automated ceiling measurements. In addition, it can also provide significant input into the determination of sky cover and present weather conditions because of its ranging capability and the information inherent in its atmospheric return signal. The ceilometer has a secondary optical system which provides information on the state of the weather, i.e. whether it is raining, snowing, foggy or clear. This information is needed as input in order to provide unambiguous data when processing the cloud return signal. A rain/snow/fog (RSF) condition is determined from the frequency content and the amplitude of the lidar atmospheric return. A condition of no restriction is assumed to exist if the atmospheric return contains no low frequency component. This system will be evaluated in comparison with other present weather observing techniques at the Weather Test Facility. Of special interest is the Laser Precipitation Discriminator developed by the Wave Propagation Laboratory, National Oceanic and Atmospheric Administration. It employs an eye-safe, helium-neon laser in a variety of modes to identify the form and character of precipitation. A prototype model of the instrument will be installed for field evaluation this fall at Otis AFB.

TABLE 2

LIDAR TRANSMISSOMETER FEATURES

- FREQUENCY DOUBLED RUBY LASER -
  - WAVELENGTH: 347.1 nm
  - OUTPUT ENERGY/PULSE: 5mJ
  - 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 mr
- 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

3.3 Slant Visual Range Lidar

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

The concept of the system was developed by HSS Incorporated, Bedford MA. A schematic drawing of the lidar is shown in Figure 5. The design of the telescope is such that the PM currents are proportional to the product of the scattered light 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 can be varied from 100 to 500 meters in front of the lidar. The specific range is determined by the pre-selected turn-on time of PM_2. The SVR lidar is undergoing tests at Hanscom AFB to evaluate the design concept. Upon successful completion of these tests the system will be moved to Otis AFB for comparison testing with tower-mounted, visibility meters.

3.4 Forward Scatter Meter/Tower System for Slant Visual Range Measurement

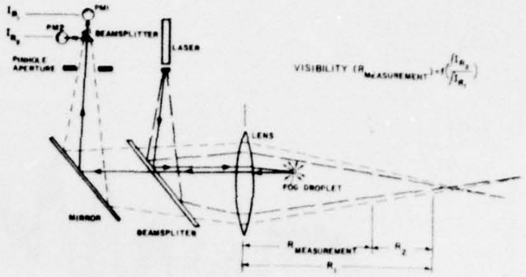

Figure 5. Optical system of frequency-doubled ruby SVR lidar.

As part of the Federal Aviation Administration program, the Research and Development Department, Crane Naval Ammunition Depot, has under development and evaluation (Lohkamp et. al., 1974) a tower system for the determination of SVR. Measurements with forward scatter visibility meters mounted on a remote tower are combined with measurements of background luminance to yield estimates of slant visual range. The efficacy of the system obviously depends primarily upon the degree of correlation between the vertical structure of atmospheric extinction coefficient as measured at the tower and the effective average extinction coefficient along the actual visual path of the pilot in the approach zone.

Experiments have been undertaken by AFGL to explore more fully the horizontal and vertical variability of fog structure based upon data gathered by the Weather Test Facility. Preliminary results of the fog variability studies, carried out exclusively in advection fog situations at Otis AFB, lend support to the scatter meter/tower approach to SVR measurement. The horizontal variability of advection fog density in the Cape Cod area tends to uniformly low. For example, Figure 6 shows observations extending over an horizontal distance of 1 km which were made during a typical advection fog episode on 1 April 1976. The values of extinction coefficient were measured by forward scatter meters located at 17 m- level on the 2 remote towers and the 2 central towers of the array shown in Figure 2. As is usually found at all observational levels from 3 m to 33 m, the remarkable horizontal homogeniety in fog density persists throughout the fog period. At the same time, a quasi-steady state increase in advection fog density tends to be established and maintained as a result of fog droplet fallout and low level scavenging processes. Measurements made at the 3m-, 17m- and 33m- levels on the 50 m- tower for the same fog episode are shown in Figure 7. While the vertical correlation of even the high-frequency components of the two time series is high, a systematic vertical gradient is stubbornly maintained. As discussed by Roach (1976), it appears likely that the quasi-periodic oscillations in fog intensity with a period of about 45 minute are caused by organized vertical motions associated with gravity-wave activity. An analysis of these oscillations in fog density, which are frequently observed in the Weather Test Facility data, will be the subject of a later paper.

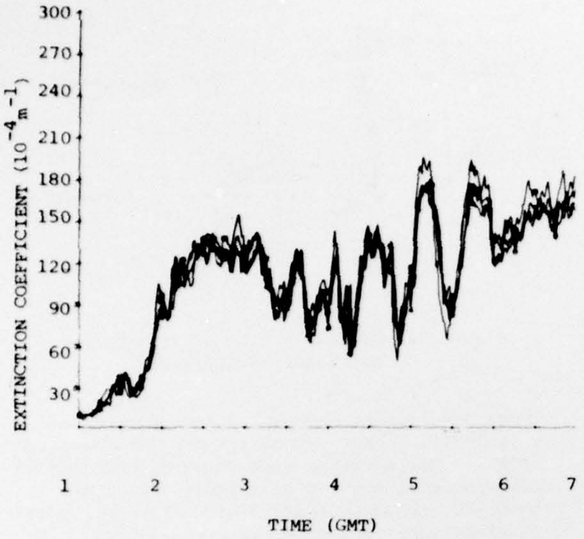

Figure 6. One-minute average values of atmospheric extinction coefficient as measured at 4 observing points during the advection fog episode of 1 April 1976 at Otis AFB. The measurements were made with forward-scatter meters located at the 17m-level on 4 towers spread over a horizontal distance of 1 km. For reference, the extinction coefficients which correspond to runway visual ranges of 1600m and 800 m (night, light setting 5) are 53 and $115 \times 10^{-4} m^{-1}$ respectively.

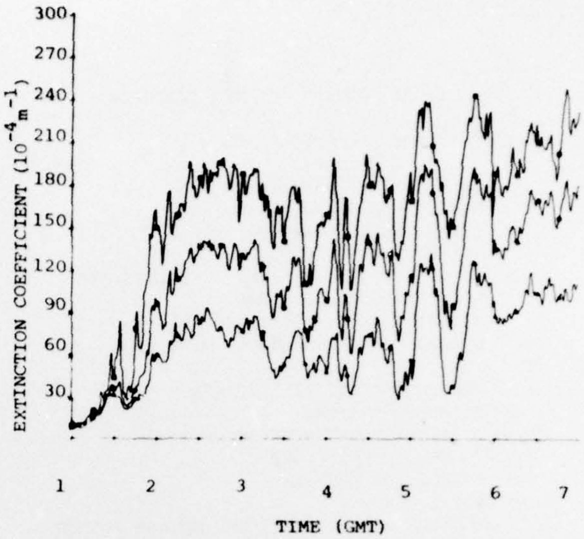

Figure 7. Same as Figure 6 except that measurements during the same episode were made at 3 levels (3m, 17 m and 33m) on the tallest tower located near the center of the Weather Test Facility. (see Figure 2)

It is important to note that in advection fog conditions such as those illustrated in Figure 7, the concepts of "prevailing" visibility and ceiling become vague and difficult to resolve because of the strong and systematic decrease in visibility with increasing height. On the other hand, it is quite meaningful to measure and describe visual range as a function of height.

It also should be emphasized that the above comments on the variability of fog density relate only to advection fog conditions as observed in a coastal environment. A much larger data base including observations in radiation fog conditions and observations from other geographical areas is required before a definitive assessment can be made of the utility of tower-mounted instruments for SVR measurements.

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