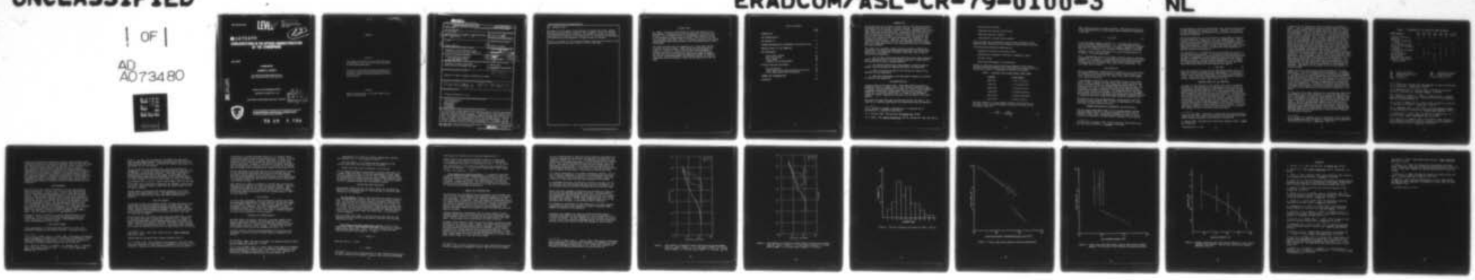
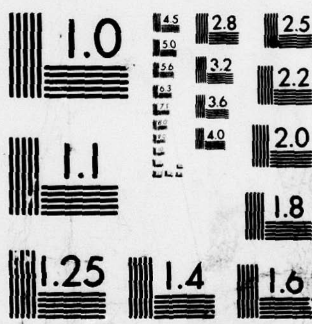
AD-A073 480 BATTELLE COLUMBUS LABS OH F/G 4/2
CONSIDERATIONS IN THE OPTICAL CHARACTERIZATION OF THE ATMOSPHER--ETC(U)
JUL 79 J E JIUSTO DAAG29-76-D-0100

UNCLASSIFIED ERADCOM/ASL-CR-79-0100-3 NL

1 OF 1
AD
A073480



END
DATE
FILMED
10-79
DDC



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

ASL-CR-79-0100-3

LEVEL II

AD

Reports Control Symbol
OSD 1366

CONSIDERATIONS IN THE OPTICAL CHARACTERIZATION OF THE ATMOSPHERE

July 1979

Prepared by

JAMES E. JIUSTO

Atmospheric Sciences Research Center
State University of New York, Albany, NY

Under Contract DAAG29-76-D-0100

EDITED BY: Richard D.H. Low

Approved for public release; distribution unlimited

US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destory this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASL-CR-79-0100-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CONSIDERATIONS IN THE OPTICAL CHARACTERIZATION OF THE ATMOSPHERE		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James E. Jiusto		8. CONTRACT OR GRANT NUMBER(s) DAAG29-76-D-0100
9. PERFORMING ORGANIZATION NAME AND ADDRESS Atmospheric Sciences Research Center State University of New York, Albany, NY		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS [redacted] 1L162111AH71 [redacted]
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Electronics Research and Development Command Adelphi, MD 20783		12. REPORT DATE Jul[redacted]79
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Atmospheric Sciences Laboratory White Sands Missile Range, NM 88002		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

ERADCOM/ASL CR-79-0100-3

18. SUPPLEMENTARY NOTES

Edited by Richard D. H. Low

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fog characteristics
Fog variability
Meteorology
Microphysics
Fog program

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

The US Army uses various types of electro-optical devices involving wavelengths from the visible to the near infrared. The performance of these sensors can be adversely affected by turbid atmospheres, especially those containing fog and haze. This report provides a brief review of the characteristics of fogs and hazes and offers a few recommendations on fog and haze measurements. In particular, attempts are made to answer such questions as: (1) whether the fog and haze characteristics found in some United States localities are comparable

cont'

20. ABSTRACT (cont)

Cont → to those in certain places in West Germany, (2) whether the present standard meterological measurements customarily made at weather stations are suitable for determining fog optical properties, (3) whether the current fog numerical modeling would be relevant to field operations, and (4) what basic measurements are needed to describe adequately the foggy and hazy environments.

Finally, an example of fog and haze measurements conducted on the campus of the State University of New York at Albany is briefly described.

EDITOR'S NOTE

Dr. James E. Jiusto, an internationally known cloud physicist, has been engaged in fog/haze/particulate investigation and research over 20 years. He is presently Chief of the Atmospheric Physics Section of the Atmospheric Sciences Research Center, State University of New York and Albany (ARSC-SUNY), and is also heavily involved in the various fog/haze/particulate study programs of the World Meteorological Organization (WMO).

The report presented here was prepared by Dr. Jiusto under the ARO Scientific Services Program. After having read and evaluated the report, Dr. Franklin E. Niles, Chief of the US Army Atmospheric Sciences Laboratory Electro-Optics Division, felt that the report merited wide circulation among Army researchers presently engaged in the various fog/haze/measurement and modeling programs, to acquaint researchers with the problems of measuring and modeling the fogs and hazes.

TABLE OF CONTENTS

INTRODUCTION

The US Army uses various types of electro-optical (EO) devices involving wavelengths from the visible to the near infrared. The performance of these sensors can be adversely affected by turbid atmospheres, particularly those containing fog and dense haze. Consequently, one would like to be able to prescribe accurately the extinction coefficient σ in fog; further one might hope to predict σ, as well as other microphysical properties, for a variety of fog types and geographical locations if significant variations occur. (They do!) During field operations, the injection of soil particles into the lower atmosphere could be considerable; this added complication is not considered here since no assessment data were available.

This report will consider a number of matters related to spatial fog variability, time variations, measurement techniques, and fog modeling. Specifically, an attempt will be made to throw some light on the following four key questions.

1. Can all fogs be characterized optically by one simple conceptual model? More specifically, are test results obtained in United States fogs applicable to fogs in Europe (Germany)?

2. Are standard meteorological measurements customarily made at weather stations suitable for determining optical fog properties?

3. What is the state-of-the-art and relevance of numerical fog modeling to field operations?

4. What basic measurements (and measurement frequency) are needed to describe fogs adequately?

FOG CHARACTERISTICS

A great variety of fog types exist. These types differ according to geographic location, synoptic airmass type, formation mechanism, season of the year, and time evolution of a given fog. From a cloud microphysics standpoint (liquid water content (LWC), drop size distribution, visibility (V) or extinction coefficient (σ),* phase of the condensate (generally liquid), temperature structures, and fog depth), they differ greatly.

Most major fog types have been classified by Willett[1] and Byers.[2] To simplify for practical application, the categorization may be reduced to:

---

*It is customarily assumed in fog work that σ is entirely due to scattering (i.e., absorption negligible)

[1]H. C. Willett, 1928, "Fog and Haze," Mo Weather Rev, 56:435

[2]H. R. Byers, 1959, General Meteorology, 3rd Ed., McGraw-Hill, New York, 481 pp

Radiation fogs (inland)

Advection fogs (coastal and maritime)

Advection-radiation (coastal)

Precipitation - frontal fogs (anywhere)

These fog types can be modified by local terrain conditions such as mountain-valley regions (cold air drainage, upslope adiabatic cooling).

The principal fog formation mechanisms are:

Radiational cooling of the ground surface

Radiative flux divergence (cooling) of atmospheric layers

Vertical mixing

Water vapor enhancement via precipitation

Because no consistent standards have been adopted for defining fog and haze density according to their associated visual range (extinction coefficient), table 1 is suggested for qualitative reference.

TABLE 1. FOG-HAZE CLASSIFICATION VERSUS VISUAL RANGE

Category	Visual Range V
Dense fog	≤ 1 km (≤ 0.5 mi)
Light fog	> 1-5 km (0.6-3 mi)
Dense haze	> 5-10 km (3-6 mi)
Light haze	> 10-16 km (6-10 mi)
Quasi-clear	> 16-32 km (10-20 mi)
Very clear	> 32 km (> 20 mi)

The visual range is of course readily linked to the extinction coefficient (in the visible wavelengths but not the infrared) by the Koschmieder expression

$$V = \frac{3.912}{\sigma} \simeq \frac{3.912}{\Sigma \pi r_i^2 N_i k_i} \quad (1)$$

where symbols have their customary meanings. Appropriate manipulation allows introduction of the liquid water content variable via expressions of the form

$$V = a\bar{r}/(LWC)^b \; . \tag{2}$$

In the well-known Trabert expression, b = 1, although other investigators find better agreement with $b \simeq 2/3$. Atlas and Bartnoff[3] maintain that the other empirical coefficient "a" becomes a constant if average drop size $\bar{r}$ is replaced by d_m, the median volume diameter of the drop spectrum. Sigma (visual wavelengths) can vary from approximately 0.4 to 400 km^{-1} in fog and dense haze.

Thus, a complete description of fog (haze) involves a host of variables--microphysical to synoptic. If one needs only to characterize the optical property σ (at infrared wavelengths), then the drop size distribution and appropriate Mie extinction coefficients must be determined. This is no small task in itself.

FOG VARIABILITY

Fogs vary tremendously from one region to another and even in one locale. For example, we now have identified four distinct fog variations that occur in Albany, NY, during the fall season that formerly were thought to be simply radiation fog.

If one attempts to apply EO sensor test results in fogs in the United States to fogs in Germany (or vice versa), then efforts should be made to at least match regions of similar geophysical characteristics. For example, coastal fogs are far different from inland fogs and should not be equated. Try also to identify the principal fog formation mechanisms and match regions accordingly. The concentrations of fog condensation nuclei (natural and man-made via pollution) can alter the number concentration and sizes of fog drops; thus the degree of urbanization and/or population density of respective regions should be compared as well.

With some on-site visits by meteorological (cloud physics) staff and analyses of station weather data, at least an approximation of roughly equivalent fog zones should be possible.

STANDARD METEOROLOGICAL MEASUREMENTS FOR DEPICTING FOG

The only regular measurement made at fully equipped weather stations (National Weather Service or military) pertaining to fog is that of horizontal visual range. Depending upon whether aircraft are in the vicinity, an estimate of fog tops might be contained in pilot reports.

---

[3]D. Atlas and S. Bartnoff, 1953, "Cloud Visibility, Radar Reflectivity, and Drop Size Distribution," J Meteorol, 10:143-148

No measurements of drop size distributions, LWC, aerosol concentrations, or other microphysical variables are made. Therefore, the so-called standard meteorological measurements are not suitable for determining fog optical properties.

Qualitative predictions of fog occurrence and some degree of severity ("patchy ground fog," "dense fog," etc.) are sometimes made. These forecasts are not very reliable as relatively little emphasis has been placed on fog prediction research by the National Oceanic and Atmospheric Administration. Efforts to numerically model and predict fog are underway at a few institutions, including SUNY (note paragraphs on numerical models of fog formation).

The sensitivity of σ to differing drop size distributions is an important aspect of the problem. It is being critically examined by Low.[4] Such work is fundamental in determining how well the drop spectra must be known to compute the optical extinction coefficient with varying degrees of accuracy. For the infrared wavelengths $\lambda = 11\mu m$, Chýlek[5] has suggested an approximation formula linking σ and LWC, the latter being more readily measurable than complete drop spectra:

$$\sigma = 128\ (\mathrm{LWC}). \tag{3}$$

Note that equation (3) holds best for fogs whose largest drops do not exceed (in significant numbers) about 28μm diameter. For wet haze, light fog, and some dense inland fogs, this criterion would generally be met. Hence, this may be considered a promising avenue to explore further in developing approximate σ models for fog.

NUMERICAL MODELS OF FOG FORMATION*

All models of the formation of fog contain a set of basic transport equations for heat and moisture in the boundary layer, with more advanced models including other processes which can influence the temperature and humidity conditions. It is now accepted that any model which attempts to accurately simulate the formation of radiation fogs must include turbulent transport equations as well as a formulation for radiative cooling of the air and ground surface. Accurate prediction of the time of fog formation must also contain equations relating to the transport of heat and moisture to soil fluxes of these quantities. Accurate descriptions of the development of the fog also require the inclusion of radiative transfer equations for fog droplets. Thus, any model which attempts to forecast fog occurrence as well as the depth and intensity of fog will be quite large and complex.

---

[4]R. D. H. Low, 1978, "A theoretical investigation of cloud/fog optical properties and their spectral correlations," ASL-TR-0024, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[5]P. Chýlek, 1978, "Extinction and liquid water content of fogs," J Atmos Sci, 35:295-300

*Prepared by Dr. G. Lala

A comparison of the features of several fog models is presented in table 2. There is considerable variation over the models in terms of the processes included; and of greater importance, there are significant differences in the way the authors treat the physical processes in their models. The most important factor in any set of prediction equations for the boundary layer variables is the modeling of the turbulent transfer processes. Under nocturnal conditions of strong stability and low windspeeds, which are common conditions for the formation of radiation fogs, the constant flux layer may be only a few meters thick; above this layer turbulence may occur in patches stimulated by gravity waves which may appear at the temperature inversion. The greatest defect of most of the approaches used is the assumption of the flux-gradient relationships and a uniform variation of the exchange coefficient with height. Both of these assumptions are at variance with the patchy nature of turbulence which occurs under stable conditions. All of the models listed in table 2 are subject to these deficiencies with the possible exception of the model of Oliver et al.[6] which uses a second-order closure description of turbulence. This method extends the usual set of equations for mean quantities to include equations for the second-order turbulent correlations of these variables. This approach offers an alternative to the exchange coefficients formulations, but at present it has not been tested in a predictive model.

Another area of fog modeling which needs improvement for accurate predictions of fog is the treatment of fog microphysics. At present, all fog models rely on a parameterization of the quantities dependent on fog drop spectra through an assumed drop size distribution and an assumed total droplet concentration. This approach has a strong impact on the results of computations of radiative transfer in fogs as well as on the distribution of fog water as determined by turbulent processes and sedimentation. Considering the current state of modeling of boundary layer processes, inclusion of detailed microphysics probably would not add significantly to the predictive capability of fog models.

For fogs which are not pure radiation fog, one-dimensional models must be extended to two or three dimensions to account for advection effects. These models are useful for understanding the processes leading to fog formation in situations where advection is important, but they are limited as forecast models because of problems of initialization. Even with one-dimensional models, there is difficulty in obtaining initial conditions with sufficient accuracy and vertical resolution from standard meteorological observations. With multidimensional models, this problem becomes more restrictive because data with good resolution are required over a large area with relatively fine horizontal resolution.

---

[6]D. A. Oliver, W. S. Lewellen, and G. G. Williamson, 1978, "The interaction between turbulent and radiative transport in the development of fog and low-level stratus," J Atmos Sci, 35:301-316

TABLE 2. A COMPARISON OF THE FEATURES OF SOME FOG MODELS

Model Features	F&C	Z&N	CAL	SUNY	Z&B	B&R	O, L&W
Turbulent diffusion-K	X	X	X	X	X	X	
Advection	X						
Turbulence second-order closure							X
K as a function of time	X		X	X	X		
Radiative flux divergence of gases		X		X	X	X	X
Radiative flux divergence of droplets		X	X		X	X	X
Air soil coupling		X	X	X	X	X	
Dew formation				X			
Radiosonde data inputs	X	X		X	X		
Emphasis on forecasting fog occurrence				X			

F&C	Fisher and Caplan[7]	Z&B	Zdunkowski and Barr[11]
Z&N	Zdunkowski and Nielsen[8]	B&R	Brown and Roach[12]
CAL	Pilié et al.[9]	O, L&W	Oliver et al.[6]
SUNY	Lala et al.[10]		

---

[7]E. L. Fisher and P. Caplan, 1963, "An experiment in numerical prediction of fog and stratus," J Atmos Sci, 20:425-437

[8]W. G. Zdunkowski and B. C. Nielsen, 1969, "A preliminary prediction analysis of radiation fog," Pure Appl Geophys, 75:278-299

[9]R. J. Pilié, W. J. Eadie, E. J. Mack, C. W. Rogers, and W. C. Kocmond, 1972, "Project fog drops part I - investigation of warm fog properties," NASW-2126, Calspan, Buffalo, NY

[10]G. G. Lala, E. Mandel, and J. E. Jiusto, 1975, "A numerical evaluation of radiation fog variables," J Atmos Sci, 32:720-728

[11]W. G. Zdunkowski and A. E. Barr, 1972, "A radiative-conductive model for the prediction of radiative fog," Boundary Layer Meteorol, 3:152-177

[12]R. Brown and W. T. Roach, 1976, "The physics of radiation fog: II - a numerical study," Quart J Roy Meteorol Soc, 102:335-354

[6]D. A. Oliver, W. S. Lewellen, and G. G. Williamson, 1978, "The interaction between turbulent and radiative transport in the development of fog and low-level stratus," J Atmos Sci, 35:301-316

Within the limitations discussed above, current models probably cannot provide much more than an indication of whether a fog will form and a very qualitative estimate of the intensity (LWC) and vertical extent of the fog. Certainly, no one model will perform well for all sets of meteorological conditions and all possible fog formation mechanisms. The prediction of the optical properties of a fog such as the scattering coefficient or visual range is limited in the present models to estimates based on measured or theoretical relationships of these quantities to liquid water content. Increased forecasting skill with fog models is dependent on a better understanding of boundary layer processes and improved parameterization of processes involving droplet spectra and concentration.

FOG MEASUREMENTS

Many of the fog field programs conducted in the past were concerned with fog dissipation. As such, only limited, if any, attention was paid to drop spectra and LWC; changes in visual range were of utmost concern. There were some notable exceptions, such as the extensive research of the Calspan Corporation (formerly the Cornell Aeronautical Laboratory, Buffalo, NY). Another factor limiting the amount of drop spectra and LWC data available was the lack of instrumentation for making such measurements easily. The instrumentation situation, while still not optimum, has improved markedly in recent years such that more complete data sets will be forthcoming. For a reasonably complete depiction of fog structure or for developing (and verifying) fog models, one requires a substantial number of boundary layer measurements. See, for example, Lala et al.[13] and Roach et al.[14]

The Army's interest is primarily in optical characterization of the atmosphere. For this area of interest, the primary variables are visual range, drop size spectra, and LWC. Some comments on appropriate instrumentation may be in order.

Liquid Water Content

Direct measurements of LWC have been made primarily in clouds with instruments designed for and flown on aircraft. A review is given by

---

[13] G. G. Lala, M. Meyer, and J. E. Jiusto, 1978, "Cloud physics and boundary layer measurements in radiation fogs," Proceedings of Conference on Cloud Physics and Atmospheric Electricity, 31 Jul - 4 Aug 1978, Issaquah, WA. Published by the American Meteorological Society, Boston, MA

[14] W. T. Roach, R. Brown, S. J. Caughly, J. A. Garland, and C. J. Readings, 1976, "The physics of radiation fog: I-a field study," Quart J Roy Meteorol Soc, 102:313-333

Ruskin.[15] In fogs, only noncommercial instruments have been used; these somewhat awkward devices include whirling tubes, fine nylon filaments and large fiber-filters. Collection efficiencies and accuracy of measurement are far from optimum.

The use of the airborne Johnson-Williams (J-W) hot-wire device is recommended.* It is the most common instrument used for cloud work and has been well calibrated over the years. Cloud drops impinging on a heated nickel-iron cool the wire and change its resistance, with the change being proportional to the amount of water collected (LWC). It is most accurate for relatively small drops (d $\lesssim$ 40μm) and moderate water density (LWC $\lesssim$ 3 g m^{-3}). Hence it would appear ideal for fog adaptation where these conditions are generally not exceeded, certainly not the latter. One would require a small wind (or vacuum) tunnel to draw air past the sensor.

Another method of determining LWC involves integration of the drop spectrum for a known volume of air. This necessitates very accurate sampling efficiency and drop sizing, the latter preferably automatically.

Drop Size Spectra

The new wave of drop-sizing devices consists of those that employ light scattering principles to automatically size individual drops. Most popular (and in increasing order of expense) are those made by Royco, Climet, and PMS (Particle Measuring Systems). The first two were essentially designed for aerosol particles and the FSSP-100 of the latter for cloud and ice elements.

We were one of the first groups to apply the Royco (Model 225) to fogs. It has worked quite well, as others have found also (e.g., Hudson[16]). We have now incorporated a pulse height analyzer with it to obtain any number of desired size channels (the basic instrument provides for only five). With any instrument that sucks air into a tube, strict attention must be paid to sampling efficiency that can deteriorate with increasingly

---

[15]R. Ruskin, 1976, "Liquid water content devices," Atmos Technology, NCAR, No. 8, 38-43

*Manufactured by Johnson-Williams Products, Mountain View, CA

[16]J. G. Hudson, 1978, "Fog microphysical measurements on the west coast," preprints, Conference on Cloud Physics and Atmospheric Electricity, 31 Jul-4 Aug 1978, Issaquah, WA, American Meteorological Society, pp 198-205

large drops or in windy conditions (Davies[17]). An impaction device is generally needed to more reliably detect drops < 15-20μm. Also the sheath airflow must be kept at ambient temperature to prevent drop evaporation and a suitable volume flow rate (versus particle concentration) maintained. A number of new features (including reduction of the size threshold from 0.3-0.5μm to 0.1μm) is planned for an updated Royco instrument to be introduced by the company in the spring of 1979.

Distinct advantages of the FSSP-100 unit are the employment of free-air in situ sensing (no tube) which should provide excellent sampling efficiency, and the capability to size drops up to ∿ 45μm diameter. With any scattering device, one must be concerned with variable indices of refraction of small haze and quasi-dry particles--not a problem for large aqueous fog drops.

Thus, there are a number of tradeoffs to consider when selecting and modifying optical devices for sizing fog and haze droplets. Often two instruments are needed to cover the size range of interest. Done properly, the results can be reasonably accurate and far preferable to the older impaction techniques involving countless hours of laborious data reduction.

Visual Range

For the visible wavelengths, the AEG Telefunken Scattered Light Meter (an integrating nephelometer) is rather ideal for fog and haze studies. It has a dynamic range (∿ 40 m to 40-60 km) that surpasses any other instrument to our knowledge. Most other nephelometers or transmissometers customarily are restricted (via Beer's law considerations) to visibilities less than ∿ 5-7 km. This range is probably adequate for fog, but not necessarily for haze studies.

Frequency of Fog Measurements

How often should one measure? Obviously, the answer depends on the specific objective and typical time fluctuations in fog variables. Regarding the latter, we find periods in fog when conditions are relatively steady state for an hour or longer. At other times periodic oscillations of 5-20 min are not uncommon (Lala et al.[13]).

For basic research involving the understanding of fog formation and development, we have found the following sampling frequencies satisfactory:

---

[17] C. N. Davies, 1968, "The entry of aerosols into sampling tubes and heads," British J Appl Phys (J Phys D), 1:021-932

[13] G. G. Lala, M. Meyer, and J. E. Jiusto, 1978, "Cloud physics and boundary layer measurements in radiation fogs," Proceedings of Conference on Cloud Physics and Atmospheric Electricity, 31 Jul - 4 Aug 1978, Issaquah, WA. Published by the American Meteorological Society, Boston, MA

Thermodynamic and visibility variables (temperature, humidity, net radiation, etc.) - 2-min sampling intervals

Drop size spectra - 5 to 30-min intervals depending on how rapidly significant visibility changes are occurring

Aerosol data (CCN, total dry aerosol) - 30 to 60 min

For fog research related to electro-optical military applications (as I vaguely understand them), the periodic measurement of visual range, drop size spectra, and LWC on a 10- to 30-min schedule should suffice. During experimental programs, these and other variables measured should be directly fed into a data-acquisition computer. Strip chart records and their subsequent analysis are fast becoming obsolete.

SELECTED ASRC-SUNY FOG RESULTS

Some selected results from our last year's Albany, NY, radiation fog program will be presented that may illustrate some of the points made. The material is from Meyer.[18]

Fog Drop Spectra. Figures 1 and 2 show drop size spectra evolution in a fog obtained with the Royco 225 sensor and pulse height analyzer. Note: (1) the rapid and dramatic change in two spectra obtained 5 min apart (0725 and 0730 L) as visibility dropped from 2.1 to 1.4 km, (2) the "bimodal" nature of the distribution (submicron peak and 10μm peak), and (3) the near constant concentration of submicron haze particles at ∿ 0.3-0.5μm. Figure 3 shows a drop distribution via impaction (gelatin drop-replicator) to better sample the larger drops. A third mode at ∿ 20μm is suggested.

Also of interest (not shown) is the fact that the 10μm peak (of lower magnitude) persisted during fog dissipation, even when visibility had recovered to 10 km.

Visual Range Versus Drop Concentration and Size. Figure 4 illustrates visual range V (AEG Scattered Light Meter) changes versus droplet concentrations (Royco 225) $\geq$ 0.5μm. For the dry and wet haze (and light fog) portion of the figure ($V > 1.5$ km):

$$V = 130\, N_c^{-0.77} \;;$$

while for fog ($V < 1.5$ km),

$$V = 80\, N_c^{-1.1} \,.$$

---

[18]M. Meyer, 1978, "Aerosol characteristics in local radiation haze and fog," MS Thesis, Department of Atmospheric Science, SUNY, NSF Grant ATM 7624048

These power law functions can be justified mathematically.[18]

Figure 5 depicts the same data expressed in terms of V versus drop size squared. These figures affirm that visibility (σ) degradation is most dependent upon particle concentration N_c for V > 1-2 km; below that discontinuity, as haze particles commence to grow substantially, droplet size dominates σ. (If one plots V against $N_c d^2$, then a single straight line results as $\sigma \propto Nd^2$.)

Visual Range Versus Relative Humidity. It is generally known that V tends to decrease as relative humidity (RH) increases, at least for humidities beyond 70 percent. Little information is found in the current literature. Figure 6 illustrates this relationship for 13 cases and hundreds of averaged data points. The trend continues to at least 60 percent RH, but the standard deviations are so large that any predictions of σ based on RH alone would be fallacious.

SUMMARY AND RECOMMENDATIONS

Fog properties vary considerably from one geographic area to another and also at a given location depending upon numerous microphysical to synoptic scale conditions. The extinction (or scattering) coefficient can vary over three orders of magnitude. Hence, one should use considerable caution in transferring the results of an EO system tested in fog in one region of this country to another location here or abroad. Attempts to match respective fog regions according to fog type, formation mechanism, geophysical land-water features, and general aerosol characteristics can and should be pursued.

Standard meteorological measurements made at regular weather stations (National Weather Service and military) provide little information, apart from horizontal visibility, on the optical characterization of the atmosphere. Fog forecasts are also qualitative and rather primitive.

Fog models offer promise of improving both the forecast capability and the definition of fog intensity (LWC). However, one should be realistic about the degree of accuracy and applicability of fog models. Several models would be necessary to depict the distinctly different types of fogs encountered (e.g., inland radiation versus coastal advection fogs). A prediction of the occurrence of fog and some parameterized measure of liquid water content appear realizable; detailed representations of droplet spectra appear remote, except in a very qualitative sense.

---

[18]M. Meyer, 1978, "Aerosol characteristics in local radiation haze and fog," MS Thesis, Department of Atmospheric Science, SUNY NSF Grant ATM 7624048

For basic understanding of prediction of fog formation, measurement programs must consider all the relevant thermodynamic, microphysical, and synoptic variables (Lala et al.[13]). For merely depicting the extinction coefficient at prescribed wavelengths, one can do with much less information. Here the key variables are drop size distribution and/or LWC. Measurements should be made, if not already made, to determine EO system performance degradation as a function of σ; then one can better evaluate the degree to which haze and fog conditions must be specified.

For a sensor wavelength of 11μm, Chýlek's expression relating σ only to LWC (relatively independent of the drop size distribution) looks promising. Similarly, Low's calculations of σ as a function of drop-size distribution forms should elucidate the importance of the problem.

As recommended previously, the particular portion of the drop size (or soil particle size) distribution that most critically influences σ can be calculated from real and model distributions of fog and haze types.

Better and faster equipment for measuring fog microphysical properties are evolving and have been mentioned in the text. The PMS FSSP-100 drop sizing probe looks promising on paper, provided that one considers the nonmonotonic relation between signal output and drop size in some portions of the spectrum. If the light acceptance angular cone of the instrument were increased, its performance could be improved.

The frequency of measurement for test programs has also been suggested, recognizing that we are just beginning to acquire information about temporal fluctuations of fog intensity.

Ultimately, one probably must resort to highly simplified optical characterization models of the atmosphere for real time application in a variety of locales. The more rigorous the initial studies are (including the σ sensitivity evaluation mentioned above), the more relevant and accurate will be this family of simplified atmospheric-optical models.

---

[13] G. G. Lala, M. Meyer, and J. E. Jiusto, 1978, "Cloud physics and boundary layer measurements in radiation fogs," Proceedings of Conference on Cloud Physics and Atmospheric Electricity, 31 Jul - 4 Aug 1978, Issaquah, WA. Published by the American Meteorological Society, Boston, MA

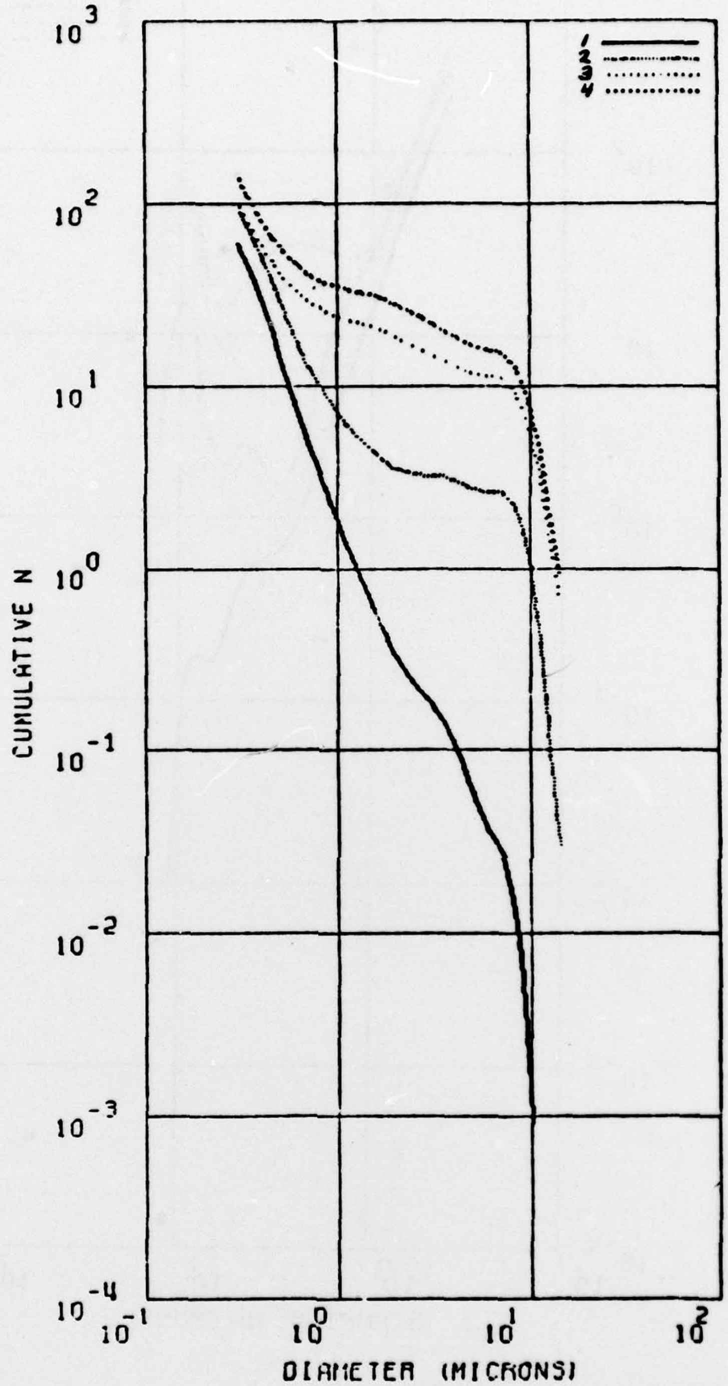


Figure 1. Time sequence of cumulative aerosol spectra during fog development (case 5). Curve 1--0725 L, V = 2.1 km; Curve 2--0730 L, V = 1.4 km; Curve 3--0800 L, V = 0.39 km; Curve 4--0827 L, V = 0.29 km. (ref 18)

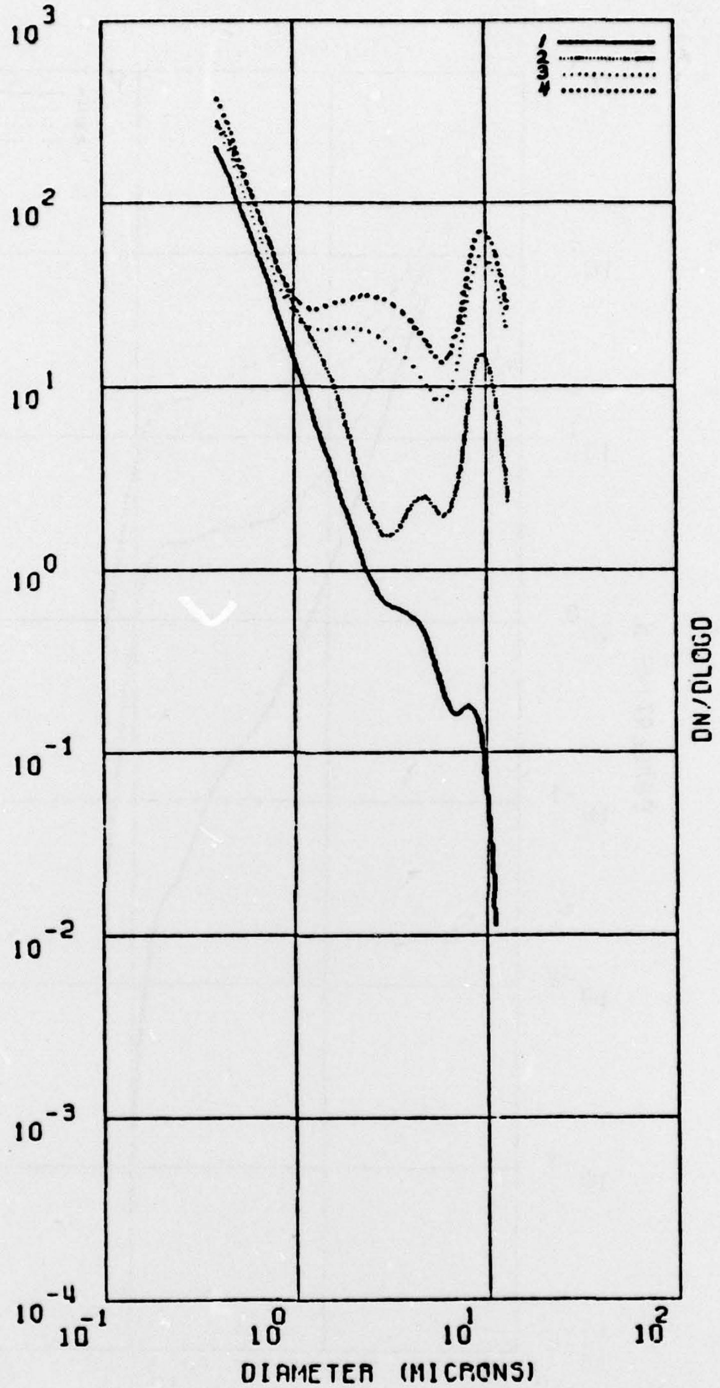


Figure 2. Time sequence of differential aerosol spectra during fog development (case 5). Curve 1--0725 L, V = 2.1 km; Curve 2--0730 L, V = 1.4 km; Curve 3--0800 L, V = 0.39 km; Curve 4--0827 L, V = 0.29 km.

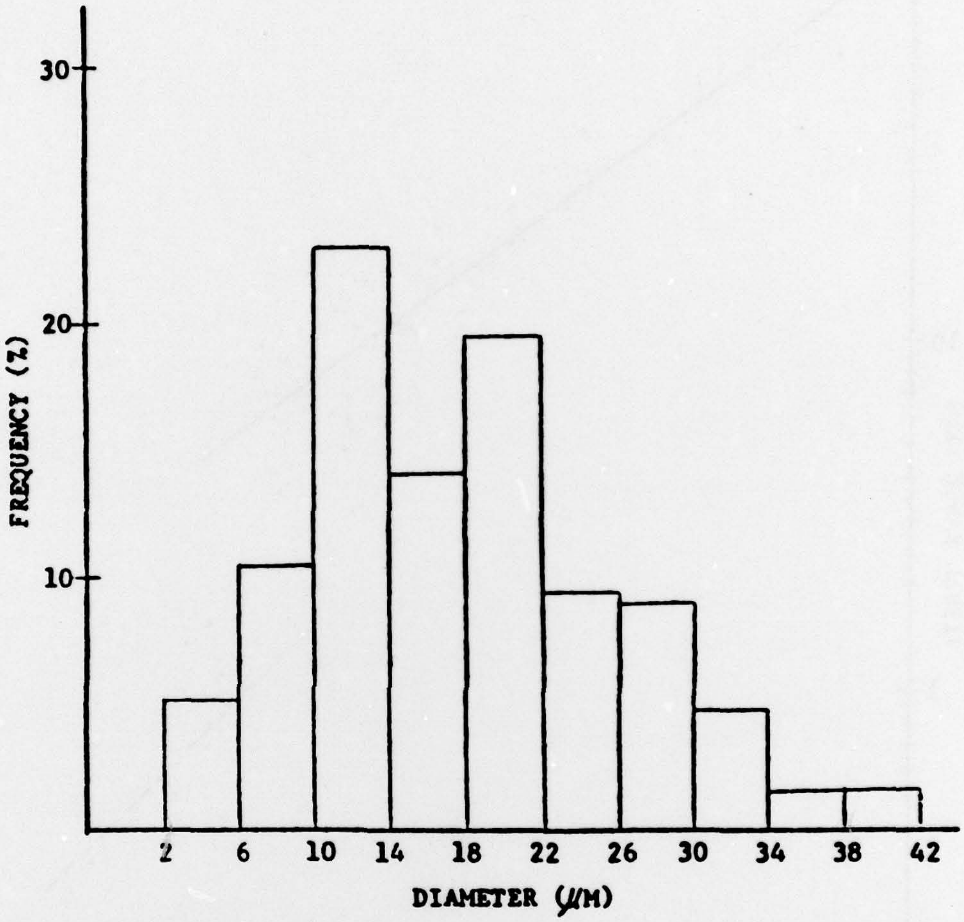


Figure 3. Drop-size frequency distribution at 0827 L (case 5).

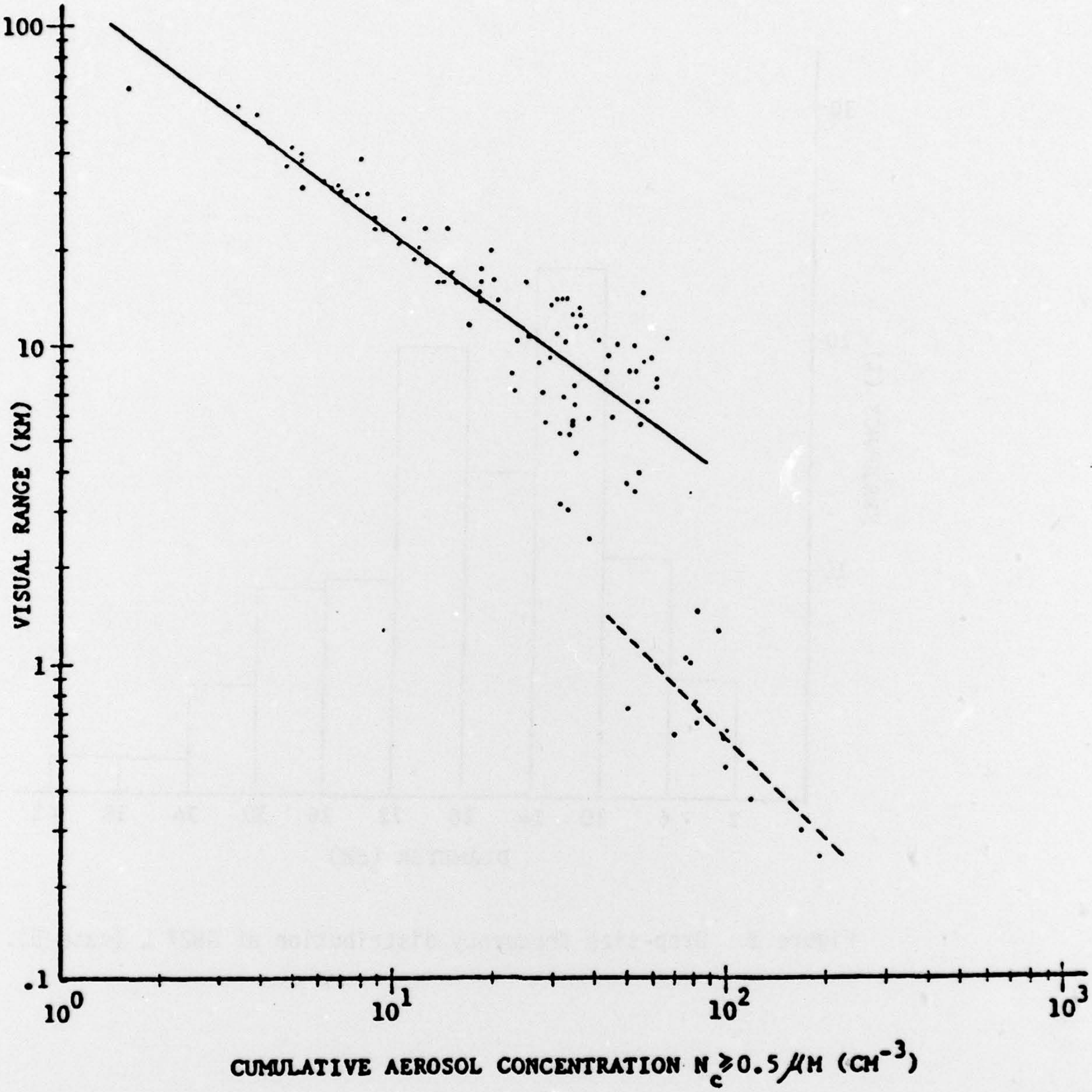


Figure 4. Visual range versus cumulative aerosol concentration.

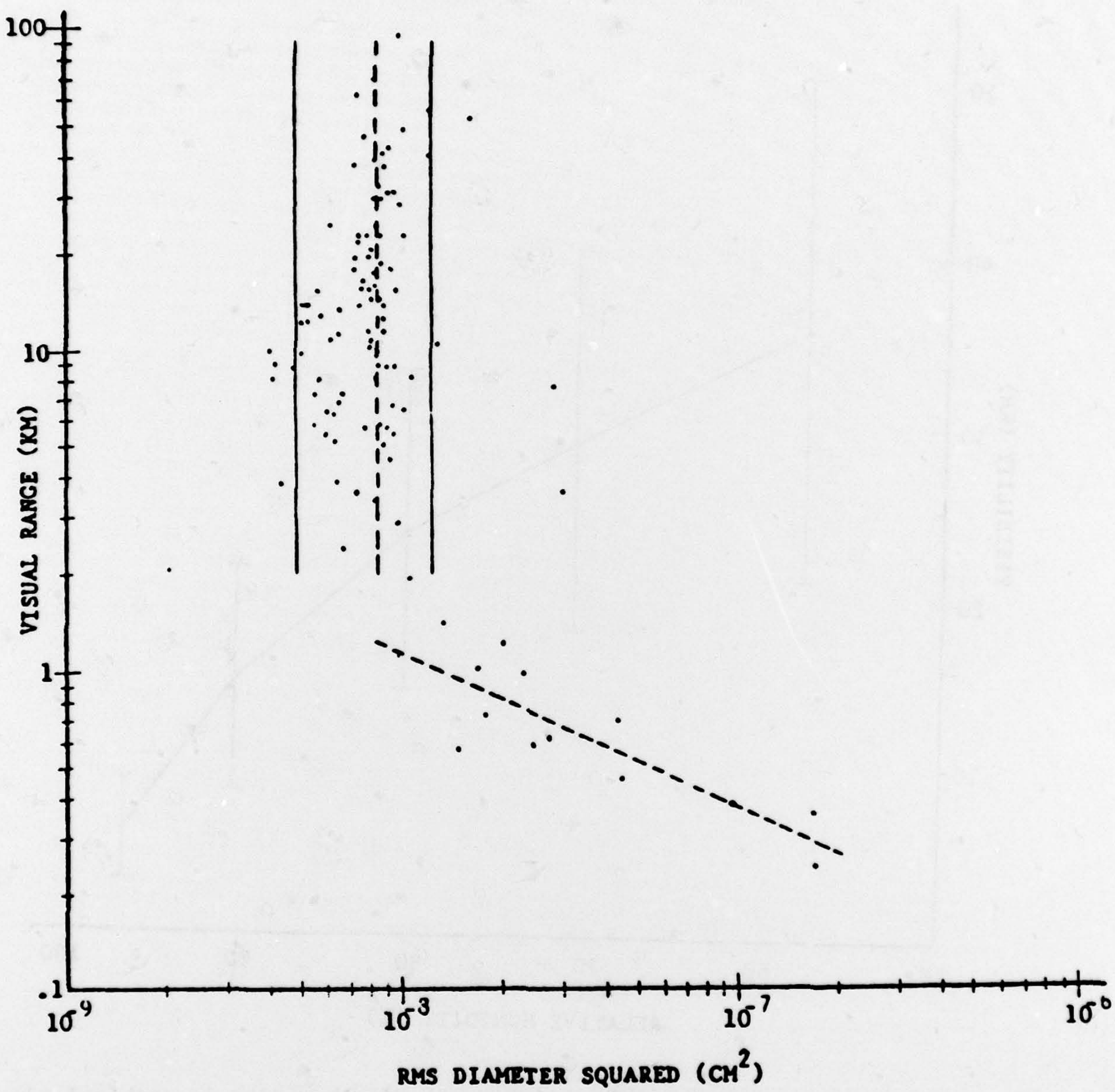


Figure 5. Visual range versus RMS diameter squared (mean surface diameter squared). Solid vertical lines indicate one standard deviation.

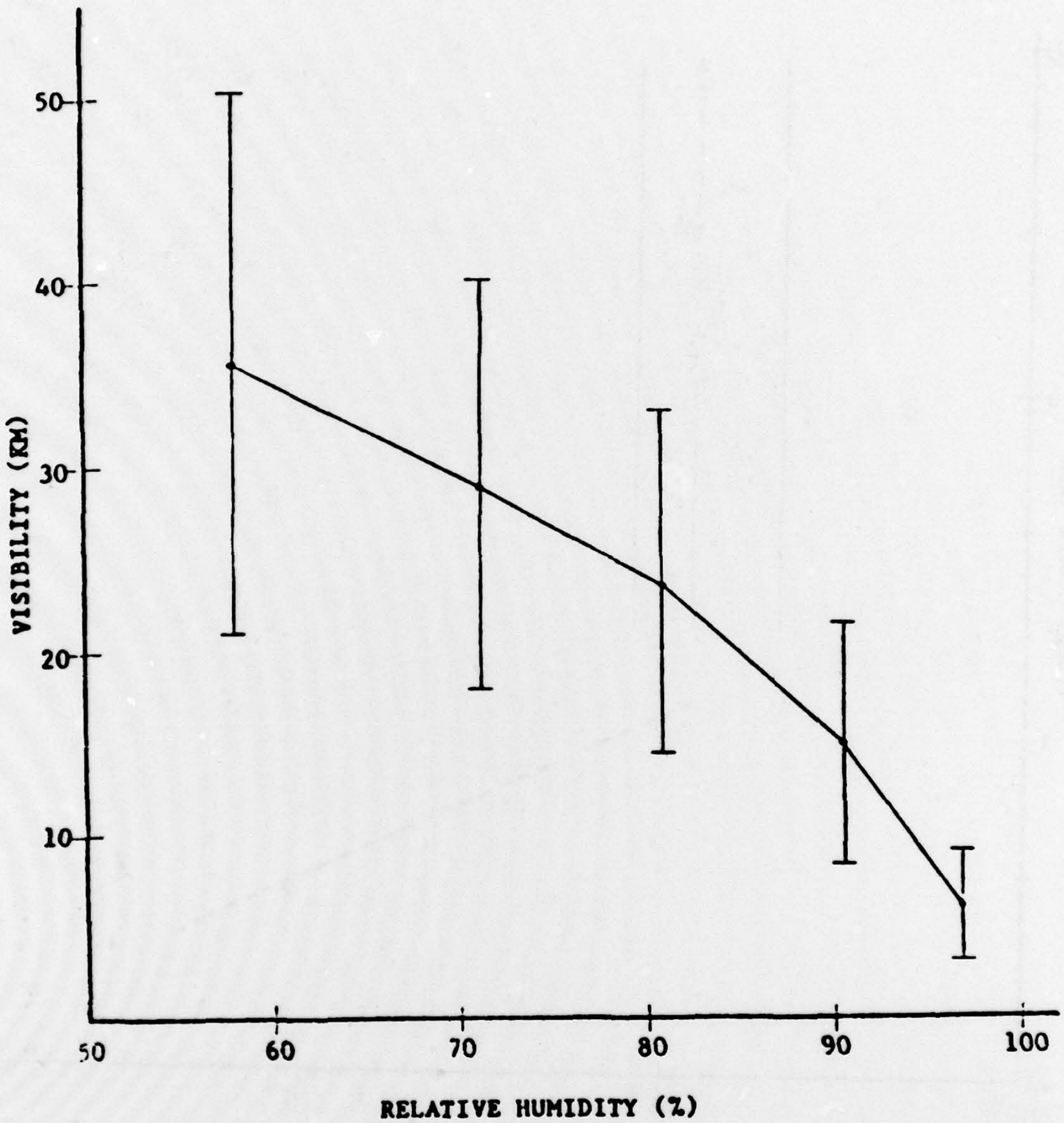


Figure 6. Average visibility versus mean relative humidity in each relative humidity classification. Vertical bars indicate one standard deviation. (ref 18)

REFERENCES

1. Willett, H. C., 1928, "Fog and Haze," Mo Weather Rev, 56:435.

2. Byers, H. R., 1959, General Meteorology, 3rd Ed., McGraw-Hill, NY, 481 pp.

3. Atlas, D., and S. Bartnoff, 1953, "Cloud visibility, radar reflectivity, and drop size distribution," J Meteorol, 10:143-148.

4. Low, R. D. H., 1978, "A theoretical investigation of cloud/fog optical properties and their spectral correlations," ASL-TR-0024, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM, 21 pp.

5. Chýlek, P., 1978, "Extinction and liquid water content of fogs," J Atmos Sci, 35:295-300.

6. Oliver, D. A., W. S. Lewellen, and G. G. Williamson, 1978, "The interaction between turbulent and radiative transport in the development of fog and low-level stratus," J Atmos Sci, 35:301-316.

7. Fisher, E. L., and P. Caplan, 1963, "An experiment in numerical prediction of fog and stratus," J Atmos Sci, 20:425-437.

8. Zdunkowski, W. G., and B. C. Nielsen, 1969, "A preliminary prediction analysis of radiation fog," Pure Appl Geophys, 75:278-299.

9. Pilié, R. J., W. J. Eadie, E. J. Mack, C. W. Rogers, and W. C. Kocmond, 1972, "Project fog drops part I - investigation of warm fog properties," NASW-2126, Calspan, Buffalo, NY.

10. Lala, G. G., E. Mandel, and J. E. Jiusto, 1975, "A numerical evaluation of radiation fog variables," J Atmos Sci, 32:720-728.

11. Zdunkowski, W. G., and A. E. Barr, 1972, "A radiative-conductive model for the prediction of radiative fog," Boundary Layer Meteorol, 3:152-177.

12. Brown, R., and W. T. Roach, 1976, "The physics of radiation fog: II - a numerical study," Quart J Roy Meteorol Soc, 102:335-354.

13. Lala, G. G., M. Meyer, and J. E. Jiusto, 1978, "Cloud physics and boundary layer measurements in radiation fogs," Proceedings of Conference on Cloud Physics and Atmospheric Electricity, 31 Jul - 4 Aug 1978, Issaquah, WA. Published by the American Meteorological Society, Boston, MA.

14. Roach, W. T., R. Brown, S. J. Caughly, J. A. Garland, and C. J. Readings, 1976, "The physics of radiation fog: I - a field study," Quart J Roy Meteorol Soc, 102:313-333.

15. Ruskin, R., 1976, "Liquid water content devices," Atmos Technology, NCAR, No. 8, 38-43.

16. Hudson, J. G., 1978, "Fog microphysical measurements on the west coast," preprints, Conference on Cloud Physics and Atmospheric Electricity, 31 Jul - 4 Aug 1978, Issaquah, WA, American Meteorological Society, pp 198-205.

17. Davies, C. N., 1968, "The entry of aerosols into sampling tubes and heads," British J Appl Phys (J Phys D), 1:021-932.

18. Meyer, M., 1978, "Aerosol characteristics in local radiation haze and fog," MS Thesis, Department of Atmospheric Science, SUNY, NSF Grant ATM 7624048, 76 pp.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979 — 677-017/14