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VISIBILITY AT SEA

An Annotated Bibliography

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INTRODUCTION

A major concern of various Codes at the Naval Weapons Center and the Naval Electronics Laboratory Center has been the effect of weather on the operation of naval electro-optical systems. A literature search was undertaken to study and evaluate research efforts and the state of the art of various aspects of the problem. The areas of interest included:

a) Measurement of visibility at sea
b) Methods for accurately determining visibility at sea
c) Cloud Free Lines of Sight (CFLOS)
d) Methods for extending visibility measurements made in the visible to the infrared
e) Lidar measurements of visibility
f) Precipitation data over oceans
g) Sources of Visibility Data

An annotated bibliography of this search was compiled and is presented alphabetically by author. The source materials are listed separately.

ANNOTATED BIBLIOGRAPHY

H.S. Appleman, "A Comparison of Simultaneous Aircraft and Surface Cloud Observations", J. Appl. Meteor., 1, 548, (1962).

Abstract: Many operations require a knowledge of the current or future cloud cover. Consequently, the question of the accuracy of surface cloud reports has frequently arisen. The following study, based on a comparison of a series of simultaneous ground observations and aerial photographs, gives an estimate of some of the problems and accuracies involved.

Conclusion ...From the results of this study, then, it is suggested that when using cloud climatologies based on surface observations an allowance be made for bias in over-estimating the low cloud cover. Furthermore, any regions covered by high clouds only can be assumed to permit visual penetration with little or no degradation in perhaps 75% of the cases, and limited penetration in the remainder.

E. A. Barnhardt and J. L. Streete, "A Method for Predicting Atmospheric Aerosol Scattering Coefficients in the Infrared," Appl. Opt., 9, 1337, (1970).

Abstract: A method for predicting scattering coefficients in the atmospheric windows from 1.0 to 15.0 microns is presented. The method avoids the assumptions that the index of refraction and the aerosol distribution are constants over the range of relative humidity values. Relative humidity is taken as the independent variable with the aerosol distribution and index of refraction dependent upon the value of relative humidity. A two-component continental and maritime aerosol distribution is used. Although strictly applicable to the 1.0-15.0 micron region, the calculations are extended with a lesser degree of accuracy into the visible region so that comparisons with measured data may be made.

E. W. Barrett and O. Ben-Dov, "Application of the Lidar to Air Pollution Measurements," J. Appl. Meteor., 6, 500, (1967).

Abstract: An urgent need exists for a technique of rapid and economical measurement of vertical profiles of atmospheric particulate concentration. It is shown in this paper that the lidar, or optical radar, is capable of meeting this need. The first part of the paper presents the physical basis of the technique wherein equations based on Mie scattering theory and the radar equation are derived which permit quantitative calculations of the particulate concentration, turbidity index, and horizontal visibility from the lidar data as functions of height. The remainder of the paper is devoted to a brief description of an operational lidar system,

some examples of the results obtained with it, and an evaluation of its performance during six months of use. A subsequent paper will present some detailed case studies of pollution episodes in the Chicago Metropolitan area.

Conclusions: The use of a vertically aimed lidar with suitably chosen parameters, together with reasonable assumptions concerning the particulate size distribution, permits the instantaneous or time-averaged vertical distributions of particulate concentration, turbidity, and horizontal visibility in the atmosphere up to heights of at least 5000 feet, with an accuracy which is probably correct to within a factor of 2, by means of equations based on the Mie scattering theory which are derived in Section 2 and the Appendix of this paper.

M. Bertolotti, L. Muzii, and D. Sette, "On the Possibility of Measuring Optical Visibility by Using a Ruby Laser," Appl. Opt., 8, 117, (1969).

Abstract: The atmospheric attenuation of a ruby laser is studied. The possibility of using the laser back scattered radiation to probe optical visibility is investigated. Some experimental measurement supporting this possibility is reported.

E. A. Bertoni, CLEAR LINES-OF-SIGHT FROM AIRCRAFT, AFCRL-67-0435, Air Force Surveys in Geophysics, No. 196, August 1967.

Introduction: In an attempt to provide consultation on the impact of cloudiness on the design of optical and infrared ground based and airborne detection and tracking systems, it became apparent that cloud data compiled from standard surface weather observations are not very applicable in obtaining desired estimates. Lund (1967, 1966) and McCabe (1965) provide statistical models for estimating the probability of a clear line-of-sight using sunshine and cloud cover observations. This paper describes and presents data from an in-flight observation program covering much of the Northern Hemisphere, initiated to collect observations of the presence, or absence, of clear lines-of-sight from aircraft at several different angles above and below the horizon.

D. C. Blanchard and L. Syzdek, "Variations in Aitken and Giant Nuclei in Marine Air," J. Phys. Oceanog., 2, 255, (1972).

Abstract: During the summer of 1970, Aitken nucleus counts were made nearly every day from atop a tower on the windward shore of Oahu, Hawaii. Contrary to expectations, the counts were not constant from one day to the next but underwent slow changes of a cyclic nature. The daily averages varied between 125 and 500 nuclei per cubic centimeter. Most interesting was the finding of

what appeared to be two cycles in the count, one having a period of about thirty days and the other, superimposed on this, having a period of 5-6 days. At the same time the nucleus counts were made, the mass of giant sea-salt particles was determined. This was found to vary with local wind speed in much the same manner as has been found by Woodcock.

The cyclic variations in Aitken nuclei have not been explained. Various local meteorological parameters, pressure, wind, cloud cover, time of day, etc., showed no correlation with the nucleus count. The magnitude of the count was about the same as that found in the same area by the CARNEGIE nearly half a century ago.

Used Gardner counter.

Mentions Shiratori's work to develop a nucleus climatology, a map of the World Ocean showing the expected nucleus count at any given location. These investigations show that the nucleus counts are high in the vicinity of continents, especially near the eastern shores, and that one must be of the order of 1000 km from continents to obtain nucleus counts representative of steady-state conditions at sea.

R. T. Brown, Jr., BACKSCATTER SIGNATURE STUDIES FOR HORIZONTAL AND SLANT RANGE VISIBILITY, Report No. RD-67-24 Sperry Rand Research Center, May 1967

Summary of Experimental Program and Results: According to the theory developed for analysis of backscatter signatures, the slope, distance-to-peak, and pulse width of the backscatter display are all dependent on the characteristics of the medium producing it. Similarly, the laser beam width, the receiver field of view, the separation between the transmitter and the receiver, and the alignment angle between the axes of the laser beam and the receiver field of view affect the characteristics of the backscatter display. Backscatter signature system tests were conducted in fog at Maynard, Massachusetts, Atlantic City, New Jersey and Arcata, California to obtain data that could be used to verify the theory and determine the effects of systematic changes in the above parameters on the characteristics of the backscatter displays. Transmissometer data were simultaneously recorded for comparison with the backscatter data and to permit the determination of atmospheric extinction coefficients from the backscatter data. Power tests were also conducted to determine the minimum laser power output that produced acceptable data.

The results of the data analysis confirmed the theoretical approach and showed that the data obtained were in fact representative of the conditions within the scattering medium (i.e., fog).

Richard T. Brown, Jr., "A NEW LIDAR FOR METEOROLOGICAL APPLICATION," J. Appl. Meteor., 12, 698, (1973).

Abstract: A new lidar has been demonstrated to be potentially useful as a meteorological tool. This lidar is the result of applying a new technology, gallium-arsenide fiber coupling. By coupling fibers to each of an array of gallium-arsenide diode lasers, a narrow well-collimated, relatively high flux density laser beam is attainable from a small package. This, in conjunction with pulse repetition rates in the kilohertz region, permits the construction of a practical lidar with a good signal-to-noise ratio and peak power within the limits of eye safety. Examples of signals from hydrometeors (rain, fog, and clouds) using a 250W peak-power lidar are presented. Cloud height measurement to 4000 feet has been attained. The possibility of measuring cloud extinction coefficients using such signals is demonstrated. The potential of measuring extinction coefficient profiles (and thus visibility profiles) through fog is also demonstrated.

Conclusions: The potential of low-power, high-pulse-repetition-rate, eye-safe lidar as a meteorological tool has been demonstrated. The gallium-arsenide injection diode laser array, when fiber coupled, becomes an optically convenient, reliable light energy source for such a lidar. Usable lidar signals can be obtained from hydrometeors such as fog, rain, snow and clouds with just a few hundred watts per pulse of transmitted power. Using relatively simple data processing techniques, information relative to the optical transparency and density structure of these meteors can be derived. The GaAs lidar shows potential for application in areas requiring unattended operation for long periods of time. There is promise of future developments making this lidar meteorologically useful in a way paralleling radar, where the shorter optical wavelengths can be used to advantage.

E. A. Bucher, "COMPUTER SIMULATION OF LIGHT PULSE PROPAGATION FOR COMMUNICATION THROUGH THICK CLOUDS," Appl. Opt. 12, 2391, (1973).

Abstract: This paper reports computer simulations of light pulse propagation through clouds. The amount and distribution of multipath time spreading was found to be independent of the detailed shape of the scattering function for sufficiently thick clouds. Moreover, the amount of multipath spreading for many scattering functions and cloud thicknesses can be predicted from a common set of data. Spatial spreading of the exit-spot diameter was found to saturate as a cloud of a given physical thickness became optically thicker and thicker. We observed that the propagation parameters for sufficiently thin clouds were dependent both on the cloud parameters and on the scattering function.

E. A. Bucher and R. M. Lerner, EXPERIMENTS ON LIGHT PULSE COMMUNICATION AND PROPAGATION THROUGH ATMOSPHERIC CLOUDS, Appl. Opt. 12, 2401, (1973).

Abstract: This paper describes the facilities and results in an experiment to investigate light pulse propagation through atmospheric clouds. The experiments were conducted with the transmitter and receiver located on two mountain peaks in a naturally cloudy area. The transmitter was a Q-switched ruby laser producing 30 nsec light pulses. The received pulses were 1-10 μsec in duration when there was a cloud in the propagation path. The multipath time lengthening of the received pulse resulted from multiple scattering inside the cloud. The extent of this multipath pulse spreading can be shown to be comparable to that predicted from computer simulation models. We also observed a number of effects in which relatively small changes in the gross cloud shape produced a change in the received signal intensity of an order of magnitude or so.

H. R. Carlon, "Infrared Emission by Fine Water Aerosols and Fogs," Appl. Opt. 9, 2000, (1970).

Abstract: Water aerosols, even when so finely divided as to be invisible, are capable of very strong absorption and emission in the infrared. This effect is pronounced in the 8-13 μ atmospheric window, owing to the 10^4 increase in the absortivity of liquid water there over that for water vapor, and it contributes to the well known continuum in this spectral region. Water aerosol is found wherever suitable condensation nuclei exist and the relative humidity is above 60%. Aerosol droplets increase in size and number with increasing relative humidity, affecting atmospheric radiance measurements accordingly. Trace quantities of aerosol can easily account for emission levels exceeding those of water vapor at 8-13 μ and are clearly indicated in cases where observed radiance levels cannot be accounted for by classical vapor band wing absorption theories. The aerosol emission mechanism is not associated with the formation or growth of the water droplets per se, but simply operates when droplets exist in the airborne state. Fog measurements are discussed and curves presented showing attenuation ratios between wavelengths in the visible and at 8-13 μ. Steam emission measurements leading to the formulation of an aerosol emission model are described briefly.

Summary: There is strong evidence to indicate that water aerosol contributes significantly to radiance levels in the infrared, not only in the obvious scattering role, but specifically as an emitter, particularly at the longer wavelengths extending to at least 15 μ. It is thought to be an important factor in determining the nature of the 8-13 μ continuum. Trace quantities of aerosol can easily account for emission levels in this wavelength region. While infrared water aerosol absorption contributes to atmospheric attenuation in transmission measurements, it is more easily observed in radiance measurements using passive radiometers. Implications of water aerosol absorption effects are very far reaching.

L. W. Carrier, G. A. Cato, and K. J. von Essen, "The Backscattering and Extinction of Visible and Infrared Radiation by Selected Major Cloud Models," Appl. Opt., 6, 1209, (1967).

Abstract: Volume backscattering functions and optical extinction coefficients are computed for eight suggested major cloud models using the Mie theory for optical wavelengths of 0.488μ, 0.694μ, 1.06μ, 4.0μ, and 10.6μ. Results show that there is no clear advantage of one wavelength over another for improving cloud transmission; however, backscattering is significantly reduced at the longer wavelengths. Variations in the optical properties of clouds are also discussed and calculations summarized to indicate the effects of cloud thickness, inhomogeniety, and geographical location on the backscatter function and extinction coefficient.

D. T. Chang and R. Wexler, RELATION OF AEROSOLS TO ATMOSPHERIC FEATURES, AFCRL-68-0360, Allied Research Associates, 15 September 1968.

Abstract: Relationships between aerosol attenuation coefficient profiles acquired over New Mexico (32N) and atmospheric features were investigated. The dependence of lower stratospheric aerosol content on air mass characteristics and the correlation between the height of the lower stratospheric aerosol layer and the height of the tropical tropopause suggests a tropical source for these aerosols. Seasonal variations in aerosol content of the surface layer were found to reflect seasonal changes in convective activity in this layer.

R. T. H. Collis, "Lidar," Appl. Opt., 9, 1782, (1970).

Abstract: Lidar uses laser energy in radar fashion to observe atmospheric backscattering as a function of range. The concomitant attenuation of energy along the intervening path complicates the evaluation of the observations, but even on a qualitative basis the delineation of clouds or of structure in the apparently clear air is of considerable value in operational meteorology and atmospheric research. Under certain conditions the atmosphere's optical parameters may be evaluated and related to meteorological significant characteristics. Advanced techniques based on resonant absorption and Raman shift backscattering are briefly noted. The current attainment and future prospects of lidar are reviewed.

R. T. H. Collis, F. G. Fernald, and J. E. Adler, "Lidar Observations of Sierra Wave Conditions," J. Appl. Meteor., 7, 227, (1968).

Abstract: Early in 1967 a series of observations using pulsed ruby lidars were made near Independence CA: the objective was to investigate the value of lidar for studying air motion in the Sierra wave, with special reference to indications of turbulence.

Although no intense wave activity occurred, appreciable wave motions were observed, both in what appeared to the eye to be clear air and in air where the particulate matter was sufficiently concentrated as to be visible in clouds. Interruptions in the smooth laminar flow in the clear air were observed, and measurements were made of the length, amplitude and height of waves shown by clouds.

With previously existing techniques, only limited observation of such phenomena have been possible. It is thus concluded that lidar observations are of considerable value in studying wave motion, even in the absence of visible clouds. There is also a possibility that lidar could indicate the presence of turbulence by revealing the breakdown of wave motion or the presence of rotors.

R. T. H. Collis, W. Viezee, E. E. Uthe, J. Oblanas, VISIBILITY MEASUREMENT FOR AIRCRAFT LANDING OPERATIONS, AFCRL-70-0598, Stanford Research Institute, 30 September 1970.

Abstract: An experimental pulsed neodymium lidar system was modified and calibrated to obtain accurate data on atmospheric extinction properties in fog and low cloud conditions. The objective was to establish the theoretical and practical basis of a system for measuring slant range visibility conditions for landing operations. To operate in conditions of fog and low cloud the lidar system's dynamic range was extended to 50dB by using a two-stage receiver system. In addition, the transmitter and receiver beams were made coaxial to make closerange observations.

Field trials were carried out at a temporary site at Half Moon Bay, California, and at the National Bureau of Standards site at Arcata, California. In May/June and August 1970, respectively. At Arcata, data were collected in conjunction with measurements by an array of up to five AN/GMQ-10 transmissometers. Observations were made in clear weather and in conditions of fog and low cloud using arrays of passive targets to provide information on atmospheric extinction. The correlation between atmospheric transmittance derived from lidar/target data and from AN/GMQ-10 transmissometers equalled that found between the data from individual transmissometers. Thus, a lidar with support of passive targets could replace a transmissometer system with comparable accuracy in determining atmospheric transmittance.

Single-ended lidar data were obtained along horizontal paths adjacent to the passive targets and to a 500 ft. base line transmissometer. Atmospheric transmittances were computed from these lidar data using analytical methods (which are discussed in detail) of evaluating atmospheric extinction coefficients from a consideration of the 'slope' of the lidar trace. A correlation coefficient of 0.97 was found between the lidar data and the transmissometer data for comparable path transmittances in a variety of low-visibility conditions.

The concept of remotely deriving extinction coefficients aloft from observations by a ground-based lidar was applied to the aircraft landing problem. Using values of extinction coefficient for atmospheric layers above the surface derived from series of lidar observations at different angles of observation, examples are given of the calculation of transmittance over the line-of-sight path from which a pilot would look (at a cockpit cut-off angle) from the critical height to the surface to acquire visual reference. No corroboration of these evaluations of slant path transmittance was available. Possible means of deriving and presenting such data for operational purposes are outlined, and the potential use of lidar for revealing the general conditions of cloud and fog conditions in the airfield approach are described.

The problem of realizing an operational system in an ultimate form is considered and some potential approached to this end are noted.

E. deBary and F. Moller, "The Vertical Distribution of Clouds," J. Appl. Meteor. 2, 806, (1963).

No abstract. Listed under Notes and Correspondence.

Reviews an investigation made by the authors in 1960 in which cloud amounts of all cloud types at altitudes up to 5 km were dealt with statistically. The basis were direct observations within the atmosphere itself. Data of this kind have been obtained very rarely, particularly when a time coverage sufficient for climatological studies is desired. Data from the German weather flights during the years 1936-1940 were felt to fulfill the requirements. Cloud observations on these flights were made regularly (twice a day) by well trained observers (professional meteorologists). Flights were made every morning and 60% in the afternoon -- flights were cancelled only when dense ground fog occurred. (Over 25,000 flights).

The authors analyzed these observations and inferred statistical data on the height distribution of cloudiness up to a 5 km altitude, as seen from different heights. Data are separated into winter, morning; winter, afternoon; summer, morning; and summer, afternoon. Ten different weather situations were evaluated separately. Figures in the original investigation include all the situations.

D. R. Dickson and J. V. Hales, "Computation of Visual Range in Fog and Low Clouds," J. Appl. Meteor. 2, 281, (1963).

Abstract: Visual ranges were computed for various values of extinction coefficient, for five sets of conditions appropriate to fog and low clouds. The computations involve basic theories of visual range as developed by Allard (1876) and Koschmieder (1924). The four values of the threshold of illumination (E_t) which Haig and Morton determined were used in the Allard theory computations.

Conclusion: The investigation indicated the feasibility of using a method such as has been described here in an automatic weather and observing and forecasting system such as the Weather Observing and Forecasting System 433L.

J. Dunbrack, VISIBILITY, CLOUD COVER, AND PRECIPITATION DATA FOR GEOGRAPHICAL AREAS OF PARTICULAR INTEREST TO NAVY WEAPONS DESIGNERS, NWC Corona, April 1969 NWCCL TP 838 AD 851 225

Abstract: This report contains information on visibility, cloud cover, and precipitation conditions in certain areas of the world. The geographical areas concerned are those in which the Navy could be interested from a tactical standpoint. One section is devoted to visibility distribution by geographical area of interest. This is followed by sections on cloudiness distribution and precipitation distribution. A brief explanation is given in each section on how to interpret the respective charts.

R. G. Eldridge, "Climatic Visibilities in the United States," J. Appl. Meteor., 5, 277, (1966).

Abstract: Climatological visibility data for fifty-three sites is used to evolve seasonal visibility maps of the United States. The analysis is presented in the form of cumulative visibility frequency distribution maps. A brief discussion of their use and limitations to describe atmospheric opacity is included.

Defines atmospheric visibility and visual range, as well as climatic visibilities. Discusses the application and limitation of visibility maps. Shows maps by season.

L. Elterman, UV, VISIBLE, AND IR ATTENUATION FOR ALTITUDES TO 50 KM, 1968. AFCRL-68-0153, April 1968, Environmental Research Papers, No. 285.

Abstract: An atmospheric attenuation model for the ultraviolet, visible, and infrared was developed in 1964, based on scattering (molecules and aerosols) and ozone absorption. Since then more measurements have been made and our knowledge of aerosol attenuation has widened. These circumstances result in attenuation model changes which are relatively unimportant for most exploratory calculations. They can be significant, however, for long slant-path high-altitude applications entailing large zenith angles, factors which characterize, for example, the measurement geometries of rockets and satellites. Accordingly, a revision of the 1964 Attenuation Model is warranted.

In this paper the optical parameters are computed spectrally and with altitude as follows: (1) pure air attenuation parameters are determined by utilizing Rayleigh scattering cross sections with molecular number densities from the standard atmosphere; (2) ozone absorption parameters are derived based on Vigroux's coefficients applied to a representative atmospheric ozone distribution; (3) seven sets of aerosol measurements are compared and a profile of aerosol attenuation coefficients vs altitude is developed. Attenuation coefficients and optical thickness due to molecular, aerosol, and ozone attenuation are computed and tabulated individually so that the influence of each can be compared. The newly derived tabulations permit various exploratory calculations, including horizontal, vertical, and slant-path transmissions at kilometer intervals to an altitude of 50 km, individually for each attenuating component or for overall atmospheric extinction (molecular + ozone + aerosol).

L. Elterman, "Relationships Between Vertical Attenuation and Surface Meteorological Range," Appl. Opt., 9, 1804, (1970).

Abstract: An examination of the haze regime, used in the sense of diminished surface meteorological range, shows that the lower and upper limits can be defined by meteorological ranges 1.2 km and 15 km, respectively. In order to develop relationships between surface haze and vertical attenuation, eight meteorological ranges are selected from within these limits; then, vertical aerosol attenuation parameters are computed by deriving an aerosol scale height for each meteorological range. A sample tabulation for one of twenty wavelengths in the uv, visible, and ir is presented and combined with previously published attenuation parameters (aerosols, molecules, and ozone) to the 50-km altitude.

Note: Says that the concept of photopic meteorological range can be widened spectrally if concurrent measurements of attenuation coefficients at other wavelengths are available. λ 0.2 μ to 2.17 μ.

G. P. Faraponova, "Relation of Transparency of the Free Atmosphere to Certain Meteorological Characteristics," Izv., Atmospheric and Oceanic Physics Series, 1, 352, 607, (translated by P. A. Keehn) (1965).

Abstract: Some relationships are obtained between the aerosol component of the coefficient of attenuation $^{K}\lambda$, aerosol ($^{\lambda}$ eff = 0.44 μ) of the individual layers of the atmosphere and the moisture characteristics. A change of atmospheric transparency during a 24-hour period is revealed. The role of temperature inversions in the distribution of the attenuation coefficient with height is noted.

R. W. Fenn, "Correlation between Atmospheric Backscattering and Meteorological Range," Appl. Opt., 5, 293, (1966).

Abstract: On the basis of our present knowledge of the distribution of natural haze particles in the atmosphere, the relation between backscatter intensity and the visual range, or the extinction coefficient, has been analyzed. It can be shown that the various processes which cause the changes in visibility (increasing particle number, changes in particle size distribution, etc.) result in rather different backscatter conditions. Only by a combination of such processes is it possible to explain a relation between the backscatter and extinction coefficient as it can be derived from experimental data. It therefore becomes clear that such a relation cannot be a unique one and that it will change from one situation to another.

W. R. Fredrickson, N. Ginsburg, R. Paulson, INFRARED SPECTRAL EMISSIVITY OF TERRAIN, Syracuse University Research Institute, April 30, 1958, AD 155552.

Abstract: Measurements of the infrared radiation from various objects and surfaces in the spectral region between 1 and 6 microns are reported, and correlation with various changing external conditions achieved.

The necessary apparatus for such measurements included a spectral radiometer, portable radiometer, surface temperature device, and some other auxiliary equipment. Complete construction details on these are given, including electronic circuitry.

The necessity of reporting data in units of watts/cm^2-micron-steradian led to an investigation of the method of reducing the amplified signal response from the detector as recorded to these units. A general treatment of the problem is given, with specific application carried out for particular instruments used in this investigation.

The difference in infrared radiation from various objects and surfaces is surprisingly small. Yet a large degree of distinguishability is achieved, as can be seen from various space scans. It was found that rapid changes in radiation occurred with changes in light and wind, and these could be correlated with changes in the surface temperature of the target, even for massive objects. Effective emissivities were determined. The washout effect was investigated. A preliminary investigation on the absorption of the atmosphere indicated that there were rapid changes in atmospheric transmission.

H. Gaertner, THE TRANSMISSION OF INFRARED IN CLOUDY ATMOSPHERE, NAVORD Report 429. US Govt Printing Office, 1947.

A comprehensive and authoritative treatment (as of 1947) discussion of all of the problems of atmospheric IR transmittance.

Contains the following:

A. The Attenuation of Light in an Atmosphere Free of Clouds and Fog
   1. Scattering by Permanent Gases, "Molecular Scattering"
      a. Lord Rayleigh's Theory
      b. The Coefficient of Transmission or Penetrability
   2. Scattering by Water-Vapor and Mist
   3. Selective Absorption by Permanent Gases of the Atmosphere and by Water Vapor
B. The Attenuation of Light in Fog
   1. Theoretical Investigation into Light Scattering and Absorption
   2. Magnitude of Fog Droplets
      a. The Optical Method
      b. The Microscopic Method
      c. Determination of Drop-Magnitudes from Speed of Fall
      d. Summary of sections a to c
   3. Conclusions from the Transmissivity of Natural Fog
   4. Experimental Investigations on the Transmissivity of Natural and Artificial Fogs
      a. Granath and Hulburt
      b. Anderson
      c. C. Müller. H. Theissing, and H. Kiessig
      d. Külb
      e. Houghton
      f. Foitzik
      g. F. Linke and H.V.D. Borne
      h. H. V. d Borne
      i. F. W. P. Götz
      j. F. Schröter
      k. Allekotte and Schönwald
      l. Sanderson
      m. Smith and Hayes
   5. Summary
C. The Attenuation of Light in Rain

H. R. Glahn, "On the Usefulness of Satellite Infrared Measurements in the Determination of Cloud Height Tops and Areal Coverage," J. Appl. Meteor., 5, 189, (1966).

Abstract: The assumptions inherent in the determination of cloud top heights and areal coverage of clouds from infrared measurements made by satellites are discussed. The problems of interpretation caused by radiometer spatial resolution being of the same order of size as individual cloud elements are studied through mathematical simulation of the viewing process. An analysis of the simulated measurements from simple, specified cloud conditions produces quantitative estimates of the errors of interpretation.

It is found that individual cloud elements of a diameter slightly less than the viewed spot can be very misleading and the height of the cloud tops might be judged to be several thousand feet below their true height; tops of larger clouds can be determined more accurately. If the actual height of the tops can be determined, either by the infrared measurements from large cloud masses or by other means, the areal coverage can be estimated rather well.

N. B. Guttmann, STUDY OF WORLDWIDE OCCURRENCE OF FOG, THUNDERSTORMS, SUPERCOOLED LOW CLOUDS AND FREEZING TEMPERATURES, NAVAIR 50-1C-60, December 1971

The charts presented in this study are the result of an extensive effort to provide naval activities a worldwide summary of the distribution of low level phenomena that directly affect aircraft and marine operations. They are designed to be used as a guide by military planners but people in the fields of scientific research, commerce, agriculture and transportation may also find them helpful. The study includes maps of frequencies of fog, supercooled fog, surface temperatures freezing or below, supercooled stratus and low cumulus, days with thunderstorms and the average height of the freezing level.

H. Harrison, J. Herbert, and A. P. Waggoner, "Mie-Theory Computations of Lidar and Nephelometric Scattering Parameters for Power Law Aerosols," Appl. Opt., 11, 2880, (1972).

Abstract: The ratios of lidar backscatter to nephelometric total scattering cross section have been compared for power law aerosols. Effects were explored of variations of size distributions, indices of refraction, and of radial inhomogeneity of the scattering particles. Reasonable values for these parameters can be chosen so that observed and computed backscatter ratios agree. The general angle-resolved differential scattering problem is discussed briefly with emphasis upon derivable information from scattering measurements in the atmosphere.

J. R. Hodkinson, "Particle Sizing by Means of the Forward Scattering Lobe," Appl. Opt. 5, 839, (1966).

Abstract: The angular distribution of scattered light in the main lobe of the Fraunhofer diffraction pattern of a particle changes rapidly with size, but is largely independent of its refractive index. Even when the particle is so small (diameter less than a few wavelengths) that its forward lobe must be calculated from the Mie theory, the relative angular distribution within the central part is found to be given approximately by the Fraunhofer formula with obliquity factor, even for particles smaller than one wavelength, except near a minimum in the particle extinction efficiency factor calculated from the Mie theory. A measurement of the ratio between the scattered intensities at a pair of convenient angles within the lobe can thus give a useful estimate of the size of the spherical and nonspherical particles without knowing their refractive index. The sizing error caused by the narrowing of the lobe near an extinction minimum is acceptable for many practical purposes, and can in any case be detected by comparing the size estimates derived from measurements at two different wavelengths. Families of curves for sizing by this simple procedure have been prepared. Sideways scattering instruments have been preferred hitherto because of their easier construction. A realization of the possibilities for sizing unknown particles should, however, stimulate the development of suitable forward scattering instruments.

F. B. House and J. R. Blankenship, APPLICATIONS OF INFRARED MEASUREMENTS IN METEOROLOGY, Air Weather Service Technical Report 157, June 1961.

Meteorological applications of infrared technology are quietly yet rapidly increasing. At a time when all aspects of meteorology are undergoing rapid development, this report should assist Air Weather Service forecasters in the difficult task of keeping abreast of current developments.

The use of infrared technology in the Air Force systems places a requirement on the Air Weather Service to furnish a specific type of meteorological support. An understanding of the effects of weather on infrared radiations is essential to the provision of meteorological support to these systems.

The effects of weather on infrared radiations logically has led to the application of infrared technology to meteorology. The relatively good accuracy of infrared mensuration should foster a rapid increase in its use in meteorology. A few of the potential applications are listed in Section E; some of these are under consideration for use in Air Weather Service.

D. R. Johnston and D. E. Burch, "Attenuation by Artificial Fogs in the Visible, Near Infrared and Far Infrared," Appl. Opt., 6, 1497, (1967).

Abstract: The attenuation coefficient ratio ($^{\alpha}\lambda/^{\alpha}0.546$) for artificial fogs has been measured at 345μ. The attenuation coefficient ratios at 0.436μ, 1.01μ, 3.5μ, 10μ, and 13.5μ were also measured so that a comparison between artificial fogs and natural fogs could be made. By comparing our results with others on natural fogs and with the theoretical work of others in the visible and the near ir, we have concluded that our artificial fogs closely resemble natural fogs. We conclude, therefore, that $^{\alpha}345/^{\alpha}0.546$ is representative of real fogs. Artificial fogs are generated and allowed to dissipate during which time attenuation of light at several wavelengths is recorded. The green line of the mercury arc at 0.546 μ was used as the standard of comparison. For radiation at 345 μ, $^{\alpha}345/^{\alpha}0.546 = 0.014 \pm 0.009$ during the generation time of the fog and 0.021 ± 0.0006 during the time the fog is allowed to dissipate.

C. Junge, "The Size Distribution and Aging of Natural Aerosols as Determined from Electrical and Optical Data on the Atmosphere," J. of Meteorology, 12, 13, (1955).

Abstract: A first attempt at surveying the complete size distribution of natural aerosol particles is made. The size range covers more than three orders of magnitude in radius, with approximate limits of 2×10^{-3} and 5×10^{-7} cm. Previously only parts of this spectrum had been carefully investigated, due to the size limits of the various experimental methods used. Particle spectra down to radii below 10^{-4} cm are well known, having been obtained by direct count under the microscope. Particles of less than 10^{-5} cm are counted in the Aitken counter, but their size distributions can only be determined from mobility measurements on those particles which are charged. However, to deduce nuclei spectra from ion spectra, the fraction of charged particles must be known. Previous determination of this fraction are examined and are shown to contain inaccuracies or errors. The expression derived here theoretically, is used to convert some of the ion-spectra data into nuclei spectra. The particle-size range between radii of 10^{-5} and 10^{-4} cm has hardly been investigated by direct measurements, because of the experimental difficulties encountered. Valuable information can be gained here from the dependence of haze scattering on wavelength.

The available data seem to indicate that the maximum number concentration is located in the size region between 10^{-5} and 10^{-6} cm radius, and that the number concentration drops to zero between 10^{-6} cm and 10^{-7} cm radius. The size range greater than 10^{-5} cm can be well represented by a power law which seems to hold for large parts of the world. It can be shown further, where ion and nuclei counts or other electrical data are available from a large number of places all over the world, that the average radius of all particles increases when the total number decreases. This can be explained by the coagulation processes.

It should be emphasized that the results obtained in this article are to be considered a rough first approach, valid only for average conditions in time and space, and that more detailed information is needed to improve our knowledge of this field.

R. J. Kauth and J. L. Penquite, "The Probability of Clear Lines of Sight Through a Cloudy Atmosphere," J. Appl. Meteor., 6, 1005, (1967).

Abstract: A statistical model has been developed which predicts the probability of observing a clear line of sight through a cloud scene. The basic model is

$$P(\theta) = P(0) \exp (1+k^2 \tan^2 \theta)^{1/2}$$

where θ is the viewing angle measured from the vertical, P(0) the probability of observing a vertical line of sight through the cloud scene, and k the "buildup" parameter, roughly the ratio of the heights to the diameters of the clouds in the scene. For cumulus clouds, k may range from 0.6 to 1.5.

This model is applicable to more than one type of cloud cover and has a minimum of parameters. However, it has not yet been adequately tested.

Discussion and Conclusions ... The model was originally designed for cumulus cloud fields for which the penetration at the zenith is generally larger than 0.7, and the value of k is near 1.0. However, it seems reasonable to apply the model to other types of clouds and to greater total cloud cover.

... developed analytical model which appears to give reasonable results, is flexible, and has a minimum of parameters. Not yet adequately tested by real data. Possible applications are suggested.

J. H. Keating, A CLIMATIC ISOVISIC AND NEPHANALYSIS ATLAS OF THE NORTH ATLANTIC NORTH PACIFIC AND INDIAN OCEANS, The MITRE Corporation, Bedford, Massachusetts, April 1966

Introduction: This atlas has been prepared in support of the Optical Environmental Study conducted by the MITRE Corporation for the Naval Research Defense Laboratory (NRDL). The climatological analysis presented in this paper is intended to support the atmospheric transmission task of the study but is provided in a format that is generally applicable to a wide range of naval engineering and planning activities.

The study provides a climatological analysis of visibility and total cloud cover for each of the mid-season months of January, April, July, and October. The geographical areas of interest were selected based upon their significance to naval operations. They are the North Atlantic Ocean, the North Pacific Ocean, and the Indian Ocean.

W. W. Kellogg, K. J. K. Buettner, and E. C. May, METEOROLOGICAL SATELLITE OBSERVATION OF THERMAL EMISSION (Part 2 of an Examination of the Application to Satellite Meteorology of Various Segments of the Electronic Spectrum) Memorandum RM-4392-NASA, December 1964.

From their conception, meteorological satellites have had many recognized observational capacities beyond that of taking cloud pictures that still remain their most widely used product. ... The parameters that may some-day be measured from satellites, include not only cloud distribution over the earth, but also cloud heights, surface temperatures (not surface air temperature, as measured in an instrument shelter), the vertical temperature distribution, flux of heat through the surface of the oceans, the heat budget of various regions of the earth, and the distribution of rainfall. Few of these have yet been accurately measured from the satellites, but most of the physical principles are at hand, and the needed instruments could be developed.

S. S. Khmelevtsov, "Propagation of Laser Radiation in a Turbulent Atmosphere," Appl. Opt. 12, 2421-2433, (1973).

Abstract: This paper reviews the investigations of regularities of laser radiation propagation in a turbulent atmosphere carried out through 1971. Special attention is paid to the influence of laser radiation specificity -- space limitation, coherence, and the possibility of its focusing on the propagation. Broadening of collimated and focused beams, their random wanderings, intensity fluctuations and coherence both in the conditions of weak fluctuations, described by the Rytov's method, and in the conditions of strong intensity fluctuations are considered.

G. L. Knestrick, T. H. Cosden, and J. A. Curcio, ATMOSPHERIC ATTENUATION COEFFICIENTS IN THE VISIBLE AND INFRARED REGIONS, NRL Report 5648, August 8, 1961. AD263441

Abstract: Atmospheric spectral attenuation coefficients have been measured in ten narrow wavelength bands between 0.4 and 2.3 microns for a variety of weather conditions using two overwater, sea-level paths of 5.5 km and 16.3 km. The wavelength bands were chosen so as to avoid molecular absorption and were isolated by interference filters. A 60-inch-diameter, high-intensity source and a 24-inch-diameter, narrow-field receiver were combined to yield relative scattering attenuation coefficients (σ) as a function of wavelength (λ). These were then scaled using values obtained at one wavelength with a visual telephotometer. Log σ vs log λ curves show a wide range of slopes and shapes, with a tendency toward less slope in the infrared (indicating that σ is becoming independent of λ in the infrared). Some correlation with relative humidity was found for relative humidities greater than 70 percent. The anomalous slope reversal between 1.68 and 2.27 μ is discussed, and a possible explanation for the reversal is given as a selective scattering by the aerosol at these wavelengths.

B. A. Kunkel, "Fog Drop-Size Distributions Measured with a Laser Hologram Camera," J. Appl. Meteor., 10, 482, (1971).

Abstract: Fog drop sizes were measured with a laser hologram camera. The camera samples volumes up to 4.5 cm^3 at a rate of five samples per minute. The measured distribution is relatively unaffected by the measuring technique, since no sample collection or dilution is involved.

The sample-to-sample variation of fog drop-size is discussed. Mean drop-size data are presented for several fog cases. The problems encountered with, and the potential future use of, this technique for measuring fog and cloud droplets are discussed.

Camera set up at Otis AFB during the summers of 64 and 65. Most of the fogs were advection fogs.

Summary: Such a system is feasible for use in a foggy environment. Changes are suggested to improve the quality and reliability of the instrument.

S. W. Kurnick, R. N. Zitter, and D. B. Williams, ATMOSPHERIC TRANSMISSION IN THE INFRARED DURING SEVERE WEATHER CONDITIONS, CML-TN-P-145-3 May 1959, The University of Chicago, Laboratories for Applied Sciences

Abstract: Infrared transmission for wavelengths from 1.7 to 12.0 has been measured for a variety of weather conditions. The results show that fogs are increasingly transparent at the longer wavelengths. Precipitations such as rain, snow, sleet, and hail show no spectral effects even when the visibility is extremely curtailed. A quantitative analysis of the fog transmission data has been made under the assumption that natural aerosols follow the size distribution law: $N(r)=C\ r^{-t}$, where $N(r)\ dr$ is the number of particles of radius r per cm^3, C is some constant, and t has a value between three and four. The wavelength dependence of optical absorption predicted by the theory agrees with the fog transmission data, and values of the parameter t as inferred from data plots are correlated in meaningful fashion with humidity and visibility conditions.

I. A. Lund, "Estimating the Probability of Clear Lines-of-Sight from Sunshine and Cloud Cover Observations," J. Appl. Meteor., 4, 714, (1965).

Abstract: Observations of hourly sunshine, angular elevation of the sun above the horizon, cloud cover, and a three-dimensional cloud model, were utilized to derive a set of cloud width, thickness, and spacing values for estimating the probability of clear lines-of-sight from any angle. Data for Tampa, Florida, were used to illustrate cloud parameters that satisfy the cloud model. The observed "typical" values of cloud width and spacing fit the model very well. The computed average earth cover was much less than the observed average cloud cover because the observers did not see all the spaces between clouds.

Discussion ... The cloud model and the sunshine data indicate that much less of the earth is covered by clouds than is indicated from surface observations of cloud cover. This is understandable because the observer sees the sides of clouds as well as their bases. This fact is important in designing and evaluating optical systems that require clear lines-of-sight through the atmosphere. Past evaluations of such systems, based on surface cloud observations, may have underestimated their usefulness.

I. A. Lund, "Methods for Estimating the Probability of Clear Lines-of-Sight, or Sunshine, through the Atmosphere," J. Appl. Meteor., 5, 625, (1966).

Abstract: Five methods for using standard cloud observations to estimate the probability of a clear line-of-sight, or sunshine, through the atmosphere are described and compared. The root-mean-square errors of the probability estimates (expressed in units of per cent) are less than 10 for four of the five methods.

I. A. Lund, "A Model for Estimating Joint Probabilities of Cloud-Free Lines-of-Sight Through the Atmosphere," J. Appl. Meteor. 12, 1040, (1973).

Abstract: Signals transmitted through the atmosphere in the visible and infrared portions of the electromagnetic spectrum can be seriously degraded by clouds between the source and the receiver. A previously published model was developed for estimating probabilities of cloud-free lines-of-sight through the atmosphere at any desired elevation angle and geographical location. This paper extends the published model to the problem of estimating probabilities of cloud-free lines-of-sight from *n* of *m* observing sites. A climatic record of sky-cover observations taken simultaneously from all *m* sites is required before the model can be applied.

I. A. Lund and M. D. Shanklin, "Photogrammetrically Determined Cloud-Free Lines-of-Sight Through the Atmosphere," J. Appl. Meteor., 11, 773, (1972).

Abstract: Relative frequencies of cloud-free lines-of-sight were determined at specified elevation angles and directions by utilizing data from photographs taken with a camera with a 180-degree (fish-eye) lens and infrared film to produce high-quality photographs of the sky. Four summers of hourly daytime data were used to find relative frequencies, comparisons between "clear" and cloud-free lines of sight, and a general method for estimating probabilities of cloud-free lines-of-sight for any location are presented and discussed.

This article seems to be particularly appropriate since the authors are also interested in the requirements for determining the utility of optical and infrared search and tracking systems. They speak of other methods which have been developed but mention that none of them are entirely satisfactory. One of the methods was earlier suggested by LUND. Ground observations do not take into account the angle of view through the atmosphere, etc., and sunshine recorders do not detect thin clouds. Applies to seeing through the entire atmosphere.

I. A. Lund, HAZE-FREE AND CLOUD-FREE LINES OF SIGHT THROUGH THE ATMOSPHERE, AFCRL-72-0540, 13 Sept. 1972

Abstract: Clear and cloud-free line-of-sight probabilities have been derived from analysis of: (1) Whole-sky photographs, (2) visual sky cover observations, (3) jointly observed sky cover and sunshine, (4) satellite observations, and (5) in-flight observations. The most accurate probabilities of cloud-free lines-of-sight through the entire atmosphere can be obtained from a model derived from several thousand whole-sky photographs and visual sky cover observations. The most accurate probabilities of both cloud-free and haze-free conditions through the entire atmosphere, or portions of the atmosphere, can be obtained from in-flight observations.

Introduction: Estimates of the probability of clear lines-of-sight through the atmosphere are required in design for determining the utility of optical and infrared communications, search and tracking systems. These estimates are also required in operational planning for visual bombing and reconnaissance. Before the required probabilities can be estimated accurately, it is extremely important to know how a clear line-of-sight is defined.

For infrared transmission, clear can usually be defined as cloud-free; for visual wave lengths, clear must be defined as both cloud-free and haze-free.

Clear line-of-sight probabilities have been derived from analysis of: (1) Whole-sky photographs, (2) visual sky cover observations, (3) jointly observed sky cover and sunshine, (4) satellite observations, and (5) in-flight observations.

I. A. Lund and M. D. Shanklin, "Universal Methods for Estimating Probabilities of Cloud-Free Lines-of-Sight Through the Atmosphere," J. Appl. Meteor., 12, 28, (1973).

Abstract: More than three years of 3-hr high contrast whole-sky photographs, sky cover observations, and cloud-type observations were utilized to develop two methods for estimating cloud-free line-of-sight probabilities through the entire atmosphere for any desired geographical location. One method requires a knowledge of the probability of each sky-cover category (tenths or eights); the other method requires both sky-cover and cloud-type information.

Supplements their 1972 paper. Has modifications that result in methods which are universally applicable to all geographical locations. Gives probabilities as a function of elevation angle and sky cover (tenths).

Conclusions: Probabilities of CFLOS through the entire atmosphere between the surface of the earth and space can be estimated for any desired geographical location from routinely observed total sky cover through the use of two equations depending upon the frequency distribution of cloud types.

J. T. McCabe, ESTIMATING MEAN CLOUD AND CLIMATOLOGICAL PROBABILITY OF CLOUD-FREE LINE-OF-SIGHT, Tech Report 186 of Air Weather Service, Nov. 1965

Preface: There are many military problems involving cloudiness and certain of them require a knowledge of the amount of cloud to be expected climatologically at one or more levels or within a layer of the atmosphere. Examples of such problems are those concerning aircraft icing and refueling rendezvous. Still other problems require information about the likelihood of clouds interfering with the sighting of a target for various observer-target arrangements, as with aerial or satellite reconnaissance and aircraft-missile interception.

This report describes a method of using standard surface-observed cloud data to estimate the mean cloud amount at and between levels and the probability of cloud-free line-of-sight between any two levels at any angle to the horizon. The method may be used manually by those who become familiar with it and who have access to summaries of mean cloud amount below various heights for the area of interest. However, manual application is not recommended because the method has been programmed for the IBM 7044 computer and is being used at the Environmental Technical Applications Center (ETAC), USAF where the basic input data are readily available for most locations.

AWS units that may have a need for information to be drawn from the programmed mean cloud and cloud-free line-of-sight outputs are invited to contact ETAC through appropriate channels, normally their squadron and wing technical services offices.

Uses deBary and Moller as base. States that within season-synoptic groupings they are probably representative of most mid-latitude regions.

J. T. McCabe, "Estimating Climatological Probability of Cloud-Free Line of Sight," Proc. IRIS 10, No. 3, Jan 1966, pp 7-12. (Unclassified Article in Secret Volume).

Abstract: A method is described which provides an estimate of the probability of cloud-free line of sight between any two levels at any angle to the horizon for locations having standard surface observed cloud data.

The method uses the mean cloud amount between the surface and each higher kilometer level to estimate the mean cloud amount at any level, the mean cloud amount above any level, and the mean cloud amount between any two levels.

Analyses of sunshine and total cloud cover by time of day provide a basis for estimating probability of cloud-free line of sight through the whole atmosphere as a function of mean total cloud cover and viewing angle. This relationship is used to estimate the probability of cloud-free line of sight at any angle between any two levels for which the mean cloudiness between the levels is known or estimated.

D. E. McCarthy, "The Reflection and Transmission of Infrared Materials. V: Spectra from 2 μ to 50 μ," Appl. Opt. 7, 1997, (1968).

Abstract: Reflection and transmission spectra of BN, CdS, Irtran 6, GaSb, GaAs, GaP, InSb, InAs, InP, RbBr, RbCl, RbI, SrTiO, and Te are presented from 2μ to 50μ.

Introduction: Reflection and transmission measurements in the wavelength region from 2μ to 50μ are presented for fourteen ir materials. Most of them are semi-conductors and may be used as long wave pass filters or in multilayer interference filters. Others, such as the rubidium halides are chiefly of academic interest. However, all should be considered in the design of optical instruments, in view of the wide choice of optical and other physical properties that they offer. Transmission measurements in the near ir, visible and uv regions have been published for five of these materials. Parts I, II, III, and IV in this series of papers contain information on the more common ir transmitting materials.

R. A. McClatchey, R. W. Fenn, J.E.A. Seaby, F.E. Volz, J.S. Garing, OPTICAL PROPERTIES OF THE ATMOSPHERE (Third Edition), AFCRL-72-0497, 24 August 1972, Environmental Research Papers, No. 411.

Abstract: A series of tables and charts is presented from which the atmospheric transmittance between any two points in the terrestrial atmosphere can be determined. This material is based on a set of five atmospheric models ranging from tropical to arctic and two aerosol models. A selected set of laser frequencies has been defined for which monochromatic transmittance values have been given. For low resolution transmittance prediction, a series of charts has been drawn providing the capability for predicting transmittance at a resolution of 20 wave-numbers. Separate sections are included on scattered solar radiation, infrared emission, refractive effects, and attenuation by cloud and fog.

This report represents the third edition of an earlier report bearing a similar title (McClatchey, et al, 1970). Although subsequent editions have been published primarily to accommodate demand, the opportunity has been used to make minor revisions, corrections, and additions. This third edition differs from the others in that the low resolution spectral curves for the uniformly mixed gases and in the short wavelength region for water vapor have been revised, providing some overall improvement in accuracy; and more importantly, an appendix has been added providing model data and equivalent sea level path data for the U.S. Standard Atmosphere, 1962.

R. A. McClatchey and J.E.A. Seaby, ATMOSPHERIC ATTENUATION OF HF AND DF LASER RADIATION, AFCRL-72-0312, 23 May 1972, Environmental Research Papers, No. 400.

Abstract: With the development of HF and DF lasers having emission lines in the range from 2800 to 3700 cm^{-1} (HF) and 2000 to 2750 cm^{-1} (DF), it is of importance to establish which of the more than 100 lines can be transmitted through a variety of atmospheric paths. The spectral region of HF emission spans a very important water vapor absorption band and, in addition, there is strong absorption by CO_2 and weaker absorption by ozone and methane. The spectral region of DF emission covers the very strong 4.3 μm CO_2 absorption by N_2O and HDO at higher frequencies (low DF vibrational transitions). There is some weak ozone absorption also in the region of DF emission. Absorption lines associated with all of these molecules were included in the calculation of synthetic spectra covering the region of HF and DF emission. After limiting the number of emission lines tobe considered in detail according to a criterion based on atmospheric attenuation, a series of tables was constructed providing quantitative attenuation information for each of 97 laser lines and for 10 different atmospheric models. Data based on two different aerosol scattering models are included in these tables.

It is concluded that due to both atmospheric attenuation and laser emission energy, it is advantageous in general to develop laser systems using the higher vibrational transitions of the HF emission and the lower vibrational transition of the DF emission.

R. K. McDonald, "Vertical and Horizontal Maritime Visibility Models," Proc. IRIS, Vol. 10, No. 2, June 1965, pp 47-51. (Unclassified Article in Secret Volume).

Probability models of vertical and horizontal atmospheric transmission have been derived for the preliminary evaluation of naval weapons systems using visible light or 3- to 5-μ sensors.

For evaluation of surface-based weapons using optical sensors, estimates may be needed of weather degradation probabilities. Time is seldom available to a systems engineer for analysis of specific geographic locales and seasons, so he must resort to models. The models presented here are designed for preliminary assessments of a naval weapons system using 3- to 5-μ and visible-wavelength sensors.

J. E. Masterson, J. L. Karney and W. E. Hoehne, "The Laser as an Operational Meteorological Tool," BAMS. 47, 695, (1966).

... But the need remains for a tool which can be used routinely by the operational forecaster to measure variables which elude radiosonde, rocket, radar, and satellite techniques. The pulsed laser may prove to be that tool. It is comparatively simple to build and operate, and it can make rapid measurements of a variety of atmospheric variables, some of which cannot be detected by other operational instruments. The laser has been used to measure the heights of the bases and tops of mid-and high-level clouds, even when the high level clouds are above obscuring lower layers of stratus. It can also measure the range and optical density of particulate and aerosol layers at temperature-inversion levels.

S. H. Melfi, "Remote Measurements of the Atmosphere Using Raman Scattering," Appl. Opt. 11, 1605, (1972).

Abstract: The Raman optical radar measurements of the atmosphere presented demonstrate that the technique may be used to obtain quantitative measurements of the spatial distribution of individual atmospheric molecular trace constituents, in particular water vapor, as well as those of the major constituents. In addition, it is shown that monitoring Raman signals from atmospheric nitrogen aids in interpreting elastic scattering measurements by eliminating attenuation effects. In general, the experimental results show good agreement with independent meteorological measurements. Finally, experimental data are utilized to estimate the Raman backscatter cross section for water vapor excited at 3471.5Å as $\sigma_{H_{2}0}/\sigma_{H_{2}} = 3.8 \pm 25\%$.

D. J. Moore, "Measurements of Condensation Nuclei over the North Atlantic," Quart. J. Roy. Met. Soc., 78, 596, (1952).

Summary: Measurements of the total concentration of condensation nuclei and the concentration and distribution of large sea-salt nuclei have been made on board an Ocean Weather Ship in the North Atlantic over a period of three weeks. Total nucleus counts varied between 77/cm^3 and 2460/cm^3, the number decreasing with increase in the intensity of vertical mixing as indicated by cloud type.

The concentration of large nuclei (mass greater than 10^{-11}g) was found to increase markedly with wind speed and wave height, but no corresponding increase was found for the total nucleus population.

An analysis of the visibility observations at the Ocean Weather Ship Stations "Item and Jig" show that the opacity for a given humidity increases with wind speed and wave height and that this increase can be accounted for by the observed increase in the concentration of large nuclei.

Consequently as the rate of production of small nuclei at the sea surface increases with wind speed such increase (for wind speeds up to 18m/sec) does not materially affect the total nucleus population a few meters above the surface.

D. J. Moore and B. J. Mason, "The concentration, size distribution and production rate of large salt nuclei over the oceans," Quarterly Journal, Roy. Meteor. Soc., 80, 583, (1954).

Summary: The sampling and measurement of large condensation nuclei (equivalent salt contents greater than 1×10^{-14}g) on board of weather ships in the North Atlantic, 200 miles from land, reveal the existence of two distinct types of size spectra. It seems that the nuclei which predominate when waves are breaking (Type I distribution) are the residues of spray droplets, but that those which occur with wind speeds of less than 7 m/sec have a (Type II) distribution which closely resembles that of continental aerosol. In winds of up to 15 m/sec the measured concentrations of large salt nuclei rarely exceeded $10/cm^3$.

From the measured concentrations and size distributions of Type I nuclei, it is deduced that in winds of 15 m/sec the rate of production at the sea surface of salt nuclei with mass greater than 10^{-13}g is about $40 cm^{-2} sec^{-1}$; very similar values have been obtained from laboratory experiments in a wind-wave tunnel. The corresponding rate for nuclei with m greater than 2×10^{-14}g would be about $100 \ cm^{-2} sec^{-1}$.

Laboratory studies show that the bursting of air bubbles of diameters between 0.3 mm and 4 mm at the surface of sea water produces small numbers of rather large drops (diameters 50-500μ), the majority of which fall back quickly into the sea. The large salt nuclei found in the atmosphere are probably the residues of smaller drops produced by disintegration of the bubble caps.

P. M. Moser, ANNUAL ABSOLUTE HUMIDITY PROBABILITIES FOR SELECTED MARINE LOCATIONS, NAVAIRDEVCEN Tech Memo ADC-20203: PMM of 24 FEB 1973

Relative humidities are computed for selected areas using data in the Summary of Synoptic Meteorological Observations (SSMO). 21 locations are used with the results given in tables and bar charts of the annual absolute humidity distribution.

F. E. Nicodemus, WEATHER EFFECTS ON INFRARED SYSTEMS FOR POINT DEFENSE, Technical Note 4056-16, Naval Weapons Center, China Lake, May 1972.

Foreword: The task of collating existing weather data applicable to infrared studies for Point Defense was undertaken by the Naval Weapons Center (NWC) under authority of the Naval Ordnance Systems Command (ORD 6215).

This report is released at the working level for informational purposes only. The text was essentially completed as an Appendix to a larger report in March 1971 and has not been subsequently revised or brought up to date. Because of the interest shown in this material, it is being published as a Technical Note to make the information more widely available.

A. M. Nathan, A POLARIZATION TECHNIQUE FOR SEEING THROUGH FOGS WITH ACTIVE OPTICAL SYSTEMS, College of Engineering, New York Univ., June 1957, Technical Report 362.01

Abstract: A polarization technique is described which effects improvements in visibility through fog, smoke, and haze when used at night with searchlight illumination systems. Targets normally undetectible can be clearly seen. The technique can be used with either visible or infrared radiation, and is applicable to image-forming or radiation-detecting active systems.

A theoretical analysis is presented of the polarization properties of various types of scattering media, and it is shown that a Mie atmosphere (spherical particles) possesses specific properties which make the application of the polarization technique uniquely effective in reducing "noise" in active optical systems. Since the main factor limiting visibility in the earth's atmosphere is the "noise" resulting from scattering of light by the spherical particles of the atmospheric aerosol, the polarization technique should be extremely practical in enhancing target detectability.

This was confirmed experimentally, and the results are described. Expressions are derived for contrast or signal-to-noise ratio in active optical systems and the improvements resulting from the use of the polarization technique are evaluated.

Patrick J. O'Reilly, POINT COMPARISONS OF TOTAL CLOUD COVER FROM SATELLITES AND FROM SURFACE OBSERVATIONS, Tech Report 246 Air Weather Service April 1973

Editor's Preface: The use of satellite imagery, both visual and Infrared, is becoming more and more in use as a means of determining global cloud cover. It is especially advantageous in those sparse-data areas of the oceans and other noninhabited territories. With each new meteorological satellite, advances in the resolution and accuracy of the imagery are being realized. While the comparisons made in this report used satellite imagery from spacecraft of several years ago (1967-1970) and the observation platforms used have been improved in many ways, the basic comparisons set forth by the author certainly retain most, if not all, of their relevancy. Thus investigators now occupied with data from more advanced satellites and with simultaneous IR and visual observations may well find that the basic comparisons performed by the author are extremely useful.

Abstract: This report compares cloud-cover observations made by ground observers and relative cloud-cover estimates from satellite-measured brightness values. Comparisons are made when each type of cloud (9 low types, 9 middle type, and 9 high type) are found alone and also with various combinations of other clouds. Over 66,000 incidences are compared for observations taken over the China mainland and portions of Southeast Asia. Satellite observations from the ESSA and ITOS series of satellites are used. Both tabulated and graphical presentations of the results are included along with the author's comments on the investigative procedures and findings.

C. Orr, Jr., F. K. Hurd, and W. J. Corbett, "Aerosol Size and Relative Humidity," J. of Colloid Science, 13, 472, (1958).

Abstract: A theoretical and experimental investigation was made of the gain and loss of water with humidity change for particles of NaCl, $(NH_4)_2SO_4$, $CaCl_2 \cdot 6H_2O$, AgI, PbI_2, and KCl having radii between 0.01 and 0.1 micron. Predictions were made using a combination of absorption theory, the Kelvin equation, Ostwald's theory, and other thermodynamic considerations. Where actual data were nonexistent, empirical relations were employed to arrive at reasonable approximations.

The indicated behavior of hygroscopic particles exposed to increasing humidity is to absorb moisture amounting to a few molecular layers at low relative humidities; to dissolve as humidity increases, become saturated droplets and at the same time undergoing an abrupt size increase; and thereafter, as humidity increases still further, to grow larger and more dilute. The indicated behavior for decreasing humidity is for the droplet size to decrease as humidity decreases and, at a humidity considerable lower than that at which the particle initially dissolved, to recrystalize, undergoing an abrupt size decrease. For nonhygroscopic compounds, no abrupt solution or recrystallization irregularities are predicted. The predictions are in satisfactory agreement with experimental findings.

Conclusions: Making assumptions which were supported by experimental data from similar systems or comparable conditions, the behavior of aerosol particles was calculated under changing humidity conditions. With better data for the properties of surfaces and supersaturated solutions, more exact predictions could undoubtedly have been obtained. The methods employed are believed valid for particles of compositions other than those studied.

G. N. Plass, "The Absorption of Laser Radiation Along Atmospheric Slant Paths," Appl. Opt., 5, 149, (1966).

Abstract: The absorption of laser radiation along atmospheric slant paths is calculated when Lambert's law is valid. Illustrative results are given for absorbing gases which are distributed uniformly throughout the atmosphere and when the temperature variation of the line intensities and half-width can be neglected. These results are then generalized to include cases of nonuniformly distributed gases with a temperature variation along the path. The effect of the overlapping of spectral lines is studied through the use of the Elsasser model. Finally, it is shown that large differences in the absorptance may occur between corresponding frequencies in the red and violet wings when there is a shift in the position of the line center with pressure. This line shift could ideally be studied with laser sources.

G. N. Plass and G. W. Kattawar, "Effect of Aerosol Variation on Radiance in the Earth's Atmosphere-Ocean System," Applied Optics, 11, 1598, (1972).

Abstract: The reflected and transmitted radiance is calculated for a realistic model of the atmosphere-ocean system. Multiple scattering to all orders as well as anisotropic scattering from aerosols are taken into account by a Monte Carlo technique. The probability for reflection or refraction at the ocean surface is calculated for each photon. Scattering and absorption by water molecules (Rayleigh) and by hydrosols (Mie) are taken into account within the ocean. The radiance is calculated for a normal aerosol distribution as well as for a three and ten times normal distribution. Calculations are also made for an aerosol layer near the earth as well as for one in the stratosphere. The upward radiance at the top of the atmosphere depends strongly on the total number of aerosols but not on their spatial distribution. Variations in the ozone amount also have little effect on the upward radiance. The calculations are made at the following wavelengths: 0.7μ, 0.9μ, 1.67μ. The radiance above and below the ocean surface as well as the flux at various levels are also discussed.

R. F. Pueschel and K. E. Noll, "Visibility and Aerosol Size Frequency Distribution," J. Appl. Meteor., 6, 1045, (1967).

Abstract: The visual quality of the atmosphere in terms of meteorological range has become a frequently used working standard in aviation and air pollution. Calculations of the meteorological range based on measured size frequency distribution of aerosols in the atmosphere are compared with visibility observations and discussed with regard to existing weather conditions. The results show the existence of strong inhomogenities in the aerosol content of air and indicate the necessity for objective means in order to quantitatively evaluate the visual quality of the atmosphere. It

follows from the calculations that changes in refractive index and wavelength within their limiting values have little influence on the total extinction of any size distribution.

Summary and Conclusions: An analysis of 16 size distributions shows that about 90% of the particles are smaller than 0.1 micron. Their contribution to light extinction, however, amounts to 5% at the most. For visibility studies, therefore evaluation of particles of size greater than 0.1 micron is sufficient.

R. R. Rapp, C. Schutz, and E. Rodriguez, "Cloud-Free Line-of-Sight Calculations," J. Appl. Met., 12, 485, (1973).

Abstract: A method for computing the probability of a cloud-free line-of-sight (CFLOS) between a given point in the atmosphere and a given point on earth, was developed. The method is based on 3-hr synoptic weather reports of clouds, and whole-sky photographs taken during daylight hours over a period of three years at Columbia, Mo. The computational procedure is an effort to eliminate an apparent oversimplification in previously published methods that results from the use of mean cloud cover, an unsatisfactory vertical cloud distribution, and sunshine data. Present results are at variance with those earlier estimates, but compatible with recent observations actually taken from aircraft. Although the CFLOS estimates obtained are, by nature, uncertain, the range of uncertainty was estimated by using published empirical data and a quantitative error analysis.

R. K. Reed and W. P. Elliott, "Precipitation at Ocean Weather Stations in the North Pacific," J. Geophysical Res., 78, No. 30, 7087, (1973).

Abstract: Determination of precipitation at ocean weather stations in the North Pacific reveals much less annual rainfall than previous estimates, except in the northwestern part of the ocean, as well as a stronger north-south gradient. Seasonal distributions were about as shown on most charts except for the northwest Pacific. The amount and isohyetal patterns at sea are quite different from those at coastal land stations.

Our findings, together with Tucker's, certainly suggest that a full reassessment of oceanic precipitation patterns is in order. We can only echo Tucker's conclusion: 'It is obvious from the charts that rainfall over island and coastal stations cannot be regarded in any way as being representative of the open sea. Consequently, the mean rainfall maps over the oceans must be inaccurate.'

D. B. Rensch, "Survey Report on Atmospheric Scattering," TR 2476-1 ElectroScience Laboratory, Ohio State University, May 1968.

Abstract: This is a survey report on theoretical and experimental work that has been done on atmospheric scattering by aerosol particles in the visible and infrared regions.

D. B. Rensch and R. K. Long, "Comparative Studies of Extinction and Backscattering by Aerosols, Fog, and Rain at 10.6 μ and 0.63 μ," Appl. Opt., 9, 1563, (1970).

Abstract: Theoretical calculations using continental, fog, and precipitation aerosol size distribution models are presented here for extinction coefficients along horizontal propagation paths at sea level. The coefficients are presented for various atmospheric conditions and for wavelengths between 0.34 μ and 10.6 μ. Finally, the theoretical results are confirmed by comparison with outdoor transmission studies at 10.6 μ and 0.63 μ.

P. K. Roa and J. S. Winston, "An Investigation of Some Synoptic Capabilities of Atmospheric "Window" Measurements from Satellite TIROS II," J. Appl. Meteor., 2, 13, (1963).

Abstract: Several samples of infrared radiation measurements in the 8-13 micron water-vapor "window" made by TIROS II are studied in relation to conventionally observed information on pressure systems, cloudiness and temperature. These cases demonstrate further the synoptic capabilities as well as some of the limitations, of these data for cloud detection; determination of cloud-top height; and observation of spatial gradients and temporal changes in the water-, land-, and snow-covered surfaces.

Conclusions: Cases are presented to show how TIROS II "window" data can be used to depict broadscale cloudiness, etc. Some of the limitations of the data are also apparent in these cases.

R. R. Rogers & R. J. Pilié, "Radar Measurements of Drop-Size Distribution," J. Atmos. Sci., 19, 503, (1962).

Weather radar is used to determine the drop-size distribution according to the velocity of the hydrometeor and the velocity components. Spectra are determined by the drop-size distribution by the Doppler method.

Measurements were made with a 3-cm wavelength Doppler radar on Mt. Withington, NM in the summer of 1961.

J. Doyne Sartor, METEOROLOGICAL ASPECTS OF INFRARED OPERATIONS, Proc. IRIS 3, Dec 1958, pp 154-160. (Unclassified Article in Confidential Volume).

The highly variable meteorological elements applicable to infrared operations are clouds, rain, and water vapor. In the lower troposphere adequate data generally exist in the regularly scheduled weather observations and data summaries. Due to the abundance of data for the lower levels, its variability from place to place and with altitude, no point is served in discussing such distributions here. The data however have certain limitations and must be handled with care. Later, some of the limitations and the techniques developed for handling them are discussed, and suggestions made for obtaining specific data for specific purposes.

At higher levels, near the top of the troposphere and above, the data are fewer but are better documented and in a form usually more suited to direct application. Only recently, however, have significant data on high-level clouds been made available.

W. E. Schneider and J. A. Garvey, "Procedures for Determining the Spectral Responsivity of an Infrared Radiometer," Appl. Opt. 7, 1141, (1968).

Abstract: With the increasing number of commercial radiometers employing rather varied and sophisticated optical designs, the determination of the spectral responsivity of these radiometers has accordingly become more involved. A joint National Bureau of Standards-U.S. Army (Missile Electronics Warfare Technical Area, White Sands Missile Range New Mexico) calibration of an ir radiometer was conducted at the White Sands Missile Range Facility. The radiometer chosen for the measurements employed an uncooled PbS detector with a 10-cm Cassegrainian optical system. The selection of this particular type of instrument permitted two methods of measurement (each employing different standards and techniques) to be investigated. In order to simulate infinitely distant point sources, a 30-cm off-axis collimator was used in both methods of calibration. The methods of calibration and the uncertainties associated with each method are described and the application of the responsivity values to field measurements is discussed. The agreement of the spectral responsivity values as determined by each method is within the estimated uncertainty computed for each procedure.

G. T. Schappert, "Technique for Measuring Visibility," Appl. Opt., 10, 2325, (1971).

Abstract: A technique for measuring atmospheric extinction of light, or visibility, from the backscattered signal of a modulated cw laser is presented. The extinction coefficient is contained in the amplitude and phase of the return signal and can be extracted in several ways from certain amplitude and/or phase measurements. No assumption about a relationship between the extinction coefficient and backscattering coefficient need be made.

W. E. Shenk and V. V. Salomonson, "A Multispectral Technique to Determine Sea Surface Temperature Using Nimbus 2 Data," J. Phys. Oceanog., 2, 157, (1972).

Abstract: Three channels of the Nimbus 2 five-channel MRIR have been employed in the development of a technique to determine sea surface temperature. Two of the channels in the 0.2-4.0 and 6.4-6.9 μm spectral regions are used to indicate a cloud-free line of sight and the third a high signal-to-noise window channel 10-11 μm, measures the equivalent blackbody temperature (T_{BB}) which is a function of the thermal emission from the sea surface and the intervening atmosphere. Equivalent blackbody temperatures and normalized reflectance thresholds were established using frequency distributions. The window T_{BB}'s were compared with ship ocean temperature measurements for a one-month period over the western North Atlantic. This comparison revealed a ±1.5K dispersion about the mean difference between the ship temperatures and window T_{BB}'s between 31-34N. An empirical method has been developed to correct for the atmospheric contribution to the observed window T_{BB}'s that considers the measurements from the other two channels and the viewing angle from the radiometer to the ocean surface.

R. M. Schotland, K. Sasses, and R. Stone, "Observations by Lidar of Linear Depolarization Ratios for Hydrometeors," J. Appl. Meteor., 10, 1011, (1971).

Abstract: Measurements by monostatic lidar have been performed in the laboratory and in the field of the linear depolarization ratios for hydrometeors. The depolarization ratios for water drops in the size range 10 to 2000 microns in diameter have been found to be less than 0.03. Similar measurements for ice crystal clouds and precipitation gave relatively high values. Laboratory studies of hydrometeors from young ice clouds of mixed type whose linear dimensions varied from 20-100 microns gave depolarization ratios of 0.38. Atmospheric observations of mixed crystals greater than 350 microns in linear dimensions gave depolarization ratios greater than 0.8.

W. L. Smith and H. B. Howell, "Vertical Distributions of Atmospheric Water Vapor from Satellite Infrared Spectrometer Measurements," J. Appl. Meteor., 10, 1026, (1971).

Abstract: In this paper, the algorithm used for calculating the water vapor distribution from SIRS-B spectral radiances is given. Examples are presented illustrating the effects of errors in the water vapor absorption coefficients and specified temperature profile on retrieval of the water vapor profile. Comparisons of satellite-derived and radiosonde-observed water vapor profiles indicate that the errors of the SIRS-derived relative humidity in the middle troposphere (i.e., the 400-600 mb layer) are less than 20%. Relative humidity errors in the lower troposphere (600-1000 mb) are somewhat larger but still less than 30%.

SIRS-B was flown on the Nimbus IV satellite with bands 11-15 μm and 18-36 μm.

Conclusions: Water vapor profiles can be inferred from satellite measurements of IR radiation with reasonable accuracy in most cases, with best results obtained in the cloud-free middle troposphere. Much more work is required to establish the true transmission functions for the atmosphere.

A. J. Stamm and T. H. Vonder Haar. "A Study of Cloud Distributions Using Reflected Radiance Measurements from the ATS Satellites," J. Appl. Meteor., 9, 498, (1970).

Abstract: Reflected radiance measurements from the multicolor spin-scan camera on Applications Technology Satellite III are used to determine the percentages of selected areas of the earth that are cloud-free. The areas chosen are meteorologically active and represent common cloud patterns. Use of several data unit sizes shows how the observed percent clear area decreases with decreasing spatial resolution of a simulated sensor. Methods of determining a cloud-no cloud threshold are discussed. The change of cloud cover over a period of a few hours is examined. It is found that clouds smaller than the instantaneous field of view (IFOV) are often not recognized as clouds and therefore tend to affect the interpretation of spacecraft camera measurements. The results of this investigation are used to suggest the optimum spatial resolution for radiometrically sounding the atmosphere from a geosynchronous satellite using an instrument described in this report.

Summary: Preliminary results based on actual measurements from one of the highest resolution sensors available to date may be interpreted and used for various applications. Shows that clouds smaller than the instrument IFOV are very important. Similar studies should use simultaneous near infra-red and thermal infrared data to see if some of the combination of threshold criteria in several spectral channels can detect cloud contamination with better precision.

J. L. Streete, "Infrared Measurements of Atmospheric Transmission at Sea Level," Appl. Opt. 7, 1545, (1968).

Abstract: Atmospheric transmittance spectra from 0.56 to 10.7 microns, obtained over a 25-km horizontal path at sea level, are presented. The sources were six 150-cm diam carbon arc searchlights. A radiometrically calibrated spectrometer equipped with a NaCl prism and a thermocouple detector was used to record the spectral distribution of the radiation transmitted through the atmosphere. The transmittance spectra were obtained for values of precipitable water vapor ranging from 21.5 cm to 43.3 cm. From these spectra the selective transmittance of four atmospheric windows was measured. A plot of selective transmittance as a function of the square root of the precipitable water vapor for the four windows shows that the transmittance in these windows is well described by the statistical model of band absorption.

J. L. Streete, J. H. Taylor, and S. L. Ball, "Near Infrared Atmospheric Absorption Over a 25-km Horizontal Path at Sea Level," Appl. Opt., 6, 489, (1967).

Abstract: Atmospheric absorption spectra obtained over a 25-km, horizontal, sea-level path in the Cape Kennedy area are presented. Six 150-cm diam carbon arc searchlights positioned from 11m to 17m above the ground were used as sources of continuous radiation. Solar spectra obtained from sea level are traced above the corresponding horizontal path spectra for comparison. The spectral region covered is 0.68μ to 4.86 μ and the spectral resolution varies over this region from about $0.6 \times 10^{-4}\mu$ to $60 \times 10^{-4}\mu$. The amount of water vapor in the path varied from 9 to 39 precipitable cm.

Note: The Laboratory of Atmospheric and Optical Physics (LAOP) at Southwestern at Memphis has developed a system for measuring and monitoring atmosphere transmission over a 25-km horizontal path for the Electro-Optics Group, Pan American World Airways, Inc., located at Patrick Air Force Base, Florida.

J. H. Taylor and J. J. Rennilson, "A Compressed-Scale system of Portable Visibility Lights for Nighttime Use," J. Appl. Meteor., 1, 548, (1962).

Abstract: A system of visibility lights for nighttime use at advanced or tactical air bases has been designed by the Vis Lab. This system enables a more precise estimate of nighttime visibility to be made than has heretofore been attainable by conventional visual observation procedures. Although the system is able to yield visibility estimates to 5 miles or more, it requires less than a 2-mile path for its installation. The accuracy of the system is achieved by control of the observers' adaptation level, as well as by use of a calibrated incandescent (searchlight) source in conjunction with highly efficient retrodirective reflectors. Portability is attained by compact design and packaging and by the use of battery power. The principles and design considerations of the system are also discussed.

G. B. Tucker, "Precipitation over the North Atlantic," Q. J. R. Met. Soc., 87, 147, (1961).

Summary: The frequency of various types of 'present weather' observations are analyzed and a method is derived using these to obtain estimates of mean monthly precipitation. The method is applied to observations from ocean weather ships in the North Atlantic to obtain the mean monthly, seasonal and annual precipitation over the ocean during the 5-year period 1953 to 1957. The results are then compared with previous estimates.

Results: Results are given as charts of mean seasonal and mean annual rainfall over the North Atlantic together with the mean monthly and annual values for each ocean weather ship. ... Some coastal station values have been included for comparison. The most noticeable result is the large difference between the rainfall over islands and coasts with on-shore prevailing winds and the rainfall over neighbouring sea areas. In general, the difference increases southwards, and in southwestern Europe there appears to be a marked discontinuity of rainfall in the vicinity of the coastline.

... It is obvious from the charts that rainfall over island and coastal stations cannot be regarded in any means as being representative of that over the open sea. Consequently, the present mean rainfall maps over the oceans must be inaccurate.

S. Twomey and H. B. Howell, "The Relative Merit of White and Monchromatic Light for the Determination of Visibility by Backscattering Methods," Appl. Opt., 4, 501, (1965)

Abstract: The response of a simulated single-ended transmissometer, based on the Mie theory of the scattering of light, has been computed for monochromatic light similar to that of a ruby laser ($\lambda = 0.7\ \mu$) and for white light ($0.4\mu \leq \lambda \leq 0.7\mu$) for many fog and haze models. The results for white light are compared with data obtained from actual field measurements. The strong dependence of backscatter on the size distribution of the scatterers and on the spectral energy distribution of the source is illustrated, and the limitations of the single-ended transmissometer as a device for determining the visibility in haze and fog are discussed. A table of Mie extinction efficiency (or scattering coefficient) and intensity function (for the backscatter direction) is presented for integral values of size parameter up to 100.

Introduction: An important problem in aviation-meteorology today is that of determining the visibility along the approach, or glide path, of an airport runway. ... The comparison of white and nearly monochromatic light as a source for measurements of backscatter and the problem of relating these measurements to the visibility along an inclined path are the primary topics to be considered in this paper.

Conclusions: ... To sum up, it may be said that the relationship between backscatter and meteorological range is clear but not entirely unambiguous. ... It is also clear that the use of monochromatic sources (lasers) adds considerably to the inherent scatter and uncertainty in the reflectivity-extinction relationship, and that such sources are therefore inferior to heterochromatic (white) sources for these applications.

S. Twomey and G. T. Severynse, "Measurements of Size Distributions of Natural Aerosols," J. Atmos. Sci., 20, 392, (1963).

Abstract: An apparatus for the determination of the size distribution of an heterogeneous aerosol is described. The apparatus employs two diffusion batteries (series of narrow rectangular channels) through which an aerosol sample is passed to obtain attrition of its particle population by diffusion

to the walls of the channels. Observations of particle concentrations after successive stages of "decay" produce a decay curve which represents an integral transform of the distribution function with respect to diffusion coefficient. After mathematical manipulation the size distribution of the aerosol is obtained.

Measurements were made at the Physical Science Lab of the Weather Bureau and in rural areas 10-20 miles upwind of Wash. D.C.

W. Viezee and J. Oblanas, "Lidar-Observed Haze Layers Associated with Thermal Structure in the Lower Atmosphere," J. Appl. Meteor., 8, 369, (1969).

Abstract: Daytime observations of the vertical temperature and humidity structure in the atmosphere below 1 km made with a Cricketsonde rocket system are compared with simultaneous observations from a ruby lidar (laser radar). Observations were made at the SRI field site in Palo Alto, CA during August 1968 in the absence of low clouds when haze and pollution were visually evident. Analyses of the data show a direct relationship between Cricketsonde and lidar data. Invariably, the temperature profile obtained by the Cricketsonde includes a subsidence inversion during the early morning. Either this inversion persists throughout the day or it is destroyed by surface heating, and the temperature lapse rate approaches the dry adiabat by midafternoon. The lidar observes a deep layer of particulate matter, the upper boundary of which rises in height from morning to afternoon. When a subsidence inversion is observed the largest change in optical density is detected at the level of the inversion. However, concentrations of particulate matter are also observed by the lidar at higher levels. By monitoring the time change in intensity and in internal stratification of the aerosol layer, the lidar can follow the life cycle of the temperature inversion.

Characteristics of the Cricketsonde and the ruby lidar are given.

Conclusions ... levels of strong reductions in aerosol concentrations are found to coincide with temperature inversions. ... lidar can provide valuable information on the structure of the lower layers of the atmospheric aerosol, from which the presence and variation with time of thermal inversions may be inferred.

W. Viezee, E. E. Uthe, and R. T. H. Collis, "Lidar Observations of Airfield Approach Conditions: An Exploratory Study," J. Appl. Meteor., 81, 274, (1969).

Abstract: Lidar (laser radar) data obtained at Hamilton AFB, CA under conditions of low ceiling and visibility are analyzed by hand and by electronic computer to explore the operational utility of lidar in determining cloud ceiling and visibility for aircraft landing operations. Hand

analyses of the data show the ability of the lidar to describe the spatial configuration of the low-cloud structure in the direction of the landing-approach path. The problems inherent in evaluating lidar observations are discussed, and initial approaches to quantitative solutions by computer are presented. It is demonstrated that operationally useful information on the ceiling conditions contained in the hand analyses can be represented by digitizing the lidar data and subjecting these data to computer analysis.

Note: Limited data for two days with limited data collection rate of 2 pulses/min. Describes method of observations and data analysis. Lidar observations related to cloud ceiling.

Mentions that neodymium version of Mark V lidar is capable of firing every 4-5 sec. Also mentions that in routine operational application of lidar that due consideration must be given to all aspects of eye safety.

H. Vogt, "Visibility Measurement Using Backscattered Light," J. Atmos. Sci., 25, 912, (1968)

Abstract: The suitability of backscattered light for the measurement of visibility is discussed on the basis of previous practical and theoretical investigations and of 2-1/2 years' tests in routine meteorological work at the Meteorological Institute of the University of Berlin. Tests have demonstrated that backscatter devices indicate visibility equally as well as other types of visibility meters with an accuracy of about ± 20%, provided that no completely abnormal distribution of aerosol particles occurs.

Concluding remarks: ... practice has shown that visibility meters using the principle of backscattering are quite suitable for routine meteorological use. Backscatter devices can be made compact and relatively uncomplicated; being single-ended they are easy to install on airfields, at coastal stations, on lighthouses or aboard ships. The scattering volume of several cubic meters is large enough to smooth out temporal changes in atmospheric opacity.

F. E. Volz, "Infrared Refractive Index of Atmospheric Aerosol Substances," Appl. Opt. 11, 755, (1972).

Abstract: The optical constants in the ir from λ 2.5 μm to 40 μm (4000-250 cm^{-1}) of dry natural aerosol substances and of sea salt are presented. The aerosol substances were obtained from rain and snow water: dust and soot by sedimentation, and water soluble salts by evaporation. The spectra of the absorption index η^{-1} were derived from our published transmittance measurements of potassium bromide disks. The real part of η of the refractive index was calculated from the specular reflectance at near normal incidence of disks of pure aerosol substance. The observed spectral features are being related to chemical constituents, notably sulfates and alcohol

soluble organics. Optical constants of composite and wet aerosol are discussed. A simple model confirms the measured transmission of a coarse dry powder of water solubles and shows that the extinction by natural aerosol should have a minimum near 8 μm and a strong maximum near 9 μm.

Conclusions: The presented optical constants of dry water solubles, dust, and soot from precipitation samples make it now possible to predict scattering and absorption in the ir by natural aerosol and to include realistic aerosol parameters in radiation models. Optical constants shown for sea salt seem not even applicable (possibly except for surf and sea spray conditions) as spectra of rain residues from such regions are indicating.

A. P. Waggoner, N. C. Ahlquist, and R. J. Charlson, "Measurement of the Aerosol Total Scatter-Backscatter Ratio," Applied Optics, 11, 2886, (1972).

Abstract: In urban Seattle, simultaneous measurements were made of back-scatter using a ruby laser radar and of the scattering portion of extinction using an integrating nephelometer. Both instruments were calibrated allowing a separation of molecular and aerosol contributions to the two scatter coefficients. During the period of the experiment, backscatter and the scattering portion of extinction were well correlated at relative humidities less than 70%. For the aerosol, the ratio of backscatter to the scattering portion of extinction was only one-third that predicted from spherical particle Mie calculations for a power law size distribution aerosol.

A. H. Woodcock, "Salt Nuclei in Marine Air as a function of Altitude and Wind Force," J. Meteor., 10, 362, (1953).

Abstract: Large differences are shown to occur in the numbers and sizes of sea-salt particles in marine air over the seas as the altitude, position, and the time of sampling are varied. Increases in the amount of air-borne salt near cloud base are related to increases in wind force at the sea surface. The greatest proportionate increase in particle number occurs at the large end of the weight range. Most of the samples reported here were taken near the Hawaiian Islands. The differences in nuclei number and size with increasing altitude in the lower atmosphere are similar in pattern in Hawaii, Florida, and South Australia.

It is suggested that bursting air bubbles in "white caps" on the open sea are a major source of the salt nuclei, and that a greater portion of the sea surface may act as a source of these particles during average winds than might be judged from the relatively small area usually covered by whitecaps.

H. L. Wright, "Atmospheric Opacity at Valentia," Quarterly J. Roy. Met. Soc., 66, 66, (1940).

Summary: To confirm the variation of atmospheric opacity with relative humidity, inferred in a previous paper from theoretical considerations, observations of visibility at Valentia are utilized to deduce values of atmospheric opacity. These values are grouped according to the relative humidity and the direction of the wind. Examination of the results shows beyond doubt that, in air free from smoke, opacity varies with relative humidity in a manner which corresponds very closely with that indicated by the theoretical equations, provided that in these equations suitable values are inserted for the number of nuclei and for a quantity depending on the mass of salt in each nucleus and its hygroscopic properties.

M. J. Young, "Variability in Estimating Total Cloud Cover from Satellite Pictures," J. Appl. Meteor., 6, 573, (1967).

Abstract: Ten qualified weather observers were used to make estimates of the total cloud cover from satellite pictures. Tests were conducted to determine the standard deviation of the estimates, the significance of the difference in the estimates, and the error in the estimates. Results indicate that the variability of the estimates was significant and suggestions are made that experience and training are necessary to cope with problems in this general area.

Conclusion ... One tends to overestimate the total cloud cover as seen in a satellite picture. Until such time as automated and reliable digitizing techniques can be developed, only careful training and experience can cope with the problem.

Two other important reports are very useful and informative, but because of copyright limitations the abstracts can not be used. A limited number of copies of these reports are available in the United States through the Naval Electronics Laboratory Center, Code 232, Ken Powers, San Diego, CA 92152. The reports are:

D. H. Arnold, D. B. Lake, and R. Sanders, "Comparative Measurements of Infra-red Transmission over a Long Oversea Path", DMP 3736, EMI Electronics LTD, Hayes, Middlesex, England Oct. 1970.

D. H. Arnold and R. Sanders, "Comparative Measurements of Infra-red Transmission over a Long Oversea Path August/September 1970", DMP 3858, EMI Electronics LTD, Hayes, Middlesex, England May 1971.

Sources of Visibility Data for Marine Areas

U.S. Navy Marine Climatic Atlas of the World, Vol. VIII The World, NAVAIR 50-1C-54, Commander, Naval Weather Service Command, 1 March 1969

This volume combines the salient features of the preceding seven volumes of this atlas series, which treat individually each of the major ocean basins, to provide a coherent presentation of the global maritime climatic regimes.

Volumes I through VII were published as follows:

Vol. I	North Atlantic Ocean - 1955	NAVAER	50-1C-528
Vol. II	North Pacific Ocean - 1957	NAVAER	50-1C-529
Vol. III	Indian Ocean, 1958	NAVAER	50-1C-530
Vol. IV	South Atlantic Ocean, 1958	NAVAER	50-1C-531
Vol. V	South Pacific Ocean, 1959	NAVAER	50-1C-532
Vol. VI	Arctic Ocean, 1963	NAVWEPS	50-1C-533
Vol. VII	Antarctic Ocean, 1965	NAVWEPS	50-1C-50

Along with other meteorological parameters these atlases present:

Visibility

Contains monthly charts showing two sets of isopleths for visibility. One provides the percentage of time the visibilities were reported to be less than two nautical miles. The other provides the percentage of time that the visibilities were reported to be greater than 5 nautical miles. These two levels were chosen because they represent relatively poor and relatively good conditions and include the extremes in both cases.

Cloudiness

Three sets of charts.

1. Total clouds, with isopleths which indicate the
   a) percentage frequency of total cloud amount less than or equal to 2/8
   b) percentage frequency of total cloud amount greater than or equal to 5/8

2. Low clouds, with isopleths which indicate the
   a) percentage frequency of low cloud amount less than or equal to 4/8
   b) percentage frequency of low cloud amount less than or equal to 7/8

3. Median cloudiness, with isopleths which indicate the midpoint of total cloudiness reported in eighths. For example, an isopleth of five would indicate that fifty percent of the observations reported five eighths or less. This can be used to approximate the average cloudiness.

Marine Tape Deck (TDF-11)

This is a collection of over 31 million maritime meteorological reports from 18 different sources. Observations were obtained from ship logs, ship weather reporting forms, published ship observations, automatic observing buoys, teletype reports, and on cards purchased from several foreign meteorological services.

Over 31 million surface marine observations are currently in Tape Data Family-11. They are filed by 10° Marsden Square, year, month without regard to individual deck number. For example, all observations for January 1962 in Marsden Square 051 would be found together, followed by all observations for February 1962, etc. The period from 1800 to June, 1968 is held on 293 reels on 9 channel, 800 bpi tape. It is not anticipated that future acquisitions will be merged into this group, but will be placed on tape in the TDF-11 format and retained as a separate file.

Copies of these tapes are held in NCC Asheville and at FNWC Monterey.

Summary of Surface Meteorological Observations (SSMO)

These summaries are prepared by the Naval Weather Service Environmental Detachment, National Weather Records Center, Asheville NC. The SSMO is also based on TDF-11, but only covers certain geographical areas of particular interest to those undertaking the SSMO. In compiling the SSMO's quality control procedures are used to eliminate dubious reports.

Among the tables presented for each month are the following which are pertinent to this study:

Table 7 - Cumulative Percentage Frequency of Occurrence of Ceiling Heights (feet, cloud amount > 4/8) and Visibility (nautical miles)

Table 7A - Percentage Frequency of Low Cloud Amount (or Middle Cloud Amount if Low Clouds are not present) and Percentage Frequency of Sky Obscured. Amounts are in oktas.

Table 10 - Percentage Frequency of Ceiling Heights (feet, cloud amount > 4/8) and Occurrence of Cloud Amount < 5/8 by Hour (GMT).

Table 11 - Percentage Frequency of Visibility (Nautical Miles) by Hour (GMT).

Table 12 - Cumulative Percentage Frequency of Ranges of Visibility (Nautical Miles) and Ceiling Height (feet, cloud amount > 4/8) by Hour (GMT).

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Weapons Center

13. ABSTRACT A major concern of various Codes at the Naval Weapons Center and the Naval Electronics Laboratory Center has been the effect of weather on the operation of naval electro-optical systems. A literature search was undertaken to study and evaluate research efforts and the state of the art of various aspects of the problem. The areas of interest included:

a) Measurement of visibility at sea
b) Methods for accurately determining visibility at sea
c) Cloud Free Lines of Sight (CFLOS)
d) Methods for extending visibility measurements made in the visible to the infrared
e) Lidar measurements of visibility
f) Precipitation data over oceans
g) Sources of Visibility Data

An annotated bibliography of this search was compiled and is presented alphabetically by author. The source materials are listed separately.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE		ROLE	WT
Visibility at Sea						
Cloud Free Lines of Sight						
Lidar						
Precipitation over Oceans						
Maritime Visibility Data Sources						