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ENGINEERING CENTER J A WEINMAN 1982 AFOSR-TR-82-0978  
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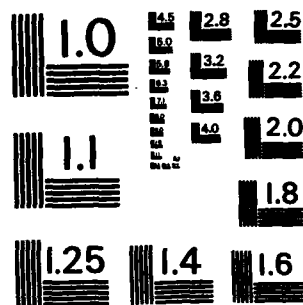
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20. (Cont.)  
and Electrical Engineers. Approximately 20 papers were presented.

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SUMMARY REPORT OF THE  
ELEVENTH INTERNATIONAL LASER RADAR CONFERENCE

JAMES A. WEINMAN

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SUMMARY REPORT OF THE ELEVENTH INTERNATIONAL LASER RADAR CONFERENCE

The Eleventh International Laser Radar Conference was held at the University of Wisconsin-Madison from June 21-25, 1982. This conference was sponsored by the Space Science and Engineering Center of the University of Wisconsin, The American Meteorological Society, NASA Langley Research Center and the U.S. Air Force Geophysical Laboratory and Office of Scientific Research. The conference was under the auspices of the Committee on Laser Atmospheric Studies of the American Meteorological Society, the Radiation Commission of IAMAP and URSI, in cooperation with the Optical Society of America and the Institute of Electrical and Electronic Engineers.

Approximately 90 papers were presented. Sessions addressed the following topics:

MIDDLE ATMOSPHERIC MEASUREMENTS (G. Megie, C.N.R.S., France)

The first six papers of this session, together with two additional short papers presented by Italian groups, were devoted to the study of stratospheric aerosol particles. Most of the measurements were made during the period of high volcanic activity which started in 1980 with the eruption of Mt. St. Helens followed by the eruptions of Mt. Alaid (April 1981), Mt. Pagan (May 1981), Mt Chicon (March 1982) and an unknown source in early 1982. The "mystery" cloud was observed by many investigators in February and March 1982, including W. Carnuth, et al., of Garmisch, Germany, G. Pioeco, et al., in Frascati, Italy and L. Stefanutti, et al., in Florence. This cloud was shown to be of volcanic origin by M. P. McCormick of NASA Langley Research Center with arguments based on the similarity of scattering ratio profiles with those

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observed for well identified eruptions and on mass considerations. The trajectories studied by the German group, lead to a possible origin close to the northeastern border of the Pacific Ocean in January 1982.

Ruby lidar observations of the stratospheric aerosols were obtained at Hampton, VA (37°N, 76°W) by T. Swissler and M. Osborn from 1979 to 1982. The data analysis gives evidence for a decay time of the peak scattering ratio for Mt. Fuego (1979), Mt. St. Helens, Mt. Alaid and the unknown volcano at 3.5 months. On the other hand, the data presented by W. Carnuth et al., yielded to a shorter decay time of 2.8 mo. for Mt. St. Helens as compared to the others which was 5-7 mo. D. Hofmann showed that two decay times could be related to temporal changes in the nature and shape of the particles from Mt. St. Helens.

From the results of T. Swissler, an estimate of the total aerosol mass loading in the stratosphere leads to a value of .25 MT for the background level and 1.2 MT for the periods of enhanced volcanic activity. Similar estimates made by M.P. McCormick using the SAGE satellite extinction measurements at  $\lambda=1 \mu\text{m}$  gave values of .32 MT for the Mt. St. Helens eruption. Large spatial and temporal inhomogenities in the aerosol particles distribution were observed from satellite measurements which showed that lidar measurements made at specific points are not representative of the entire globe. Comparisons between balloon borne particle counter measurements performed at Laramie, WY by D. Hofmann and J. Rosen and the lidar data from the German group in Garmisch showed that bimodal particle size distribution with maxima at radii  $0.07 \mu\text{m}$  and  $1 \mu\text{m}$  could account for the observations. Calculations of the expected scattering ratios between heights of 25 to 30 km

revealed the presence of large particles at these levels due to transport by diffusion processes. Measurements after the Mt. St. Helens eruption by J. Goad of the NASA Langley Research Center showed that depolarization ratios were 0.18 for fresh volcanic material. A decrease with time was then observed leading to values of 0.05 six months later. A background value of .018 was again obtained nine months after the eruption.

G. Kent of I.F.A.O.R.S. presented a comparison between SAGE satellite and lidar aerosol measurements. Variations in the vertical profiles of the scattering ratio are observed between low latitudes (5-15°N) and middle latitudes (20-35°). That analysis also showed that the ratio of the lidar backscatter coefficient at  $\lambda = 0.69 \mu\text{m}$  to the satellite measured extinction coefficients at  $\lambda = 1 \mu\text{m}$  steadily decreases between 20 and 30 km. This result was supported by further comparisons between SAGE measured extinction coefficients at  $\lambda = 0.45 \mu\text{m}$  and  $\lambda = 1 \mu\text{m}$ . The interpretation of this phenomenon is still under study.

The paper presented by C. Gardner et al., of the University of Illinois, described measurements of the temporal and spatial variations of the mesospheric sodium layer using a steerable lidar system. The data analysis gave evidence for the propagation of internal gravity waves at mesospheric altitudes. Examples of the retrieval of the vertical and horizontal wavelengths, period and direction of propagation of the waves were presented.



METEOROLOGICAL PARAMETERS: TEMPERATURE, DENSITY, HUMIDITY (G. Flocco,

Universita di Roma, Italy)

The first two papers in this session were concerned with molecular density measurements in the presence of an aerosol background. The paper by Bedo, Champion and Swirbalus of the Air Force Geophysical Laboratory treated the feasibility and the design of a balloon borne system. Lefrere and Megie of the Centre Nationale Recherche Scientifique described ground based dual wavelength experiments under conditions of large aerosol loading to determine temperature profiles in the 10-20 km region.

G. Schwemmer, M. Dombrowski and C.L. Korb of Goddard Space Flight Center described a dual wavelength near IR lidar in an advanced stage of development for determining atmospheric pressure and temperature.

Four papers dealt with humidity measurements by DIAL. P. Lebow et al. of the University of Maryland, described experiments on the effects of ambient temperature and humidity on laser beam absorption using a pair of absorption lines. Y.Z. Zhao, et al. of the Institute of Atmospheric Physics of the Peoples Republic of China described experiments with a dual ground-based system using a ruby laser. A.F. Carter of NASA Langley Research Center discussed airborne measurements of water vapor profiles in the lower troposphere, and C. Cahen, et al., from France, described simultaneous measurements of water vapor and aerosol content at  $\lambda = 0.72 \mu\text{m}$ .

The last two papers were concerned with the application of the Raman method: D. Renaut, C. Brun and P. Capitini from France showed water vapor and aerosol profiles obtained with two systems operating at  $\lambda_1=0.347 \mu\text{m}$ ,  $\lambda_2=0.266 \mu\text{m}$ . M. Hansen et al., from Goddard Space Flight Center described the design and construction of a Raman lidar to measure water vapor profiles.

BOUNDARY LAYER DYNAMICS (A.I. Carswell, York University, Toronto, Canada)

The papers in this session demonstrated the rapid advances being made in the applications of lidar technology in studies of boundary layer dynamics. In the first presentation R. Schwiesow, from NOAA ERL, described the results of a computer simulation of the use of a high angular resolution lidar for characterizing the vertical profile of refractive turbulence under daytime conditions. The technique involves the use of image size and energy to determine the turbulence intensity and the study showed that with a rather modest size, diffraction limited lidar, daytime  $C_n^2$  profiles can be obtained to altitudes of at least 20 km.

The remaining papers were all presentations of experimental lidar boundary layer studies undertaken in various parts of the world. R. Boers, of the University of Wisconsin, described recent measurements that showed the utility of a color enhanced video display for showing boundary layer behavior. That system was part of a ground based ruby lidar. W. Renger of DFVLR also used color enhanced displays to describe results of his airborne measurements with a YAG laser over the Inn Valley in Austria. H. Shimizu of the Japanese National Institute for Environmental Studies described a different image enhancement technique

which has been utilized by his group on the LAMP lidar. They found that edge enhancement technique greatly improved the identification in a grey scale display of distinct structures within a convective cell.

In the final paper, E. Browell presented data from airborne lidar measurements of the mixed layer made during the summers of 1980 and 1981 using the NASA Langley UV DIAL lidar system. These measurements clearly showed how such lidar data can be used for long range transport studies and for analysis of the and dynamics of the mixed layer under complex conditions such as a coastal environment.

#### WIND MEASUREMENTS (R.M. Schotland, University of Arizona, Tucson, AZ)

This session contained eight papers dealing with various aspects of the lidar wind measurement problem. Seven of these papers were concerned with the characteristics of infrared doppler measurements of the tropospheric wind field. The remaining paper reported boundary layer wind studies obtained from temporal and spatial correlation of the horizontal aerosol field. Successful results were obtained by systems based upon both approaches.

The success of these techniques depends upon the availability of adequate aerosol concentration in the atmosphere. These required aerosol concentrations do not seem to present a problem, particularly in the boundary layer. However, information is lacking on detailed aerosol spatial and temporal statistics on a worldwide basis. This information is particularly lacking in the southern hemisphere. One of the conclusions of the session was that the statistics of the relevant aerosol properties should be established before any spacecraft borne wind measurement program is initiated.

The second common theme of this session dealt with methods for deducing wind fields from observations by considering the spatial and temporal variability of the wind field. This problem was further complicated by the limited sampling rates of the lidar.

AEROSOL SCATTERING PROPERTIES (K. Sassen, University of Utah, Salt Lake City)

The polarized angular scattering behavior of near-spheres with size parameter  $\sim 10$  was considered from the standpoint of polar nephelometer measurements and theoretical simulations by A. Coletti and G. Grams of Georgia Institute of Technology. The agreement between measurements and Mie theory for "equivalent" spheres was understandably inexact; the framework of an approximate theoretical model utilizing geometrical optics considerations was invoked. The presenter suggested that such a model may find application for treating scattering problems in the upper atmosphere or outside the terrestrial atmosphere.

The modeling of atmospheric aerosol backscattering at  $\text{CO}_2$  wavelengths by G.S. Kent et al. from IFAORS comprehensively summarized the optical properties of aerosols at the  $10.6 \mu\text{m}$  wavelength. Backscattering cross sections were theoretically derived from measured aerosol properties and compared to  $\text{CO}_2$  laser data. The agreement was said to be "relatively good", although problems with humidity effects and aerosol variability were recognized. Importantly, it was shown that the  $\beta_{10.6 \mu\text{m}}$  values were quite sensitive to the presence of even low numbers of large aerosol particles, with radii in excess of  $1 \mu\text{m}$  and that measurements of such large particles were scarce.

Lidar atmospheric optical measurements in the  $8\text{-}12 \mu\text{m}$  window region were discussed by D.M. Winker and R.M. Schotland of the University

of Arizona. The research program is to add to the data base of aerosol backscattering properties at  $10.6\text{ }\mu\text{m}$  by deriving quantitative backscattering measurements from the desert aerosol by applying a least squares regression technique to data from a scanning lidar.

The condensation and growth of cloud droplets was explored by applying Coherent Anti-Stokes Raman Scattering, CARS, to droplet measurements in the Mie Size Range. A. Gross and J. Cooney of Drexel University discussed the design factors for a laboratory device and the theoretical background of CARS radiation. CARS scattering calculations (for benzene droplets) showed that an enormous increase in CARS scattering efficiency over normal Raman scattering and CARS scattering in bulk media were possible for certain size parameters. The general unfamiliarity with this technique and the magnitude of the CARS scattering enhancement evoked numerous questions.

The use of  $10.6\text{ }\mu\text{m}$  cw Laser Doppler Velocimeter, as a means of obtaining aerosol size distributions was discussed by H.B. Jeffreys of Applied Research, Inc. After reviewing the technique, some data obtained from an aircraft platform was illustrated. The relationship between focal-volume size and aerosol concentrations (i.e., aircraft altitude) on the preliminary data collected was stressed.

In summary, this session dealt primarily with discussions of familiar techniques (with the exception of the CARS paper). Three of the papers considered  $\text{CO}_2$  laser designs for aerosol studies, and some comprehensive data should be forthcoming at the next conference.

VISIBILITY AND EXTINCTION PROPERTIES (R.W. Fenn, A.F.G.L. Hansom Field, MA)

This session was divided into two portions. The eleven papers in this session addressed several aspects of lidar studies.

Of primary interest was the problem of inverting lidar signals to yield extinction coefficient profiles. Several papers discussed the accuracies that could be achieved with different techniques under conditions ranging from low altitude dust and fog measurements to stratospheric aerosol soundings. Critical questions pertaining to all methods were raised concerning the potential effects of beam overlap, multiple scattering, temporal and spatial inhomogeneities, etc. There appears to be no generally valid and accepted method to invert lidar measurements.

Several investigators have made efforts to compare lidar measurements with simultaneous measurements of transmittance, scattering aerosol size distributions and radiometer observations. Although very good agreement was found in some cases, the physical causes for this agreement was not always understood.

Several instrument developments that will provide more operationally useful lidar systems were described. The need for eye-safe lidars is being recognized and significant progress in this area is indicated in the near future.

In general, the papers presented in this session emphasized questions of measurement accuracy and data processing, however there was little consideration was given to the atmospheric physics of the observed results.

MULTIPLE SCATTERING, CLOUDS, AND HYDROMETERS (B.M. Herman, University of Arizona, Tucson, AZ)

In recent years techniques have been developed to compute multiple scattering effects on the measured lidar returns. It has since become evident that these effects can be appreciable when optically thick media such as smoke or dust clouds and precipitation are probed. Furthermore, there is considerable information content in the multiply scattered light returns. In this session, several papers were presented which were concerned with multiply scattered light and its measurement and interpretation. P. Brusaglioni et al., from Florence Italy, opened the session with an analysis of multiple scattering effects on transmitted lidar pulses, and analyzed field of view effects on the amount of detected multiple scattering. This was followed by an analysis of double scattering in enhancing the Raman-shifted Mie scattering from clouds by S. Egert et al., from the Hebrew University of Jerusalem. S. Pal and A.I. Carswell of York University then presented an analysis and measurements of anisotropy in the multiply back scattered signal around the illuminated volume. This effect appears to be a function of particle size.

In a second paper, A.I. Carswell, et al., utilized a unique laboratory apparatus to analyze the wavelength dependence of the polarization of back-scattered laser light. A dependence was found which was determined to be due to changes in the proportion of multiple to single scattering, rather than to inherent changes in the properties of the scattering itself.

A series of lidar studies of cloud properties followed these interesting papers. K. Sassen of the University of Utah, showed comparisons between lidar and Ku-band radar observed during the passage of a

frontal cloud. Generally both systems showed reasonable agreement on cloud boundaries, although the polarization lidar seemed to show somewhat greater sensitivity, particularly when ice crystals were present. Attenuation of the lidar beams, in the case presented, did not seem important. I. Singstad of the University of Bergen, Norway followed with a study of the Stokes parameters of laser light reflected from cirrus clouds and he suggested that the polarization parameters may be interpreted in terms of crystal orientation. J. Spinhirne and M. Hansen of the NASA Goddard Space Flight Center showed detailed studies of lidar measurements of backscatter and polarization measurements from clouds obtained from a lidar on a high altitude aircraft. Details of cloud top development and ice-water phases were presented.

The session ended with two interesting papers, one by D.J.Fang and C.H. Chen of the Comsat Laboratory which described a laser rain gauge system and another by G. Davidson, et al., of Photometrics, Inc., which presented measurements of transmission through falling snow.

The abstracts of the papers presented at this conference are documented in NASA Conference Publication 2228 (NASA CP-2228). Original copies of this document may be purchased from the Space Science & Engineering Center, University of Wisconsin-Madison, Madison, WI 53706. Reproductions of this document are also available from the National Technical Information Service, Springfield, VA 22161.

The success of this conference was the result of efforts by Susan Spellman, Robert Fox and John Roberts of the Space Science and Engineering Center. The contributions of Dr. M. Patrick McCormick who hosted the organizing meeting and arranged for publication of the abstract book, Messrs. Don Bedo, Herman Gerber, Chalmers Sechrist and Tom



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