

23-3-71

AN OPTICAL STUDY  
OF  
ATMOSPHERIC AEROSOLS

by  
D. J. Gambling, M.Sc.

A Thesis  
presented for the degree of  
DOCTOR OF PHILOSOPHY  
at the  
UNIVERSITY OF ADELAIDE  
(Physics Department)

August 1970



FRONTISPIECE. The author (right) and colleague, K. Bartusek, with the mobile instrumentation van housing the laser radar.

## CONTENTS

	<u>Page</u>
SUMMARY	(i)
PREFACE	(iii)
ACKNOWLEDGEMENTS	(iv)
CHAPTER ONE - A SURVEY OF CURRENT KNOWLEDGE OF AEROSOLS	1
1.1    The Size of Aerosols	3
1.2    Size Distribution and Concentration	4
1.2.1    Continental Aerosols	5
1.2.2    Maritime Aerosols	11
1.2.3    Aerosols in the Lower Stratosphere	13
1.3    Chemical Composition	17
1.3.1    Tropospheric Aerosols	17
1.3.2    Aerosols in the Lower Stratosphere	19
1.4    Aerosols above 30 km	20
1.5    Remote Optical Probing of the Upper Atmosphere	21
1.5.1    Twilight Experiments	22
1.5.2    Searchlight Experiments	23
1.5.3    The Laser Radar	24
CHAPTER TWO - THE LASER RADAR	26
2.1    Transmitter	26
2.1.1    Laser Generator	26
2.1.2    Laser Power Supply	28

	<u>Page</u>	
2.1.3	Cooling System	28
2.1.4	Characteristics of the Laser Output	29
2.1.5	The Collimator	31
2.2	The Receiver System	34
2.2.1	The Optical Receiver	34
2.2.2	Electronic Recording System	38
2.2.2.1	Digital Recording System	38
2.2.2.2	Analogue Recording System	40
2.2.3	Electrical Noise Problems	42
CHAPTER THREE - THEORETICAL SCATTERING CONSIDERATIONS		43
3.1	The Lidar Equation	43
3.2	Solution of the Lidar Equation	45
3.3	Quantities Derived from the Lidar Data	47
3.4	Mie Scattering Theory	49
3.5	Some Computational Results using Mie's Theory	52
CHAPTER FOUR - DATA REDUCTION		63
4.1	Pulse Counting System	63
4.1.1	Resolving Time Corrections	63
4.1.2	Background Corrections	64
4.1.3	Statistical Errors	66
4.1.4	Count Rate Corrections	67
4.1.5	Overlapping of the Data	69
4.2	Analogue Recording System	71
4.3	Processing Common to both Recording Systems	71

	<u>Page</u>
4.3.1 Normalising the Lidar Results	72
4.3.2 Corrections for Transmission	76
4.4 Computations	77
CHAPTER FIVE - STRATOSPHERIC OBSERVATIONS	78
5.1 10 - 30 km Region. General Characteristics	80
5.2 Transport of Tracers in the Lower Stratosphere	86
5.3 30 - 60 km Altitude Region	96
CHAPTER SIX - TROPOSPHERIC OBSERVATIONS	98
6.1 General Characteristics of the Scattering Ratio Profiles	99
6.2 Rapid Fluctuations in Aerosol Scattering	104
6.3 Diurnal Variations	105
6.4 Observations of Cirrus Cloud	106
CHAPTER SEVEN - SOME ASPECTS OF THE TWILIGHT PHENOMENON	108
7.1 Experimental Aspects	110
7.2 Results	112
7.3 Comparison of Twilight and Laser Results	114
7.4 Theoretical Twilight Model	121
CHAPTER EIGHT - CONCLUDING REMARKS	129
8.1 Stratospheric Observations	129
8.2 Tropospheric Observations	132
8.3 Discussion	134
8.4 Twilight Observations	139
8.5 Future Work	140

BIBLIOGRAPHY

143

APPENDIX - Preprint of a Paper: "Stratospheric Aerosol Measurements by Optical Radar" by K. Bartusek, D. J. Gambling and W. G. Elford. J. Atmos. Terr. Phys., 1970 (in the press).

SUMMARY

In recent years aerosols have become of increasing importance in several fields of meteorology. However, our knowledge of the properties and distribution of aerosols above the first few kilometres of the atmosphere has been limited by difficulties experienced using present techniques.

This thesis describes an investigation of aerosols in the atmosphere, by means of their light scattering properties, using a ruby laser radar. Since its advent in 1960, the laser beam has proved to be the most satisfactory of existing remote optical probes. The laser radar described here is capable of measuring atmospheric scattering from nearly ground level to altitudes of 60 km.

Interpretation of existing laser radar measurements using a single wavelength and scattering angle does, however, depend on a priori knowledge of certain aerosol properties. This shortcoming of the present laser radar technique, and other theoretical aspects of light scattering by aerosols, are discussed in some detail. Recent measurements of stratospheric aerosol number densities using balloon-borne optical counters indicate that the stratospheric aerosol is predominantly volatile and hence remains undetected by collection experiments. As little is known of the size distribution of volatile stratospheric aerosols, a theoretical investigation is made of their optical scattering characteristics. Aided

by the results of the theoretical analysis, present optical measurements are examined in order to deduce aerosol size distributions compatible with the observations.

Results of laser radar measurements of stratospheric aerosols conducted in South Australia are presented. The vertical profiles are broadly in agreement with observations reported by other workers in the northern hemisphere. An annual variation apparent in the laser radar observations is remarkably similar to that of ozone in the stratosphere, and the importance of large scale transport mechanisms in the stratosphere is discussed.

Results of tropospheric aerosol measurements are presented, showing vertical profiles typical of the coastal regions. The relation between temperature inversions, humidity and aerosol layers observed in the troposphere is investigated.

The reliability of the twilight scattering experiment used by several workers to study stratospheric aerosols is discussed, and a comparison is made of the results of twilight and laser radar experiments conducted at the same time and locality. A theoretical model of the twilight phenomenon based on primary scattering is developed, and calculations are performed to deduce the relative effects of the various aerosol layers in the troposphere and stratosphere on the twilight profile.



PREFACE

To the best of the author's knowledge, this thesis contains no material previously published or written by another person, except where due reference is made in the text. It contains no material which has been submitted or accepted for the award of any other degree or diploma in any University.

(D. J. Gambling)

University of Adelaide  
14/8/70

ACKNOWLEDGEMENTS

The work described in this thesis was undertaken in the Physics Department of the University of Adelaide under the supervision of Dr. W. G. Elford. The author is grateful to Dr. Elford for his advice and guidance during the course of the work.

The author is indebted to his colleague, Mr. K. Bartusek, who was responsible for the initial design and construction of the laser radar, and who assisted with the final installation and operation of the equipment. Thanks are also due to Mr. L. Thomas, who constructed much of the electronic and ancillary equipment, and who assisted in the operation of the laser radar. Mr. M. Manuel was responsible for most of the mechanical construction.

Acknowledgement is due to the Director of the Mawson Institute for Antarctic Research, Dr. Jacka, who made available the Mt. Torrens field station during the early stages of the observations. The author is grateful to the Weapons Research Establishment for the loan of the instrumentation van, and in particular, to Mr. B. Rofe, who made the arrangements.

The author is indebted to the Director of the Commonwealth Bureau of Meteorology for providing the meteorological data used in the analysis. The author is particularly grateful for the assistance of Mr. V. Deering of the Meteorological Office at Adelaide Airport, and to Mr. L. Mitchell of the Regional Office.

Thanks are due to Dr. B. Pittock and Dr. B. Hicks of the Division of Meteorological Physics, C.S.I.R.O., and to Dr. E. K. Bigg of the Division of Radiophysics, C.S.I.R.O., who made their records available.

Finance for the laser project was provided by the Commonwealth Department of Supply, and the University of Adelaide. The author was a holder of a Post-Graduate Studentship from the Department of Supply.