REMOTE SENSING OF ATMOSPHERES AND OCEANS

Edited by Adarsh Deepak

REMOTE SENSING OF ATMOSPHERES AND OCEANS

edited by

ADARSH DEEPAK

Institute for Atmospheric Optics and Remote Sensing Hampton, Virginia

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PREFACE

This volume contains the technical proceedings of the Interactive Workshop on Interpretation of Remotely Sensed Data, held in Williamsburg, Virginia, May 23-25, 1979.

The workshop was organized to provide an interdisciplinary forum to assess the state-of-the-art in the interpretation of measurements obtained in remote sounding of various atmospheric and ocean parameters, and to identify those important problems in which further research efforts are needed. Seventy scientists from the industry, universities, government agencies, and research laboratories attended the workshop, in which thirty papers were presented. Complete texts of twenty-five of these papers, and their discussions, are included in this volume.

The workshop program was divided into ten sessions, each covering a specific topic and chaired by the following scientists: A. Deepak, Recent Advances in Inversion Methods; L. D. Kaplan, Atmospheric Temperature Sounding; J. Lenoble, Interpretation of Aerosol Sounding; A. E. S. Green, Gaseous Constituent Retrievals; D. H. Staelin, Remote Sounding by Microwaves; E. R. Westwater, Wind Sounding; H. E. Fleming and M. T. Chahine, Ocean Parameter Sounding; M. P. McCormick and B. J. Conrath, Recent Results from Space. The papers included the following topics: remote sounding of atmospheric temperature, trace gases, precipitation and aerosols, sea surface temperature, ocean color, and winds. The papers discussed the current state of knowledge, as well as the results of the latest investigations in their specific areas of research. Ample time was allowed for discussions following each paper. Discussions were recorded and the transcripts postedited.

The scope of the workshop included areas of research that were not discussed in the First Interactive Workshop on Inversion Methods in Atmospheric Remote Sounding, held in Williamsburg, Virginia, in December 1976, the proceedings for which were published by Academic Press in December 1977. Dr. Douglas DePriest, Office of Naval Research (ONR), in his introductory remarks, drew attention to the importance of mathematical and statistical methodologies in the remote sensing of oceanographic, terrestrial, and atmospheric quantities.

xiv PREFACE

To ensure proper representation of major disciplines involved, a workshop program committee composed of the following scientists was set up: A. Deepak (Chairman), Institute for Atmospheric Optics and Remote Sensing (IFAORS); M. T. Chahine, Jet Propulsion Laboratory; D. J. DePriest, Office of Naval Research; H. E. Fleming, Naval Postgraduate School, Monterey, B. M. Herman, University of Arizona; M. P. McCormick, NASA-Langley Research Center; W. L. Smith, NOAA/University of Wisconsin; and D. Staelin, Massachusetts Institute of Technology.

The editor wishes to acknowledge the enthusiastic support and cooperation of the members of the Technical Program Committee, session chairmen, speakers, and participants for making this a stimulating and valuable workshop for everyone. Special thanks are due the authors for their cooperation in enabling a prompt publication of the workshop proceedings. It is a pleasure to acknowledge the valuable assistance of Mrs. M. D. Crotts and S. A. Allen, IFAORS, in organizing the workshop, and H. Malcahy and M. Goodwin, IFAORS, in preparing and typing the final manuscripts.

The Workshop was cosponsored by the Office of Naval Research and the Institute for Atmospheric Optics and Remote Sensing, in cooperation with NASA-Langley Research Center.

A. Deepak

CONTENTS

Participants	ix
Photograph of Speakers and Chairmen	xii
Preface	xiii
	•
RECENT ADVANCES IN INVERSION METHODS	
Recent Developments—A. Despak, Chairman	
necessi Developments—A. Deepak, Chairman	
	•
A Differential Inversion Method for High Resolution Atmospheric	1
Remote Sensing Mian M. Abbas	
Mian M. Abbas	
Some Adaptive Filtering Techniques Applied to the Passive Remote	19
Sensing Problem	
P. M. Toldalagi	
·	
·	_
REMOTE SOUNDING OF ATMOSPHERIC PARAMETER	S
Atmospheric Temperature Sounding-L. D. Kaplan, Cho	iirman
Temperature Retrievals from TIROS-N	45
J. Susskind and A. Rosenberg	
Performance of the HIRS/2 Instrument on TIROS-N	67
E. W. Koenig	

vi CONTENTS

Interpretation of Aerosol Sounding—J. Lenoble, Chairman	1
Retrieval of Aerosol Size Distributions from Scattering and Extinction Measurements in the Presence of Multiple Scattering A. Deepak, M. A. Box, and G. P. Box	95
Atmospheric Effects in Remote Sensing of Ground and Ocean Reflectances P. Y. Deschamps, M. Herman, J. Lenoble, D. Tanre, and M. Viollier	115
Analysis and Interpretation of Lidar Observations of the Stratospheric Aerosol P. Hamill, T. J. Swissler, M. Osborn, and M. P. McCormick	149
Gaseous Constituent Retrievals—A. E. S. Green, Chairman	1
Remote Sensing of Ozone in the Middle Ultraviolet A. E. S. Green and James D. Talman	171
Role of Multiple Scattering in Ozone Profile Retrieval from Satellite Measuments in the Ultraviolet S. L. Taylor, P. K. Bhartia, V. G. Kaveeshwar, K. F. Klenk, Albert J. Fleig, and C. L. Mateer	219
Interpretation of NO ₂ Spire Spectral Data Using the AFGL Fascode Computer Model H. J. P. Smith, R. M. Nadile, A. T. Stair, D. G. Frodsham, and D. J. Baker	233
Remote Sounding by Microwaves—D. H. Staelin, Chairman	•
Progress in Passive Microwave Remote Sensing: Nonlinear Retrieval Techniques David H. Staelin	259
Inversion of Multiwavelength Radiometer Measurements by Three-Dimensional Filtering P. W. Rosenkranz and W. T. Baumann	277

- Francisco

Henry E. Fleming

REMOTE SOUNDING OF WINDS

Wind Sounding—E. R. Westwater, Chairman

Design of a Ground-Based Remote Sensing System Using Radio Wavelengths to Profile Lower Atmospheric Winds, Temperature, and Humidity D. C. Hogg, F. O. Guiraud, C. G. Little, R. G. Strauch, M. T. Decker, and E. R. Westwater					
CO ₂ Laser Radar for Atmospheric Energy Measurements Charles A. Di Marzio, Albert V. Jelalian, and Douglas W. Toomey					
Satellite-Based Microwave Retrievals of Temperature and Thermal Winds: Effects of Channel Selection and a Priori Mean on Retrieval Accuracy Norman C. Grody					
REMOTE SOUNDING OF OCEAN PARAMETERS Ocean Parameter Sounding—H. E. Fleming and M. T. Ch Chairmen	ahine,				
Infrared Remote Sensing of Sea Surface Temperature M. T. Chahine	411				
The Split Window Retrieval Algorithm for Sea Surface Temperature Derived from Satellite Measurements L. M. McMillin	437				
Atmospheric Correction of Nimbus-7 Coastal Zone Color Scanner Imagery Howard R. Gordon, James L. Mueller, and Robert C. Wrigley	457				
Theory and Application of the Truncated Normal Distribution for Remotely Sensed Data D. S. Crosby and D. J. DePriest	485				
Application of the Truncated Normal Distribution Technique to the Derivation of Sea Surface Temperatures	503				

Deriving	Sea Surface	Temperatures	from	TIROS-N	Data
C	Walton				

547

INTERPRETATION OF RECENT RESULTS FROM SPACE

Recent Results from Space—M. P. McCormick and B. J. Conrath, Chairmen

Interpretation of Solar Extinction Data for Stratospheric Aerosols T. J. Pepin	581
A Fast and Accurate Radiance Algorithm for Application to Inversion of Limb Measurements	591
Larry L. Gordley and James M. Russell III	
Thermal Structure of Jupiter's Atmosphere Obtained by Inversion of Voyager 1 Infrared Measurements	611
Barney J. Conrath and Daniel Gautier	
Preliminary Results from NIMBUS-7 Stratospheric and Mesospheric Sounder C. D. Rodgers	631

Index 639

A DIFFERENTIAL INVERSION METHOD FOR HIGH RESOLUTION ATMOSPHERIC REMOTE SENSING

Mian M. Abbas

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The spectral lines of atmospheric gases may be fully resolved with high resolution observations by techniques, such as infrared heterodyne spectrometers. An inversion method suitable for such observations is discussed and is found to have several advantages over conventional methods. The method is based on matching the derivatives of the observed radiances or transmittances with the calculated values for the modeled atmosphere. The proposed method provides a significant narrowing of the weighting functions and improvement in the overall accuracy of the retrieved profiles. The method is applied to inversion of ozone absorption lines in the earth's atmosphere and the results are compared with those obtained with a conventional method.

I. INTRODUCTION

The spectral lines of atmospheric gases may be detected and fully resolved by using high resolution techniques such as infrared heterodyne spectrometers. An inversion method is presented, which is suitable for such measurements and is found to have several advantages over conventional methods.

The proposed method is based on matching the derivatives of observed radiances or transmittances with the calculated values of a modeled atmosphere and leads to a significant

2 MIAN M. ABBAS

narrowing of the weighting functions and an improvement in the overall accuracy of the retrieved profiles. The method is applied to inversion of ozone absorption lines in the earth's atmosphere and the results are compared with those obtained by using a conventional method.

Atmospheric remote sensing techniques are based on measuring the outcoming radiation at a selected set of frequencies and finding an inverse solution to the radiative transfer equation in terms of either the concentration or the temperature profile of the atmosphere. With low resolution instruments ($\Delta v > \alpha$), only average spectral intensities are measured since individual lines cannot be resolved. An evaluation of atmospheric profiles is made through an analytic inversion over an absorption band, where the observed radiances or transmittances generally represent an average over several lines. With recent advances in techniques of infrared heterodyning and tunable diode lasers, however, where resolving powers as high as 10^6 to 10^7 may be achieved, it is now possible to fully resolve individual spectral lines with detection sensitivities approaching the quantum detection limit (see, for example, Refs. 1 to 6).

An inversion of individual spectral lines provides more accurate information about vertical distribution of stratospheric constituents than is possible with lower resolution measurements because of two factors. First, if it is assumed that the spectral parameters and the lineshape function of the observed line are accurately known (or have been determined by laboratory measurements), the accuracy of the retrieved profiles is higher because no averaging over a number of lines is required. Second, the interference from other gases may be virtually eliminated by a proper choice of the observed line.

An inversion method is discussed here which appears to have several advantages over the usual methods, and is applicable to ultra-high resolution measurements where the

lineshape is fully resolved. The inversion process is based on finding an inverse solution to the derivative of the radiative transfer equation with respect to frequency. In the iterative technique employed, the slope of the observed line is matched with the slope of the synthetic line computed for the retrieved atmospheric parameters.

II. DUSCUSSION OF METHOD

The outcoming spectral intensity from a nonscattering atmosphere is given by the radiative transfer equation

$$I_{V}(P,T) = B_{V}(T_{S}) \tau_{V}^{S} + \int_{Y_{S}}^{Y_{t}} B_{V}(T) K(P,T) dy$$
 (1)

where $B_V(T_S)$ is the Planck function, T_V^S is the transmittance from the surface to the top of the atmosphere and $K(P,T) = \partial T_V/\partial y$ (with $y = -\ln P$) is the weighting function. The atmospheric transmittance T_V is

$$\tau_{v} = \exp(-\int_{i}^{\infty} k_{vi} du_{i})$$
 (2)

where k_{Vi} is the absorption coefficient and du is the element of column density of the absorbing gas.

The derivative of the spectral intensity with respect to frequency is given by

$$i_{v} = B_{v}(T_{s}) \dot{\tau}_{v}^{s} + \int_{Y_{s}} B_{v}(T) \dot{K}_{v}(P,T) dy$$
 (3)

where the dot over a symbol refers to a derivative with respect to frequency, and it is assumed that the frequency interval is sufficiently small so that $B_{V} = 0$.

For atmospheric observations in the solar occultation mode, the second term in Eqs. (1) and (3) is generally negligible so that the observed radiance and its derivative are MIAN M. ABBAS

$$I_{v} = B_{v}(T_{s}) \tau_{v}^{s} \tag{4}$$

and

4

$$I_{V} = B_{V}(T_{S}) \dot{\tau}_{V}^{S}$$
 (5)

The differential quantities I_{ν} and τ_{ν} may be measured directly in systems based on tunable diode lasers or they may be computed from a smoothed spectral line profile obtained from high resolution measurements.

The discussion in this paper is limited to inversion of ground-based solar occultation measurements of the earth's atmosphere for evaluation of concentration profiles which may be obtained through an inverse solution of Eq. (5). From Eq. (2)

$$\frac{\tau_{v}}{\tau_{v}} = \frac{1}{g} \int_{0}^{P} \sum_{i} \dot{k}_{vi} \quad (P,T) \quad q_{i}(P) \quad dP$$
 (6)

Equation (6) may be solved through an iterative procedure with k_{V} as a weighting function. The plots of k_{V} as a function of height are expected to be narrower and at higher levels in the atmosphere than the corresponding functions k_{V} . This effect may be seen from the expressions for k_{V} and k_{V} in a pressure broadening regime where

$$k_{V}(P,T) = \frac{1}{\pi} \frac{S(T) \alpha(P,T)}{(v - v_{O})^{2} + \alpha^{2}(P,T)}$$
(7)

and

$$k_{v} = \frac{-2 \text{ S(T) } \alpha(P,T) (v - v_{o})}{\pi[(v - v_{o})^{2} + \alpha^{2}(P,T)]^{2}}$$
(8)