REMOTE SENSING OF ATMOSPHERES AND OCEANS

Edited by
Adarsh Deepak

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edited by

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Institute for Atmospheric Optics
and Remote Sensing
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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 Aërosol 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.

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

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A DIFFERENTIAL INVERSION METHOD FOR HIGH RESOLUTION ATMOSPHERIC REMOTE SENSING

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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

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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 ($\Delta\nu > \alpha$), 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

$$I_\nu(P,T) = B_\nu(T_s)\ \tau_\nu^s + \int_{y_s}^{y_t} B_\nu(T)\ K(P,T)\ dy \tag{1}$$

where $B_\nu(T_s)$ is the Planck function, τ_ν^s is the transmittance from the surface to the top of the atmosphere and $K(P,T) = \partial\tau_\nu/\partial y$ (with $y = -\ell n\ P$) is the weighting function. The atmospheric transmittance τ_ν is

$$\tau_\nu = \exp(-\int \sum_i k_{\nu i}\ du_i) \tag{2}$$

where $k_{\nu i}$ is the absorption coefficient and du_i is the element of column density of the absorbing gas.

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

$$\dot{I}_\nu = B_\nu(T_s)\ \dot{\tau}_\nu^s + \int_{y_s} B_\nu(T)\ \dot{K}_\nu(P,T)\ dy \tag{3}$$

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 $\dot{B}_\nu = 0$.

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

$$I_\nu = B_\nu(T_s)\ \tau_\nu^s \tag{4}$$

and

$$\dot{I}_\nu = B_\nu(T_s)\ \dot{\tau}_\nu^s \tag{5}$$

The differential quantities $\dot{I}_\nu$ and $\dot{\tau}_\nu$ 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)

$$\frac{\dot{\tau}_\nu}{\tau_\nu} = \frac{1}{g}\int_0^P \sum_i \dot{k}_{\nu i}\ (P,T)\ q_i(P)\ dP \tag{6}$$

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

$$k_\nu(P,T) = \frac{1}{\pi}\ \frac{S(T)\ \alpha(P,T)}{(\nu - \nu_o)^2 + \alpha^2(P,T)} \tag{7}$$

and

$$\dot{k}_\nu = \frac{-2\ S(T)\ \alpha(P,T)\ (\nu - \nu_o)}{\pi[(\nu - \nu_o)^2 + \alpha^2(P,T)]^2} \tag{8}$$