Estimation of Aerosol Optical Depth, Pressure Elevation, Water Vapor and Calculation of Apparent Surface Reflectance from Radiance Measured by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Using A Radiative Transfer Code

Robert O. Green[1], James E. Conel[1] and Dar A. Roberts[2]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 9 109
[2]University of Washington, Seattle, WA 98195

ABSTRACT

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is an imaging spectrometer that measures spatial images of the total up welling spectra] radiance from 400 to 2500" nm at 10 nm spectral intervals. Quantitative research and application objectives for surface investigations require conversion of the measured radiance to surface reflectance or surface leaving radiance. '1'0 calculate apparent surface reflectance an estimation of aerosol optical depth is required for compensation of aerosol scattering and absorption across the spectral range. Determination of other atmospheric characteristics such as atmospheric water vapor and surface pressure is also required. in this paper we describe a set of algorithms to estimate aerosol optical depth, atmospheric water vapor, and surface pressure height from the AVIRIS measured radiance. Based upon these determined atmospheric parameters we describe an algorithm to calculate apparent Surface reflectance from the. AVIRIS measured radiance using a radiative transfer code.

1.() 1N'1'ROI>LJC'I'1ON

An AVIRIS data set was acquired over a portion of the San Francisco peninsula that included the Jasper Ridge ecological preserve on the 2nd of June 1992. This scene covers 10 by 11 km with 20 by 20 m spatial resolution and includes a variety of vegetated and unvegetated surface cover types. Figure 1 shows a radiance spectrum for a dry grass area in the ecological preserve. The shape of this spectrum results from the solar irradiance, molecular and aerosol scattering of the atmosphere, gas absorption of the atmosphere, illumination geometry and the reflectance of the surface. This Jasper Ridge data set was selected to evaluate a group of algorithms to estimate the absorption and scattering characteristics of the atmosphere directly from AVIRIS data. These derived atmospheric parameters are used to constrain an inversion algorithm for calculation of apparent surface reflectance from AVIRIS-measured upwelling spectral radiance. The MODTRAN2 (Berk et al., 1989) radiative transfer code is used to model the atmosphere in each of these algorithms.

2.() AEROSOL OPTICAL DEPTH

Under low visibility conditions the radiance scattered from atmospheric aerosols may comprise a significant proportion of the total radiance reaching the AVIRIS sensor. A plot showing the aerosol scattered radiance contribution to the total radiance from a ().2S reflectance surface with a S km rural atmosphere visibility is given in Figure 2.

A nonlinear least square spectral fitting (NLLSSF) algorithm has been developed to estimate the aerosol optical depth directly from the AVIRIS measured radiance. 'l'his algorithm optimizes the fit between the AVIRIS radiance and a MODTRAN2 modeled radiance with the aerosol optical depth as the primary fitting parameter. Parameters modeling the reflectance magnitude, reflectance slope and the leaf chlorophyll absorption are also included in the fitting algorithm. For this experiment at Jasper Ridge the MODTRA N2 rural aerosol model was used. Figure 3 shows the results of the, NLLSSF algorithm for a forest target in the Jasper Ridge scene. The algorithm determined an aerosol optical depth of 0.42 at 500 nm for this spectrum. Aerosol optical depths were calculated for the entire Jasper Ridge AVIRIS data set. The determined values ranged from 0.27 in the peninsula mountains to 0.S3 near the San Francisco bay. Research planned in the future will investigate the sensitivity of this algorithm to the modeling of surface spectral reflectance and assumption of aerosol model.

3.0 SURFACE PRESSURE HEIGHT

In order to compensate for atmospheric absorption due to well mixed atmospheric gases and the effect of atmospheric molecular scattering, an algorithm has been developed to estimate the surface pressure elevation from the AVIRIS measured radiance. This algorithm assesses the strength of the 760 nm oxygen absorption band measured in the AVIRIS data. The oxygen band strength is calibrated to surface pressure. elevation using the oxygen band model in the, MODTRAN2 radiative transfer code. A precursor oxygen ant] carbon dioxide absorption band algorithm for estimating surface pressure elevation was described and applied to an AVIRIS data set acquired over Mountain Pass, California in 1990 (Green et ai., 1991a), The cur-rent algorithm uses a NLLSSF procedure between the A VIRIS measured radiance and MODTRAN2 calculated radiance. Parameters constraining the pressure elevation, the reflectance magnitude anti the reflectance slope in the 760 nm spectral region are allowed to vary in the fit. To improve the estimation of pressure elevation the AVIRIS data were averaged over 11 by 11 spatial samples to increase the effective precision of the. data. Figure 4 shows the fit results for the dry grass area of the Jasper Ridge AVIRIS data. A pressure elevation of 250 m was determined for this spectrum. In 1993 work is planned to establish accuracy and precision uncertainty estimates for this approach to estimation or surface pressure elevation. When applied to the entire. Jasper Ridge AVIRIS data set, pressure. elevations were calculated that ranged from 0 m towards the San Francisco Bay to 800" m in the mountains on the peninsula. These estimates are consistent with the. topography of the region.

4.0 ATMOSPHERIC WATER VAPOR

Over most of the AVIRIS spectral range the strongest atmospheric absorber is water vapor. The effect on the upwelling radiance arriving at AVIRIS is shown in Figure 5 as the atmosphere varies from a water free to humid state. in addition to absorbing strongly in the AVIRIS spectral range, the abundance of water vapor in the terrestrial atmosphere varies greatly both spatially and temporally. An example showing greater than 20 percent variation in the spatial and temporal distribution of water vapor has been described for a series of four AVIRIS data set acquired at 12 minute intervals over Roger Dry Lake, California (Green et al., 1991 b).

To compensate for water vapor absorption in AV1 RIS spectra, a determination of total path water vapor is required for each spatial element. Water vapor algorithms for AVIRIS have been developed (Conel et al 1988, Green et al 1989, and Green, et al. 1991a) based initially on the LOWTRAN (Kneizys et al., 1987) and currently on the MODTRAN2 (Berk et al., 1989) radiative transfer code. The MODTRAN2 water vapor algorithm fits the A VIRIS measured radiance for the 940 nm water band to a radiance spectrum generated by the radiative transfer code. A non linear least squares spectral fitting procedure is used with parameters allowing the atmospheric water vapor amount, the reflectance magnitude, the reflectance slope and a scaled surface leaf liquid water absorption spectrum to vary. Figure 6 shows an atmospheric water vapor transmission spectrum and plant leaf reflectance spectrum. In the 940 spectral region, over vegetated targets, the leaf water absorption must be compensated for in the algorithm to avoid incorrect estimation the atmospheric water vapor. Atmospheric aerosol scattering and absorption effects are. compensated through constraint of the aerosol optical depth for the MODTRAN2 model atmosphere used. Figure 7 shows the fit between the AVIRIS measured and the N].1 .SSF spectrum for the 940 nm water vapor band over the green grass target in the Jasper Ridge AVIRIS data. Figure 8 shows the surface liquid leaf water reflectance spectrum required to achieve this fit. When applied to the entire AVIRIS Jasper Ridge data set a range in atmospheric water vapor from 9 m 22 perciptable millimeters of atmospheric water vapor is mapped. This water vapor distribution data set is required to constrain the algorithm for the inversion of measured radiance to apparent surface reflectance.

5.() REFLECTANCE CA] .CULATION

Calculation of surface spectral reflectance. from the total upwelling radiance measured by AVIRIS using a radiative transfer code has been pursued since the flights of AVIRIS in 1989 (Green, et al. 1990, Green, et al. 1991, Green et al. 1992). This algorithm begins with equation (1) that shows the total radiance measured by AVIRIS (L_t) as the exoatmospheric solar irradiance (F) multiplied by the. two way transmission of the atmosphere (T_{du}) multiplied by the surface reflectance (p) summed with the atmospheric path radiance (L_p).

$$L_t = (F * T_{du} * p) / \pi + L_p \qquad (1)$$

Using the water vapor, pressure. elevation anti aerosol optical depth estimations derived in the previous algorithms, the two way transmitted radiance anti atmospheric path radiance spectrum are calculated for each spatial element with MODTRAN2. Computer look up tables are used to accelerate these calculations. With these determined parameters the surface reflectance is calculate.(i as shown in equation (2).

$$\rho = (L_t - L^*))/ (F/\pi * T_{du}) \qquad (2)$$

Figure 9 shows the AVIRIS measured radiance for the Stanford University polo field in the Jasper Ridge scene. in Figure 10 the calculated apparent reflectance is shown in conjunction with a field reflectance spectrum acquired at a later date from the same target. The mean agreement is 6 percent excluding the regions of strong atmospheric absorption. in Figures 11 anti 12 the measured radiance and calculated reflectance spectra are show for green vegetation in the Jasper Ridge data over a 3 by 3 AVIRIS spatial Clement area. Inspection of these calculated reflectance spectra shows compensation for the solar irradiance, atmospheric absorption and atmospherically scattered radiance. Future work will emphasize estimation of the contributions to the remaining disagreement between the calculated and field measured spectra. Discrepancies may be attributed to the AVIRIS sensor calibration, the radiative transfer code and the field measurements.

6.0 CONCLUSION

Algorithms are described that allow estimation of the absorption and scattering characteristics of the atmosphere from the AVIRIS measured radiance. With estimation of these atmospheric parameters, apparent surface reflectance may be calculated from the AVIRIS measured radiance. These algorithms are based on the MODTRAN2 radiative transfer code for modeling the absorption and scattering properties of the atmosphere as well its the illumination geometry at the time the AVIRIS data were. acquired. This approach to calculation of apparent reflectance requires no independent in situ measurements. A preliminary validation is given for the algorithms through the calculation of apparent reflectance of the polo field and comparison with a field measured spectrum. As these algorithms are further validated, they offer an approach to provide apparent surface reflectance data directly to Earth Science investigators. From analysis of remotely measure.d reflectance spectra, many constituents of the surface may be identified and there expressed concentration determined based on molecular absorption and material scattering, characteristics.

7.0 ACKNOWLEDGMENTS

This research was carried out at the Jet Propulsion Laboratory, California institute of technology, under contract with the National Aeronautics and Space Administration.

8.0 REFERENCES

Berk, a., L.S.Bernstein, and D.C. Robertson, "MODTRAN: A moderate resolution model for LOWTRAN 7", I'ins] re.pen, GL-TR-0122, AFGL, Hanscomb AFB, MA, 42 pp., 1989

Conel, J.E., R.O.Green, R.E.Alley, C.J.Bruegge, V.Carrere, J.S.Margolis, G.Vane, "1". G.Chrien, P.N.Slater, S.F.Biggar, P.M.Teillet, R.D. Jackson and M.S.Moran, In-flight radiometric calibration of the Airborne Visible/Infrared imaging Spectrometer (A VI RI S), SPIE Vol. 924, Recent Advance in sensors, radiometry and data processing for remote sensing, 1988.

Green, R.O., G. Vane, and J.E. Conel, Determination of aspects of the in-flight spectra], radiometric, spatial and signal-to-noise performance of the Airborne Visible/Infrarcxl Imaging Spectrometer over Mountain Pass, Ca., in Proceeding of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Performance Evaluation Workshop, JPL Pub. 88-38, 162.-184, 1988.

Green, Robert 0., "Retrieval of Reflectance from Calibrated Radiance Imagery Measured by the. Airborne. Visible/Infrared Imaging Spectrometer (A VI RIS) for Lithological Mapping of the Clark Mountains, California", Proc. Second AVIRIS Workshop, J]>], Publication 90-54, pp. 167-175,1990.

Green, Robert 0., "Retrieval of Reflectance From AVIRIS-Measured Radiance Using a Radiative Transfer Code.", Proc. Third AVIRIS Workshop, JPL Publication 91-28, pp. 200-21 (), 1991a.

Green, Robert O., James E. Conel, Jack S. Margolis, Carol J. Bruegge, and Gordon L. Hoover, "An Inversion Algorithm for Retrieval of Atmospheric and leaf Water Absorption From AVIRIS Radiance With Compensation for Atmospheric Scatting", Proc. '1'bird AVIRIS Workshop, JPL Publication 91-28, pp. 51-61. 1991b.

Kneizys, F.X., E.P. Shettle, G.P. Anderson, L. W. Abrew, J.H. Chetwynd, J.E.A. Shelby, and W.O. Gallery, Atmospheric Transmittance/Radiance; computer Code LOWTRAN 7, AFGL Hanscom AFB, MA., 1987.

9.0 FIGURES

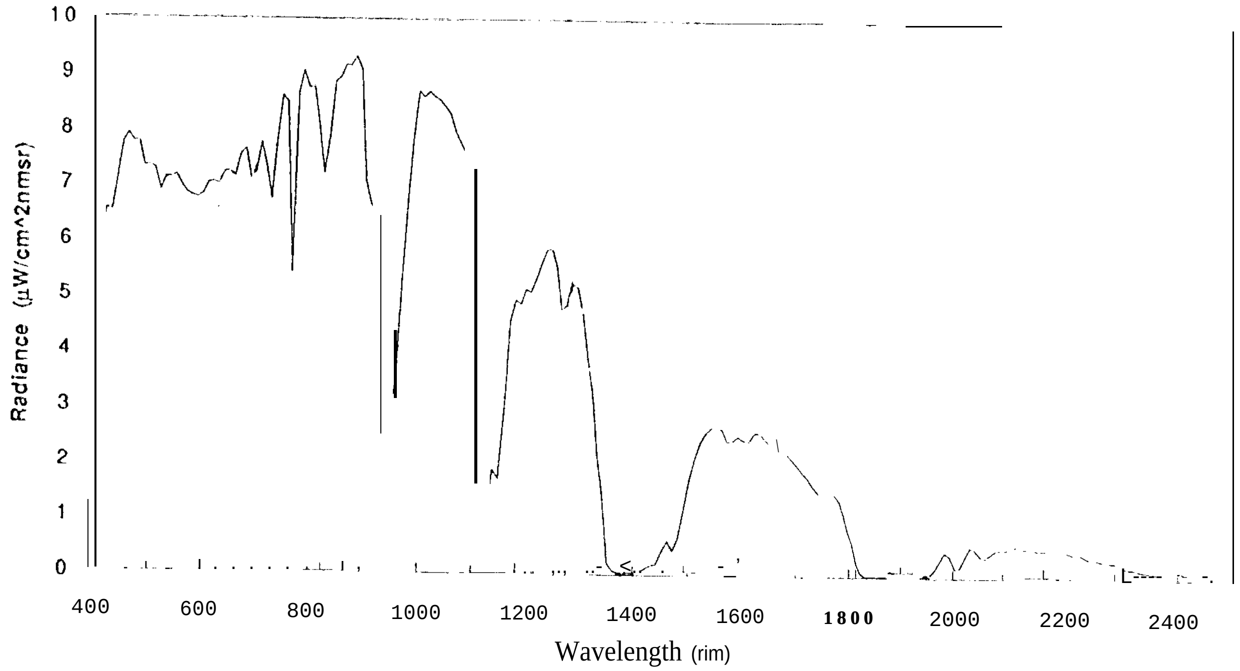

Figure 1. AVIRIS-measured radiance for a dry grass region of the ecological preserve at Jasper Ridge, CA.

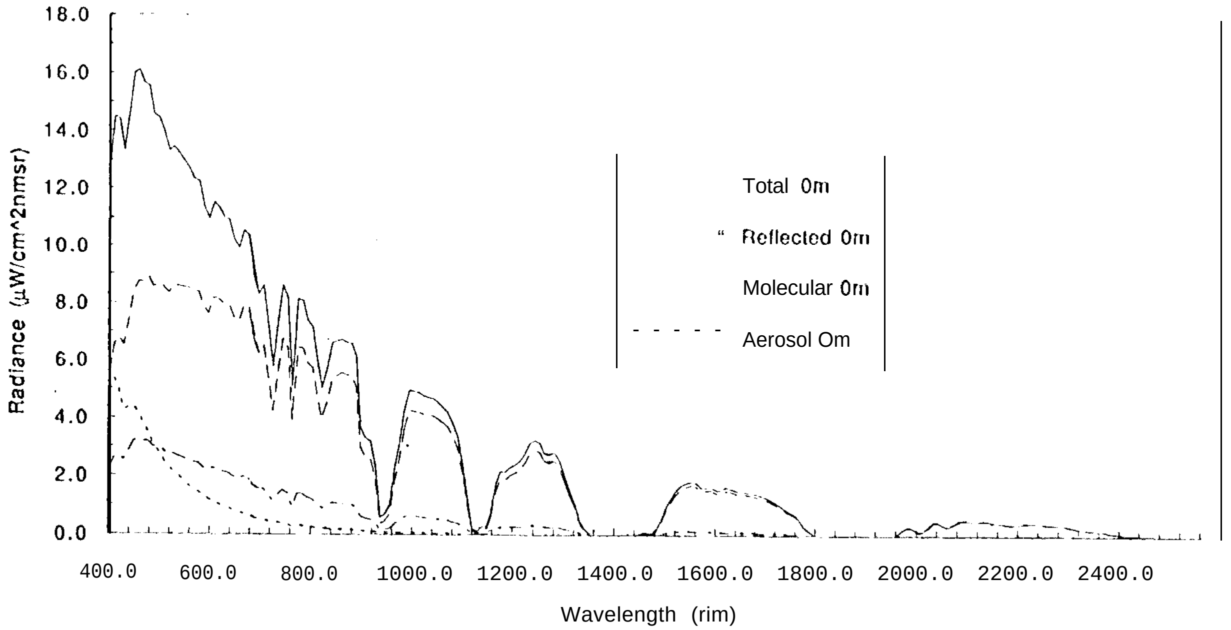

Figure 2. A plot showing the MODTRAN2a modeled total radiance for a 25 percent reflectance target at 0 m elevation with a 5 km visibility atmosphere. Also show are the reflected, molecular scattered and aerosol scattered radiance components of the total upwelling radiance.

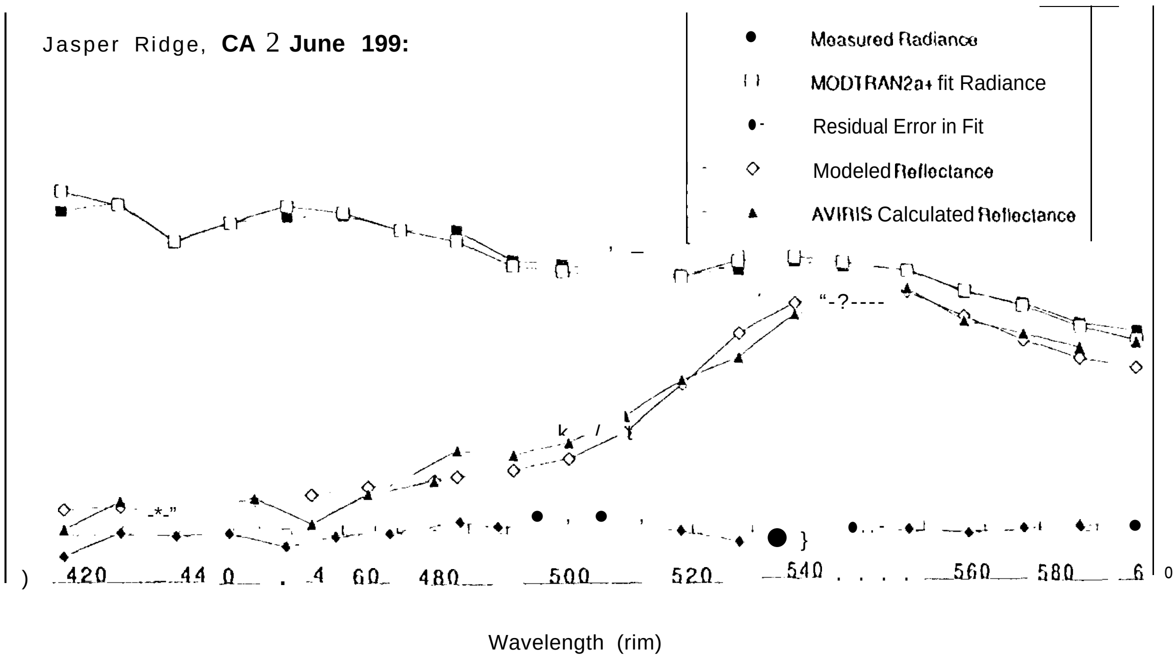

Figure 3. The nonlinear least squares fit between the AVIRIS measured radiance and the MODTRAN2 modeled radiance for estimation of aerosol optical depth. The modeled reflectance required for this fit in the 400" to 600 nm spectral region is also shown as is the resulting AVIRIS calculated reflectance.

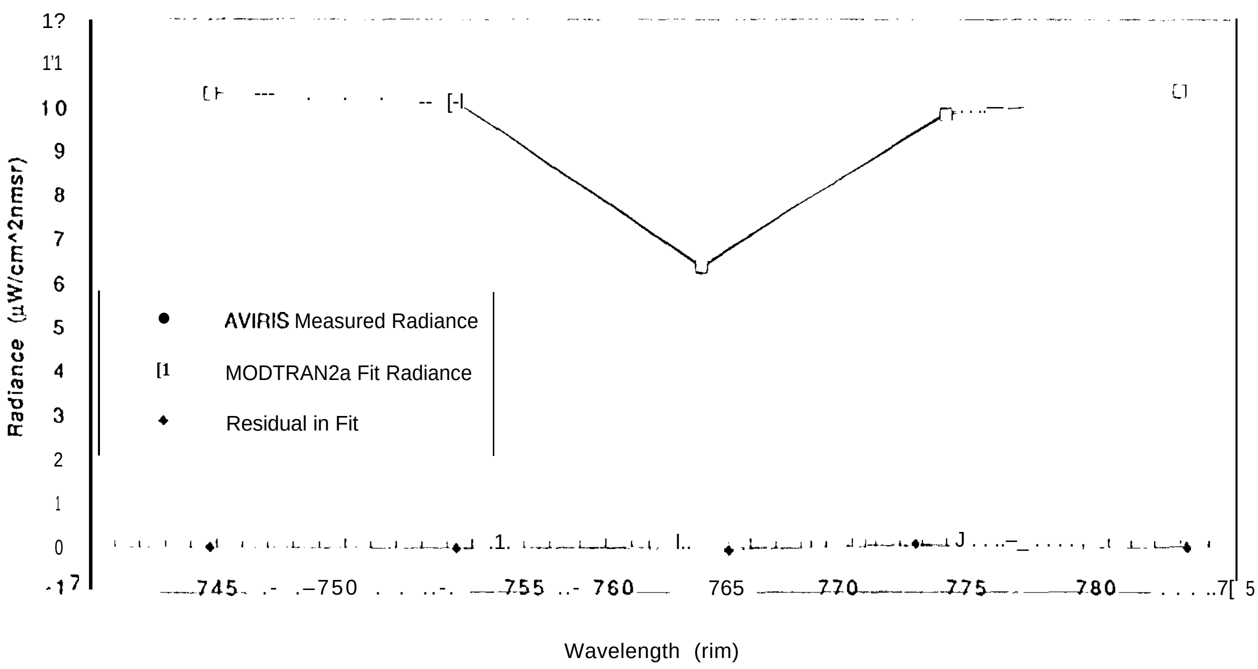

Figure 4. The fit with residual between the MODTRAN2 nonlinear least square fit spectrum and the AVIRIS measured spectrum for the estimation of surface pressure elevation from the oxygen band at 760 nm.

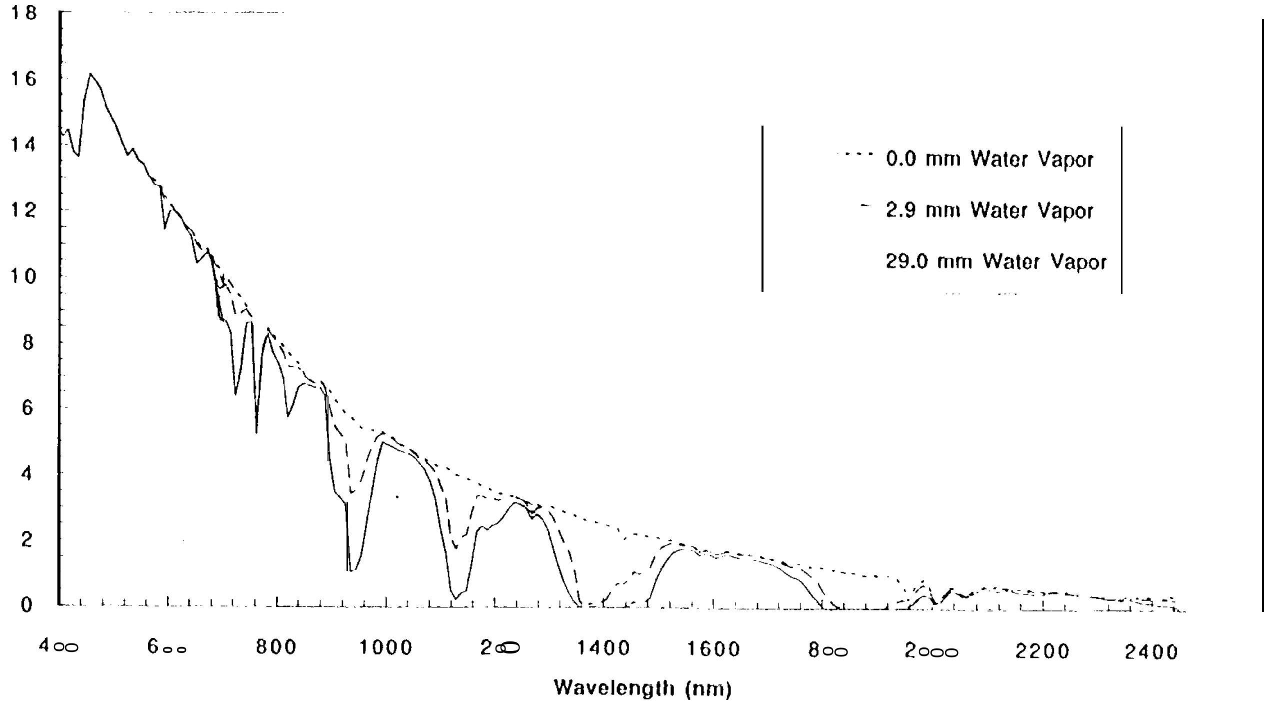

Figure 5. Influence of atmospheric water vapor amount on the upwelling radiance arriving at the AVIRIS aperture.

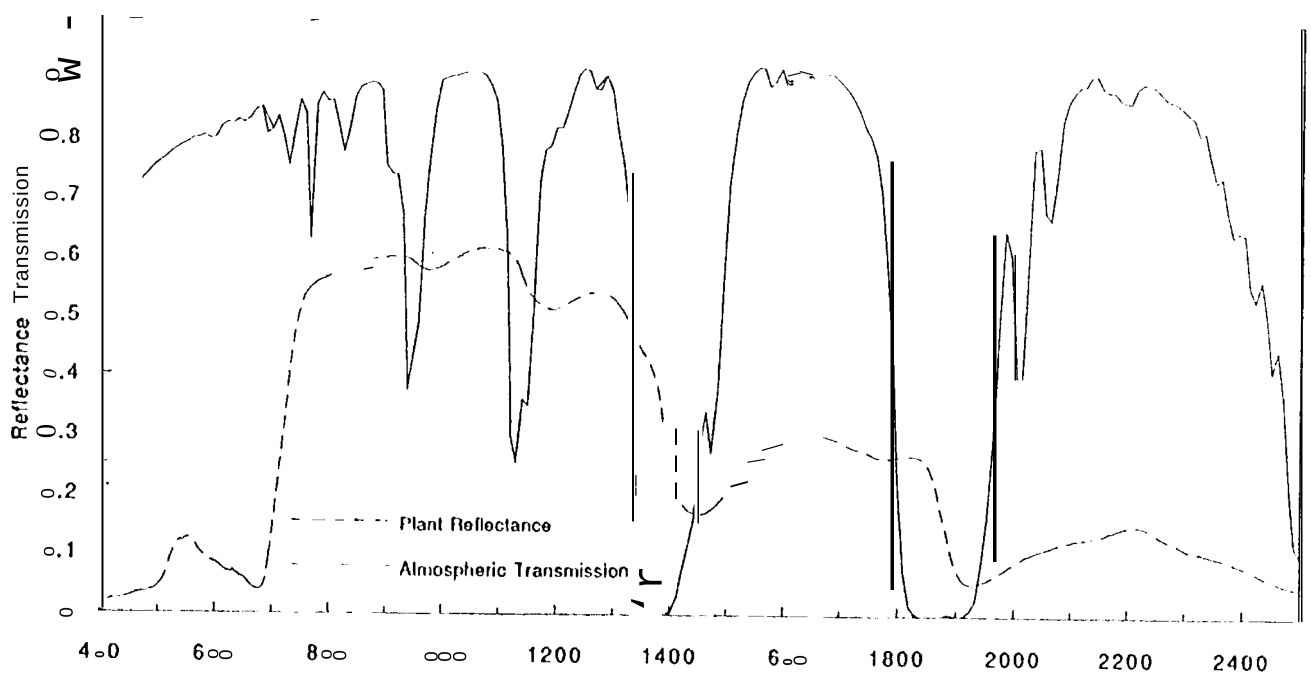

Figure 6. Plot of an atmosphere absorption spectrum with a plant reflectance spectrum showing the partial overlap of atmospheric water vapor and leaf liquid water absorption in the 940 nm spectral region.

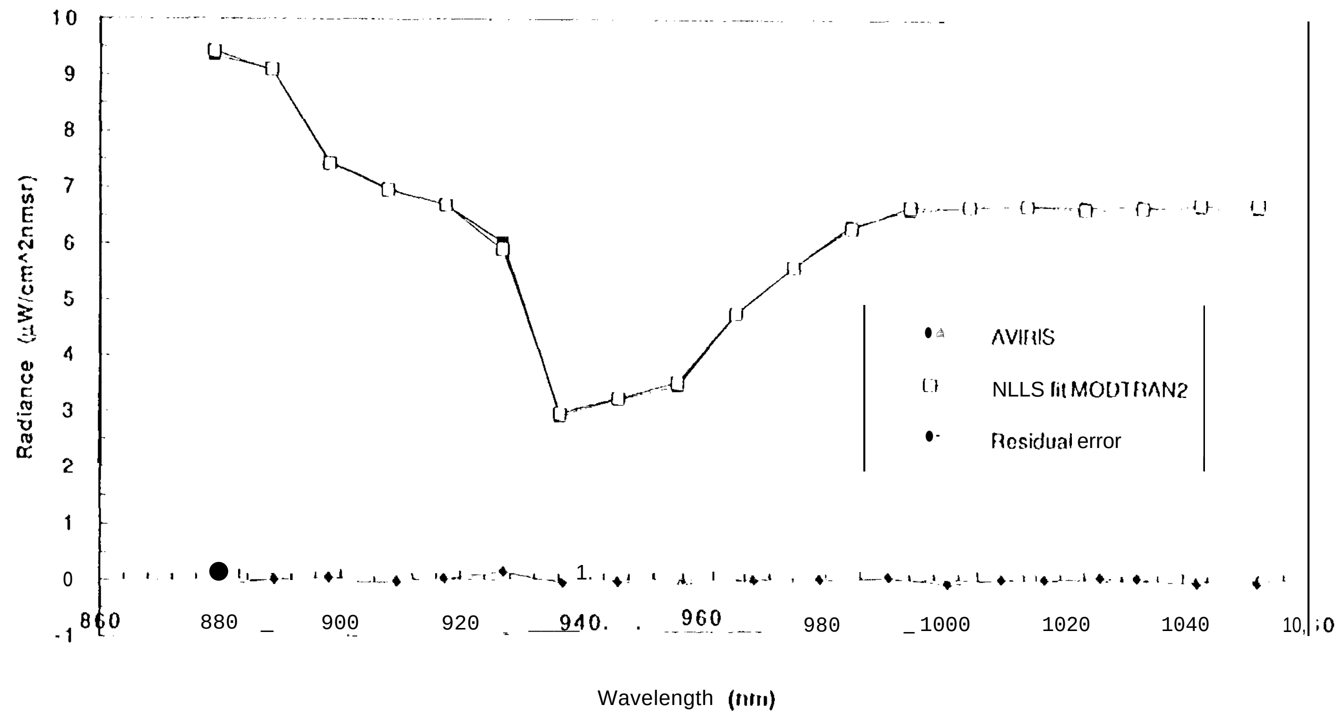

Figure 7. Fit with residual between the AVIRIS measured radiance and the MODTRAN2 modeled radiance in the 940 nm spectral region for an area of green grass in the Jasper Ridge AVIRIS data set.

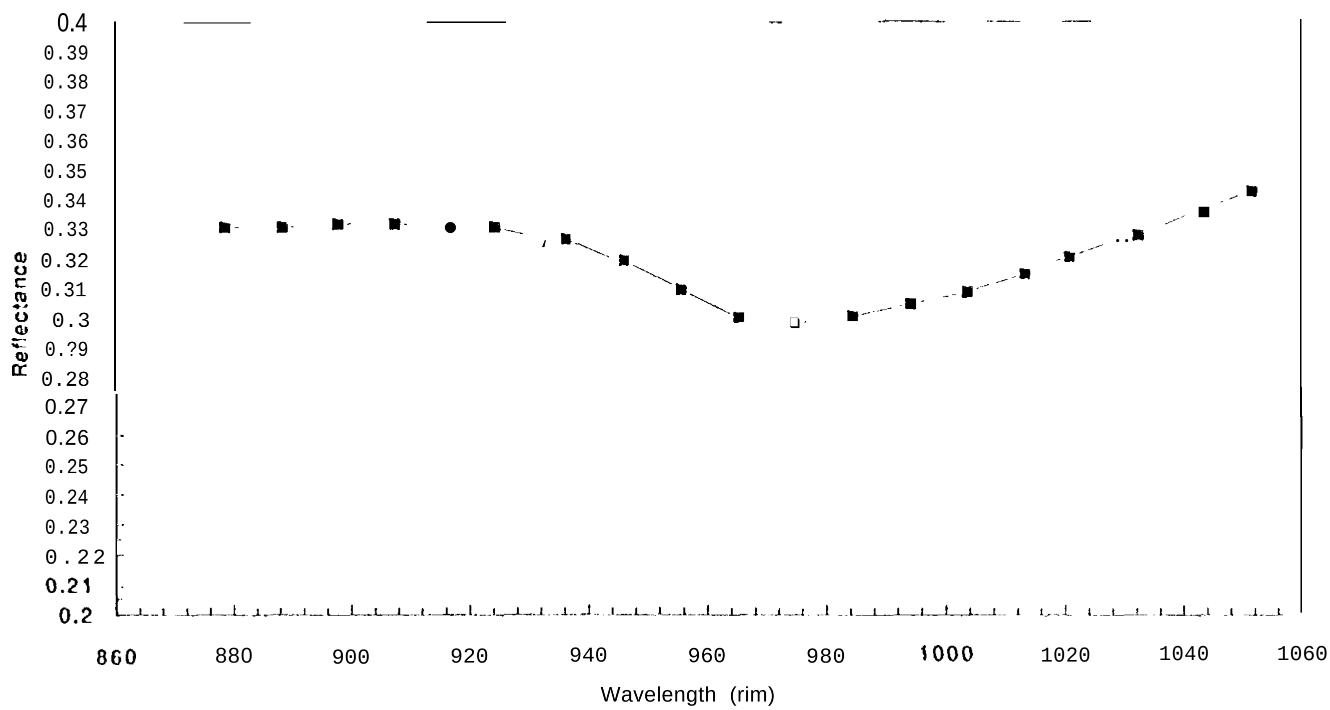

Figure 8. Surface reflectance with leaf water absorption]) required to achieve accurate, fit between the measured radiance. and modeled radiance for the spectrum in Figure 4.

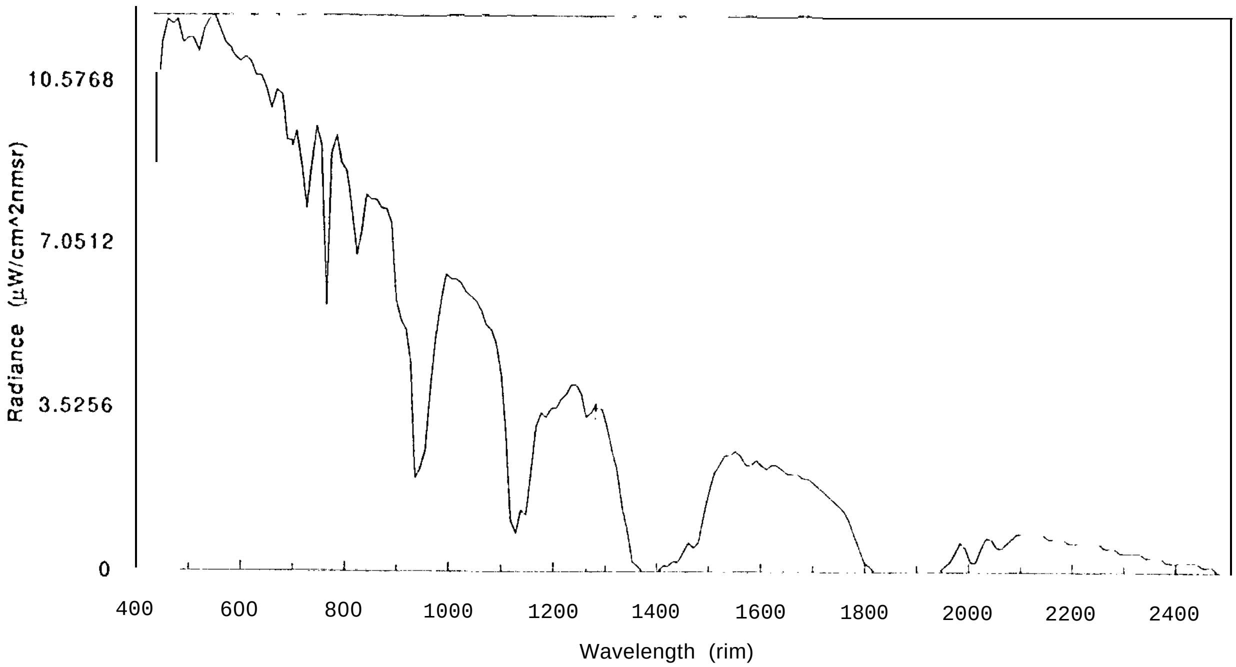

Figure 9. AVIRIS measured radiance over the Stanford University polo field.

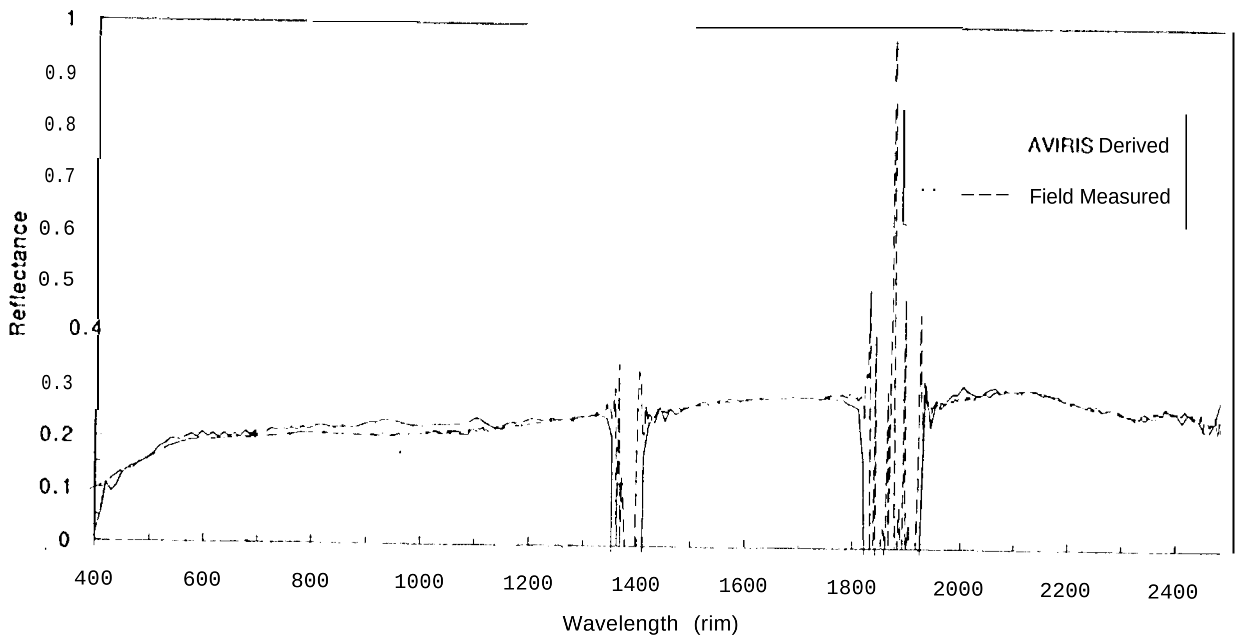

Figure lo. Calculated apparent reflectance and measured reflectance for the polo field.

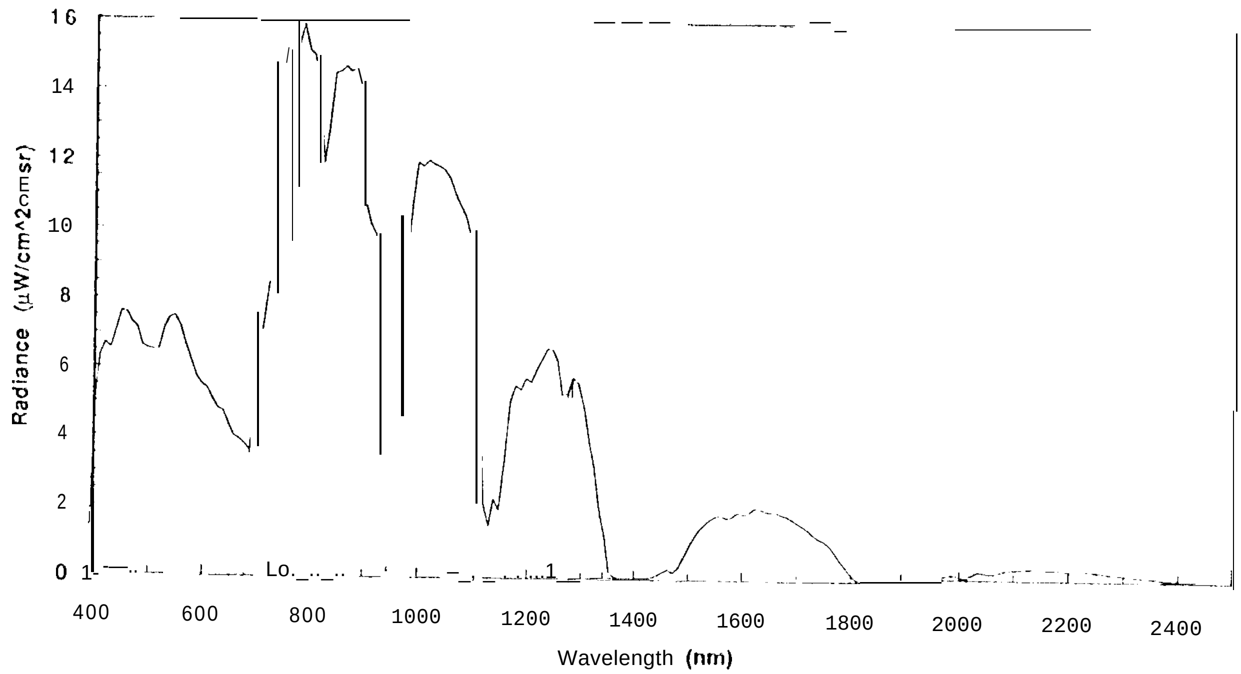

Figure 11. AVIRIS measured radiance for a region of green grass in the AVIRIS Jasper Ridge data set.

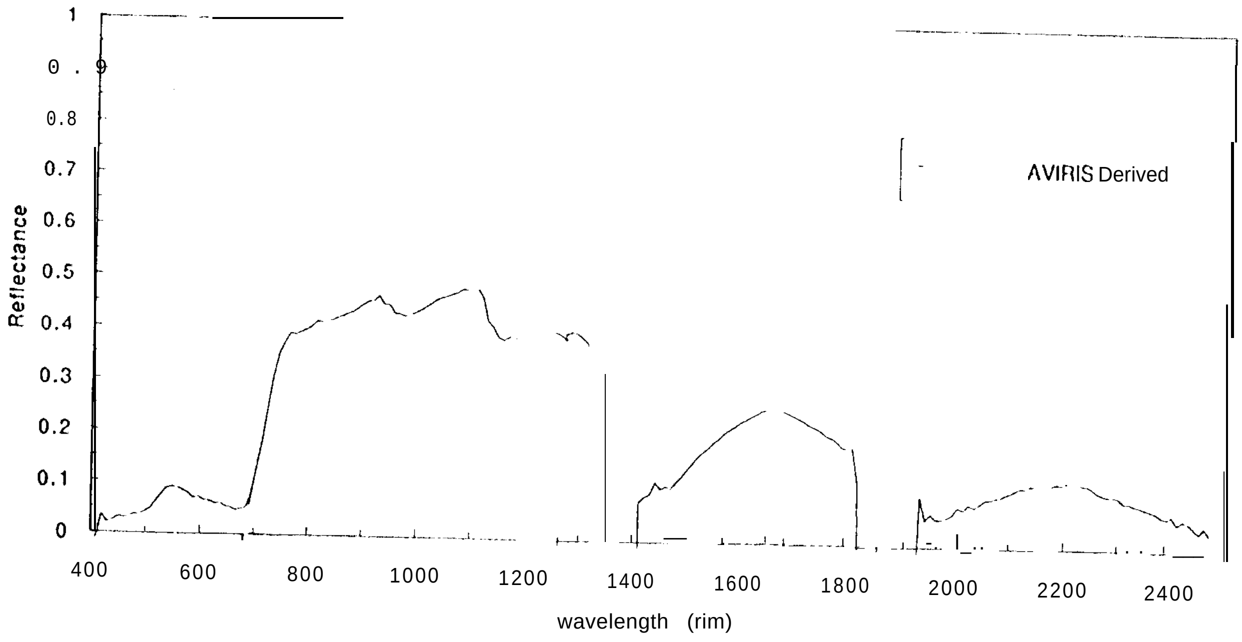

Figure 12. Calculated apparent surface reflectance for the green grins target.

TRANSFER OF COPYRIGHT TO THE SOCIETY OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS

Title of Paper: [illegible] RE OF CE

SPIE CODE NO. 1937-02

Author(s):

The undersigned hereby assign(s) to the Society of Photo-Optical Instrumentation Engineers (the "Society") copyright ownership in the above-titled paper, effective if and when the paper is accepted for publication by the Society and to the extent transferable under applicable national law.

Authors, or their employers in the case of works made for hire, retain an irrevocable, royalty-free, nonexclusive license to: (1) reproduce the paper, either in whole or in part, in copies or in any other form; (2) distribute copies or reproductions of the paper; (3) prepare derivative works based upon the paper, such derivative works to include (but not to be limited to) lectures, lecture notes, press releases, reviews, text books, or reprint books; (4) direct the Society to grant permission to third parties to republish all or part of the article or translations thereof, provided, however, that without any limitation whatever on such right, the Society shall be entitled, at its option, to negotiate and to receive reasonable royalties in respect of any such republication; (5) refuse permission to third parties to republish all or part of the article or translations thereof, with the exception of the permission contained in the copyright statement appearing in the front of the book or journal.

If the work that forms the basis of this paper was done under a contract with a governmental agency or other entity that retains certain rights in the copyright, this transfer of copyright is subject to any rights that such governmental agency or other entity may have acquired. The Society shall retain all proprietary rights with respect to the journal or book as a whole.

WHO SHOULD SIGN: This form must be signed by (1) at least one author who is not a U.S. Government employee and (2) the author's employer if the paper was prepared within the scope of the author's employment or was ordered or commissioned by the employer.

[signature] Signature	Barbara L. Carter Signature
Robert O. Gleary Print Name	Barbara L. Carter Print Name
Title / Date	Adm. Ass't. Doc. Review Title / 8/26/93 Date

U.S. GOVERNMENT EMPLOYMENT CERTIFICATION

If any author was a U.S. Government employee when this paper was prepared, and the author prepared this paper as part of the author's official duties, such author should sign the following form:

I hereby certify that this paper was prepared by me as part of my official duties as an employee of the United States Government.

Signature	Signature
Print Name	Print Name
Title / Date	Title / Date

This signed statement must be returned to the Society with the manuscript (in case of a paper to be published in the proceedings of a conference) or with the galley proofs (in case of a paper to be published in the Society's journals), or the paper cannot be published.

Director of Publications, SPIE, P.O. Box 10, Bellingham, Washington 98227-0010 USA. Phone 206/676-3290 Pacific Time.
FAX 206/647-1445