INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book. These are also available as one exposure on a standard 35mm slide or as a 17" x 23" black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 1337432

**Radiometric sensitivity comparisons of multispectral imaging
systems**

Lu, Nadine Chi-Mei, M.S.

The University of Arizona, 1989

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

RADIOMETRIC SENSITIVITY COMPARISONS
OF MULTISPECTRAL IMAGING SYSTEMS

by
Nadine Chi-mei Lu

A Thesis Submitted to the Faculty of the
COMMITTEE ON OPTICAL SCIENCES
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF SCIENCE
In the Graduate College
THE UNIVERSITY OF ARIZONA

1989

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Madeline C. Lee

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

P.N. Slater
P.N. Slater
Chairman, Committee on Remote Sensing
Professor of Optical Sciences

31 May 1989
Date

ACKNOWLEDGMENTS

The author would like to thank the many individuals who helped to provide much of the data upon which this work is based: T. Chrien, V. Duval, H. Sobel, D. Vane, G. Vane, and M. White of the Jet Propulsion Laboratory; M. Dinguirard of CNES; J. Lansing, Jr. of Hughes SBRC; H. Montgomery of NASA GSFC; and S. Weinswig of ITT. I would also like to acknowledge J. Palmer and R. Schowengerdt for their constructive criticisms. Thanks also to P. Slater for his patience and encouragement and to S. Macenka of JPL for his support.

A special thank you to my parents for always being there when I need them, and to my sister for helping me through a tough time. And finally, a heartfelt thanks to T.G.C. for putting up with all my complaints.

TABLE OF CONTENTS

		Page
	LIST OF FIGURES	5
	LIST OF TABLES	7
	ABSTRACT	9
CHAPTER 1	INTRODUCTION	10
CHAPTER 2	SIGNAL CALCULATION	16
CHAPTER 3	NOISE CALCULATION	24
CHAPTER 4	LIMITING NOISES	27
CHAPTER 5	RADIOMETRIC SENSITIVITY COMPARISONS	48
CHAPTER 6	CONCLUSION	59
	APPENDIX	61
	REFERENCES	92

LIST OF FIGURES

	Page
Figure 1. Types of Multispectral Imaging Systems.....	13
Figure 2. Conceptual model of signal decomposition.	17
Figure 3. Flux incident on the detector.	19
Figure 4. Numerical aperture and F/number.....	20
Figure 5. The signal received at the sensor.	23
Figure 6. The noise equivalent bandwidth	25
Figure 7. Noise versus reflectance at $\approx 0.49 \mu\text{m}$. Visibility = 23 km.....	31
Figure 8. Noise versus reflectance at $\approx 0.49 \mu\text{m}$. Visibility = 23 km.....	32
Figure 9. Noise versus reflectance at $\approx 0.62 \mu\text{m}$. AVHRR band 1.....	33
Figure 10. Noise versus reflectance at $0.6 \mu\text{m}$. AVIRIS A.....	34
Figure 11. Noise versus reflectance at $0.62 \mu\text{m}$. HIRIS.....	35
Figure 12. Noise versus reflectance at $0.62 \mu\text{m}$. MODIS-N.....	36
Figure 13. Noise versus reflectance at $0.65 \mu\text{m}$. SPOT-1 HRV band 2.....	37
Figure 14. Noise versus reflectance at $0.66 \mu\text{m}$. TM band 3.....	38
Figure 15. Noise versus reflectance at $0.66 \mu\text{m}$. ETM band 3.....	39
Figure 16. Noise versus reflectance at $\approx 0.84 \mu\text{m}$. Visibility = 23 km.....	40
Figure 17. Noise versus reflectance at $\approx 0.84 \mu\text{m}$. Visibility = 23 km.....	41
Figure 18. Noise versus reflectance at $\approx 1.24 \mu\text{m}$. Visibility = 23 km.....	42
Figure 19. Noise versus reflectance at $\approx 1.64 \mu\text{m}$. (AVIRIS C, HIRIS, and MODIS-N) Visibility = 23 km.	43
Figure 20. Noise versus reflectance at $\approx 1.64 \mu\text{m}$. (ETM and TM) Visibility = 23 km.	44
Figure 21. Noise versus reflectance at $\approx 2.2 \mu\text{m}$. (AVIRIS D, HIRIS, and MODIS-N) Visibility = 23 km.	45

Figure 22. Noise versus reflectance at $\approx 2.2 \mu\text{m}$. (ETM and TM) Visibility = 23 km.	46
Figure 23. Noise equivalent change in reflectance vs reflectance at $\approx 0.49 \mu\text{m}$	51
Figure 24. Noise equivalent change in reflectance vs reflectance at $\approx 0.62 \mu\text{m}$	52
Figure 25. Noise equivalent change in reflectance vs reflectance at $\approx 0.84 \mu\text{m}$ and $\approx 1.24 \mu\text{m}$	53
Figure 26. Noise equivalent change in reflectance vs reflectance at $\approx 1.64 \mu\text{m}$ and $\approx 2.2 \mu\text{m}$	54
Figure 27. $NE\Delta\rho$ vs ρ for Thematic Mapper band 1 for different saturation reflectances.	57

LIST OF TABLES

	Page
Table 1. A Summary of Sensors and Spectral Bands Evaluated.	12
Table 2. Values used for AVHRR calculations.....	28
Table 3. Values used for AVIRIS calculations.	28
Table 4. Values used for ETM calculations.	29
Table 5. Values used for HIRIS calculations.	29
Table 6. Values used for MODIS-N calculations.12,13.....	30
Table 7. Values used for SPOT-1 HRV calculations.	30
Table 8. Values used for TM calculations.....	30
Table 9. NE $\Delta\rho$ for SPOT-1 HRV band 1 with 8 and 10-bit quantization.	58
Table A1. Calculated values for AVHRR. Visibility = 23 km.	61
Table A2. Calculated values for AVHRR. Visibility = 5 km.....	61
Table A3. Calculated values for AVHRR. Rayleigh Atmosphere.....	62
Table A4. Calculated values for AVIRIS A. Visibility = 23 km.....	62
Table A5. Calculated values for AVIRIS A. Visibility = 5 km.	63
Table A6. Calculated values for AVIRIS A. Rayleigh Atmosphere.....	64
Table A7. Calculated values for AVIRIS B. Visibility = 23 km.....	65
Table A8. Calculated values for AVIRIS B. Visibility = 5 km.	66
Table A9. Calculated values for AVIRIS B. Rayleigh Atmosphere.....	67
Table A10. Calculated values for AVIRIS C. Visibility = 23 km.	68
Table A11. Calculated values for AVIRIS C. Visibility = 5 km.....	69
Table A12. Calculated values for AVIRIS C. Rayleigh Atmosphere.	70
Table A13. Calculated values for AVIRIS D. Visibility = 23 km.	71

Table A14. Calculated values for AVIRIS D. Visibility = 5 km.....	72
Table A15. Calculated values for AVIRIS D. Rayleigh Atmosphere.	73
Table A16. Calculated values for ETM. Visibility = 23 km.....	74
Table A17. Calculated values for ETM PAN band. Visibility = 23 km.....	74
Table A18. Calculated values for ETM. Visibility = 5 km.	75
Table A19. Calculated values for ETM PAN band. Visibility = 5 km.	75
Table A20. Calculated values for ETM. Rayleigh Atmosphere.....	76
Table A21. Calculated values for ETM PAN band. Rayleigh Atmosphere.....	76
Table A22(a). Calculated values for HIRIS. Visibility = 23 km.....	77
Table A22(b). Calculated values for HIRIS. Visibility = 23 km.	78
Table A23(a). Calculated values for HIRIS. Visibility = 5 km.....	79
Table A23(b). Calculated values for HIRIS. Visibility = 5 km.....	80
Table A24(a). Calculations for HIRIS. Rayleigh Atmosphere.....	81
Table A24(b). Calculations for HIRIS. Rayleigh Atmosphere.	82
Table A25. Calculations for MODIS-N. Visibility = 23 km.	83
Table A26. Calculations for MODIS-N. Visibility = 5 km.....	84
Table A27. Calculations for MODIS-N. Rayleigh Atmosphere.	85
Table A28. Calculations for SPOT-1 HRV. Visibility = 23 km.....	86
Table A29. Calculations for SPOT-1 HRV PAN band. Visibility = 23 km.....	86
Table A30. Calculations for SPOT-1 HRV. Visibility = 5 km.....	87
Table A31. Calculations for SPOT-1 HRV PAN band. Visibility = 5 km.	87
Table A32. Calculations for SPOT-1 HRV. Rayleigh Atmosphere.....	88
Table A33. Calculations for SPOT-1 HRV PAN band. Rayleigh Atmosphere.....	88
Table A34. Calculations for TM. Visibility = 23 km.....	89
Table A35. Calculations for TM. Visibility = 5 km.	90
Table A36. Calculations for TM. Rayleigh Atmosphere.....	91

ABSTRACT

Multispectral imaging systems provide much of the basic data used by the land and ocean civilian remote sensing community. There are numerous multispectral imaging systems which have been and are being developed. A common way to compare the radiometric performance of these sensors is to examine their noise equivalent change in reflectance, $NE\Delta\rho$. The $NE\Delta\rho$ of a sensor is the reflectance difference that is equal to the noise in the recorded signal. This thesis compares the noise equivalent change in reflectance of seven different multispectral imaging systems (AVHRR, AVIRIS, ETM, HIRIS, MODIS-N, SPOT-1 HRV, and TM) for a set of three atmospheric conditions (continental aerosol with 23 km visibility, continental aerosol with 5 km visibility, and a Rayleigh atmosphere), five values of ground reflectance (0.01, 0.10, 0.25, 0.50, and 1.00), a nadir viewing angle, and a solar zenith angle of forty-five degrees.

CHAPTER 1

INTRODUCTION

Multispectral imaging systems provide much of the basic data used by the land and ocean civilian remote sensing community. They provide both spectral and spatial digital data related to the earth's surface. From these data, thematic maps of the surface can be compiled and changes in the condition of the surface can be determined as a function of time. The performance of such systems has usually been compared on the basis of their spatial resolution and the location and width of their spectral responses. Relatively little attention has been paid to the radiometric resolution or sensitivity of the sensors, except in the case of studies of ocean color. This situation has changed with the advent of quantitative radiometric imaging spectrometry as applied to studies of global change. The work described here has been conducted to compare the radiometric sensitivities of some of the sensors already in use with some of those planned for future use in the Landsat and Earth Observing System programs.

The radiometric performances of these sensors are predicted during the design phase. Generally, different assumptions regarding atmospheric conditions and ground reflectance are used which makes direct performance comparisons impossible. To provide a common basis for comparison, the radiometric sensitivities and noise sources in seven multispectral imaging systems are described here for three atmospheric conditions (a continental aerosol with 23 kilometer visibility, a continental aerosol with 5 kilometer visibility, and a Rayleigh atmosphere), five values of ground reflectance (0.01, 0.10, 0.25, 0.50, and 1.00), a solar zenith angle of forty-five degrees (45°), and a nadir viewing angle. The parameters were chosen to provide a standard condition for evaluation. The continental aerosol with twenty-three kilometer visibility was chosen as a "standard" atmosphere. The atmosphere was varied to explore the effect of aerosols on the radiometric

sensitivity of a sensor: a five kilometer visibility atmosphere contains more aerosols than the standard twenty-three kilometer visibility atmosphere, and a Rayleigh atmosphere contains no aerosols. The ground reflectance was also varied in order to explore its effect on the radiometric sensitivity of a sensor: the ground reflectance would vary with the scene being observed. For example, an ocean would have a low ground reflectance value, whereas a snow field would have a high ground reflectance value.

The systems evaluated here are: the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), the High-Resolution Imaging Spectrometer (HIRIS), the Moderate-Resolution Imaging Spectrometer-Nadir (MODIS-N), the Systeme Probatoire d'Observation de la Terre High-Resolution Visible (SPOT-1 HRV), the Advanced Very High Resolution Radiometer (AVHRR), the Thematic Mapper (TM), and the Enhanced Thematic Mapper (ETM). AVIRIS, SPOT-1 HRV, AVHRR, and TM are already operational. HIRIS, MODIS-N, and ETM are currently under development. A brief description of the sensors is presented in Table 1. In Table 1, only those spectral bands for which calculations were done are listed.

With the exception of AVIRIS, which is an airborne instrument that is flown at an altitude of twenty kilometers (20 km), all the sensors are satellite based. The sensors surveyed utilize four basic types of multispectral imaging systems. These are illustrated in Figure 1. The first (Figure 1a) is the "whiskbroom" method of multispectral imaging with discrete detectors or linear arrays. An area on the ground, often called a pixel (picture element)* is sampled by a series of detectors, each of which responds to radiant energy in a

* Strictly speaking the term "ground instantaneous field-of-view (GIFOV)" should be used, pixel, however, is more convenient. Note, the precise meaning of the latter is the area defined by the sampling intervals in the in-track and cross-track directions.

Table 1. A Summary of Sensors and Spectral Bands Evaluated.

Sensor	GIFOV	Swath Width	Band	Spectral Coverage	$\Delta\lambda$ (nm)	Encoding (bits)
AVIRIS	20 m	10 km	---	0.4-2.45 μm	10	10
HIRIS	30 m	30 km	---	0.4-2.5 μm	10	12
MODIS-N	1000 m 1000 m 1000 m 1000 m 500 m 500 m 500 m	1790 km	5 6 9 13 20 21 23	<u>center wavelength</u> 0.435 μm 0.490 μm 0.620 μm 0.865 μm 1.240 μm 1.640 μm 2.130 μm	10 10 10 10 20 20 50	12
SPOT-1 HRV	20 m 20 m 20 m 10 m	60 km	1 2 3 PAN	0.550 μm 0.653 μm 0.838 μm 0.623 μm	117 89 115 220	8 8 8 6
AVHRR	1000 m	3000 km	1 2	0.630 μm 0.862 μm	100 275	10
TM	30 m	185 km	1 2 3 4 5 7	0.486 μm 0.571 μm 0.661 μm 0.838 μm 1.677 μm 2.217 μm	70 89 76 134 227 268	8
ETM *	15 m	185 km	PAN	0.700 μm	400	8

* Bands 1, 2, 3, 4, 5, and 7 of ETM were taken to be the same as those of TM

NOTE: the Method of Moments Bandwidth Normalization (J.M. Palmer 1984) was used for the calculation of $\Delta\lambda$ for SPOT-1 and TM. For the other systems, the "full-width at half-max" was used.

a. Whiskbroom Multispectral Imaging with Discrete Detectors or Linear Arrays.

b. Pointable Pushbroom Multispectral Imaging with Linear Arrays.

c. Whiskbroom Imaging Spectrometry with Linear Array.

d. Pointable Pushbroom Imaging Spectrometry with Area Array.

Figure 1. Types of multispectral imaging systems.

selected spectral interval. Spectral filters and/or beam splitters and spectrometers are used to select the portions of the spectrum which are of interest. A mirror is used to generate the scan across the surface of the earth perpendicular to the flight path (cross-track) so that each pixel in the scene (swath) is imaged.

The second type of multispectral imaging system (Figure 1b) is the "pushbroom" method of imaging with linear arrays of detectors. In this type of sensor, there is a detector element for each cross-track pixel. Usually, filters and/or beamsplitters are used to select a different spectral bandpass for each linear array. A cross-track pointing mirror can be used with the system to increase the frequency of scene acquisition and to provide a stereoscopic capability.

The third type of multispectral imaging system (Figure 1c) is a type of imaging spectrometer. It utilizes a whiskbroom approach using linear arrays which is analogous to the method illustrated in Figure 1a, except that energy from a pixel, after passing through a spectrometer, is spectrally sampled in a continuous manner. The spectral range and resolution are determined by the spectrometer and the number and size of the detectors in the linear array. Note that all the spectral bands are recorded simultaneously.

The fourth type of multispectral imaging system (Figure 1d) is also a type of imaging spectrometer which incorporates a pushbroom approach using an area array. Each row of detectors samples the same area on the ground as the other rows (a column corresponds to the swath) and thus provides the spatial resolution in the same manner as the pushbroom sensor illustrated in Figure 1b. However, each column corresponds to a different spectral region as in the method illustrated in Figure 1c. The spectral bands are recorded simultaneously, and the spectral resolution depends upon the number and size of

the detectors in a row. In other words, the detector columns in the array, which are cross-track, provide the spatial resolution, and the detectors in the rows of the array provide the spectral resolution. The pointing mirror is used as in Figure 1b to increase the frequency of scene acquisition.

AVIRIS is a whiskbroom imaging spectrometer using a linear array (Figure 1c). HIRIS is a pushbroom imaging spectrometer using an area array (Figure 1d). SPOT-1 HRV uses the pushbroom method of imaging with linear arrays (Figure 1b). And, AVHRR, TM, ETM, and MODIS-N use the whiskbroom method with discrete detectors or linear arrays (Figure 1a).

In order to compare the radiometric sensitivities and limiting noise sources of these sensors, the signal or measured output of the detector must be evaluated along with the noise sources associated with this measurement. Once the signal and the noise have been calculated, the radiometric sensitivity of the sensor for a given set of conditions may be determined.

CHAPTER 2

SIGNAL CALCULATION

Earth observing instruments operating in the 0.4 to 2.5 micrometer spectral range measure the radiance reflected by the earth when illuminated by the sun. The following describes the various interactions between the solar radiation, the surface, and the atmosphere. A conceptual model of signal decomposition is illustrated in Figure 2.

Light may travel a direct path from the sun to the target on the ground to the sensor (Figure 2a); it may be scattered by the atmosphere to the sensor before reaching the ground (Figure 2b); it may be scattered by the atmosphere before reaching the ground and then reflected to the sensor (Figure 2c); and, it may travel a direct path from the sun to areas surrounding the target and be subsequently scattered to the sensor without containing any information about the target (Figure 2d); finally, light may travel a path which provides a coupling effect between the atmosphere and the surface (Figure 2e). In the last two cases, the atmosphere introduces cross-talk between the radiance from the target and the radiance from the surround.²

To model the radiance received at the sensor, an atmospheric radiative transfer program was used. This program, "Simulation of the Satellite Signal in the Solar Spectrum (5S)", was developed at the Laboratoire d'Optique Atmosphérique, Université des Sciences et Techniques de Lille, France by Tanré et al.² The version used for this study was adapted by the Remote Sensing Group, Optical Sciences Center, University of Arizona. Changes include allowance for terrain elevation and sensor altitude, and the addition of more spectral band profiles.

Figure 2. Conceptual model of signal decomposition.
(after Tanré et al 1986)

The "5S" program provides the radiance received at the sensor in three parts: intrinsic atmospheric radiance (L_a), background radiance (L_b), and pixel radiance[†] (L_s). The latter is composed of the signal components shown in Figures 2a, 2c, and 2e which contain information about the ground area of interest. The background radiance, L_b , is the component in Figure 2d which contains information about areas surrounding the ground area of interest, and the intrinsic atmospheric radiance, L_a , is the component in Figure 2b which contains no information about the ground. The path radiance (L_p) is composed of the intrinsic atmospheric radiance and the background radiance: it contains no information about the ground target of interest.

$$L_p = L_a + L_b \quad (2.1)$$

The atmospheric model was designated as mid-latitude summer, continental aerosol, solar zenith angle of forty-five degrees (45°), sensor zenith angle of zero degrees (0°) (i.e., nadir viewing), and the date was chosen to provide a solar distance of about one astronomical-unit (1 AU). Calculations were made for a Rayleigh atmosphere (no aerosols), and for visibilities of twenty-three kilometers (23 km) and five kilometers (5 km). The ground reflectance was modeled as homogeneous and constant across the band. Values of reflectance, ρ , equal to 0.01, 0.10, 0.25, 0.50, and 1.00 were used.

To calculate the signal from the radiance received at the sensor, we need to consider just how much power is incident on the detector, the losses due to the optics, and how well the detector can transform the incident power to the measured signal.

[†] Strictly speaking, the term "atmospherically attenuated ground instantaneous field-of-view radiance" should be used; however, pixel radiance is more convenient.

The small angle approximation for the flux incident on the detector is given by

$$\Phi_d = L \cdot A \cdot \Omega \quad (2.2)$$

where Φ_d = flux incident on the detector (W),

L = radiance ($\text{W}/\text{m}^2\text{-sr}$),

$A \cdot \Omega$ = throughput or étendue ($\text{m}^2\text{-sr}$).

To meet the criteria for the small angle approximation, the distance from the source to the detector must be much larger than the maximum dimension of the source or detector. This is always the case for airborne and satellite remote sensing systems.

Figure 3. Flux incident on the detector.

$$\Phi_d = L \cdot A_s \cdot \Omega_{os} = L \cdot A_o \cdot \Omega_{so} = L \cdot A_o \cdot \Omega_{do} = L \cdot A_d \cdot \Omega_{od} \quad (2.3)$$

where A_s = area of the source (m^2),

Ω_{os} = solid angle subtended by the pupil as seen from the source (sr),

Ω_{so} = solid angle subtended by the source as seen from the pupil (sr),

A_o = area of the pupil (m^2),

Ω_{do} = solid angle subtended by the detector as seen from the pupil (sr),

Ω_{od} = solid angle subtended by the pupil as seen from the detector (sr),

A_d = area of the detector (m^2).

Equation (2.3) illustrates that the throughput is an invariant. The flux incident on the detector may also be expressed in terms of the F/number of the optical system, Equation (2.7).

Figure 4. The case of a curved principal surface for a well-corrected optical system of low F/number where l'_m is the distance along the marginal ray from the second principal surface to the second principal focus, and P and P' are the first and second principal points. (Slater, 1980)

The quantity $\sin\theta'_m$ is referred to as the numerical aperture (NA) of the image-forming system. For the case illustrated in Figure 4, the Abbe sine condition implies that the second principal surface, P', will be a spherical surface of radius f' . For an object at infinity, as is the case shown in Figure 4, this means that $l'_m = f'$.

Now, the F/number corresponding to an object at infinity is defined as

$$F/\# = \frac{f'}{D} \quad (2.4)$$

where f' = effective focal length,

D = diameter of the entrance pupil.

And, for the case of a single lens as illustrated in Figure 4, the entrance pupil is the aperture stop. Thus,

$$\sin \theta'_m = \frac{D}{2 f'} = \frac{1}{2 (F/\#)} = NA. \quad (2.5)$$

And now, the projected solid angle can be expressed as

$$\Omega_{od} \approx \pi \sin^2 \theta'_m = \frac{\pi}{4 (F/\#)^2}. \quad (2.6)$$

So, for an extended source with the object at a large distance the flux incident on the detector is

$$\Phi_d = \frac{\pi}{4 (F/\#)^2} \cdot A_d \cdot L \quad (2.7)$$

where A_d = area of the detector (m^2),

L = radiance at the sensor ($W/(m^2 \cdot sr)$),

$F/\#$ = the F/number of the system.

The equations given above for Φ_d do not take into account losses in the transmittance of the optics. A factor τ_o , the transmittance of the optics, must be included in the calculation of the signal. To calculate the output signal from the sensors account must be taken of the responsivity of the detector, $\mathfrak{R}$, given by the ratio of output signal to input source.

$$\mathfrak{R} = \frac{\text{output signal}}{\text{input source}} \quad (2.8)$$

and for this application the responsivity is given in amperes/watt.

Finally, the signal due to the radiance received at the sensor may be expressed as:

$$\text{Signal} = A \Omega \tau_o \mathfrak{R} L = A_d \frac{\pi}{4 (F/\#)^2} \tau_o \mathfrak{R} L \quad (A). \quad (2.9)$$

If the signal is to be calculated in terms of electrons instead of amperes, then the quantum efficiency of the detector, η , is used. The quantum efficiency of a detector is defined as the number of independent output events per incident photon.⁴ In this case, the signal due to the radiance received at the sensor may be expressed as:

$$\text{Signal} = A\Omega \tau_o \eta \frac{\lambda}{hc} t_i L = A_d \frac{\pi}{4 (F/\#)^2} t_i \tau_o \eta \frac{\lambda}{hc} L \quad (\text{electrons}) \quad (2.10)$$

where η = quantum efficiency,

λ = wavelength of interest or center wavelength (m),

h = Planck's constant = 6.62×10^{-34} Js²,

c = speed of light = 3×10^8 m/s,

t_i = integration time (s),

and, $\frac{hc}{\lambda}$ = energy per photon (J).

Depending upon the information available about the sensor [References 6-14], the signal of interest, S_s , is calculated from either Equation (2.9) in amperes or from Equation (2.10) in electrons using L_s , the pixel radiance, for L . Similarly, the signal due to the path radiance is calculated using L_p , the path radiance, in place of L . The total signal, S_T , received at the sensor is the combination of the signal due to the pixel radiance and the signal due to the path radiance as illustrated in Figure 5. The signal due to the path radiance is actually a noise contribution because it contains no information about the ground area of interest.

CHAPTER 3

NOISE CALCULATION

The next step in calculating the signal-to-noise ratio, SNR, and subsequently the radiometric sensitivity is to calculate the noise in the sensor. In order to do this we must determine the noise sources to be considered, namely: quantization noise, photon noise, and other noise such as readout noise.

The quantization noise is defined as

$$N_q = \frac{S_{T,\max}}{\sqrt{12} \cdot 2^{\text{NADB}}} \quad (\text{electrons or A}) \quad (3.1)^3$$

where $S_{T,\max}$ = maximum total signal for the sensor at the wavelength of interest,

NADB = number of analog-to-digital bits.

The noise is given in the same units as the signal. The quantization noise is a measure of the loss of information resulting from the conversion of the incoming signal, which is analog, to a finite set of discrete values (a digital representation). The number of analog-to-digital bits, NADB, is related to the number of quantization levels that are used in the signal representation. The number of quantization levels is 2^{NADB} .

The photon noise is due to the statistical fluctuations in the arrival of incident photons. These obey Poisson statistics so that the rms variation about the mean n of the number of incident photons is given by $\sqrt{n}$. This variation is a measure of the uncertainty to which n can be determined; it is often referred to as the noise associated with the signal. Thus, if n_p is the number of incident photons, $\sqrt{n_p}$ is the noise. If η is the quantum efficiency of the detector, then the output signal generated is $n_p\eta$, and the output noise is $\sqrt{n_p\eta}$.

When the signal is calculated in terms of electrons, the photon noise is defined as

$$N_s = \sqrt{S_T} \quad (\text{electrons}) \quad (3.2)$$

where S_T = the total signal (electrons). However, when the signal is calculated in terms of current, the photon noise is defined as

$$N_s = \sqrt{2qS_TB} \quad (\text{A}) \quad (3.3)$$

where S_T = the total signal (A),

q = the charge on an electron = 1.6×10^{-19} Coulombs,

B = noise bandwidth (Hz).

The noise bandwidth is illustrated in Figure 6.

The "other" noise includes noise contributions from sources other than those previously mentioned. For example, readout noise is a result of the sampling process used to sense the charge in the detector. The values used for this noise are taken from the information available about each sensor: all the contributing noises were not usually enumerated in the descriptions, so "other" noise is precisely that ... noise sources that do not include photon or quantization noise. "Other" noise is designated N_o . It was given in electrons for some sensors and in amperes for other sensors.

The total noise is the rss combination of the noises mentioned. It is expressed as

$$N_T = \sqrt{N_s^2 + N_q^2 + N_o^2} \quad (\text{electrons or A}) \quad (3.4)$$

where all the noises are in the same units.

The signal-to-noise ratio, SNR, may now be calculated. It is defined as

$$\text{SNR} = \frac{S_s}{N_T} \quad (3.5)$$

where S_s = signal due to pixel radiance (electrons or A),

N_T = total noise (electrons or A), i.e. the noise associated with the total radiance at the sensor,

and the resultant SNR is unitless.

CHAPTER 4

LIMITING NOISES

Values for the quantization, photon, and total noise may be calculated for each system for a specific set of conditions (atmosphere, ground reflectance, et cetera) from the equations previously stated. An analysis of these noises will demonstrate which is the limiting noise (quantization, photon, or "other"). It is important to note that the limiting noise encountered in the detection of radiant energy is the photon noise which arises from the quantum nature of the signal itself. Thus, a sensor that is photon noise limited will not be significantly improved by a reduction in the other noise sources. However, if the limiting noise is not photon noise, then it is possible that an improvement in the radiometric sensitivity of the sensor may be achieved by a reduction in the limiting noise. This type of analysis will also indicate whether the reduction of a noise will cause a significant improvement in the radiometric performance of a sensor. For example, reducing the maximum ground reflectance the system can detect to something less than unity or increasing the number of quantization levels are methods of reducing the quantization noise. These techniques are particularly useful for low reflectance scenes as they allow for a contrast stretch of the image. However, if the system is not quantization noise limited, a large improvement in radiometric sensitivity will not result. This will be examined further in Section 5.

The calculations of the signal and noise for the seven sensors utilized radiances obtained from "5S" using the conditions previously mentioned and the information shown in Tables 2 through 8. Presented in Figures 7 through 22 are the results of the noise calculations for selected bands of the seven sensors. The complete set of results for all bands calculated are to be found in the Appendix.

Table 2. Values used for AVHRR calculations.⁶

AVHRR			
Band	Responsivity (A/W)	Transmittance	No (A)
1	0.370	0.092	1.18E-11
2	0.540	0.117	1.18E-11
F/2.28			
Detector area		2.70E-07	m ²
AΩ		4.08E-08	m ² -sr

Table 3. Values used for AVIRIS calculations.^{8,9}

AVIRIS				
Spectrometer	wavelength (μm)	QE	Transmittance	No (e-)
A	0.410	0.338	0.073	722
	0.490	0.505	0.161	722
	0.500	0.526	0.169	722
	0.600	0.521	0.192	722
	0.700	0.532	0.165	722
B	0.700	0.536	0.130	887
	0.800	0.369	0.125	887
	0.840	0.463	0.133	887
	0.900	0.603	0.142	887
	1.000	0.660	0.154	887
	1.100	0.540	0.150	887
	1.200	0.625	0.132	887
	1.250	0.668	0.126	887
C	1.250	0.668	0.120	948
	1.300	0.710	0.143	948
	1.350	0.753	0.157	948
	1.400	0.795	0.169	948
	1.500	0.880	0.157	948
	1.600	0.829	0.139	948
	1.700	0.778	0.156	948
	1.800	0.727	0.142	948
D	1.900	0.676	0.164	981
	2.000	0.645	0.194	981
	2.100	0.635	0.159	981
	2.200	0.635	0.143	981
	2.300	0.635	0.161	981
	2.400	0.635	0.153	981
	2.450	0.635	0.075	981
Integration time		87 μsec		
AΩ		1.38E-08	m ² -sr	

Table 4. Values used for ETM calculations.⁷

ETM				
Band	Responsivity	Transmittance	No (A)	AΩ (m ² -sr)
1	0.260	0.780	2.03E-12	1.86E-10
2	0.360	0.840	2.03E-12	1.86E-10
3	0.440	0.820	2.03E-12	1.86E-10
4	0.460	0.860	2.03E-12	1.86E-10
5	1.020	0.670	5.13E-12	1.86E-10
7	1.430	0.710	5.13E-12	1.86E-10
PAN	0.480	0.790	6.15E-12	4.04E-11

Table 5. Values used for HIRIS calculations.^{10,11}

HIRIS			
wavelength (μm)	QE	Transmittance	No (e ⁻)
0.450	0.560	0.089	300
0.490	0.630	0.130	300
0.550	0.670	0.176	300
0.600	0.690	0.170	300
0.620	0.690	0.167	300
0.800	0.560	0.059	300
0.860	0.380	0.046	300
1.000	0.100	0.051	300
1.240	0.490	0.237	1000
1.640	0.560	0.277	1000
2.130	0.660	0.291	1000
2.200	0.660	0.290	1000
2.400	0.660	0.290	1000
F/3.8			
Integration time		4.5 msec	
Detector area		2.70E-09	m ²
AΩ		1.47E-10	m ² -sr

Table 6. Values used for MODIS-N calculations.^{12,13}

MODIS-N				
wavelength (μm)	QE	Detector area	Integration time	$A\Omega$ ($\text{m}^2\text{-sr}$)
0.435	0.700	$1.65\text{e-}7 \text{ m}^2$	814 μsec	6.61E-08
0.490	0.750	$1.65\text{e-}7 \text{ m}^2$	814 μsec	6.61E-08
0.620	0.790	$1.65\text{e-}7 \text{ m}^2$	814 μsec	6.61E-08
0.865	0.470	$1.65\text{e-}7 \text{ m}^2$	814 μsec	6.61E-08
1.240	0.500	$4.13\text{e-}8 \text{ m}^2$	407 μsec	1.65E-08
1.640	0.500	$4.13\text{e-}8 \text{ m}^2$	407 μsec	1.65E-08
2.130	0.500	$4.13\text{e-}8 \text{ m}^2$	407 μsec	1.65E-08
F/1.4				
Transmittance		0.320		
No (e-)		500		

Table 7. Values used for SPOT-1 HRV calculations.¹⁴

SPOT/HRV				
Band	QE	Transmittance	No (e-)	Detector area
1	0.605	0.150	833	$4.42\text{E-}10 \text{ m}^2$
2	0.680	0.140	769	$4.42\text{E-}10 \text{ m}^2$
3	0.593	0.130	977	$4.42\text{E-}10 \text{ m}^2$
PAN	0.595	0.140	748	$2.21\text{E-}10 \text{ m}^2$
F/3.3				
Integration time:		3.0 msec	Bands 1-3	
		1.5 msec	PAN Band	
$A\Omega$ ($\text{m}^2\text{-sr}$):		3.19E-11	Bands 1-3	
		1.59E-11	PAN Band	

Table 8. Values used for TM calculations.⁷

TM			
Band	Responsivity	Transmittance	No (A)
1	0.330	0.770	2.2E-12
2	0.400	0.770	2.2E-12
3	0.450	0.900	2.2E-12
4	0.560	0.760	2.3E-12
5	1.200	0.690	4.9E-12
7	1.600	0.650	4.8E-12
$A\Omega$		1.92E-10	$\text{m}^2\text{-sr}$

Figure 7. Noise versus reflectance at ≈ 0.49 micrometers. Visibility = 23 kilometers.

Figure 8. Noise versus reflectance at ≈ 0.49 micrometers. Visibility = 23 kilometers.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 9. Noise versus reflectance at ≈ 0.62 micrometers. AVHRR band 1.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 10. Noise versus reflectance at 0.6 micrometers. AVIRIS A.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 11. Noise versus reflectance at 0.62 micrometers. HIRIS.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 12. Noise versus reflectance at 0.62 micrometers. MODIS-N.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 13. Noise versus reflectance at 0.65 micrometers. SPOT-1 HRV band 2.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 14. Noise versus reflectance at 0.66 micrometers. TM band 3.

(a) Rayleigh Atmosphere

(b) Visibility = 23 km

(c) Visibility = 5 km

Figure 15. Noise versus reflectance at 0.66 micrometers. ETM band 3.

Figure 16. Noise versus reflectance at ≈ 0.84 micrometers. Visibility = 23 kilometers.

Figure 17. Noise versus reflectance at ≈ 0.84 micrometers. Visibility = 23 kilometers.

Figure 18. Noise versus reflectance at ≈ 1.24 micrometers. Visibility = 23 kilometers.

Figure 19. Noise versus reflectance at ≈ 1.64 micrometers. Visibility = 23 kilometers.

Figure 20. Noise versus reflectance at ≈ 1.64 micrometers. Visibility = 23 kilometers.

Figure 21. Noise versus reflectance at ≈ 2.2 micrometers. Visibility = 23 kilometers.

Figure 22. Noise versus reflectance at ≈ 2.2 micrometers. Visibility = 23 kilometers.

The limiting noise for AVHRR is quantization noise for all the bands which were calculated. Also quantization noise limited are MODIS-N at wavelengths of 0.49 and 0.62 micrometers and at 0.84 micrometers for reflectances less than 0.40, and SPOT-1 HRV band 1 which is centered at 0.55 micrometers.

The systems that are photon noise limited are: MODIS-N at 0.84 micrometers for reflectances greater than 0.4 and at wavelengths of 1.24, 1.64, and 2.2 micrometers; HIRIS at wavelengths of 0.49 and 0.62 micrometers; and TM and ETM for bands 1, 3, and 4 which are centered at 0.49, 0.66, and 0.84 micrometers respectively. For these sensors at these wavelengths a reduction of quantization or "other" noise will probably not produce a significant improvement in radiometric sensitivity because the total noise is determined primarily by the photon noise which is signal dependent.

The systems that are "other" noise limited are: SPOT-1 HRV bands 2 and 3 which are centered at 0.65 and 0.84 micrometers respectively; AVIRIS for all bands in Figures 7 through 22; HIRIS at wavelengths of 0.84, 1.24, 1.64, and 2.2 micrometers; and TM and ETM for bands 5 and 7 which are centered at 1.68 and 2.2 micrometers respectively.

As the visibility decreases (i.e., the aerosols in the atmosphere increase), the change is only in the signal dependent noises, N_q (quantization noise) and N_s (photon noise). This is due to differences in the amount of signal received at the sensor for different atmospheres.

The noise information presented here is intended to provide some insight into how the radiometric sensitivity of the sensors might be improved if necessary. These data should be considered in conjunction with the results presented in the following section.

CHAPTER 5 RADIOMETRIC SENSITIVITY COMPARISONS

The noise equivalent change in reflectance, or $NE\Delta\rho$, is the most common way to compare the radiometric sensitivities of multispectral imaging systems. The $NE\Delta\rho$ of a sensor is the reflectance difference that is equal to the noise in the recorded signal. In other words, it is the change in ground reflectance discernible with a signal-to-noise ratio (SNR) of unity. Thus, a SNR of one hundred (100), calculated for an average reflectance of unity, gives rise to a $NE\Delta\rho$ of one percent (1%), and when calculated for an average reflectance of one-half (0.5), gives rise to a $NE\Delta\rho$ of one-half of one percent (0.5%). $NE\Delta\rho$ is an arbitrary measure of radiometric sensitivity most suitably used in a comparative rather than an absolute context. This is because a SNR of unity does not provide a highly confident estimate of a reflectance change, particularly in a cluttered scene (i.e., a SNR of unity means that the signal is equal to the noise and in a cluttered scene the two may be difficult to distinguish). However, in the work described here, the concern is with the comparison of sensors and $NE\Delta\rho$ is perfectly adequate for that purpose. In fact, it is preferred to SNR because it provides a number associated with the observable change of interest. It is therefore more readily appreciated as a description of radiometric sensitivity.

$NE\Delta\rho$ is defined as

$$NE\Delta\rho = \frac{\rho}{SNR} \quad (5.1)$$

where ρ = ground reflectance

SNR = signal-to-noise ratio.

In researching this project, it was found that the definition used for a "photon-noise limited" SNR in the design stage requirements sometimes differed with the sensor. In some cases the photon-limited SNR was given by

$$\text{SNR} = \frac{S_S}{\sqrt{S_T}} \quad (5.2)$$

where S_S = signal due to pixel radiance,

S_T = signal due to both pixel and path radiance = total signal.

In other cases the photon-limited signal-to-noise ratio was defined as

$$\text{SNR} = \frac{S_T}{\sqrt{S_T}} = \sqrt{S_T} \quad (5.3)$$

where S_T = signal due to both pixel and path radiance = total signal.

(Please refer to Figure 5.)

When the SNR was defined as in Equation (5.3), the noise equivalent change in reflectance was defined as

$$\text{NE}\Delta\rho = \frac{\rho}{\text{SNR} \left(1 - \frac{S_P}{S_T}\right)} \quad (5.4)$$

where ρ = ground reflectance,

SNR = signal-to-noise ratio as defined in Equation (5.3),

S_P = signal due to path radiance,

S_T = total signal due to path and pixel radiance.

In this work, Equations (5.1) and (3.5) were used to determine the radiometric sensitivity as measured by $\text{NE}\Delta\rho$. Note that when only photon noise is considered, Equation (3.5) is equivalent to Equation (5.2).

In summary,

$$NE\Delta\rho = \frac{\rho}{SNR} \quad (5.1)$$

where ρ = ground reflectance

SNR = signal-to-noise ratio.

$$SNR = \frac{S_s}{N_T} \quad (3.5)$$

where S_s = signal due to pixel radiance (electrons or A),

N_T = total noise (electrons or A).

Figures 23 through 26 present the results of $NE\Delta\rho$ calculations for bands of the seven sensors selected to represent the range 0.49, 0.62, 0.84, 1.24, 1.64, and 2.2 micrometers, a sampling of the visible, near-infrared, and short-wave infrared wavelength ranges. The results for all three sets of atmospheres (i.e., 23 kilometer visibility, 5 kilometer visibility, and a Rayleigh atmosphere) are presented only for the shorter wavelengths of 0.49 and 0.62 micrometers: effects due to aerosols should be more pronounced at shorter wavelengths. It should be noted that the values used in these calculations are based upon nominal values and may change. This is especially true for the sensors under development (ETM, HIRIS, and MODIS-N). For example, the values used for the transmittance of HIRIS are from an early stage in the development of the project and the final values will certainly differ. Also, "5S" is an approximate not an exact code; however, the same code results were used in all cases. These considerations make this a reliable relative comparison, but the actual accuracy of the results is probably only valid to a factor of two.

Figure 23. Noise equivalent change in reflectance versus reflectance at $\approx$ 0.49 micrometers.

Figure 24. Noise equivalent change in reflectance versus reflectance at ≈ 0.62 micrometers.

Figure 25. Noise equivalent change in reflectance versus reflectance. Visibility = 23 km.

Figure 26. Noise equivalent change in reflectance versus reflectance. Visibility = 23 km.

If one examines all the wavelengths for which calculations were done (results are presented in the Appendix), it should be noted that the very high values of $NE\Delta\rho$ at the lowest wavelengths follow from the predominance of the path radiance due to Rayleigh fourth power scattering. Also, the presence of water bands in the earth's atmosphere at wavelengths of about 1.35, 1.4, 1.8, 1.9, and 2.45 micrometers may be observed in the extremely high values of $NE\Delta\rho$ calculated for AVIRIS at these wavelengths. The signal in these regions approaches zero, because the water bands cause the transmittance of the atmosphere to be very low, and the $NE\Delta\rho$ subsequently approaches infinity.

Of the sensors compared, all but AVIRIS, which is flown on an aircraft, are satellite sensors. Among the satellite sensors it was found that the whiskbroom high-resolution (i.e., small GIFOV) type sensors had the highest values of $NE\Delta\rho$, pushbroom type sensors had the next highest $NE\Delta\rho$, and whiskbroom type sensors with a large GIFOV had the lowest $NE\Delta\rho$.

The whiskbroom high-resolution type sensors (TM and ETM) have 30 meter GIFOVs and throughputs that are two orders of magnitude smaller than the throughputs of the moderate-resolution whiskbroom type sensors (AVHRR and MODIS-N) which have GIFOVs of 1000 meters (500 meters for the longer wavelengths for MODIS-N). In this case a trade-off is being made between spatial resolution and radiometric sensitivity. The higher spatial resolution (smaller GIFOV) yields a lower radiometric sensitivity (larger $NE\Delta\rho$), and the lower spatial resolution (larger GIFOV) yields a higher radiometric sensitivity (smaller $NE\Delta\rho$). This is also true for the pushbroom type sensors. SPOT-1 HRV has a twenty meter GIFOV for the bands presented here, and HIRIS has a thirty meter GIFOV. The throughput of HIRIS is about five times larger than that of SPOT-1 HRV, and the radiometric sensitivity of HIRIS is greater than that of SPOT-1 for all but

band 3 of SPOT-1 HRV which is centered at about 0.84 micrometers. At 0.84 micrometers, the transmittance of the optics for HIRIS takes a dip and simultaneously the quantum efficiency of the detector is dropping-off causing a drop in the signal and subsequently a worsening of the $NE\Delta\rho$. In Figures 23 through 26, the sensors keep the same relative positions until Figure 25a when HIRIS and AVIRIS move "out-of-line". The reason behind the departure for HIRIS was discussed previously. AVIRIS is suffering because the "other" noise is becoming more dominant.

Another feature to note is that a steep slope in the " $NE\Delta\rho$ versus ρ " curve implies that the sensor is photon-noise limited at that wavelength. For example, HIRIS, TM, and ETM at 0.62 micrometers (see Figures 24 and 11, 14, and 15), and MODIS-N at 1.24, 1.64, and 2.2 micrometers (see Figures 25b and 18c, 26a and 19c, and 26b and 21c). In Figures 23 and 24, it can be seen that the radiometric sensitivity decreases (i.e., $NE\Delta\rho$ increases) as the aerosols increase (i.e., visibility decreases). It was noted in Figures 9 through 15 that the increase in aerosols affected only the signal dependent noises. The implication being that the $NE\Delta\rho$ is affected by an increase in aerosols because the signal-to-noise ratio worsens when there are more aerosols present in the atmosphere.

The maximum total signal used for the calculation of quantization noise was taken to be the total signal at unity ground reflectance; however, some bands of the sensors may saturate before unity reflectance. For example, band 1 of the Thematic Mapper saturates for a reflectance of approximately 0.4 at a solar zenith angle of forty-five degrees; however, as can be seen in Figure 27, this results in an improvement of the $NE\Delta\rho$ on the order of only 0.03%. Having the sensor saturate at a low reflectance provides a contrast stretch to the image for low reflectance scenes. However, since, as Figure 8b illustrates,

TM band 1 is not quantization-noise limited, the reduction in quantization noise achieved by the lower saturation signal does not result in a large improvement in the $NE\Delta\rho$.

On the other hand, if we were to reduce the quantization noise for a sensor that is quantization-noise limited, SPOT-1 HRV band 1 for example (see Figure 8a), there is a greater improvement in the $NE\Delta\rho$. Table 9 shows the $NE\Delta\rho$ for 8-bit quantization, which is what is used for the SPOT-1 HRV, the $NE\Delta\rho$ for 10-bit quantization, assuming the "other" noise remains constant, and the absolute difference in the $NE\Delta\rho$ (i.e., how much lower the 10-bit quantization $NE\Delta\rho$ is). An increase to 10-bit quantization results in a reduction of the quantization noise by a factor of four. As was mentioned previously, the increase in quantization levels is especially useful for low reflectance scenes. This can be

seen in Table 9 where the improvement in $NE\Delta\rho$ is greatest for low values of ground reflectance.

Table 9. $NE\Delta\rho$ for SPOT-1 HRV band 1 with 8 and 10-bit quantization.

ρ	$NE\Delta\rho$ (%) 10-bit	$NE\Delta\rho$ (%) 8-bit	difference
0.01	0.1757	0.2446	0.069
0.10	0.1799	0.2462	0.066
0.25	0.1863	0.2486	0.062
0.50	0.1958	0.2522	0.056
1.00	0.2111	0.2574	0.046

CHAPTER 6

CONCLUSION

The radiometric sensitivities of seven multispectral imaging sensors, present (AVHRR, AVIRIS, SPOT-1 HRV, and TM) and future (ETM, HIRIS, and MODIS-N), have been calculated and compared for a specific set of conditions...

- mid-latitude summer
- solar zenith angle of 45°
- nadir viewing angle
- continental aerosol with visibilities of 23 km and 5 km
- Rayleigh atmosphere
- constant ground reflectance over the band
- reflectance values of 0.01, 0.10, 0.25, 0.50, and 1.00.

The noise equivalent change in reflectance, $NE\Delta\rho$, was used as the measure of the radiometric sensitivity of the sensor, and the limiting noise of the sensor was examined for its effect on the $NE\Delta\rho$ and for possible means of improving performance. For example, it was illustrated that a reduction in the quantization noise, say by reducing the reflectance at which the sensor saturates, will result in only a slight improvement in $NE\Delta\rho$ if the sensor is not quantization-noise limited.

It is important to note that this is only a first-order comparison and does not take all details into account, such as information about detector cross talk that may be available for some of the sensors. This comparison is not accurate on an absolute scale, since the values used in the calculations are nominal values and may change. Also, "5S", the radiometric transfer program used, is an approximate not an exact code. However, since the same code results were used in all cases, the sensors have been compared to one another from a

common basis with consistent definitions thereby providing an accurate relative comparison. The numbers quoted about the performance of a sensor may be based upon different definitions depending on their source: for instance, different definitions of SNR may be used, or the calculations may be for different sets of conditions, atmospheres, reflectances, et cetera. Calculations from a common definition and basis were key to this comparison.

This study does not evaluate the effect of data processing methods for improving the signal-to-noise ratio. For example, pixel aggregation and image motion compensation (as is planned for HIRIS)¹⁰ could be used to reduce the noise equivalent change in reflectance. Also not taken into account is the fact that some bands may saturate before unity reflectance. For example, band 1 of the Thematic Mapper which saturates for a reflectance of approximately 0.4 at a solar zenith angle of forty-five degrees; however, this results in only a slight improvement (on the order of 0.03%) of the $NE\Delta\rho$ and the relative comparison is still valid.

When trying to determine which sensor is "the best", many factors must be taken into account. This work only examines the radiometric sensitivity expressed as $NE\Delta\rho$; there are other things to consider, such as the spatial resolution and spectral resolution that are required for the application being considered.

In summary, the calculation of the signal and its components was discussed along with some of the sources of noise in a multispectral imaging system and methods of calculating them. From the signal and noise calculations the noise equivalent change in reflectance was computed and through this parameter a comparison of the radiometric sensitivities of multispectral imaging systems was made.

APPENDIX

Note that in the following tables:

Ss = signal due to pixel radiance

Sp = signal due to path radiance

Nq = quantization noise

Ns = photon noise

Nt = total noise

NEDr is the noise equivalent change in reflectance, $NE\Delta\rho$.

Table A1. Calculated values for AVHRR. Visibility = 23 km.

AVHRR		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.630	3.63E-10	2.02E-09	1.43E-11	3.33E-12	1.88E-11	0.0518%
0.10		3.67E-09	2.70E-09	1.43E-11	5.43E-12	1.93E-11	0.0526%
0.25		9.31E-09	3.86E-09	1.43E-11	7.82E-12	2.01E-11	0.0540%
0.50		1.91E-08	5.88E-09	1.43E-11	1.08E-11	2.14E-11	0.0560%
1.00		4.04E-08	1.03E-08	1.43E-11	1.53E-11	2.40E-11	0.0595%
0.01	0.862	2.35E-09	3.33E-09	3.37E-11	3.93E-12	3.59E-11	0.0366%
0.10		3.46E-09	1.33E-08	3.37E-11	7.86E-12	3.66E-11	0.0371%
0.25		5.35E-09	3.02E-08	3.37E-11	1.18E-11	3.76E-11	0.0378%
0.50		8.58E-09	5.91E-08	3.37E-11	1.66E-11	3.94E-11	0.0390%
1.00		1.53E-08	1.20E-07	3.37E-11	2.36E-11	4.28E-11	0.0410%

Table A2. Calculated values for AVHRR. Visibility = 5 km.

AVHRR		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.630	1.92E-10	4.24E-09	1.25E-11	4.54E-12	1.78E-11	0.0926%
0.10		1.95E-09	5.48E-09	1.25E-11	5.87E-12	1.82E-11	0.0930%
0.25		5.03E-09	7.65E-09	1.25E-11	7.67E-12	1.88E-11	0.0936%
0.50		1.06E-08	1.16E-08	1.25E-11	1.01E-11	2.00E-11	0.0943%
1.00		2.36E-08	2.08E-08	1.25E-11	1.43E-11	2.24E-11	0.0948%

Table A3. Calculated values for AVHRR. Rayleigh Atmosphere.

AVHRR		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.630	4.77E-10	1.21E-09	1.49E-11	2.80E-12	1.92E-11	0.0403%
0.10		4.79E-09	1.33E-09	1.49E-11	5.33E-12	1.97E-11	0.0412%
0.25		1.21E-08	1.54E-09	1.49E-11	7.95E-12	2.06E-11	0.0427%
0.50		2.45E-08	1.90E-09	1.49E-11	1.11E-11	2.20E-11	0.0450%
1.00		5.03E-08	2.65E-09	1.49E-11	1.57E-11	2.46E-11	0.0490%

Table A4. Calculated values for AVIRIS A. Visibility = 23 km.

AVIRIS A		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.410	6.62E+02	2.39E+04	4.41E+01	1.57E+02	7.40E+02	1.1173%
0.01	0.490	4.05E+03	5.81E+04	2.00E+02	2.49E+02	7.90E+02	0.1950%
0.01	0.500	4.56E+03	5.85E+04	2.19E+02	2.51E+02	7.95E+02	0.1745%
0.01	0.600	6.29E+03	3.82E+04	2.52E+02	2.11E+02	7.93E+02	0.1262%
0.01	0.700	5.39E+03	1.93E+04	1.97E+02	1.57E+02	7.65E+02	0.1419%
0.10	0.410	6.80E+03	3.11E+04	4.41E+01	1.95E+02	7.49E+02	1.1021%
0.10	0.490	4.12E+04	7.05E+04	2.00E+02	3.34E+02	8.20E+02	0.1993%
0.10	0.500	4.64E+04	7.17E+04	2.19E+02	3.44E+02	8.29E+02	0.1788%
0.10	0.600	6.34E+04	5.05E+04	2.52E+02	3.37E+02	8.36E+02	0.1319%
0.10	0.700	5.43E+04	2.73E+04	1.97E+02	2.86E+02	8.01E+02	0.1475%
0.25	0.410	1.77E+04	3.25E+04	4.41E+01	2.24E+02	7.57E+02	1.0719%
0.25	0.490	1.06E+05	9.20E+04	2.00E+02	4.45E+02	8.71E+02	0.2060%
0.25	0.500	1.19E+05	9.47E+04	2.19E+02	4.62E+02	8.85E+02	0.1860%
0.25	0.600	1.61E+05	7.16E+04	2.52E+02	4.82E+02	9.04E+02	0.1403%
0.25	0.700	1.37E+05	4.09E+04	1.97E+02	4.22E+02	8.59E+02	0.1563%
0.50	0.410	3.78E+04	4.28E+04	4.41E+01	2.84E+02	7.77E+02	1.0281%
0.50	0.490	2.21E+05	1.31E+05	2.00E+02	5.93E+02	9.56E+02	0.2158%
0.50	0.500	2.49E+05	1.36E+05	2.19E+02	6.20E+02	9.76E+02	0.1965%
0.50	0.600	3.32E+05	1.08E+05	2.52E+02	6.64E+02	1.01E+03	0.1526%
0.50	0.700	2.81E+05	6.42E+04	1.97E+02	5.87E+02	9.51E+02	0.1695%
1.00	0.410	8.79E+04	6.84E+04	4.41E+01	3.95E+02	8.24E+02	0.9380%
1.00	0.490	4.90E+05	2.20E+05	2.00E+02	8.42E+02	1.13E+03	0.2303%
1.00	0.500	5.46E+05	2.30E+05	2.19E+02	8.81E+02	1.16E+03	0.2124%
1.00	0.600	7.05E+05	1.89E+05	2.52E+02	9.46E+02	1.22E+03	0.1725%
1.00	0.700	5.86E+05	1.14E+05	1.97E+02	8.37E+02	1.12E+03	0.1916%

Table A5. Calculated values for AVIRIS A. Visibility = 5 km.

AVIRIS A		Visibility = 5km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.410	2.48E+02	3.49E+04	3.63E+01	1.87E+02	7.47E+02	3.0151%
0.01	0.490	1.76E+03	9.96E+04	1.69E+02	3.18E+02	8.07E+02	0.4572%
0.01	0.500	2.02E+03	1.03E+05	1.85E+02	3.24E+02	8.13E+02	0.4014%
0.01	0.600	3.21E+03	7.97E+04	2.19E+02	2.88E+02	8.08E+02	0.2514%
0.01	0.700	3.04E+03	4.60E+04	1.75E+02	2.22E+02	7.75E+02	0.2547%
0.10	0.410	2.53E+03	3.87E+04	3.63E+01	2.03E+02	7.51E+02	2.9692%
0.10	0.490	1.80E+04	1.18E+05	1.69E+02	3.69E+02	8.28E+02	0.4604%
0.10	0.500	2.06E+04	1.23E+05	1.85E+02	3.79E+02	8.36E+02	0.4054%
0.10	0.600	3.26E+04	1.02E+05	2.19E+02	3.67E+02	8.39E+02	0.2576%
0.10	0.700	3.10E+04	6.21E+04	1.75E+02	3.05E+02	8.03E+02	0.2591%
0.25	0.410	6.64E+03	4.54E+04	3.63E+01	2.28E+02	7.58E+02	2.8559%
0.25	0.490	4.68E+04	1.50E+05	1.69E+02	4.44E+02	8.64E+02	0.4614%
0.25	0.500	5.36E+04	1.59E+05	1.85E+02	4.61E+02	8.76E+02	0.4089%
0.25	0.600	8.40E+04	1.41E+05	2.19E+02	4.74E+02	8.91E+02	0.2653%
0.25	0.700	7.95E+04	9.01E+04	1.75E+02	4.12E+02	8.49E+02	0.2671%
0.50	0.410	1.45E+04	5.84E+04	3.63E+01	2.70E+02	7.72E+02	2.6633%
0.50	0.490	1.01E+05	2.11E+05	1.69E+02	5.58E+02	9.28E+02	0.4616%
0.50	0.500	1.15E+05	2.25E+05	1.85E+02	5.83E+02	9.46E+02	0.4122%
0.50	0.600	1.77E+05	2.11E+05	2.19E+02	6.23E+02	9.79E+02	0.2762%
0.50	0.700	1.66E+05	1.40E+05	1.75E+02	5.53E+02	9.26E+02	0.2787%
1.00	0.410	3.55E+04	9.31E+04	3.63E+01	3.59E+02	8.07E+02	2.2724%
1.00	0.490	2.36E+05	3.63E+05	1.69E+02	7.74E+02	1.07E+03	0.4550%
1.00	0.500	2.67E+05	3.90E+05	1.85E+02	8.11E+02	1.10E+03	0.4118%
1.00	0.600	3.98E+05	3.79E+05	2.19E+02	8.82E+02	1.16E+03	0.2913%
1.00	0.700	3.65E+05	2.55E+05	1.75E+02	7.87E+02	1.08E+03	0.2963%

Table A6. Calculated values for AVIRIS A. Rayleigh Atmosphere.

AVIRIS A		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.410	1.00E+03	1.99E+04	4.72E+01	1.45E+02	7.38E+02	0.7362%
0.01	0.490	5.79E+03	4.39E+04	2.13E+02	2.23E+02	7.85E+02	0.1356%
0.01	0.500	6.43E+03	4.27E+04	2.31E+02	2.22E+02	7.90E+02	0.1228%
0.01	0.600	8.30E+03	2.34E+04	2.64E+02	1.78E+02	7.89E+02	0.0950%
0.01	0.700	6.82E+03	9.76E+03	2.06E+02	1.29E+02	7.62E+02	0.1116%
0.10	0.410	1.02E+04	2.15E+04	4.72E+01	1.78E+02	7.45E+02	0.7275%
0.10	0.490	5.86E+04	4.81E+04	2.13E+02	3.27E+02	8.21E+02	0.1400%
0.10	0.500	6.49E+04	4.68E+04	2.31E+02	3.34E+02	8.28E+02	0.1276%
0.10	0.600	8.36E+04	2.57E+04	2.64E+02	3.31E+02	8.37E+02	0.1001%
0.10	0.700	6.86E+04	1.08E+04	2.06E+02	2.82E+02	8.02E+02	0.1169%
0.25	0.410	2.64E+04	2.42E+04	4.72E+01	2.25E+02	7.58E+02	0.7165%
0.25	0.490	1.49E+05	5.52E+04	2.13E+02	4.52E+02	8.78E+02	0.1470%
0.25	0.500	1.65E+05	5.38E+04	2.31E+02	4.68E+02	8.91E+02	0.1348%
0.25	0.600	2.11E+05	2.97E+04	2.64E+02	4.91E+02	9.12E+02	0.1080%
0.25	0.700	1.72E+05	1.26E+04	2.06E+02	4.30E+02	8.65E+02	0.1255%
0.50	0.410	5.59E+04	2.92E+04	4.72E+01	2.92E+02	7.80E+02	0.6975%
0.50	0.490	3.09E+05	6.78E+04	2.13E+02	6.14E+02	9.71E+02	0.1573%
0.50	0.500	3.40E+05	6.61E+04	2.31E+02	6.38E+02	9.90E+02	0.1455%
0.50	0.600	4.28E+05	3.65E+04	2.64E+02	6.82E+02	1.03E+03	0.1199%
0.50	0.700	3.48E+05	1.55E+04	2.06E+02	6.03E+02	9.63E+02	0.1384%
1.00	0.410	1.26E+05	4.11E+04	4.72E+01	4.09E+02	8.31E+02	0.6574%
1.00	0.490	6.61E+05	9.57E+04	2.13E+02	8.70E+02	1.15E+03	0.1740%
1.00	0.500	7.25E+05	9.31E+04	2.31E+02	9.04E+02	1.18E+03	0.1628%
1.00	0.600	8.84E+05	5.07E+04	2.64E+02	9.67E+02	1.24E+03	0.1397%
1.00	0.700	7.08E+05	2.16E+04	2.06E+02	8.54E+02	1.14E+03	0.1607%

Table A7. Calculated values for AVIRIS B. Visibility = 23 km.

AVIRIS B		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.700	4.28E+03	1.53E+04	1.57E+02	1.40E+02	9.12E+02	0.2131%
0.01	0.800	3.05E+03	7.19E+03	1.05E+02	1.01E+02	8.99E+02	0.2950%
0.01	0.840	3.93E+03	8.13E+03	1.33E+02	1.10E+02	9.04E+02	0.2297%
0.01	0.900	3.29E+03	5.62E+03	1.09E+02	9.44E+01	8.99E+02	0.2731%
0.01	1.000	6.13E+03	7.99E+03	1.98E+02	1.19E+02	9.17E+02	0.1494%
0.01	1.100	2.38E+03	2.44E+03	7.50E+01	6.94E+01	8.93E+02	0.3744%
0.01	1.200	3.49E+03	2.99E+03	1.09E+02	8.05E+01	8.97E+02	0.2567%
0.01	1.250	3.95E+03	3.06E+03	1.21E+02	8.37E+01	8.99E+02	0.2274%
0.10	0.700	4.31E+04	2.17E+04	1.57E+02	2.54E+02	9.36E+02	0.2171%
0.10	0.800	3.06E+04	1.07E+04	1.05E+02	2.03E+02	9.16E+02	0.2992%
0.10	0.840	3.96E+04	1.23E+04	1.33E+02	2.28E+02	9.25E+02	0.2337%
0.10	0.900	3.31E+04	8.64E+03	1.09E+02	2.04E+02	9.17E+02	0.2767%
0.10	1.000	6.18E+04	1.27E+04	1.98E+02	2.73E+02	9.49E+02	0.1537%
0.10	1.100	2.39E+04	4.01E+03	7.50E+01	1.67E+02	9.06E+02	0.3790%
0.10	1.200	3.52E+04	4.96E+03	1.09E+02	2.00E+02	9.16E+02	0.2604%
0.10	1.250	3.94E+04	5.15E+03	1.21E+02	2.11E+02	9.20E+02	0.2333%
0.25	0.700	1.09E+05	3.24E+04	1.57E+02	3.76E+02	9.76E+02	0.2237%
0.25	0.800	7.72E+04	1.65E+04	1.05E+02	3.06E+02	9.44E+02	0.3056%
0.25	0.840	9.99E+04	1.93E+04	1.33E+02	3.45E+02	9.61E+02	0.2406%
0.25	0.900	8.35E+04	1.38E+04	1.09E+02	3.12E+02	9.47E+02	0.2835%
0.25	1.000	1.55E+05	2.06E+04	1.98E+02	4.19E+02	1.00E+03	0.1612%
0.25	1.100	6.00E+04	6.60E+03	7.50E+01	2.58E+02	9.27E+02	0.3864%
0.25	1.200	8.83E+04	8.29E+03	1.09E+02	3.11E+02	9.46E+02	0.2679%
0.25	1.250	9.88E+04	8.63E+03	1.21E+02	3.28E+02	9.53E+02	0.2411%
0.50	0.700	2.23E+05	5.10E+04	1.57E+02	5.23E+02	1.04E+03	0.2338%
0.50	0.800	1.57E+05	2.66E+04	1.05E+02	4.28E+02	9.91E+02	0.3156%
0.50	0.840	2.03E+05	3.12E+04	1.33E+02	4.84E+02	1.02E+03	0.2515%
0.50	0.900	1.69E+05	2.26E+04	1.09E+02	4.38E+02	9.95E+02	0.2945%
0.50	1.000	3.14E+05	3.40E+04	1.98E+02	5.90E+02	1.08E+03	0.1727%
0.50	1.100	1.21E+05	1.10E+04	7.50E+01	3.63E+02	9.61E+02	0.3975%
0.50	1.200	1.78E+05	1.39E+04	1.09E+02	4.38E+02	9.95E+02	0.2799%
0.50	1.250	1.99E+05	1.46E+04	1.21E+02	4.62E+02	1.01E+03	0.2531%
1.00	0.700	4.65E+05	9.05E+04	1.57E+02	7.45E+02	1.17E+03	0.2513%
1.00	0.800	3.24E+05	4.76E+04	1.05E+02	6.10E+02	1.08E+03	0.3338%
1.00	0.840	4.17E+05	5.60E+04	1.33E+02	6.88E+02	1.13E+03	0.2710%
1.00	0.900	3.46E+05	4.07E+04	1.09E+02	6.22E+02	1.09E+03	0.3143%
1.00	1.000	6.40E+05	6.17E+04	1.98E+02	8.38E+02	1.24E+03	0.1932%
1.00	1.100	2.46E+05	2.00E+04	7.50E+01	5.16E+02	1.03E+03	0.4182%
1.00	1.200	3.61E+05	2.54E+04	1.09E+02	6.21E+02	1.09E+03	0.3018%
1.00	1.250	4.03E+05	2.67E+04	1.21E+02	6.56E+02	1.11E+03	0.2751%

Table A8. Calculated values for AVIRIS B. Visibility = 5 km.

AVIRIS B		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.700	2.42E+03	3.65E+04	1.39E+02	1.97E+02	9.19E+02	0.3804%
0.01	0.800	1.87E+03	1.87E+04	9.30E+01	1.43E+02	9.03E+02	0.4831%
0.01	0.900	2.15E+03	1.56E+04	9.72E+01	1.33E+02	9.02E+02	0.4196%
0.01	1.000	4.17E+03	2.35E+04	1.76E+02	1.66E+02	9.20E+02	0.2207%
0.01	1.100	1.67E+03	7.51E+03	6.72E+01	9.58E+01	8.95E+02	0.5344%
0.01	1.200	2.54E+03	9.41E+03	9.79E+01	1.09E+02	8.99E+02	0.3544%
0.01	1.250	2.94E+03	9.82E+03	1.09E+02	1.13E+02	9.01E+02	0.3069%
0.10	0.700	2.46E+04	4.93E+04	1.39E+02	2.72E+02	9.38E+02	0.3812%
0.10	0.800	1.89E+04	2.63E+04	9.30E+01	2.13E+02	9.17E+02	0.4849%
0.10	0.900	2.17E+04	2.26E+04	9.72E+01	2.11E+02	9.17E+02	0.4221%
0.10	1.000	4.23E+04	3.48E+04	1.76E+02	2.78E+02	9.46E+02	0.2236%
0.10	1.100	1.70E+04	1.14E+04	6.72E+01	1.69E+02	9.05E+02	0.5327%
0.10	1.200	2.58E+04	1.45E+04	9.79E+01	2.01E+02	9.15E+02	0.3543%
0.10	1.250	2.93E+04	1.53E+04	1.09E+02	2.11E+02	9.18E+02	0.3135%
0.25	0.700	6.31E+04	7.15E+04	1.39E+02	3.67E+02	9.70E+02	0.3842%
0.25	0.800	4.83E+04	3.94E+04	9.30E+01	2.96E+02	9.40E+02	0.4868%
0.25	0.900	5.52E+04	3.47E+04	9.72E+01	3.00E+02	9.41E+02	0.4260%
0.25	1.000	1.07E+05	5.43E+04	1.76E+02	4.02E+02	9.90E+02	0.2305%
0.25	1.100	4.30E+04	1.81E+04	6.72E+01	2.47E+02	9.23E+02	0.5365%
0.25	1.200	6.53E+04	2.33E+04	9.79E+01	2.98E+02	9.41E+02	0.3603%
0.25	1.250	7.41E+04	2.46E+04	1.09E+02	3.14E+02	9.47E+02	0.3196%
0.50	0.700	1.32E+05	1.11E+05	1.39E+02	4.93E+02	1.02E+03	0.3883%
0.50	0.800	1.00E+05	6.24E+04	9.30E+01	4.03E+02	9.79E+02	0.4891%
0.50	0.900	1.14E+05	5.58E+04	9.72E+01	4.12E+02	9.83E+02	0.4315%
0.50	1.000	2.20E+05	8.80E+04	1.76E+02	5.55E+02	1.06E+03	0.2408%
0.50	1.100	8.80E+04	2.95E+04	6.72E+01	3.43E+02	9.53E+02	0.5418%
0.50	1.200	1.33E+05	3.83E+04	9.79E+01	4.14E+02	9.84E+02	0.3696%
0.50	1.250	1.51E+05	4.06E+04	1.09E+02	4.38E+02	9.95E+02	0.3296%
1.00	0.700	2.90E+05	2.02E+05	1.39E+02	7.01E+02	1.14E+03	0.3929%
1.00	0.800	2.16E+05	1.14E+05	9.30E+01	5.74E+02	1.06E+03	0.4911%
1.00	0.900	2.43E+05	1.02E+05	9.72E+01	5.87E+02	1.07E+03	0.4401%
1.00	1.000	4.65E+05	1.61E+05	1.76E+02	7.91E+02	1.20E+03	0.2584%
1.00	1.100	1.84E+05	5.40E+04	6.72E+01	4.88E+02	1.01E+03	0.5505%
1.00	1.200	2.77E+05	7.01E+04	9.79E+01	5.89E+02	1.07E+03	0.3857%
1.00	1.250	3.14E+05	7.43E+04	1.09E+02	6.23E+02	1.09E+03	0.3472%

Table A9. Calculated values for AVIRIS B. Rayleigh Atmosphere.

AVIRIS B		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.700	5.42E+03	7.75E+03	1.63E+02	1.15E+02	9.09E+02	0.1679%
0.01	0.800	3.74E+03	3.05E+03	1.09E+02	8.24E+01	8.98E+02	0.2400%
0.01	0.900	3.95E+03	1.97E+03	1.14E+02	7.70E+01	8.98E+02	0.2273%
0.01	1.000	7.23E+03	2.31E+03	2.07E+02	9.77E+01	9.16E+02	0.1266%
0.01	1.100	2.74E+03	6.09E+02	7.83E+01	5.79E+01	8.92E+02	0.3257%
0.01	1.200	4.00E+03	6.20E+02	1.13E+02	6.80E+01	8.97E+02	0.2241%
0.01	1.250	4.43E+03	5.99E+02	1.26E+02	7.09E+01	8.99E+02	0.2027%
0.10	0.700	5.45E+04	8.58E+03	1.63E+02	2.51E+02	9.36E+02	0.1719%
0.10	0.800	3.75E+04	3.34E+03	1.09E+02	2.02E+02	9.16E+02	0.2446%
0.10	0.900	3.96E+04	2.19E+03	1.14E+02	2.04E+02	9.17E+02	0.2318%
0.10	1.000	7.23E+04	2.49E+03	2.07E+02	2.74E+02	9.51E+02	0.1314%
0.10	1.100	2.75E+04	6.09E+02	7.83E+01	1.68E+02	9.06E+02	0.3289%
0.10	1.200	4.00E+04	6.20E+02	1.13E+02	2.02E+02	9.17E+02	0.2290%
0.10	1.250	4.46E+04	5.99E+02	1.26E+02	2.13E+02	9.21E+02	0.2063%
0.25	0.700	1.37E+05	9.97E+03	1.63E+02	3.83E+02	9.80E+02	0.1790%
0.25	0.800	9.39E+04	3.85E+03	1.09E+02	3.13E+02	9.47E+02	0.2520%
0.25	0.900	9.91E+04	2.50E+03	1.14E+02	3.19E+02	9.49E+02	0.2395%
0.25	1.000	1.81E+05	2.72E+03	2.07E+02	4.29E+02	1.01E+03	0.1390%
0.25	1.100	6.89E+04	6.60E+02	7.83E+01	2.64E+02	9.29E+02	0.3367%
0.25	1.200	1.00E+05	6.76E+02	1.13E+02	3.18E+02	9.49E+02	0.2368%
0.25	1.250	1.12E+05	5.99E+02	1.26E+02	3.35E+02	9.56E+02	0.2144%
0.50	0.700	2.76E+05	1.23E+04	1.63E+02	5.37E+02	1.05E+03	0.1901%
0.50	0.800	1.89E+05	4.71E+03	1.09E+02	4.40E+02	9.96E+02	0.2638%
0.50	0.900	1.99E+05	3.07E+03	1.14E+02	4.49E+02	1.00E+03	0.2517%
0.50	1.000	3.63E+05	3.18E+03	2.07E+02	6.05E+02	1.09E+03	0.1507%
0.50	1.100	1.38E+05	7.61E+02	7.83E+01	3.73E+02	9.65E+02	0.3496%
0.50	1.200	2.01E+05	6.76E+02	1.13E+02	4.49E+02	1.00E+03	0.2495%
0.50	1.250	2.23E+05	6.59E+02	1.26E+02	4.73E+02	1.01E+03	0.2269%
1.00	0.700	5.62E+05	1.72E+04	1.63E+02	7.61E+02	1.18E+03	0.2101%
1.00	0.800	3.81E+05	6.43E+03	1.09E+02	6.23E+02	1.09E+03	0.2856%
1.00	0.900	4.00E+05	4.12E+03	1.14E+02	6.36E+02	1.10E+03	0.2742%
1.00	1.000	7.29E+05	4.05E+03	2.07E+02	8.56E+02	1.25E+03	0.1715%
1.00	1.100	2.77E+05	8.62E+02	7.83E+01	5.27E+02	1.03E+03	0.3737%
1.00	1.200	4.02E+05	7.33E+02	1.13E+02	6.34E+02	1.10E+03	0.2729%
1.00	1.250	4.47E+05	6.59E+02	1.26E+02	6.69E+02	1.12E+03	0.2500%

Table A10. Calculated values for AVIRIS C. Visibility = 23 km.

AVIRIS C		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	1.250	3.77E+03	2.91E+03	1.15E+02	8.17E+01	9.58E+02	0.2545%
0.01	1.300	3.97E+03	2.85E+03	1.21E+02	8.26E+01	9.59E+02	0.2414%
0.01	1.350	1.82E+02	9.10E+01	6.72E+00	1.65E+01	9.48E+02	5.2105%
0.01	1.400	0.00E+00	0.00E+00	3.93E-01	0.00E+00	9.48E+02	∞
0.01	1.500	3.53E+03	1.88E+03	1.08E+02	7.36E+01	9.57E+02	0.2710%
0.01	1.600	3.87E+03	1.78E+03	1.15E+02	7.52E+01	9.58E+02	0.2472%
0.01	1.700	3.53E+03	1.41E+03	1.04E+02	7.03E+01	9.56E+02	0.2711%
0.01	1.800	5.28E+02	2.11E+02	1.65E+01	2.72E+01	9.49E+02	1.7948%
0.10	1.250	3.75E+04	4.91E+03	1.15E+02	2.06E+02	9.77E+02	0.2602%
0.10	1.300	3.95E+04	4.80E+03	1.21E+02	2.11E+02	9.79E+02	0.2476%
0.10	1.350	2.18E+03	1.82E+02	6.72E+00	4.86E+01	9.49E+02	4.3471%
0.10	1.400	1.07E+02	0.00E+00	3.93E-01	1.04E+01	9.48E+02	88.3243%
0.10	1.500	3.58E+04	3.41E+03	1.08E+02	1.98E+02	9.74E+02	0.2723%
0.10	1.600	3.84E+04	3.14E+03	1.15E+02	2.04E+02	9.76E+02	0.2541%
0.10	1.700	3.49E+04	2.59E+03	1.04E+02	1.94E+02	9.73E+02	0.2787%
0.10	1.800	5.60E+03	4.23E+02	1.65E+01	7.76E+01	9.51E+02	1.6982%
0.25	1.250	9.41E+04	8.22E+03	1.15E+02	3.20E+02	1.01E+03	0.2675%
0.25	1.300	9.91E+04	8.17E+03	1.21E+02	3.28E+02	1.01E+03	0.2548%
0.25	1.350	5.55E+03	3.64E+02	6.72E+00	7.69E+01	9.51E+02	4.2842%
0.25	1.400	3.22E+02	0.00E+00	3.93E-01	1.79E+01	9.48E+02	73.6124%
0.25	1.500	8.98E+04	5.89E+03	1.08E+02	3.09E+02	1.00E+03	0.2792%
0.25	1.600	9.62E+04	5.55E+03	1.15E+02	3.19E+02	1.01E+03	0.2615%
0.25	1.700	8.76E+04	4.47E+03	1.04E+02	3.03E+02	1.00E+03	0.2856%
0.25	1.800	1.40E+04	6.34E+02	1.65E+01	1.21E+02	9.56E+02	1.7127%
0.50	1.250	1.90E+05	1.39E+04	1.15E+02	4.51E+02	1.06E+03	0.2785%
0.50	1.300	2.00E+05	1.37E+04	1.21E+02	4.62E+02	1.06E+03	0.2660%
0.50	1.350	1.12E+04	6.37E+02	6.72E+00	1.09E+02	9.54E+02	4.2633%
0.50	1.400	6.44E+02	0.00E+00	3.93E-01	2.54E+01	9.48E+02	73.6256%
0.50	1.500	1.81E+05	1.00E+04	1.08E+02	4.37E+02	1.05E+03	0.2905%
0.50	1.600	1.93E+05	9.53E+03	1.15E+02	4.51E+02	1.06E+03	0.2729%
0.50	1.700	1.76E+05	7.76E+03	1.04E+02	4.29E+02	1.05E+03	0.2972%
0.50	1.800	2.80E+04	1.16E+03	1.65E+01	1.71E+02	9.63E+02	1.7198%
1.00	1.250	3.84E+05	2.54E+04	1.15E+02	6.40E+02	1.15E+03	0.2992%
1.00	1.300	4.04E+05	2.51E+04	1.21E+02	6.55E+02	1.16E+03	0.2867%
1.00	1.350	2.26E+04	1.27E+03	6.72E+00	1.54E+02	9.61E+02	4.2567%
1.00	1.400	1.29E+03	1.07E+02	3.93E-01	3.74E+01	9.49E+02	73.6563%
1.00	1.500	3.65E+05	1.85E+04	1.08E+02	6.19E+02	1.14E+03	0.3119%
1.00	1.600	3.90E+05	1.76E+04	1.15E+02	6.39E+02	1.15E+03	0.2945%
1.00	1.700	3.54E+05	1.43E+04	1.04E+02	6.07E+02	1.13E+03	0.3191%
1.00	1.800	5.64E+04	2.11E+03	1.65E+01	2.42E+02	9.79E+02	1.7337%

Table A11. Calculated values for AVIRIS C. Visibility = 5 km.

AVIRIS C		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	1.250	2.80E+03	9.36E+03	1.04E+02	1.10E+02	9.60E+02	0.3434%
0.01	1.300	2.92E+03	9.15E+03	1.09E+02	1.10E+02	9.61E+02	0.3285%
0.01	1.350	1.82E+02	4.55E+02	6.10E+00	2.52E+01	9.48E+02	5.2115%
0.01	1.400	0.00E+00	0.00E+00	3.63E-01	0.00E+00	9.48E+02	∞
0.01	1.500	2.83E+03	6.47E+03	9.88E+01	9.64E+01	9.58E+02	0.3391%
0.01	1.600	3.04E+03	5.97E+03	1.06E+02	9.49E+01	9.59E+02	0.3156%
0.01	1.700	2.82E+03	4.59E+03	9.61E+01	8.61E+01	9.57E+02	0.3391%
0.01	1.800	4.23E+02	6.34E+02	1.53E+01	3.25E+01	9.49E+02	2.2439%
0.10	1.250	2.79E+04	1.45E+04	1.04E+02	2.06E+02	9.76E+02	0.3497%
0.10	1.300	2.98E+04	1.44E+04	1.09E+02	2.10E+02	9.77E+02	0.3282%
0.10	1.350	1.73E+03	7.28E+02	6.10E+00	4.96E+01	9.49E+02	5.4913%
0.10	1.400	1.07E+02	0.00E+00	3.63E-01	1.04E+01	9.48E+02	88.3243%
0.10	1.500	2.83E+04	1.05E+04	9.88E+01	1.97E+02	9.73E+02	0.3445%
0.10	1.600	3.09E+04	9.95E+03	1.06E+02	2.02E+02	9.75E+02	0.3156%
0.10	1.700	2.87E+04	7.88E+03	9.61E+01	1.91E+02	9.72E+02	0.3388%
0.10	1.800	4.65E+03	1.06E+03	1.53E+01	7.55E+01	9.51E+02	2.0451%
0.25	1.250	7.06E+04	2.34E+04	1.04E+02	3.07E+02	1.00E+03	0.3549%
0.25	1.300	7.52E+04	2.32E+04	1.09E+02	3.14E+02	1.00E+03	0.3339%
0.25	1.350	4.28E+03	1.27E+03	6.10E+00	7.45E+01	9.51E+02	5.5593%
0.25	1.400	2.15E+02	0.00E+00	3.63E-01	1.47E+01	9.48E+02	110.412%
0.25	1.500	7.11E+04	1.73E+04	9.88E+01	2.97E+02	9.98E+02	0.3511%
0.25	1.600	7.78E+04	1.67E+04	1.06E+02	3.07E+02	1.00E+03	0.3220%
0.25	1.700	7.22E+04	1.34E+04	9.61E+01	2.93E+02	9.97E+02	0.3452%
0.25	1.800	1.17E+04	1.90E+03	1.53E+01	1.17E+02	9.55E+02	2.0356%
0.50	1.250	1.44E+05	3.86E+04	1.04E+02	4.27E+02	1.04E+03	0.3634%
0.50	1.300	1.53E+05	3.85E+04	1.09E+02	4.38E+02	1.05E+03	0.3427%
0.50	1.350	8.64E+03	2.09E+03	6.10E+00	1.04E+02	9.54E+02	5.5165%
0.50	1.400	5.37E+02	1.07E+02	3.63E-01	2.54E+01	9.48E+02	88.3507%
0.50	1.500	1.44E+05	2.88E+04	9.88E+01	4.16E+02	1.04E+03	0.3603%
0.50	1.600	1.58E+05	2.80E+04	1.06E+02	4.31E+02	1.05E+03	0.3322%
0.50	1.700	1.46E+05	2.28E+04	9.61E+01	4.11E+02	1.04E+03	0.3556%
0.50	1.800	2.37E+04	3.28E+03	1.53E+01	1.64E+02	9.62E+02	2.0321%
1.00	1.250	2.99E+05	7.07E+04	1.04E+02	6.08E+02	1.13E+03	0.3785%
1.00	1.300	3.18E+05	7.06E+04	1.09E+02	6.23E+02	1.14E+03	0.3588%
1.00	1.350	1.79E+04	3.73E+03	6.10E+00	1.47E+02	9.59E+02	5.3523%
1.00	1.400	1.07E+03	2.15E+02	3.63E-01	3.59E+01	9.49E+02	88.3823%
1.00	1.500	2.97E+05	5.32E+04	9.88E+01	5.92E+02	1.12E+03	0.3773%
1.00	1.600	3.23E+05	5.15E+04	1.06E+02	6.12E+02	1.13E+03	0.3505%
1.00	1.700	2.99E+05	4.22E+04	9.61E+01	5.84E+02	1.12E+03	0.3743%
1.00	1.800	4.82E+04	6.13E+03	1.53E+01	2.33E+02	9.76E+02	2.0257%

Table A12. Calculated values for AVIRIS C. Rayleigh Atmosphere.

AVIRIS C		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	1.250	4.22E+03	5.71E+02	1.20E+02	6.92E+01	9.58E+02	0.2269%
0.01	1.300	4.42E+03	5.25E+02	1.26E+02	7.03E+01	9.59E+02	0.2167%
0.01	1.350	2.73E+02	0.00E+00	7.00E+00	1.65E+01	9.48E+02	3.4736%
0.01	1.400	0.00E+00	0.00E+00	4.24E-01	0.00E+00	9.48E+02	∞
0.01	1.500	4.00E+03	2.35E+02	1.12E+02	6.51E+01	9.57E+02	0.2391%
0.01	1.600	4.19E+03	2.09E+02	1.19E+02	6.63E+01	9.58E+02	0.2286%
0.01	1.700	3.76E+03	1.18E+02	1.07E+02	6.23E+01	9.56E+02	0.2541%
0.01	1.800	6.34E+02	0.00E+00	1.70E+01	2.52E+01	9.48E+02	1.4956%
0.10	1.250	4.25E+04	5.71E+02	1.20E+02	2.08E+02	9.78E+02	0.2301%
0.10	1.300	4.45E+04	5.25E+02	1.26E+02	2.12E+02	9.80E+02	0.2199%
0.10	1.350	2.46E+03	0.00E+00	7.00E+00	4.96E+01	9.49E+02	3.8643%
0.10	1.400	1.07E+02	0.00E+00	4.24E-01	1.04E+01	9.48E+02	88.3243%
0.10	1.500	3.97E+04	2.35E+02	1.12E+02	2.00E+02	9.75E+02	0.2458%
0.10	1.600	4.21E+04	2.09E+02	1.19E+02	2.06E+02	9.77E+02	0.2321%
0.10	1.700	3.80E+04	1.18E+02	1.07E+02	1.95E+02	9.74E+02	0.2564%
0.10	1.800	6.02E+03	0.00E+00	1.70E+01	7.76E+01	9.51E+02	1.5790%
0.25	1.250	1.06E+05	5.71E+02	1.20E+02	3.27E+02	1.01E+03	0.2377%
0.25	1.300	1.11E+05	5.25E+02	1.26E+02	3.34E+02	1.01E+03	0.2275%
0.25	1.350	6.19E+03	0.00E+00	7.00E+00	7.87E+01	9.51E+02	3.8438%
0.25	1.400	3.22E+02	0.00E+00	4.24E-01	1.79E+01	9.48E+02	73.6124%
0.25	1.500	9.91E+04	2.35E+02	1.12E+02	3.15E+02	1.01E+03	0.2536%
0.25	1.600	1.05E+05	3.14E+02	1.19E+02	3.25E+02	1.01E+03	0.2395%
0.25	1.700	9.50E+04	1.18E+02	1.07E+02	3.08E+02	1.00E+03	0.2639%
0.25	1.800	1.50E+04	0.00E+00	1.70E+01	1.23E+02	9.56E+02	1.5924%
0.50	1.250	2.13E+05	6.28E+02	1.20E+02	4.62E+02	1.06E+03	0.2495%
0.50	1.300	2.23E+05	5.25E+02	1.26E+02	4.73E+02	1.07E+03	0.2393%
0.50	1.350	1.24E+04	0.00E+00	7.00E+00	1.11E+02	9.55E+02	3.8569%
0.50	1.400	7.51E+02	0.00E+00	4.24E-01	2.74E+01	9.48E+02	63.1114%
0.50	1.500	1.98E+05	3.53E+02	1.12E+02	4.46E+02	1.05E+03	0.2656%
0.50	1.600	2.11E+05	3.14E+02	1.19E+02	4.59E+02	1.06E+03	0.2516%
0.50	1.700	1.90E+05	2.35E+02	1.07E+02	4.36E+02	1.05E+03	0.2759%
0.50	1.800	3.01E+04	0.00E+00	1.70E+01	1.74E+02	9.64E+02	1.5999%
1.00	1.250	4.26E+05	6.28E+02	1.20E+02	6.53E+02	1.16E+03	0.2716%
1.00	1.300	4.46E+05	6.00E+02	1.26E+02	6.69E+02	1.17E+03	0.2614%
1.00	1.350	2.48E+04	0.00E+00	7.00E+00	1.58E+02	9.61E+02	3.8690%
1.00	1.400	1.50E+03	0.00E+00	4.24E-01	3.88E+01	9.49E+02	63.1378%
1.00	1.500	3.97E+05	4.71E+02	1.12E+02	6.30E+02	1.14E+03	0.2882%
1.00	1.600	4.22E+05	4.19E+02	1.19E+02	6.50E+02	1.16E+03	0.2740%
1.00	1.700	3.80E+05	2.35E+02	1.07E+02	6.17E+02	1.14E+03	0.2986%
1.00	1.800	6.02E+04	0.00E+00	1.70E+01	2.45E+02	9.79E+02	1.6256%

Table A13. Calculated values for AVIRIS D. Visibility = 23 km.

AVIRIS D		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	1.900	0.00E+00	0.00E+00	1.69E-01	0.00E+00	9.81E+02	∞
0.01	2.000	9.98E+02	2.85E+02	3.10E+01	3.58E+01	9.82E+02	0.9845%
0.01	2.100	1.57E+03	3.62E+02	4.75E+01	4.39E+01	9.83E+02	0.6276%
0.01	2.200	1.25E+03	2.27E+02	3.81E+01	3.84E+01	9.82E+02	0.7859%
0.01	2.300	1.47E+03	2.67E+02	4.09E+01	4.17E+01	9.83E+02	0.6686%
0.01	2.400	9.27E+02	1.32E+02	2.53E+01	3.26E+01	9.82E+02	1.0589%
0.01	2.450	3.34E+02	6.68E+01	9.39E+00	2.00E+01	9.81E+02	2.9387%
0.10	1.900	0.00E+00	0.00E+00	1.69E-01	0.00E+00	9.81E+02	∞
0.10	2.000	1.05E+04	5.70E+02	3.10E+01	1.05E+02	9.87E+02	0.9360%
0.10	2.100	1.63E+04	8.44E+02	4.75E+01	1.31E+02	9.91E+02	0.6091%
0.10	2.200	1.31E+04	5.68E+02	3.81E+01	1.17E+02	9.89E+02	0.7564%
0.10	2.300	1.40E+04	6.68E+02	4.09E+01	1.21E+02	9.89E+02	0.7051%
0.10	2.400	8.74E+03	3.97E+02	2.53E+01	9.56E+01	9.86E+02	1.1277%
0.10	2.450	3.21E+03	1.34E+02	9.39E+00	5.78E+01	9.83E+02	3.0658%
0.25	1.900	1.20E+02	0.00E+00	1.69E-01	1.09E+01	9.81E+02	204.979%
0.25	2.000	2.65E+04	9.98E+02	3.10E+01	1.66E+02	9.95E+02	0.9388%
0.25	2.100	4.07E+04	1.45E+03	4.75E+01	2.05E+02	1.00E+03	0.6159%
0.25	2.200	3.27E+04	1.02E+03	3.81E+01	1.84E+02	9.99E+02	0.7629%
0.25	2.300	3.51E+04	1.07E+03	4.09E+01	1.90E+02	1.00E+03	0.7115%
0.25	2.400	2.17E+04	6.62E+02	2.53E+01	1.50E+02	9.93E+02	1.1423%
0.25	2.450	8.08E+03	2.67E+02	9.39E+00	9.14E+01	9.85E+02	3.0483%
0.50	1.900	2.39E+02	0.00E+00	1.69E-01	1.55E+01	9.81E+02	204.992%
0.50	2.000	5.32E+04	1.85E+03	3.10E+01	2.35E+02	1.01E+03	0.9492%
0.50	2.100	8.16E+04	2.53E+03	4.75E+01	2.90E+02	1.02E+03	0.6277%
0.50	2.200	6.56E+04	1.93E+03	3.81E+01	2.60E+02	1.02E+03	0.7743%
0.50	2.300	7.04E+04	2.00E+03	4.09E+01	2.69E+02	1.02E+03	0.7228%
0.50	2.400	4.36E+04	1.19E+03	2.53E+01	2.12E+02	1.00E+03	1.1517%
0.50	2.450	1.62E+04	4.67E+02	9.39E+00	1.29E+02	9.90E+02	3.0488%
1.00	1.900	5.98E+02	0.00E+00	1.69E-01	2.45E+01	9.81E+02	164.024%
1.00	2.000	1.07E+05	3.28E+03	3.10E+01	3.32E+02	1.04E+03	0.9706%
1.00	2.100	1.64E+05	4.70E+03	4.75E+01	4.11E+02	1.06E+03	0.6496%
1.00	2.200	1.32E+05	3.52E+03	3.81E+01	3.68E+02	1.05E+03	0.7965%
1.00	2.300	1.41E+05	3.74E+03	4.09E+01	3.81E+02	1.05E+03	0.7449%
1.00	2.400	8.76E+04	2.12E+03	2.53E+01	2.99E+02	1.03E+03	1.1718%
1.00	2.450	3.25E+04	8.01E+02	9.39E+00	1.83E+02	9.98E+02	3.0683%

Table A14. Calculated values for AVIRIS D. Visibility = 5 km.

AVIRIS D		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nl (e-)	NEDr
0.01	1.900	0.00E+00	0.00E+00	1.35E-01	0.00E+00	9.81E+02	∞
0.01	2.000	8.55E+02	9.98E+02	2.92E+01	4.30E+01	9.82E+02	1.1489%
0.01	2.100	1.45E+03	1.21E+03	4.50E+01	5.15E+01	9.83E+02	0.6801%
0.01	2.200	1.14E+03	9.09E+02	3.64E+01	4.52E+01	9.83E+02	0.8647%
0.01	2.300	1.20E+03	9.35E+02	3.92E+01	4.62E+01	9.83E+02	0.8173%
0.01	2.400	7.95E+02	3.97E+02	2.42E+01	3.45E+01	9.82E+02	1.2354%
0.01	2.450	2.67E+02	1.34E+02	9.02E+00	2.00E+01	9.81E+02	3.6733%
0.10	1.900	0.00E+00	0.00E+00	1.35E-01	0.00E+00	9.81E+02	∞
0.10	2.000	9.12E+03	1.71E+03	2.92E+01	1.04E+02	9.87E+02	1.0821%
0.10	2.100	1.42E+04	2.41E+03	4.50E+01	1.29E+02	9.90E+02	0.6966%
0.10	2.200	1.16E+04	1.82E+03	3.64E+01	1.16E+02	9.88E+02	0.8527%
0.10	2.300	1.26E+04	1.87E+03	3.92E+01	1.20E+02	9.89E+02	0.7875%
0.10	2.400	7.82E+03	1.06E+03	2.42E+01	9.42E+01	9.86E+02	1.2613%
0.10	2.450	2.87E+03	3.34E+02	9.02E+00	5.66E+01	9.83E+02	3.4220%
0.25	1.900	1.20E+02	0.00E+00	1.35E-01	1.09E+01	9.81E+02	204.979%
0.25	2.000	2.29E+04	3.14E+03	2.92E+01	1.61E+02	9.95E+02	1.0837%
0.25	2.100	3.57E+04	4.34E+03	4.50E+01	2.00E+02	1.00E+03	0.7024%
0.25	2.200	2.90E+04	3.30E+03	3.64E+01	1.80E+02	9.98E+02	0.8609%
0.25	2.300	3.14E+04	3.47E+03	3.92E+01	1.87E+02	9.99E+02	0.7956%
0.25	2.400	1.95E+04	1.99E+03	2.42E+01	1.46E+02	9.92E+02	1.2738%
0.25	2.450	7.28E+03	7.35E+02	9.02E+00	8.95E+01	9.85E+02	3.3833%
0.50	1.900	2.39E+02	0.00E+00	1.35E-01	1.55E+01	9.81E+02	204.992%
0.50	2.000	4.60E+04	5.42E+03	2.92E+01	2.27E+02	1.01E+03	1.0941%
0.50	2.100	7.17E+04	7.71E+03	4.50E+01	2.82E+02	1.02E+03	0.7125%
0.50	2.200	5.83E+04	5.80E+03	3.64E+01	2.53E+02	1.01E+03	0.8694%
0.50	2.300	6.31E+04	6.01E+03	3.92E+01	2.63E+02	1.02E+03	0.8057%
0.50	2.400	3.92E+04	3.58E+03	2.42E+01	2.07E+02	1.00E+03	1.2788%
0.50	2.450	1.46E+04	1.27E+03	9.02E+00	1.26E+02	9.89E+02	3.3969%
1.00	1.900	4.79E+02	0.00E+00	1.35E-01	2.19E+01	9.81E+02	205.017%
1.00	2.000	9.36E+04	9.98E+03	2.92E+01	3.22E+02	1.03E+03	1.1031%
1.00	2.100	1.45E+05	1.45E+04	4.50E+01	4.00E+02	1.06E+03	0.7296%
1.00	2.200	1.18E+05	1.10E+04	3.64E+01	3.59E+02	1.05E+03	0.8861%
1.00	2.300	1.28E+05	1.14E+04	3.92E+01	3.73E+02	1.05E+03	0.8229%
1.00	2.400	7.92E+04	6.76E+03	2.42E+01	2.93E+02	1.02E+03	1.2929%
1.00	2.450	2.95E+04	2.47E+03	9.02E+00	1.79E+02	9.97E+02	3.3784%

Table A15. Calculated values for AVIRIS D. Rayleigh Atmosphere.

AVIRIS D		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	1.900	0.00E+00	0.00E+00	1.69E-01	0.00E+00	9.81E+02	∞
0.01	2.000	1.14E+03	0.00E+00	3.18E+01	3.38E+01	9.82E+02	0.8614%
0.01	2.100	1.69E+03	0.00E+00	4.86E+01	4.11E+01	9.83E+02	0.5827%
0.01	2.200	1.36E+03	0.00E+00	3.89E+01	3.69E+01	9.82E+02	0.7204%
0.01	2.300	1.47E+03	0.00E+00	4.16E+01	3.83E+01	9.83E+02	0.6685%
0.01	2.400	9.27E+02	0.00E+00	2.57E+01	3.05E+01	9.82E+02	1.0588%
0.01	2.450	3.34E+02	0.00E+00	9.56E+00	1.83E+01	9.81E+02	2.9386%
0.10	1.900	0.00E+00	0.00E+00	1.69E-01	0.00E+00	9.81E+02	∞
0.10	2.000	1.13E+04	0.00E+00	3.18E+01	1.06E+02	9.87E+02	0.8769%
0.10	2.100	1.72E+04	0.00E+00	4.86E+01	1.31E+02	9.91E+02	0.5751%
0.10	2.200	1.38E+04	0.00E+00	3.89E+01	1.17E+02	9.89E+02	0.7190%
0.10	2.300	1.47E+04	0.00E+00	4.16E+01	1.21E+02	9.89E+02	0.6731%
0.10	2.400	9.14E+03	0.00E+00	2.57E+01	9.56E+01	9.86E+02	1.0787%
0.10	2.450	3.41E+03	0.00E+00	9.56E+00	5.84E+01	9.83E+02	2.8856%
0.25	1.900	1.20E+02	0.00E+00	1.69E-01	1.09E+01	9.81E+02	204.979%
0.25	2.000	2.82E+04	0.00E+00	3.18E+01	1.68E+02	9.96E+02	0.8822%
0.25	2.100	4.30E+04	0.00E+00	4.86E+01	2.07E+02	1.00E+03	0.5834%
0.25	2.200	3.44E+04	0.00E+00	3.89E+01	1.86E+02	9.99E+02	0.7254%
0.25	2.300	3.69E+04	0.00E+00	4.16E+01	1.92E+02	1.00E+03	0.6782%
0.25	2.400	2.28E+04	0.00E+00	2.57E+01	1.51E+02	9.93E+02	1.0894%
0.25	2.450	8.48E+03	0.00E+00	9.56E+00	9.21E+01	9.85E+02	2.9045%
0.50	1.900	2.39E+02	0.00E+00	1.69E-01	1.55E+01	9.81E+02	204.992%
0.50	2.000	5.64E+04	0.00E+00	3.18E+01	2.38E+02	1.01E+03	0.8947%
0.50	2.100	8.62E+04	0.00E+00	4.86E+01	2.94E+02	1.03E+03	0.5949%
0.50	2.200	6.89E+04	0.00E+00	3.89E+01	2.62E+02	1.02E+03	0.7378%
0.50	2.300	7.39E+04	0.00E+00	4.16E+01	2.72E+02	1.02E+03	0.6894%
0.50	2.400	4.56E+04	0.00E+00	2.57E+01	2.13E+02	1.00E+03	1.1019%
0.50	2.450	1.70E+04	0.00E+00	9.56E+00	1.30E+02	9.90E+02	2.9172%
1.00	1.900	5.98E+02	0.00E+00	1.69E-01	2.45E+01	9.81E+02	164.024%
1.00	2.000	1.13E+05	0.00E+00	3.18E+01	3.36E+02	1.04E+03	0.9202%
1.00	2.100	1.72E+05	0.00E+00	4.86E+01	4.15E+02	1.07E+03	0.6188%
1.00	2.200	1.38E+05	0.00E+00	3.89E+01	3.71E+02	1.05E+03	0.7614%
1.00	2.300	1.48E+05	0.00E+00	4.16E+01	3.84E+02	1.05E+03	0.7141%
1.00	2.400	9.13E+04	0.00E+00	2.57E+01	3.02E+02	1.03E+03	1.1250%
1.00	2.450	3.39E+04	0.00E+00	9.56E+00	1.84E+02	9.98E+02	2.9423%

Table A16. Calculated values for ETM. Visibility = 23 km.

ETM		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	5.34E-12	8.53E-11	1.08E-12	1.23E-12	2.61E-12	0.4879%
0.01	0.571	1.03E-11	8.23E-11	1.75E-12	1.24E-12	2.95E-12	0.2865%
0.01	0.661	1.03E-11	4.72E-11	1.56E-12	9.78E-13	2.74E-12	0.2671%
0.01	0.838	1.53E-11	3.37E-11	2.09E-12	9.03E-13	3.05E-12	0.1990%
0.01	1.677	1.10E-11	4.74E-12	1.31E-12	5.12E-13	5.32E-12	0.4844%
0.01	2.217	7.08E-12	1.47E-12	8.28E-13	3.77E-13	5.21E-12	0.7357%
0.10	0.486	5.43E-11	1.02E-10	1.08E-12	1.61E-12	2.81E-12	0.5177%
0.10	0.571	1.04E-10	1.06E-10	1.75E-12	1.87E-12	3.27E-12	0.3134%
0.10	0.661	1.04E-10	6.47E-11	1.56E-12	1.67E-12	3.06E-12	0.2956%
0.10	0.838	1.54E-10	5.05E-11	2.09E-12	1.84E-12	3.45E-12	0.2238%
0.10	1.677	1.10E-10	8.66E-12	1.31E-12	1.40E-12	5.48E-12	0.4984%
0.10	2.217	7.09E-11	3.12E-12	8.28E-13	1.11E-12	5.31E-12	0.7489%
0.25	0.486	1.39E-10	1.32E-10	1.08E-12	2.13E-12	3.13E-12	0.5616%
0.25	0.571	2.66E-10	1.46E-10	1.75E-12	2.62E-12	3.74E-12	0.3525%
0.25	0.661	2.62E-10	9.46E-11	1.56E-12	2.44E-12	3.54E-12	0.3369%
0.25	0.838	3.88E-10	7.88E-11	2.09E-12	2.79E-12	4.03E-12	0.2596%
0.25	1.677	2.75E-10	1.52E-11	1.31E-12	2.20E-12	5.73E-12	0.5204%
0.25	2.217	1.78E-10	5.87E-12	8.28E-13	1.75E-12	5.48E-12	0.7718%
0.50	0.486	2.92E-10	1.86E-10	1.08E-12	2.82E-12	3.64E-12	0.6227%
0.50	0.571	5.49E-10	2.17E-10	1.75E-12	3.57E-12	4.46E-12	0.4065%
0.50	0.661	5.38E-10	1.46E-10	1.56E-12	3.37E-12	4.24E-12	0.3940%
0.50	0.838	7.88E-10	1.27E-10	2.09E-12	3.90E-12	4.87E-12	0.3090%
0.50	1.677	5.53E-10	2.62E-11	1.31E-12	3.10E-12	6.14E-12	0.5550%
0.50	2.217	3.56E-10	1.05E-11	8.28E-13	2.47E-12	5.75E-12	0.8085%
1.00	0.486	6.46E-10	3.10E-10	1.08E-12	3.99E-12	4.60E-12	0.7123%
1.00	0.571	1.18E-09	3.73E-10	1.75E-12	5.08E-12	5.74E-12	0.4880%
1.00	0.661	1.13E-09	2.57E-10	1.56E-12	4.80E-12	5.44E-12	0.4821%
1.00	0.838	1.62E-09	2.28E-10	2.09E-12	5.55E-12	6.27E-12	0.3863%
1.00	1.677	1.11E-09	4.85E-11	1.31E-12	4.40E-12	6.88E-12	0.6176%
1.00	2.217	7.14E-10	1.98E-11	8.28E-13	3.50E-12	6.26E-12	0.8766%

Table A17. Calculated values for ETM PAN band. Visibility = 23 km.

ETM		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	PAN	1.17E-11	6.06E-11	5.82E-14	1.10E-12	6.25E-12	0.5336%
0.10		1.18E-10	8.08E-11	2.17E-13	1.82E-12	6.42E-12	0.5435%
0.25		2.99E-10	1.15E-10	4.84E-13	2.63E-12	6.70E-12	0.5599%
0.50		6.13E-10	1.75E-10	9.39E-13	3.62E-12	7.20E-12	0.5868%
1.00		1.29E-09	3.06E-10	1.88E-12	5.15E-12	8.24E-12	0.6385%

Table A18. Calculated values for ETM. Visibility = 5 km.

ETM		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	2.30E-12	1.42E-10	9.08E-13	1.55E-12	2.71E-12	1.1783%
0.01	0.571	5.05E-12	1.59E-10	1.51E-12	1.65E-12	3.02E-12	0.5986%
0.01	0.661	5.60E-12	1.05E-10	1.38E-12	1.35E-12	2.80E-12	0.5008%
0.01	0.838	9.60E-12	8.78E-11	1.86E-12	1.27E-12	3.03E-12	0.3156%
0.01	1.677	8.91E-12	1.57E-11	1.21E-12	6.39E-13	5.31E-12	0.5959%
0.01	2.217	6.25E-12	4.83E-12	7.89E-13	4.29E-13	5.21E-12	0.8332%
0.10	0.486	2.35E-11	1.67E-10	9.08E-13	1.78E-12	2.85E-12	1.2102%
0.10	0.571	5.14E-11	1.98E-10	1.51E-12	2.04E-12	3.25E-12	0.6317%
0.10	0.661	5.69E-11	1.38E-10	1.38E-12	1.80E-12	3.04E-12	0.5347%
0.10	0.838	9.71E-11	1.24E-10	1.86E-12	1.92E-12	3.35E-12	0.3453%
0.10	1.677	8.94E-11	2.65E-11	1.21E-12	1.39E-12	5.45E-12	0.6095%
0.10	2.217	6.26E-11	9.76E-12	7.89E-13	1.10E-12	5.31E-12	0.8474%
0.25	0.486	6.13E-11	2.11E-10	9.08E-13	2.13E-12	3.08E-12	1.2561%
0.25	0.571	1.33E-10	2.68E-10	1.51E-12	2.58E-12	3.61E-12	0.6799%
0.25	0.661	1.46E-10	1.96E-10	1.38E-12	2.39E-12	3.42E-12	0.5850%
0.25	0.838	2.48E-10	1.87E-10	1.86E-12	2.69E-12	3.85E-12	0.3883%
0.25	1.677	2.25E-10	4.47E-11	1.21E-12	2.12E-12	5.68E-12	0.6309%
0.25	2.217	1.57E-10	1.80E-11	7.89E-13	1.71E-12	5.46E-12	0.8697%
0.50	0.486	1.31E-10	2.92E-10	9.08E-13	2.66E-12	3.46E-12	1.3173%
0.50	0.571	2.81E-10	3.94E-10	1.51E-12	3.35E-12	4.20E-12	0.7459%
0.50	0.661	3.07E-10	3.00E-10	1.38E-12	3.18E-12	4.01E-12	0.6542%
0.50	0.838	5.13E-10	2.98E-10	1.86E-12	3.67E-12	4.59E-12	0.4475%
0.50	1.677	4.56E-10	7.56E-11	1.21E-12	2.97E-12	6.05E-12	0.6642%
0.50	2.217	3.16E-10	3.19E-11	7.89E-13	2.41E-12	5.72E-12	0.9051%
1.00	0.486	3.08E-10	4.98E-10	9.08E-13	3.66E-12	4.28E-12	1.3906%
1.00	0.571	6.39E-10	6.97E-10	1.51E-12	4.71E-12	5.35E-12	0.8377%
1.00	0.661	6.80E-10	5.42E-10	1.38E-12	4.51E-12	5.13E-12	0.7548%
1.00	0.838	1.10E-09	5.44E-10	1.86E-12	5.23E-12	5.91E-12	0.5366%
1.00	1.677	9.33E-10	1.40E-10	1.21E-12	4.23E-12	6.76E-12	0.7239%
1.00	2.217	6.40E-10	6.02E-11	7.89E-13	3.41E-12	6.21E-12	0.9709%

Table A19. Calculated values for ETM PAN band. Visibility = 5 km.

ETM		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	PAN	6.45E-12	1.27E-10	5.82E-14	1.49E-12	6.33E-12	0.9806%
0.10		6.55E-11	1.64E-10	2.17E-13	1.95E-12	6.46E-12	0.9851%
0.25		1.68E-10	2.29E-10	4.84E-13	2.57E-12	6.68E-12	0.9929%
0.50		3.52E-10	3.46E-10	9.39E-13	3.41E-12	7.09E-12	1.0065%
1.00		7.79E-10	6.19E-10	1.88E-12	4.82E-12	8.04E-12	1.0322%

Table A20. Calculated values for ETM. Rayleigh Atmosphere.

ETM		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	7.63E-12	6.45E-11	1.14E-12	1.10E-12	2.57E-12	0.3370%
0.01	0.571	1.40E-11	5.43E-11	1.83E-12	1.07E-12	2.94E-12	0.2101%
0.01	0.661	1.33E-11	2.63E-11	1.63E-12	8.11E-13	2.73E-12	0.2050%
0.01	0.838	1.87E-11	1.38E-11	2.18E-12	7.36E-13	3.07E-12	0.1640%
0.01	1.677	1.20E-11	5.34E-13	1.36E-12	4.57E-13	5.33E-12	0.4434%
0.01	2.217	7.48E-12	1.13E-13	8.45E-13	3.55E-13	5.21E-12	0.6968%
0.10	0.486	7.72E-11	7.04E-11	1.14E-12	1.57E-12	2.81E-12	0.3633%
0.10	0.571	1.41E-10	5.97E-11	1.83E-12	1.83E-12	3.29E-12	0.2339%
0.10	0.661	1.33E-10	2.90E-11	1.63E-12	1.64E-12	3.08E-12	0.2307%
0.10	0.838	1.87E-10	1.52E-11	2.18E-12	1.84E-12	3.50E-12	0.1868%
0.10	1.677	1.20E-10	5.97E-13	1.36E-12	1.42E-12	5.49E-12	0.4574%
0.10	2.217	7.48E-11	1.32E-13	8.45E-13	1.12E-12	5.32E-12	0.7105%
0.25	0.486	1.97E-10	8.04E-11	1.14E-12	2.15E-12	3.17E-12	0.4022%
0.25	0.571	3.56E-10	6.89E-11	1.83E-12	2.66E-12	3.81E-12	0.2682%
0.25	0.661	3.36E-10	3.37E-11	1.63E-12	2.48E-12	3.60E-12	0.2676%
0.25	0.838	4.70E-10	1.76E-11	2.18E-12	2.85E-12	4.12E-12	0.2194%
0.25	1.677	3.00E-10	6.86E-13	1.36E-12	2.24E-12	5.76E-12	0.4795%
0.25	2.217	1.87E-10	1.51E-13	8.45E-13	1.77E-12	5.49E-12	0.7335%
0.50	0.486	4.07E-10	9.81E-11	1.14E-12	2.90E-12	3.72E-12	0.4567%
0.50	0.571	7.25E-10	8.48E-11	1.83E-12	3.67E-12	4.58E-12	0.3158%
0.50	0.661	6.79E-10	4.16E-11	1.63E-12	3.46E-12	4.33E-12	0.3190%
0.50	0.838	9.43E-10	2.16E-11	2.18E-12	4.01E-12	4.99E-12	0.2647%
0.50	1.677	6.01E-10	8.39E-13	1.36E-12	3.16E-12	6.18E-12	0.5143%
0.50	2.217	3.74E-10	1.89E-13	8.45E-13	2.50E-12	5.77E-12	0.7704%
1.00	0.486	8.73E-10	1.37E-10	1.14E-12	4.10E-12	4.72E-12	0.5401%
1.00	0.571	1.51E-09	1.18E-10	1.83E-12	5.20E-12	5.88E-12	0.3899%
1.00	0.661	1.39E-09	5.79E-11	1.63E-12	4.91E-12	5.55E-12	0.4001%
1.00	0.838	1.90E-09	2.96E-11	2.18E-12	5.67E-12	6.41E-12	0.3366%
1.00	1.677	1.20E-09	1.16E-12	1.36E-12	4.47E-12	6.94E-12	0.5775%
1.00	2.217	7.49E-10	2.64E-13	8.45E-13	3.53E-12	6.28E-12	0.8393%

Table A21. Calculated values for ETM PAN band. Rayleigh Atmosphere.

ETM		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	PAN	1.51E-11	3.65E-11	5.82E-14	9.27E-13	6.22E-12	0.4107%
0.10		1.52E-10	4.01E-11	2.17E-13	1.79E-12	6.41E-12	0.4214%
0.25		3.83E-10	4.64E-11	4.84E-13	2.67E-12	6.72E-12	0.4389%
0.50		7.75E-10	5.70E-11	9.39E-13	3.72E-12	7.25E-12	0.4675%
1.00		1.59E-09	7.95E-11	1.88E-12	5.27E-12	8.32E-12	0.5229%

Table A22(a). Calculated values for HIRIS. Visibility = 23 km.

HIRIS		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.450	1.61E+03	3.69E+04	2.25E+01	1.96E+02	3.59E+02	0.2234%
0.01	0.490	3.12E+03	4.76E+04	3.91E+01	2.25E+02	3.77E+02	0.1209%
0.01	0.550	5.31E+03	4.77E+04	5.80E+01	2.30E+02	3.83E+02	0.0721%
0.01	0.600	5.57E+03	3.56E+04	5.63E+01	2.03E+02	3.67E+02	0.0659%
0.01	0.620	5.76E+03	3.28E+04	5.71E+01	1.96E+02	3.63E+02	0.0630%
0.01	0.800	1.68E+03	4.15E+03	1.46E+01	7.64E+01	3.10E+02	0.1842%
0.01	0.860	8.77E+02	1.74E+03	7.36E+00	5.11E+01	3.04E+02	0.3472%
0.01	1.000	2.40E+02	3.21E+02	1.93E+00	2.37E+01	3.01E+02	1.2525%
0.01	1.240	4.31E+03	3.55E+03	3.33E+01	8.87E+01	1.00E+03	0.2328%
0.01	1.640	3.99E+03	1.78E+03	2.96E+01	7.60E+01	1.00E+03	0.2516%
0.01	2.130	2.45E+03	5.44E+02	1.83E+01	5.47E+01	1.00E+03	0.4088%
0.01	2.200	2.11E+03	4.22E+02	1.58E+01	5.03E+01	1.00E+03	0.4750%
0.01	2.400	1.22E+03	1.53E+02	9.42E+00	3.71E+01	1.00E+03	0.8170%
0.10	0.450	1.64E+04	4.29E+04	2.25E+01	2.44E+02	3.87E+02	0.2364%
0.10	0.490	3.18E+04	5.75E+04	3.91E+01	2.99E+02	4.25E+02	0.1339%
0.10	0.550	5.38E+04	6.07E+04	5.80E+01	3.38E+02	4.56E+02	0.0848%
0.10	0.600	5.62E+04	4.69E+04	5.63E+01	3.21E+02	4.43E+02	0.0789%
0.10	0.620	5.82E+04	4.38E+04	5.71E+01	3.19E+02	4.42E+02	0.0759%
0.10	0.800	1.69E+04	6.12E+03	1.46E+01	1.52E+02	3.37E+02	0.1986%
0.10	0.860	8.78E+03	2.65E+03	7.36E+00	1.07E+02	3.19E+02	0.3627%
0.10	1.000	2.41E+03	5.11E+02	1.93E+00	5.40E+01	3.05E+02	1.2669%
0.10	1.240	4.32E+04	5.90E+03	3.33E+01	2.22E+02	1.02E+03	0.2373%
0.10	1.640	3.96E+04	3.22E+03	2.96E+01	2.07E+02	1.02E+03	0.2579%
0.10	2.130	2.50E+04	1.23E+03	1.83E+01	1.62E+02	1.01E+03	0.4046%
0.10	2.200	2.16E+04	9.84E+02	1.58E+01	1.50E+02	1.01E+03	0.4673%
0.10	2.400	1.30E+04	4.59E+02	9.42E+00	1.16E+02	1.01E+03	0.7736%
0.25	0.450	4.22E+04	5.35E+04	2.25E+01	3.09E+02	4.32E+02	0.2554%
0.25	0.490	8.15E+04	7.47E+04	3.91E+01	3.95E+02	4.98E+02	0.1526%
0.25	0.550	1.37E+05	8.29E+04	5.80E+01	4.69E+02	5.60E+02	0.1020%
0.25	0.600	1.43E+05	6.62E+04	5.63E+01	4.57E+02	5.50E+02	0.0962%
0.25	0.620	1.48E+05	6.26E+04	5.71E+01	4.59E+02	5.51E+02	0.0932%
0.25	0.800	4.28E+04	9.47E+03	1.46E+01	2.29E+02	3.77E+02	0.2206%
0.25	0.860	2.21E+04	4.17E+03	7.36E+00	1.62E+02	3.41E+02	0.3852%
0.25	1.000	6.05E+03	8.27E+02	1.93E+00	8.29E+01	3.11E+02	1.2864%
0.25	1.240	1.08E+05	9.92E+03	3.33E+01	3.44E+02	1.06E+03	0.2440%
0.25	1.640	9.93E+04	5.60E+03	2.96E+01	3.24E+02	1.05E+03	0.2646%
0.25	2.130	6.26E+04	2.18E+03	1.83E+01	2.55E+02	1.03E+03	0.4121%
0.25	2.200	5.41E+04	1.83E+03	1.58E+01	2.37E+02	1.03E+03	0.4748%
0.25	2.400	3.25E+04	9.19E+02	9.42E+00	1.83E+02	1.02E+03	0.7830%

Table A22(b). Calculated values for HIRIS. Visibility = 23 km.

HIRIS		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.50	0.450	8.92E+04	7.27E+04	2.25E+01	4.02E+02	5.02E+02	0.2816%
0.50	0.490	1.71E+05	1.06E+05	3.91E+01	5.26E+02	6.07E+02	0.1775%
0.50	0.550	2.84E+05	1.22E+05	5.80E+01	6.37E+02	7.07E+02	0.1243%
0.50	0.600	2.94E+05	9.99E+04	5.63E+01	6.28E+02	6.98E+02	0.1187%
0.50	0.620	3.04E+05	9.54E+04	5.71E+01	6.32E+02	7.02E+02	0.1155%
0.50	0.800	8.69E+04	1.52E+04	1.46E+01	3.19E+02	4.38E+02	0.2524%
0.50	0.860	4.49E+04	6.77E+03	7.36E+00	2.27E+02	3.76E+02	0.4195%
0.50	1.000	1.22E+04	1.36E+03	1.93E+00	1.17E+02	3.22E+02	1.3169%
0.50	1.240	2.18E+05	1.66E+04	3.33E+01	4.85E+02	1.11E+03	0.2547%
0.50	1.640	2.00E+05	9.67E+03	2.96E+01	4.57E+02	1.10E+03	0.2756%
0.50	2.130	1.25E+05	3.95E+03	1.83E+01	3.60E+02	1.06E+03	0.4235%
0.50	2.200	1.08E+05	3.23E+03	1.58E+01	3.34E+02	1.05E+03	0.4866%
0.50	2.400	6.51E+04	1.68E+03	9.42E+00	2.58E+02	1.03E+03	0.7936%
1.00	0.450	2.01E+05	1.18E+05	2.25E+01	5.65E+02	6.40E+02	0.3186%
1.00	0.490	3.78E+05	1.77E+05	3.91E+01	7.45E+02	8.04E+02	0.2129%
1.00	0.550	6.13E+05	2.10E+05	5.80E+01	9.07E+02	9.57E+02	0.1562%
1.00	0.600	6.25E+05	1.74E+05	5.63E+01	8.93E+02	9.44E+02	0.1511%
1.00	0.620	6.43E+05	1.67E+05	5.71E+01	9.00E+02	9.50E+02	0.1478%
1.00	0.800	1.79E+05	2.72E+04	1.46E+01	4.54E+02	5.45E+02	0.3037%
1.00	0.860	9.22E+04	1.22E+04	7.36E+00	3.23E+02	4.41E+02	0.4781%
1.00	1.000	2.49E+04	2.47E+03	1.93E+00	1.66E+02	3.43E+02	1.3742%
1.00	1.240	4.42E+05	3.03E+04	3.33E+01	6.88E+02	1.21E+03	0.2744%
1.00	1.640	4.02E+05	1.78E+04	2.96E+01	6.48E+02	1.19E+03	0.2964%
1.00	2.130	2.52E+05	7.35E+03	1.83E+01	5.09E+02	1.12E+03	0.4450%
1.00	2.200	2.18E+05	6.04E+03	1.58E+01	4.73E+02	1.11E+03	0.5085%
1.00	2.400	1.30E+05	3.22E+03	9.42E+00	3.66E+02	1.06E+03	0.8162%

Table A23(a). Calculated values for HIRIS. Visibility = 5 km.

HIRIS		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.450	6.46E+02	5.76E+04	1.87E+01	2.41E+02	3.85E+02	0.5966%
0.01	0.490	1.36E+03	8.01E+04	3.30E+01	2.85E+02	4.15E+02	0.3053%
0.01	0.550	2.53E+03	8.99E+04	4.97E+01	3.04E+02	4.30E+02	0.1703%
0.01	0.600	2.83E+03	7.27E+04	4.89E+01	2.75E+02	4.10E+02	0.1448%
0.01	0.620	3.02E+03	6.89E+04	4.99E+01	2.68E+02	4.06E+02	0.1341%
0.01	0.800	1.03E+03	1.06E+04	1.29E+01	1.08E+02	3.19E+02	0.3095%
0.01	0.860	5.58E+02	4.63E+03	6.55E+00	7.20E+01	3.09E+02	0.5531%
0.01	1.000	1.64E+02	9.29E+02	1.72E+00	3.31E+01	3.02E+02	1.8389%
0.01	1.240	3.16E+03	1.10E+04	3.00E+01	1.19E+02	1.01E+03	0.3184%
0.01	1.640	3.22E+03	5.77E+03	2.73E+01	9.48E+01	1.00E+03	0.3117%
0.01	2.130	2.18E+03	1.77E+03	1.74E+01	6.28E+01	1.00E+03	0.4601%
0.01	2.200	1.97E+03	1.41E+03	1.50E+01	5.81E+01	1.00E+03	0.5091%
0.01	2.400	1.22E+03	7.66E+02	9.03E+00	4.46E+01	1.00E+03	0.8172%
0.10	0.450	6.64E+03	6.57E+04	1.87E+01	2.69E+02	4.03E+02	0.6072%
0.10	0.490	1.39E+04	9.44E+04	3.30E+01	3.29E+02	4.47E+02	0.3216%
0.10	0.550	2.58E+04	1.11E+05	4.97E+01	3.70E+02	4.79E+02	0.1858%
0.10	0.600	2.89E+04	9.27E+04	4.89E+01	3.49E+02	4.63E+02	0.1603%
0.10	0.620	3.07E+04	8.90E+04	4.99E+01	3.46E+02	4.61E+02	0.1502%
0.10	0.800	1.05E+04	1.48E+04	1.29E+01	1.59E+02	3.40E+02	0.3247%
0.10	0.860	5.63E+03	6.64E+03	6.55E+00	1.11E+02	3.20E+02	0.5677%
0.10	1.000	1.65E+03	1.38E+03	1.72E+00	5.50E+01	3.05E+02	1.8507%
0.10	1.240	3.21E+04	1.71E+04	3.00E+01	2.22E+02	1.02E+03	0.3195%
0.10	1.640	3.22E+04	9.76E+03	2.73E+01	2.05E+02	1.02E+03	0.3176%
0.10	2.130	2.19E+04	3.68E+03	1.74E+01	1.60E+02	1.01E+03	0.4622%
0.10	2.200	1.91E+04	2.95E+03	1.50E+01	1.49E+02	1.01E+03	0.5290%
0.10	2.400	1.16E+04	1.53E+03	9.03E+00	1.15E+02	1.01E+03	0.8650%
0.25	0.450	1.73E+04	8.00E+04	1.87E+01	3.12E+02	4.33E+02	0.6247%
0.25	0.490	3.61E+04	1.20E+05	3.30E+01	3.95E+02	4.97E+02	0.3441%
0.25	0.550	6.67E+04	1.48E+05	4.97E+01	4.63E+02	5.54E+02	0.2077%
0.25	0.600	7.44E+04	1.28E+05	4.89E+01	4.49E+02	5.43E+02	0.1823%
0.25	0.620	7.90E+04	1.24E+05	4.99E+01	4.50E+02	5.44E+02	0.1721%
0.25	0.800	2.67E+04	2.21E+04	1.29E+01	2.21E+02	3.73E+02	0.3488%
0.25	0.860	1.44E+04	1.01E+04	6.55E+00	1.56E+02	3.38E+02	0.5892%
0.25	1.000	4.18E+03	2.14E+03	1.72E+00	7.95E+01	3.10E+02	1.8543%
0.25	1.240	8.10E+04	2.75E+04	3.00E+01	3.29E+02	1.05E+03	0.3250%
0.25	1.640	8.09E+04	1.64E+04	2.73E+01	3.12E+02	1.05E+03	0.3237%
0.25	2.130	5.50E+04	6.67E+03	1.74E+01	2.48E+02	1.03E+03	0.4685%
0.25	2.200	4.78E+04	5.48E+03	1.50E+01	2.31E+02	1.03E+03	0.5370%
0.25	2.400	2.91E+04	2.91E+03	9.03E+00	1.79E+02	1.02E+03	0.8730%

Table A23(b). Calculated values for HIRIS. Visibility = 5 km.

HIRIS		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.50	0.450	3.75E+04	1.07E+05	1.87E+01	3.80E+02	4.85E+02	0.6470%
0.50	0.490	7.75E+04	1.67E+05	3.30E+01	4.95E+02	5.80E+02	0.3738%
0.50	0.550	1.42E+05	2.16E+05	4.97E+01	5.98E+02	6.71E+02	0.2367%
0.50	0.600	1.57E+05	1.91E+05	4.89E+01	5.90E+02	6.64E+02	0.2113%
0.50	0.620	1.66E+05	1.87E+05	4.99E+01	5.95E+02	6.68E+02	0.2008%
0.50	0.800	5.54E+04	3.50E+04	1.29E+01	3.01E+02	4.25E+02	0.3835%
0.50	0.860	2.97E+04	1.61E+04	6.55E+00	2.14E+02	3.69E+02	0.6212%
0.50	1.000	8.59E+03	3.47E+03	1.72E+00	1.10E+02	3.19E+02	1.8601%
0.50	1.240	1.65E+05	4.53E+04	3.00E+01	4.59E+02	1.10E+03	0.3332%
0.50	1.640	1.64E+05	2.77E+04	2.73E+01	4.38E+02	1.09E+03	0.3333%
0.50	2.130	1.11E+05	1.17E+04	1.74E+01	3.50E+02	1.06E+03	0.4787%
0.50	2.200	9.63E+04	9.70E+03	1.50E+01	3.26E+02	1.05E+03	0.5462%
0.50	2.400	5.83E+04	5.36E+03	9.03E+00	2.52E+02	1.03E+03	0.8840%
1.00	0.450	8.91E+04	1.77E+05	1.87E+01	5.16E+02	5.97E+02	0.6694%
1.00	0.490	1.82E+05	2.87E+05	3.30E+01	6.85E+02	7.48E+02	0.4118%
1.00	0.550	3.24E+05	3.81E+05	4.97E+01	8.39E+02	8.93E+02	0.2757%
1.00	0.600	3.53E+05	3.41E+05	4.89E+01	8.33E+02	8.87E+02	0.2513%
1.00	0.620	3.72E+05	3.36E+05	4.99E+01	8.42E+02	8.95E+02	0.2406%
1.00	0.800	1.20E+05	6.38E+04	1.29E+01	4.28E+02	5.23E+02	0.4374%
1.00	0.860	6.35E+04	2.95E+04	6.55E+00	3.05E+02	4.28E+02	0.6733%
1.00	1.000	1.81E+04	6.34E+03	1.72E+00	1.56E+02	3.38E+02	1.8671%
1.00	1.240	3.43E+05	8.30E+04	3.00E+01	6.53E+02	1.19E+03	0.3480%
1.00	1.640	3.36E+05	5.12E+04	2.73E+01	6.22E+02	1.18E+03	0.3509%
1.00	2.130	2.24E+05	2.21E+04	1.74E+01	4.96E+02	1.12E+03	0.4977%
1.00	2.200	1.95E+05	1.83E+04	1.50E+01	4.62E+02	1.10E+03	0.5651%
1.00	2.400	1.18E+05	1.01E+04	9.03E+00	3.58E+02	1.06E+03	0.8998%

Table A24(a). Calculations for HIRIS. Rayleigh Atmosphere.

HIRIS		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.450	2.36E+03	2.93E+04	2.40E+01	1.78E+02	3.50E+02	0.1482%
0.01	0.490	4.45E+03	3.57E+04	4.13E+01	2.00E+02	3.63E+02	0.0815%
0.01	0.550	7.27E+03	3.23E+04	6.09E+01	1.99E+02	3.65E+02	0.0502%
0.01	0.600	7.41E+03	2.20E+04	5.89E+01	1.72E+02	3.51E+02	0.0473%
0.01	0.620	7.59E+03	1.95E+04	5.96E+01	1.65E+02	3.47E+02	0.0457%
0.01	0.800	2.08E+03	1.79E+03	1.52E+01	6.22E+01	3.07E+02	0.1476%
0.01	0.860	1.06E+03	6.77E+02	7.69E+00	4.17E+01	3.03E+02	0.2856%
0.01	1.000	2.83E+02	9.64E+01	2.02E+00	1.95E+01	3.01E+02	1.0639%
0.01	1.240	4.89E+03	7.19E+02	3.47E+01	7.49E+01	1.00E+03	0.2052%
0.01	1.640	4.33E+03	1.70E+02	3.06E+01	6.71E+01	1.00E+03	0.2317%
0.01	2.130	2.59E+03	0.00E+00	1.87E+01	5.09E+01	1.00E+03	0.3872%
0.01	2.200	2.25E+03	0.00E+00	1.61E+01	4.74E+01	1.00E+03	0.4453%
0.01	2.400	1.38E+03	0.00E+00	9.59E+00	3.71E+01	1.00E+03	0.7262%
0.10	0.450	2.40E+04	3.17E+04	2.40E+01	2.36E+02	3.82E+02	0.1596%
0.10	0.490	4.50E+04	3.91E+04	4.13E+01	2.90E+02	4.19E+02	0.0931%
0.10	0.550	7.34E+04	3.56E+04	6.09E+01	3.30E+02	4.50E+02	0.0614%
0.10	0.600	7.45E+04	2.43E+04	5.89E+01	3.14E+02	4.38E+02	0.0589%
0.10	0.620	7.64E+04	2.15E+04	5.96E+01	3.13E+02	4.38E+02	0.0573%
0.10	0.800	2.08E+04	1.96E+03	1.52E+01	1.51E+02	3.36E+02	0.1616%
0.10	0.860	1.06E+04	7.47E+02	7.69E+00	1.07E+02	3.18E+02	0.3000%
0.10	1.000	2.83E+03	1.03E+02	2.02E+00	5.41E+01	3.05E+02	1.0788%
0.10	1.240	4.90E+04	7.19E+02	3.47E+01	2.23E+02	1.03E+03	0.2090%
0.10	1.640	4.34E+04	1.70E+02	3.06E+01	2.09E+02	1.02E+03	0.2357%
0.10	2.130	2.65E+04	0.00E+00	1.87E+01	1.63E+02	1.01E+03	0.3818%
0.10	2.200	2.28E+04	0.00E+00	1.61E+01	1.51E+02	1.01E+03	0.4442%
0.10	2.400	1.36E+04	0.00E+00	9.59E+00	1.17E+02	1.01E+03	0.7388%
0.25	0.450	6.14E+04	3.58E+04	2.40E+01	3.12E+02	4.33E+02	0.1765%
0.25	0.490	1.15E+05	4.49E+04	4.13E+01	4.00E+02	5.01E+02	0.1092%
0.25	0.550	1.86E+05	4.11E+04	6.09E+01	4.76E+02	5.66E+02	0.0762%
0.25	0.600	1.88E+05	2.80E+04	5.89E+01	4.65E+02	5.56E+02	0.0740%
0.25	0.620	1.93E+05	2.49E+04	5.96E+01	4.66E+02	5.58E+02	0.0724%
0.25	0.800	5.22E+04	2.26E+03	1.52E+01	2.33E+02	3.80E+02	0.1822%
0.25	0.860	2.66E+04	8.72E+02	7.69E+00	1.66E+02	3.43E+02	0.3223%
0.25	1.000	7.07E+03	1.15E+02	2.02E+00	8.48E+01	3.12E+02	1.1017%
0.25	1.240	1.23E+05	7.67E+02	3.47E+01	3.51E+02	1.06E+03	0.2160%
0.25	1.640	1.09E+05	2.55E+02	3.06E+01	3.30E+02	1.05E+03	0.2427%
0.25	2.130	6.63E+04	0.00E+00	1.87E+01	2.57E+02	1.03E+03	0.3895%
0.25	2.200	5.69E+04	0.00E+00	1.61E+01	2.39E+02	1.03E+03	0.4516%
0.25	2.400	3.40E+04	0.00E+00	9.59E+00	1.84E+02	1.02E+03	0.7479%

Table A24(b). Calculations for HIRIS. Rayleigh Atmosphere.

HIRIS		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.50	0.450	1.28E+05	4.32E+04	2.40E+01	4.14E+02	5.12E+02	0.1999%
0.50	0.490	2.37E+05	5.51E+04	4.13E+01	5.41E+02	6.20E+02	0.1306%
0.50	0.550	3.79E+05	5.07E+04	6.09E+01	6.56E+02	7.24E+02	0.0954%
0.50	0.600	3.82E+05	3.44E+04	5.89E+01	6.45E+02	7.14E+02	0.0935%
0.50	0.620	3.90E+05	3.07E+04	5.96E+01	6.49E+02	7.17E+02	0.0919%
0.50	0.800	1.05E+05	2.77E+03	1.52E+01	3.28E+02	4.45E+02	0.2121%
0.50	0.860	5.34E+04	1.08E+03	7.69E+00	2.33E+02	3.80E+02	0.3561%
0.50	1.000	1.42E+04	1.32E+02	2.02E+00	1.20E+02	3.23E+02	1.1390%
0.50	1.240	2.46E+05	7.67E+02	3.47E+01	4.96E+02	1.12E+03	0.2274%
0.50	1.640	2.17E+05	2.55E+02	3.06E+01	4.66E+02	1.10E+03	0.2543%
0.50	2.130	1.32E+05	0.00E+00	1.87E+01	3.64E+02	1.06E+03	0.4018%
0.50	2.200	1.14E+05	0.00E+00	1.61E+01	3.38E+02	1.06E+03	0.4631%
0.50	2.400	6.81E+04	0.00E+00	9.59E+00	2.61E+02	1.03E+03	0.7584%
1.00	0.450	2.80E+05	6.01E+04	2.40E+01	5.83E+02	6.56E+02	0.2344%
1.00	0.490	5.08E+05	7.76E+04	4.13E+01	7.65E+02	8.23E+02	0.1620%
1.00	0.550	7.93E+05	7.11E+04	6.09E+01	9.30E+02	9.79E+02	0.1234%
1.00	0.600	7.87E+05	4.78E+04	5.89E+01	9.14E+02	9.64E+02	0.1224%
1.00	0.620	8.03E+05	4.28E+04	5.96E+01	9.20E+02	9.69E+02	0.1207%
1.00	0.800	2.12E+05	3.78E+03	1.52E+01	4.64E+02	5.53E+02	0.2610%
1.00	0.860	1.08E+05	1.50E+03	7.69E+00	3.30E+02	4.46E+02	0.4148%
1.00	1.000	2.85E+04	1.69E+02	2.02E+00	1.69E+02	3.44E+02	1.2097%
1.00	1.240	4.92E+05	8.63E+02	3.47E+01	7.02E+02	1.22E+03	0.2484%
1.00	1.640	4.34E+05	4.24E+02	3.06E+01	6.59E+02	1.20E+03	0.2759%
1.00	2.130	2.65E+05	0.00E+00	1.87E+01	5.15E+02	1.12E+03	0.4245%
1.00	2.200	2.28E+05	0.00E+00	1.61E+01	4.77E+02	1.11E+03	0.4862%
1.00	2.400	1.36E+05	0.00E+00	9.59E+00	3.69E+02	1.07E+03	0.7831%

Table A25. Calculations for MODIS-N. Visibility = 23 km.

MODIS-N		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.435	4.49E+05	1.23E+07	6.67E+03	3.58E+03	7.58E+03	0.0169%
0.01	0.490	7.46E+05	1.14E+07	9.35E+03	3.48E+03	9.99E+03	0.0134%
0.01	0.620	1.03E+06	5.85E+06	1.02E+04	2.62E+03	1.05E+04	0.0102%
0.01	0.865	6.21E+05	1.21E+06	5.20E+03	1.35E+03	5.40E+03	0.0087%
0.01	1.240	1.20E+05	9.82E+04	9.30E+02	4.67E+02	1.15E+03	0.0096%
0.01	1.640	8.36E+04	3.74E+04	6.22E+02	3.48E+02	8.70E+02	0.0104%
0.01	2.130	1.05E+05	2.31E+04	7.72E+02	3.58E+02	9.87E+02	0.0094%
0.10	0.435	4.57E+06	1.42E+07	6.67E+03	4.33E+03	7.97E+03	0.0174%
0.10	0.490	7.59E+06	1.37E+07	9.35E+03	4.62E+03	1.04E+04	0.0137%
0.10	0.620	1.04E+07	7.81E+06	1.02E+04	4.27E+03	1.11E+04	0.0106%
0.10	0.865	6.22E+06	1.85E+06	5.20E+03	2.84E+03	5.95E+03	0.0096%
0.10	1.240	1.21E+06	1.65E+05	9.30E+02	1.17E+03	1.58E+03	0.0131%
0.10	1.640	8.32E+05	6.76E+04	6.22E+02	9.49E+02	1.24E+03	0.0149%
0.10	2.130	1.06E+06	4.97E+04	7.72E+02	1.05E+03	1.40E+03	0.0132%
0.25	0.435	1.18E+07	1.74E+07	6.67E+03	5.41E+03	8.60E+03	0.0182%
0.25	0.490	1.95E+07	1.79E+07	9.35E+03	6.11E+03	1.12E+04	0.0143%
0.25	0.620	2.64E+07	1.12E+07	1.02E+04	6.13E+03	1.19E+04	0.0113%
0.25	0.865	1.57E+07	2.92E+06	5.20E+03	4.31E+03	6.78E+03	0.0108%
0.25	1.240	3.03E+06	2.76E+05	9.30E+02	1.82E+03	2.10E+03	0.0174%
0.25	1.640	2.09E+06	1.18E+05	6.22E+02	1.49E+03	1.69E+03	0.0202%
0.25	2.130	2.64E+06	9.24E+04	7.72E+02	1.65E+03	1.89E+03	0.0179%
0.50	0.435	2.51E+07	2.33E+07	6.67E+03	6.96E+03	9.65E+03	0.0192%
0.50	0.490	4.08E+07	2.52E+07	9.35E+03	8.13E+03	1.24E+04	0.0152%
0.50	0.620	5.42E+07	1.70E+07	1.02E+04	8.44E+03	1.32E+04	0.0122%
0.50	0.865	3.18E+07	4.74E+06	5.20E+03	6.04E+03	7.99E+03	0.0126%
0.50	1.240	6.09E+06	4.64E+05	9.30E+02	2.56E+03	2.77E+03	0.0227%
0.50	1.640	4.19E+06	2.03E+05	6.22E+02	2.10E+03	2.24E+03	0.0268%
0.50	2.130	5.30E+06	1.63E+05	7.72E+02	2.34E+03	2.51E+03	0.0237%
1.00	0.435	5.71E+07	3.76E+07	6.67E+03	9.73E+03	1.18E+04	0.0207%
1.00	0.490	9.03E+07	4.23E+07	9.35E+03	1.15E+04	1.48E+04	0.0164%
1.00	0.620	1.15E+08	2.97E+07	1.02E+04	1.20E+04	1.58E+04	0.0137%
1.00	0.865	6.53E+07	8.54E+06	5.20E+03	8.59E+03	1.01E+04	0.0154%
1.00	1.240	1.23E+07	8.47E+05	9.30E+02	3.63E+03	3.78E+03	0.0306%
1.00	1.640	8.45E+06	3.74E+05	6.22E+02	2.97E+03	3.08E+03	0.0364%
1.00	2.130	1.06E+07	3.07E+05	7.72E+02	3.31E+03	3.43E+03	0.0323%

Table A26. Calculations for MODIS-N. Visibility = 5 km.

MODIS-N		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.435	1.74E+05	1.87E+07	5.53E+03	4.34E+03	7.05E+03	0.0404%
0.01	0.490	3.25E+05	1.91E+07	7.90E+03	4.41E+03	9.06E+03	0.0279%
0.01	0.620	5.40E+05	1.23E+07	8.91E+03	3.58E+03	9.62E+03	0.0178%
0.01	0.865	3.95E+05	3.24E+06	4.63E+03	1.91E+03	5.04E+03	0.0127%
0.01	1.240	8.87E+04	3.09E+06	8.38E+02	6.30E+02	1.16E+03	0.0131%
0.01	1.640	6.76E+04	1.22E+05	5.73E+02	4.35E+02	8.76E+02	0.0130%
0.01	2.130	9.24E+04	7.74E+04	7.33E+02	4.12E+02	9.78E+02	0.0106%
0.10	0.435	1.80E+06	2.10E+07	5.53E+03	4.78E+03	7.32E+03	0.0407%
0.10	0.490	3.32E+06	2.26E+07	7.90E+03	5.09E+03	9.41E+03	0.0283%
0.10	0.620	5.47E+06	1.59E+07	8.91E+03	4.62E+03	1.01E+04	0.0184%
0.10	0.865	4.00E+06	4.65E+06	4.63E+03	2.94E+03	5.51E+03	0.0138%
0.10	1.240	8.94E+05	4.79E+05	8.38E+02	1.17E+03	1.53E+03	0.0171%
0.10	1.640	6.75E+05	2.05E+05	5.73E+02	9.38E+02	1.21E+03	0.0179%
0.10	2.130	9.25E+05	1.54E+05	7.33E+02	1.04E+03	1.37E+03	0.0148%
0.25	0.435	4.71E+06	2.53E+07	5.53E+03	5.47E+03	7.79E+03	0.0414%
0.25	0.490	8.63E+06	2.87E+07	7.90E+03	6.11E+03	1.00E+04	0.0289%
0.25	0.620	1.41E+07	2.21E+07	8.91E+03	6.02E+03	1.08E+04	0.0191%
0.25	0.865	1.02E+07	7.06E+06	4.63E+03	4.15E+03	6.24E+03	0.0153%
0.25	1.240	2.26E+06	7.68E+05	8.38E+02	1.74E+03	2.00E+03	0.0221%
0.25	1.640	1.70E+06	3.45E+05	5.73E+02	1.43E+03	1.62E+03	0.0238%
0.25	2.130	2.32E+06	2.81E+05	7.33E+02	1.61E+03	1.84E+03	0.0198%
0.50	0.435	1.02E+07	3.32E+07	5.53E+03	6.59E+03	8.61E+03	0.0422%
0.50	0.490	1.85E+07	4.00E+07	7.90E+03	7.65E+03	1.10E+04	0.0297%
0.50	0.620	2.97E+07	3.34E+07	8.91E+03	7.94E+03	1.20E+04	0.0201%
0.50	0.865	2.11E+07	1.13E+07	4.63E+03	5.69E+03	7.35E+03	0.0175%
0.50	1.240	4.61E+06	1.26E+06	8.38E+02	2.42E+03	2.61E+03	0.0284%
0.50	1.640	3.44E+06	5.83E+05	5.73E+02	2.01E+03	2.14E+03	0.0312%
0.50	2.130	4.67E+06	4.93E+05	7.33E+02	2.27E+03	2.44E+03	0.0261%
1.00	0.435	2.45E+07	5.39E+07	5.53E+03	8.86E+03	1.05E+04	0.0427%
1.00	0.490	4.34E+07	6.86E+07	7.90E+03	1.06E+04	1.32E+04	0.0304%
1.00	0.620	6.64E+07	6.01E+07	8.91E+03	1.12E+04	1.44E+04	0.0216%
1.00	0.865	4.51E+07	2.07E+07	4.63E+03	8.11E+03	9.35E+03	0.0207%
1.00	1.240	9.58E+06	2.32E+06	8.38E+02	3.45E+03	3.58E+03	0.0374%
1.00	1.640	7.05E+06	1.08E+06	5.73E+02	2.85E+03	2.95E+03	0.0419%
1.00	2.130	9.47E+06	9.30E+05	7.33E+02	3.22E+03	3.34E+03	0.0353%

Table A27. Calculations for MODIS-N. Rayleigh Atmosphere.

MODIS-N		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.435	6.68E+05	1.00E+07	7.12E+03	3.27E+03	7.85E+03	0.0117%
0.01	0.490	1.06E+06	8.54E+06	9.87E+03	3.10E+03	1.04E+04	0.0097%
0.01	0.620	1.36E+06	3.48E+06	1.06E+04	2.20E+03	1.09E+04	0.0080%
0.01	0.865	7.51E+05	4.69E+05	5.44E+03	1.10E+03	5.57E+03	0.0074%
0.01	1.240	1.37E+05	1.95E+04	9.69E+02	3.96E+02	1.16E+03	0.0085%
0.01	1.640	9.07E+04	4.45E+03	6.43E+02	3.08E+02	8.71E+02	0.0096%
0.01	2.130	1.12E+05	2.31E+03	7.89E+02	3.38E+02	9.93E+02	0.0089%
0.10	0.435	6.78E+06	1.08E+07	7.12E+03	4.19E+03	8.28E+03	0.0122%
0.10	0.490	1.08E+07	9.35E+06	9.87E+03	4.49E+03	1.09E+04	0.0101%
0.10	0.620	1.36E+07	3.85E+06	1.06E+04	4.18E+03	1.14E+04	0.0084%
0.10	0.865	7.51E+06	5.18E+05	5.44E+03	2.83E+03	6.15E+03	0.0082%
0.10	1.240	1.37E+06	2.02E+04	9.69E+02	1.18E+03	1.61E+03	0.0117%
0.10	1.640	9.11E+05	5.33E+03	6.43E+02	9.57E+02	1.26E+03	0.0138%
0.10	2.130	1.12E+06	2.31E+03	7.89E+02	1.06E+03	1.41E+03	0.0126%
0.25	0.435	1.74E+07	1.22E+07	7.12E+03	5.44E+03	8.97E+03	0.0129%
0.25	0.490	2.74E+07	1.07E+07	9.87E+03	6.18E+03	1.17E+04	0.0106%
0.25	0.620	3.44E+07	4.45E+06	1.06E+04	6.23E+03	1.23E+04	0.0090%
0.25	0.865	1.88E+07	6.03E+05	5.44E+03	4.41E+03	7.02E+03	0.0093%
0.25	1.240	3.42E+06	2.02E+04	9.69E+02	1.86E+03	2.15E+03	0.0157%
0.25	1.640	2.28E+06	5.33E+03	6.43E+02	1.51E+03	1.72E+03	0.0188%
0.25	2.130	2.80E+06	3.46E+03	7.89E+02	1.67E+03	1.92E+03	0.0171%
0.50	0.435	3.65E+07	1.47E+07	7.12E+03	7.15E+03	1.01E+04	0.0138%
0.50	0.490	5.67E+07	1.32E+07	9.87E+03	8.36E+03	1.29E+04	0.0114%
0.50	0.620	6.97E+07	5.49E+06	1.06E+04	8.67E+03	1.37E+04	0.0099%
0.50	0.865	3.78E+07	7.44E+05	5.44E+03	6.21E+03	8.27E+03	0.0109%
0.50	1.240	6.85E+06	2.15E+04	9.69E+02	2.62E+03	2.84E+03	0.0207%
0.50	1.640	4.56E+06	7.11E+03	6.43E+02	2.14E+03	2.29E+03	0.0251%
0.50	2.130	5.59E+06	3.46E+03	7.89E+02	2.37E+03	2.54E+03	0.0227%
1.00	0.435	8.06E+07	2.04E+07	7.12E+03	1.01E+04	1.23E+04	0.0153%
1.00	0.490	1.21E+08	1.86E+07	9.87E+03	1.18E+04	1.54E+04	0.0127%
1.00	0.620	1.43E+08	7.64E+06	1.06E+04	1.23E+04	1.63E+04	0.0113%
1.00	0.865	7.61E+07	1.03E+06	5.44E+03	8.78E+03	1.03E+04	0.0136%
1.00	1.240	1.37E+07	2.29E+04	9.69E+02	3.71E+03	3.87E+03	0.0282%
1.00	1.640	9.12E+06	9.78E+03	6.43E+02	3.02E+03	3.13E+03	0.0343%
1.00	2.130	1.12E+07	4.62E+03	7.89E+02	3.35E+03	3.47E+03	0.0310%

Table A28. Calculations for SPOT-1 HRV. Visibility = 23 km.

SPOT-1 HRV		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.551	5.08E+03	4.76E+04	8.93E+02	2.30E+02	1.24E+03	0.2446%
0.01	0.653	4.50E+03	2.17E+04	6.91E+02	1.62E+02	1.05E+03	0.2327%
0.01	0.838	5.45E+03	1.19E+04	7.41E+02	1.32E+02	1.23E+03	0.2265%
0.10	0.551	5.14E+04	6.01E+04	8.93E+02	3.34E+02	1.27E+03	0.2462%
0.10	0.653	4.54E+04	2.96E+04	6.91E+02	2.74E+02	1.07E+03	0.2358%
0.10	0.838	5.48E+04	1.78E+04	7.41E+02	2.69E+02	1.26E+03	0.2294%
0.25	0.551	1.31E+05	8.17E+04	8.93E+02	4.61E+02	1.31E+03	0.2486%
0.25	0.653	1.15E+05	4.30E+04	6.91E+02	3.98E+02	1.11E+03	0.2407%
0.25	0.838	1.38E+05	2.79E+04	7.41E+02	4.07E+02	1.29E+03	0.2341%
0.50	0.551	2.72E+05	1.20E+05	8.93E+02	6.26E+02	1.37E+03	0.2522%
0.50	0.653	2.36E+05	6.63E+04	6.91E+02	5.50E+02	1.17E+03	0.2483%
0.50	0.838	2.80E+05	4.50E+04	7.41E+02	5.70E+02	1.35E+03	0.2415%
1.00	0.551	5.87E+05	2.05E+05	8.93E+02	8.90E+02	1.51E+03	0.2574%
1.00	0.653	4.96E+05	1.16E+05	6.91E+02	7.83E+02	1.30E+03	0.2613%
1.00	0.838	5.77E+05	8.08E+04	7.41E+02	8.11E+02	1.47E+03	0.2550%

Table A29. Calculations for SPOT-1 HRV PAN band. Visibility = 23 km.

SPOT-1 HRV		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	PAN	2.85E+03	1.81E+04	4.25E+00	1.45E+02	7.63E+02	0.2679%
0.10		2.88E+04	2.37E+04	1.42E+01	2.29E+02	7.83E+02	0.2725%
0.25		7.31E+04	3.34E+04	3.10E+01	3.26E+02	8.18E+02	0.2797%
0.50		1.50E+05	5.03E+04	5.97E+01	4.48E+02	8.75E+02	0.2909%
1.00		3.19E+05	8.73E+04	1.20E+02	6.37E+02	9.91E+02	0.3106%

Table A30. Calculations for SPOT-1 HRV. Visibility = 5 km.

SPOT-1 HRV		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.551	2.42E+03	8.86E+04	7.66E+02	3.02E+02	1.17E+03	0.4842%
0.01	0.653	2.43E+03	4.75E+04	6.08E+02	2.23E+02	1.01E+03	0.4137%
0.01	0.838	3.42E+03	3.10E+04	6.59E+02	1.86E+02	1.19E+03	0.3493%
0.10	0.551	2.47E+04	1.09E+05	7.66E+02	3.65E+02	1.19E+03	0.4819%
0.10	0.653	2.47E+04	6.23E+04	6.08E+02	2.95E+02	1.02E+03	0.4143%
0.10	0.838	3.46E+04	4.40E+04	6.59E+02	2.80E+02	1.21E+03	0.3505%
0.25	0.551	6.39E+04	1.45E+05	7.66E+02	4.57E+02	1.22E+03	0.4777%
0.25	0.653	6.35E+04	8.81E+04	6.08E+02	3.89E+02	1.05E+03	0.4151%
0.25	0.838	8.82E+04	6.63E+04	6.59E+02	3.93E+02	1.24E+03	0.3524%
0.50	0.551	1.36E+05	2.10E+05	7.66E+02	5.88E+02	1.28E+03	0.4700%
0.50	0.653	1.33E+05	1.35E+05	6.08E+02	5.18E+02	1.11E+03	0.4156%
0.50	0.838	1.82E+05	1.06E+05	6.59E+02	5.37E+02	1.30E+03	0.3551%
1.00	0.551	3.10E+05	3.69E+05	7.66E+02	8.24E+02	1.40E+03	0.4516%
1.00	0.653	2.96E+05	2.43E+05	6.08E+02	7.34E+02	1.22E+03	0.4134%
1.00	0.838	3.92E+05	1.93E+05	6.59E+02	7.65E+02	1.41E+03	0.3585%

Table A31. Calculations for SPOT-1 HRV PAN band. Visibility = 5 km.

SPOT-1 HRV		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	PAN	1.48E+03	3.66E+04	4.25E+00	1.95E+02	7.74E+02	0.5237%
0.10		1.50E+04	4.66E+04	1.42E+01	2.48E+02	7.89E+02	0.5246%
0.25		3.88E+04	6.41E+04	3.10E+01	3.21E+02	8.15E+02	0.5260%
0.50		8.17E+04	9.58E+04	5.97E+01	4.21E+02	8.61E+02	0.5275%
1.00		1.83E+05	1.71E+05	1.20E+02	5.95E+02	9.64E+02	0.5270%

Table A32. Calculations for SPOT-1 HRV. Rayleigh Atmosphere.

SPOT-1 HRV		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	0.551	6.97E+03	3.26E+04	9.38E+02	1.99E+02	1.27E+03	0.1823%
0.01	0.653	5.85E+03	1.23E+04	7.21E+02	1.35E+02	1.06E+03	0.1817%
0.01	0.838	6.65E+03	4.85E+03	7.74E+02	1.07E+02	1.25E+03	0.1883%
0.10	0.551	7.02E+04	3.58E+04	9.38E+02	3.26E+02	1.30E+03	0.1846%
0.10	0.653	5.87E+04	1.36E+04	7.21E+02	2.69E+02	1.09E+03	0.1852%
0.10	0.838	6.66E+04	5.35E+03	7.74E+02	2.68E+02	1.28E+03	0.1916%
0.25	0.551	1.78E+05	4.13E+04	9.38E+02	4.68E+02	1.34E+03	0.1883%
0.25	0.653	1.48E+05	1.57E+04	7.21E+02	4.04E+02	1.13E+03	0.1910%
0.25	0.838	1.67E+05	6.19E+03	7.74E+02	4.16E+02	1.31E+03	0.1969%
0.50	0.551	3.64E+05	5.08E+04	9.38E+02	6.44E+02	1.41E+03	0.1940%
0.50	0.653	2.99E+05	1.94E+04	7.21E+02	5.64E+02	1.20E+03	0.1999%
0.50	0.838	3.35E+05	7.59E+03	7.74E+02	5.86E+02	1.38E+03	0.2055%
1.00	0.551	7.61E+05	7.13E+04	9.38E+02	9.12E+02	1.55E+03	0.2039%
1.00	0.653	6.12E+05	2.71E+04	7.21E+02	7.99E+02	1.32E+03	0.2162%
1.00	0.838	6.76E+05	1.04E+04	7.74E+02	8.29E+02	1.50E+03	0.2214%

Table A33. Calculations for SPOT-1 HRV PAN band. Rayleigh Atmosphere.

SPOT-1 HRV		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (e-)	Sp (e-)	Nq (e-)	Ns (e-)	Nt (e-)	NEDr
0.01	PAN	3.77E+03	1.13E+04	4.25E+00	1.23E+02	7.59E+02	0.2014%
0.10		3.79E+04	1.24E+04	1.42E+01	2.24E+02	7.82E+02	0.2064%
0.25		9.56E+04	1.44E+04	3.10E+01	3.32E+02	8.20E+02	0.2144%
0.50		1.94E+05	1.77E+04	5.97E+01	4.60E+02	8.81E+02	0.2270%
1.00		4.00E+05	2.47E+04	1.20E+02	6.52E+02	1.00E+03	0.2498%

Table A34. Calculations for TM. Visibility = 23 km.

TM		Visibility = 23 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	6.91E-12	1.10E-10	1.39E-12	1.40E-12	2.96E-12	0.4278%
0.01	0.571	1.08E-11	8.66E-11	1.84E-12	1.27E-12	3.14E-12	0.2895%
0.01	0.661	1.19E-11	5.47E-11	1.81E-12	1.05E-12	3.04E-12	0.2554%
0.01	0.838	1.70E-11	3.75E-11	2.32E-12	9.52E-13	3.40E-12	0.1999%
0.01	1.677	1.37E-11	5.93E-12	1.64E-12	5.72E-13	5.20E-12	0.3785%
0.01	2.217	7.49E-12	1.56E-12	8.75E-13	3.88E-13	4.89E-12	0.6537%
0.10	0.486	7.02E-11	1.32E-10	1.39E-12	1.84E-12	3.19E-12	0.4541%
0.10	0.571	1.10E-10	1.11E-10	1.84E-12	1.92E-12	3.45E-12	0.3147%
0.10	0.661	1.20E-10	7.50E-11	1.81E-12	1.80E-12	3.37E-12	0.2810%
0.10	0.838	1.71E-10	5.61E-11	2.32E-12	1.94E-12	3.80E-12	0.2222%
0.10	1.677	1.37E-10	1.08E-11	1.64E-12	1.57E-12	5.40E-12	0.3929%
0.10	2.217	7.50E-11	3.29E-12	8.75E-13	1.14E-12	5.01E-12	0.6679%
0.25	0.486	1.80E-10	1.71E-10	1.39E-12	2.42E-12	3.55E-12	0.4929%
0.25	0.571	2.79E-10	1.53E-10	1.84E-12	2.68E-12	3.93E-12	0.3515%
0.25	0.661	3.04E-10	1.10E-10	1.81E-12	2.62E-12	3.87E-12	0.3184%
0.25	0.838	4.31E-10	8.75E-11	2.32E-12	2.94E-12	4.39E-12	0.2547%
0.25	1.677	3.44E-10	1.90E-11	1.64E-12	2.46E-12	5.72E-12	0.4153%
0.25	2.217	1.88E-10	6.21E-12	8.75E-13	1.80E-12	5.20E-12	0.6923%
0.50	0.486	3.78E-10	2.40E-10	1.39E-12	3.21E-12	4.13E-12	0.5467%
0.50	0.571	5.77E-10	2.28E-10	1.84E-12	3.66E-12	4.65E-12	0.4028%
0.50	0.661	6.23E-10	1.69E-10	1.81E-12	3.63E-12	4.62E-12	0.3705%
0.50	0.838	8.75E-10	1.41E-10	2.32E-12	4.11E-12	5.25E-12	0.3001%
0.50	1.677	6.92E-10	3.28E-11	1.64E-12	3.47E-12	6.23E-12	0.4501%
0.50	2.217	3.76E-10	1.11E-11	8.75E-13	2.54E-12	5.50E-12	0.7310%
1.00	0.486	8.36E-10	4.00E-10	1.39E-12	4.54E-12	5.23E-12	0.6257%
1.00	0.571	1.24E-09	3.92E-10	1.84E-12	5.21E-12	5.94E-12	0.4806%
1.00	0.661	1.31E-09	2.98E-10	1.81E-12	5.17E-12	5.90E-12	0.4512%
1.00	0.838	1.80E-09	2.53E-10	2.32E-12	5.85E-12	6.70E-12	0.3717%
1.00	1.677	1.39E-09	6.06E-11	1.64E-12	4.92E-12	7.13E-12	0.5118%
1.00	2.217	7.55E-10	2.09E-11	8.75E-13	3.59E-12	6.06E-12	0.8023%

Table A35. Calculations for TM. Visibility = 5 km.

TM		Visibility = 5 km					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	2.98E-12	1.84E-10	1.18E-12	1.76E-12	3.05E-12	1.0264%
0.01	0.571	5.30E-12	1.67E-10	1.58E-12	1.69E-12	3.20E-12	0.6027%
0.01	0.661	6.49E-12	1.21E-10	1.60E-12	1.46E-12	3.08E-12	0.4757%
0.01	0.838	1.07E-11	9.75E-11	2.06E-12	1.34E-12	3.37E-12	0.3157%
0.01	1.677	1.11E-11	1.96E-11	1.51E-12	7.15E-13	5.18E-12	0.4646%
0.01	2.217	6.61E-12	5.11E-12	8.35E-13	4.42E-13	4.89E-12	0.7402%
0.10	0.486	3.04E-11	2.16E-10	1.18E-12	2.02E-12	3.21E-12	1.0552%
0.10	0.571	5.41E-11	2.09E-10	1.58E-12	2.09E-12	3.42E-12	0.6334%
0.10	0.661	6.59E-11	1.60E-10	1.60E-12	1.94E-12	3.34E-12	0.5063%
0.10	0.838	1.08E-10	1.38E-10	2.06E-12	2.02E-12	3.69E-12	0.3422%
0.10	1.677	1.12E-10	3.31E-11	1.51E-12	1.55E-12	5.36E-12	0.4791%
0.10	2.217	6.62E-11	1.03E-11	8.35E-13	1.13E-12	5.00E-12	0.7555%
0.25	0.486	7.92E-11	2.72E-10	1.18E-12	2.42E-12	3.47E-12	1.0965%
0.25	0.571	1.40E-10	2.81E-10	1.58E-12	2.65E-12	3.79E-12	0.6782%
0.25	0.661	1.69E-10	2.27E-10	1.60E-12	2.57E-12	3.74E-12	0.5517%
0.25	0.838	2.75E-10	2.08E-10	2.06E-12	2.83E-12	4.19E-12	0.3810%
0.25	1.677	2.82E-10	5.59E-11	1.51E-12	2.37E-12	5.65E-12	0.5016%
0.25	2.217	1.66E-10	1.90E-11	8.35E-13	1.76E-12	5.18E-12	0.7796%
0.50	0.486	1.70E-10	3.78E-10	1.18E-12	3.02E-12	3.92E-12	1.1517%
0.50	0.571	2.96E-10	4.14E-10	1.58E-12	3.44E-12	4.38E-12	0.7397%
0.50	0.661	3.56E-10	3.48E-10	1.60E-12	3.42E-12	4.37E-12	0.6145%
0.50	0.838	5.69E-10	3.31E-10	2.06E-12	3.87E-12	4.95E-12	0.4349%
0.50	1.677	5.70E-10	9.46E-11	1.51E-12	3.32E-12	6.11E-12	0.5364%
0.50	2.217	3.34E-10	3.37E-11	8.35E-13	2.47E-12	5.46E-12	0.8176%
1.00	0.486	3.98E-10	6.44E-10	1.18E-12	4.16E-12	4.85E-12	1.2182%
1.00	0.571	6.71E-10	7.33E-10	1.58E-12	4.83E-12	5.54E-12	0.8255%
1.00	0.661	7.88E-10	6.28E-10	1.60E-12	4.86E-12	5.56E-12	0.7060%
1.00	0.838	1.22E-09	6.04E-10	2.06E-12	5.51E-12	6.32E-12	0.5166%
1.00	1.677	1.17E-09	1.75E-10	1.51E-12	4.73E-12	6.97E-12	0.5975%
1.00	2.217	6.77E-10	6.37E-11	8.35E-13	3.51E-12	6.00E-12	0.8875%

Table A36. Calculations for TM. Rayleigh Atmosphere.

TM		Rayleigh Atmosphere					
reflectance	wavelength (μm)	Ss (A)	Sp (A)	Nq (A)	Ns (A)	Nt (A)	NEDr
0.01	0.486	9.87E-12	8.34E-11	1.47E-12	1.25E-12	2.93E-12	0.2964%
0.01	0.571	1.47E-11	5.71E-11	1.93E-12	1.09E-12	3.12E-12	0.2125%
0.01	0.661	1.54E-11	3.04E-11	1.89E-12	8.73E-13	3.03E-12	0.1965%
0.01	0.838	2.08E-11	1.53E-11	2.42E-12	7.75E-13	3.43E-12	0.1650%
0.01	1.677	1.50E-11	6.68E-13	1.70E-12	5.11E-13	5.21E-12	0.3468%
0.01	2.217	7.91E-12	1.20E-13	8.93E-13	3.65E-13	4.90E-12	0.6192%
0.10	0.486	9.99E-11	9.10E-11	1.47E-12	1.78E-12	3.19E-12	0.3195%
0.10	0.571	1.48E-10	6.28E-11	1.93E-12	1.87E-12	3.47E-12	0.2349%
0.10	0.661	1.55E-10	3.36E-11	1.89E-12	1.77E-12	3.40E-12	0.2197%
0.10	0.838	2.08E-10	1.69E-11	2.42E-12	1.93E-12	3.86E-12	0.1855%
0.10	1.677	1.50E-10	7.47E-13	1.70E-12	1.58E-12	5.42E-12	0.3610%
0.10	2.217	7.91E-11	1.40E-13	8.93E-13	1.15E-12	5.02E-12	0.6338%
0.25	0.486	2.55E-10	1.04E-10	1.47E-12	2.44E-12	3.60E-12	0.3537%
0.25	0.571	3.74E-10	7.25E-11	1.93E-12	2.72E-12	4.00E-12	0.2674%
0.25	0.661	3.89E-10	3.90E-11	1.89E-12	2.67E-12	3.94E-12	0.2532%
0.25	0.838	5.21E-10	1.95E-11	2.42E-12	3.00E-12	4.49E-12	0.2152%
0.25	1.677	3.76E-10	8.58E-13	1.70E-12	2.50E-12	5.76E-12	0.3833%
0.25	2.217	1.98E-10	1.60E-13	8.93E-13	1.82E-12	5.21E-12	0.6581%
0.50	0.486	5.26E-10	1.27E-10	1.47E-12	3.30E-12	4.23E-12	0.4016%
0.50	0.571	7.62E-10	8.91E-11	1.93E-12	3.76E-12	4.77E-12	0.3128%
0.50	0.661	7.87E-10	4.82E-11	1.89E-12	3.73E-12	4.72E-12	0.3001%
0.50	0.838	1.05E-09	2.39E-11	2.42E-12	4.22E-12	5.38E-12	0.2569%
0.50	1.677	7.51E-10	1.05E-12	1.70E-12	3.54E-12	6.28E-12	0.4178%
0.50	2.217	3.96E-10	2.00E-13	8.93E-13	2.57E-12	5.52E-12	0.6969%
1.00	0.486	1.13E-09	1.78E-10	1.47E-12	4.66E-12	5.36E-12	0.4749%
1.00	0.571	1.58E-09	1.25E-10	1.93E-12	5.33E-12	6.08E-12	0.3838%
1.00	0.661	1.61E-09	6.71E-11	1.89E-12	5.28E-12	6.02E-12	0.3745%
1.00	0.838	2.11E-09	3.29E-11	2.42E-12	5.98E-12	6.85E-12	0.3239%
1.00	1.677	1.50E-09	1.45E-12	1.70E-12	5.00E-12	7.21E-12	0.4794%
1.00	2.217	7.92E-10	2.80E-13	8.93E-13	3.63E-12	6.08E-12	0.7685%

REFERENCES

1. P.N. Slater, *Remote Sensing: Optics and Optical Systems*, Addison-Wesley (1980).
2. D. Tanré, C. Deroo, P. Duhaut, M. Herman, J.J. Morcrette, J. Perbos, P.Y. Deschamps, "Simulation of the Satellite Signal in the Solar Spectrum (5S)" (1986)
3. A.V. Oppenheim and R.W. Schaffer, *Digital Signal Processing*, Prentice Hall (1975).
4. J.M. Palmer, "Supplementary Notes for Optical Sciences 509" (1988).
5. J.M. Palmer, "Effective Bandwidths for LANDSAT-4 and LANDSAT-D' Multispectral Scanner and Thematic Mapper Subsystems", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. GE-22, No. 3 (1984).
6. S. Weinswig, ITT, Fort Wayne. Personal communication regarding AVHRR (1988).
7. J.C. Lansing, Jr., Santa Barbara Research Center, Hughes Aircraft Company. Personal communication regarding TM and ETM (1988).
8. G. Vane, "AVIRIS: A Description of the Sensor, Ground Data Processing Facility, Laboratory Calibration, and First Results", Jet Propulsion Laboratory, JPL Publication 87-38 (1987).
9. T.G. Chrien and H.R. Sobel, Jet Propulsion Laboratory, Pasadena. Personal communication regarding AVIRIS (1988).
10. NASA, HIRIS Instrument Panel Report, Earth Observing System Report Volume IIc, NASA (1987).
11. V. Duval and M.L. White, Jet Propulsion Laboratory, Pasadena. Personal communication regarding HIRIS (1988).
12. ITT, Phase "A" Study MODIS-N Report, ITT, Fort Wayne (1985).
13. H.E. Montgomery, NASA Goddard Space Flight Center. Personal communication regarding MODIS-N (1988).
14. M. Dinguirard and G. Begni, CNES, Toulouse, France. Personal communication regarding SPOT HRV (1988).