AD-A103 493 SCIENCE APPLICATIONS INC LA JOLLA CA F/G 4/1
SATELLITE MEASUREMENTS OF ATMOSPHERIC AEROSOLS.(U)
AUG 81 M GRIGGS N00014-77-C-0489
UNCLASSIFIED SAI-131-81-275-LJ NL

END
DATE
FILMED
0 8!
DTIC

LEVEL III (12)

A092158

AD A103493

SCIENCE APPLICATIONS, INC.

81 8 31 174

SAI-131-81-275-LJ

ANNUAL REPORT

CONTRACT N00014-77-C-0489

SATELLITE MEASUREMENTS OF ATMOSPHERIC AEROSOLS

August 26, 1981

Principal Investigator:

M. Griggs
Science Applications, Inc.
Electronic Vision & Systems Division
11526 Sorrento Valley Road, Suite A
San Diego, California 92121

Prepared for:

Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

SCIENCE APPLICATIONS, LA JOLLA, CALIFORNIA
ALBUQUERQUE • ANN ARBOR • ARLINGTON • ATLANTA • BOSTON • CHICAGO • HUNTSVILLE
LOS ANGELES • McLEAN • PALO ALTO • SANTA BARBARA • SUNNYVALE • TUCSON
P.O. Box 2351, 1200 Prospect Street, La Jolla, California 92037

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
SAI-131-81-275-LJ

2. GOVT ACCESSION NO.
AD-A103 493

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Satellite Measurements of Atmospheric Aerosols

5. TYPE OF REPORT & PERIOD COVERED
Annual Report, November 15, 1980 to August 26, 1981

6. PERFORMING ORG. REPORT NUMBER
SAI-131-81-275-LJ

7. AUTHOR(s)
M. Griggs

8. CONTRACT OR GRANT NUMBER(s)
N00014-77-C-0489

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Science Applications, Inc.
P. O. Box 2351
La Jolla, CA 92037

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of Naval Research, Code 465
800 North Quincy Street
Arlington, VA 22217

12. REPORT DATE
August 26, 1981

13. NUMBER OF PAGES
15

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
Same as report.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Maritime Aerosols
Satellite Measurements
Error Analysis
Ocean Radiance
Aerosol Scattering
Sun Photometer Measurements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Analysis of NOAA-6 AVHRR data and ground-truth measurements at two locations has found a radiance-aerosol content relationship which agrees very well with that previously determined for Landsat 2 data. A new technique was developed to use AVHRR Channels 1 and 2 radiances to infer aerosol size distribution information, in addition to the optical thickness. The technique was successfully tested with a small data set obtained in a ground-truth experiment on the USNS Hayes.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT

Analysis of NOAA-6 AVHRR data and ground-truth measurements at two locations has found a radiance-aerosol content relationship which agrees very well with that previously determined for Landsat 2 data. Problems were again found in the radiometric calibration of the satellite sensor, but comparison of Channels 1 and 2 radiance values resulted in correction factors being determined for both channels. A new technique was developed to use AVHRR Channels 1 and 2 radiances to infer aerosol size distribution information, in addition to the optical thickness. The technique was successfully tested with a small data set obtained in a ground-truth experiment on the USNS Hayes.

ACKNOWLEDGEMENT

The author would like to thank Dr. L. Ruhnke for providing the sunphotometer data obtained on the USNS Hayes, and for his encouragement in this investigation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The investigation of the satellite technique[1,2] to measure tropospheric aerosols over the ocean has continued both experimentally and theoretically. Ground-truth measurements and NOAA-6 satellite measurements have been obtained at San Diego and on the USNS Hayes in the Atlantic. These data have been analyzed and compared with the earlier Landsat 2 results. Theoretical calculations were made, and led to the preliminary development of a new method to use the NOAA-6 AVHRR Channels 1 and 2 radiance data to infer information on the aerosol size distribution in addition to the optical thickness. This has great potential in the use of satellite data to routinely predict the useful range for FLIR systems, and other electro-optical systems, over the oceans.

The further development of this technique can ultimately lead to a computer code to automatically convert the measured satellite radiances to global ocean maps of aerosol optical thickness (as a function of wavelength), surface visibility, predicted slant range, and a size distribution parameter if desired. In addition to the routine production of daily global aerosol maps for Naval operations, the data could be used to build a climatology base for aerosol properties over the oceans for use in Naval systems planning.

2. SATELLITE AND GROUND-TRUTH MEASUREMENTS

Ground-truth data were acquired at the time of the NOAA-6 satellite overpasses (approximately 0730 l.s.t.), at San Diego and on the USNS Hayes off the Virginia coast. The Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-6 has four channels, two of which are useful for this investigation, and provides daily coverage with 1 km spatial resolution. The useful channels for this study are Channel 1, at 0.65 μm (almost identical to the Landsat MSS5), and Channel 2, at 0.85 μm.

Four sets of useful satellite-ground truth coincidences were obtained on the USNS Hayes, and seventeen sets were obtained at San Diego. The sunphotometer observations on the USNS Hayes included measurements at 0.5 μm and 0.88 μm, thus permitting a direct comparison of the size distribution parameter determined from the AVHRR radiances at 0.65 μm and 0.85 μm. The San Diego ground-truth unfortunately had useful measurements only at 0.5 μm, so that the satellite values of size distribution could not be checked.

3. THEORETICAL CALCULATIONS

It was shown previously[2] that the radiance-aerosol content relationship varies with the size distribution, which is typically well represented in the real atmosphere by the Junge distribution:

$$dn(r) = Cr^{-\nu} \, d \log r \; (cm^{-3}) \tag{1}$$

where n(r) is the number of particles with radius r, and C is a constant depending on the number of particles per unit volume.

The previous calculations showed that the spectral variation in the visible-near infrared region of the upwelling radiance in nadir viewing is sensitive to the aerosol size distribution. The earlier Landsat data were not sensitive enough to investigate the use of satellite spectral measurements to infer the size distribution, but the AVHRR on NOAA-6 has two channels in the visible-near IR region, and is a 10-bit system, which should be sensitive to the small radiance changes due to changes in the size distribution. Thus calculations were made so that a two-channel analysis of the AVHRR radiance data could be made in order to infer ν in addition to the aerosol content (N).

Calculations were made for $\nu = 2.5$ and $\nu = 3.5$ at 0.85 μm for aerosol contents N and 2N at just four sun zenith angles (60°, 66°, 72° and 78°). Similar calculations were made at 0.65 μm for $\nu = 2.5$ to supplement the existing detailed 0.65 μm calculations for $\nu = 3.5$.

In order to infer ν from the satellite data the Channels 1 and 2 radiances (after correcting the Channel 2 radiance for water vapor absorption) are compared with the theoretical radiances for the sun and view angles at the time of the measurement. Model values of N and ν are chosen so that the model radiances agree with the measured radiances in both AVHRR Channels. Thus to analyze the satellite data, interpolation/extrapolation must be made for the non-tabulated values of sun angle and ν. This is currently done manually, and assumes a linear variation of the radiances with both parameters. This procedure must be computerized if more extensive satellite data are analyzed in the future.

The ground-truth measurements of the aerosol optical thickness (τ_A) may be used to determine a value of ν for comparison with the satellite value if multispectral sunphotometer data are available. If a Junge distribution is assumed, it has been shown (e.g., Bullrich[3]), to a close approximation, that:

$$\tau_A = B\lambda^{-(\nu-2)} \tag{2}$$

where B is a constant.

Thus values of τ_A at two wavelengths can be used to calculate ν. These wavelengths should be the same as those of the satellite measurements for an ideal ground-truth experiment.

4. DATA ANALYSIS

The AVHRR data obtained at San Diego and on the USNS Hayes have been analyzed using the table-look-up code developed previously[4] for interpreting just the Channel 1 radiance, and by the two-channel analysis discussed in Section 3.

4.1 CHANNEL 1 ANALYSIS

The results for San Diego and the USNS Hayes are given in Fig. 1 which shows that the measured radiances (normalized to nadir viewing with a sun zenith angle of 63°) are lower than anticipated, based on the MSS5 regression line for San Diego. However, it is believed that these radiances are low due to radiometric calibration errors in the AVHRR sensor, based on a comparison of the radiances measured in Channels 1 and 2. It is recalled[1,2] that the radiometric calibration of sensors has been a problem in intercomparing the radiance-aerosol content relationship for different satellites.

Figure 2 shows the Channel 1 radiances plotted against the Channel 2 radiances for the same ocean pixel without any correction for sun or viewing angles (the Channel 2 radiance is corrected for water vapor absorption as discussed below). It is seen that the mean curve does not pass through the origin, suggesting that the AVHRR radiance calibrations are in error, since both channels should indicate zero radiance at the same time. Theoretical radiance values are also plotted in Fig. 2 for the same sun and viewing angles of the measured radiances, and indeed indicate that, regardless of the aerosol content and size distribution, the mean curves can be extended through the origin. The middle of the three dashed curves in Fig. 2 show where radiances for ~0.5N should theoretically lie. The mean of the measured data (the solid curve) can be shifted to this location by adding 0.5 $mw/cm^2/\mu m/sr$ to Channel 1 radiances, and by subtracting 0.25 $mw/cm^2/\mu m/sr$ from Channel 2 radiances. It is important to note that these corrections were derived independent of any radiance-aerosol content relationship.

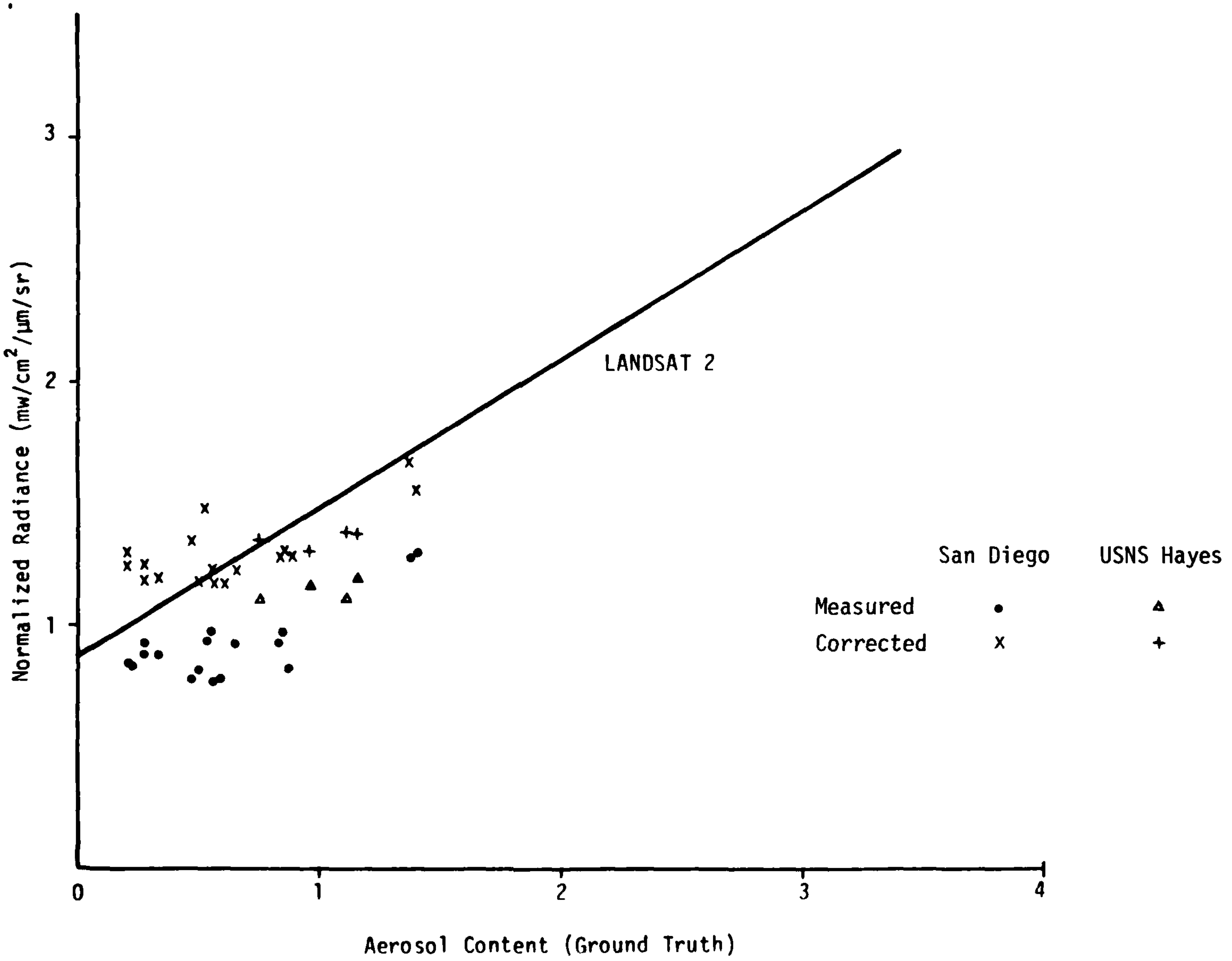

Figure 1. AVHRR Channel 1 Normalized Radiance vs Aerosol Content.

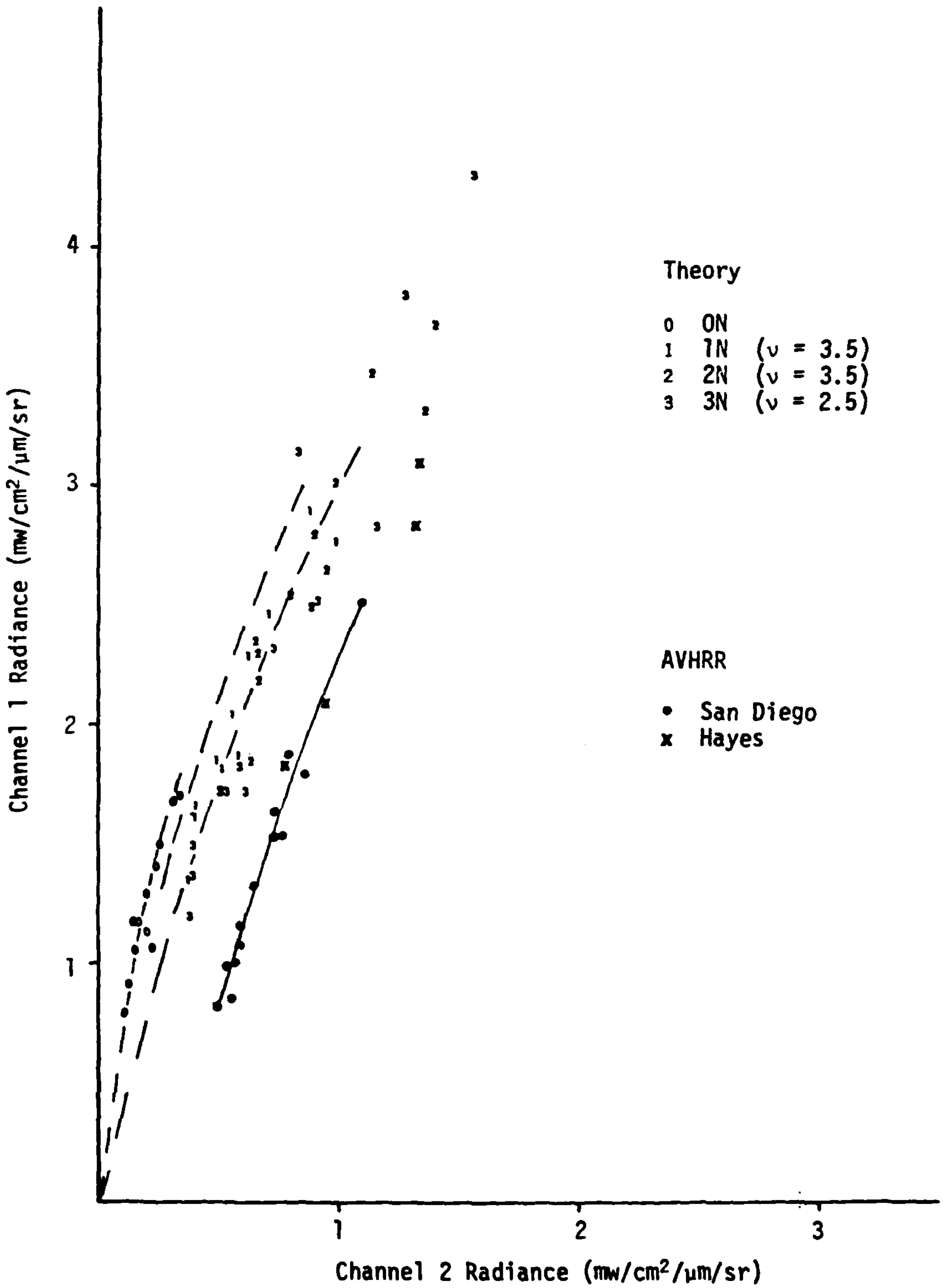

Figure 2. Theoretical and Measured AVHRR Channel 1 Radiances Versus Channel 2 Radiances.

With the corrected values of the Channel 1 radiances, it is seen in Fig. 1 that normalized radiances show excellent agreement with the Landsat relationship. It is noted that a group of five data points with $N < 0.35$ shows radiances greater than expected. These measurements were obtained for sun zenith angles greater than 73° where the flat earth model used in developing the table-look-up code was expected to introduce uncertainties.

4.2 TWO CHANNEL ANALYSIS

A preliminary investigation has been made into the use of AVHRR Channels 1 and 2 to infer N and ν, as discussed in Section 3, for the San Diego and USNS Hayes data. The results of this analysis are given in Figs. 3 and 4 and in Table 1.

Results for only 11 San Diego data sets are shown since the results for the sun zenith angles greater than 73° are considered unreliable as explained in Section 4.1. (Channel 2 satellite data was also unavailable for one of the other overpasses.)

The results in Fig. 3 shows good agreement between the N values determined from the satellite and the ground-truth, with indication that the satellite may slightly underestimate the larger N values. The reasons for this could lie in the assumptions made in the table-look-up code, in the sunphotometer accuracy, or in the satellite radiance accuracy; with this limited data set it is not possible to presently identify the reason.

The results in Fig. 4 show excellent agreement between the ν values determined from the satellite and the ground-truth on the USNS Hayes. The two channel analysis was also carried out on the San Diego data to infer satellite values of N and ν, but unfortunately no multispectral ground-truth data were available to compute ν values for comparison. However, as shown in Table 1, the satellite values of ν generally range between 3.5 and 4.7 which are values typically measured by other methods; even the two high values of 6.0 and 6.5 have been measured (by other techniques) occasionally by other workers.(5) It is noted that the two channel analysis results in values of N different from those of the Channel 1 analysis, but overall does not seem to improve on the agreement with the ground-truth values.

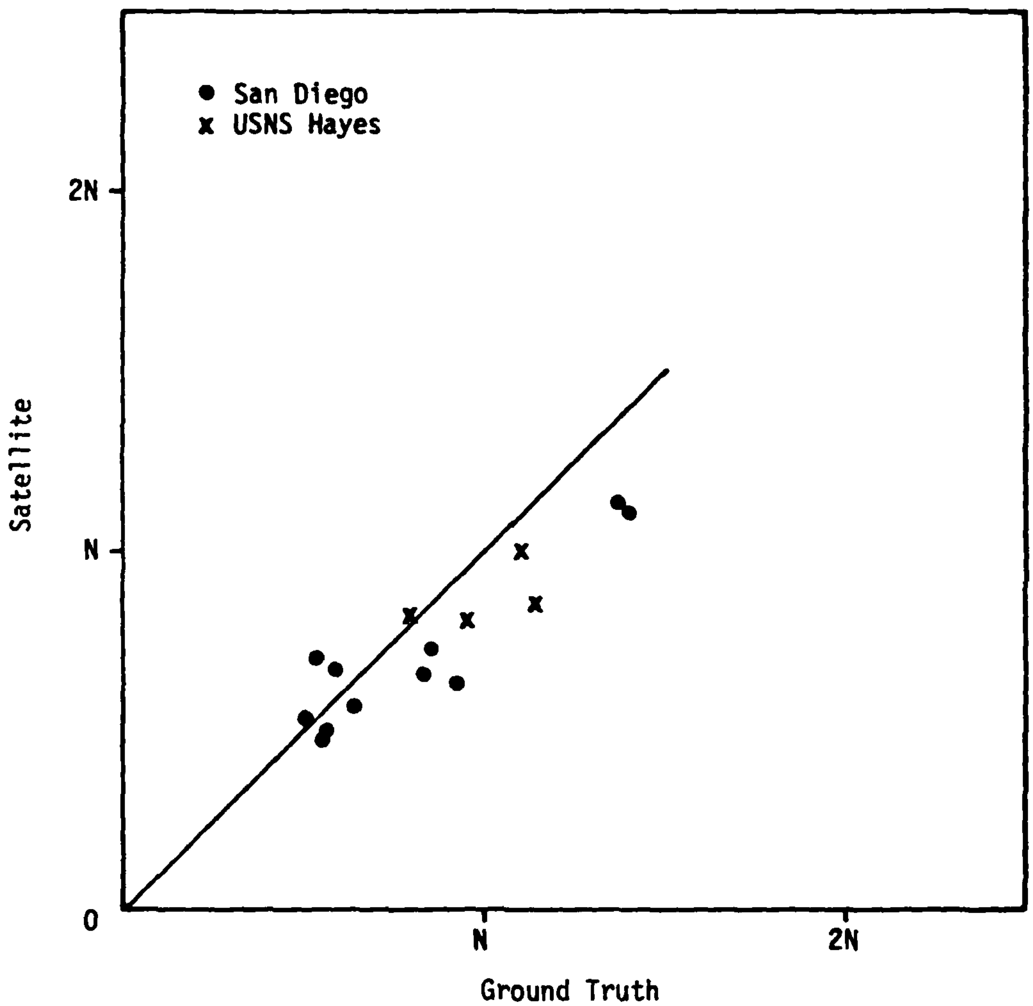

Figure 3. Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content.

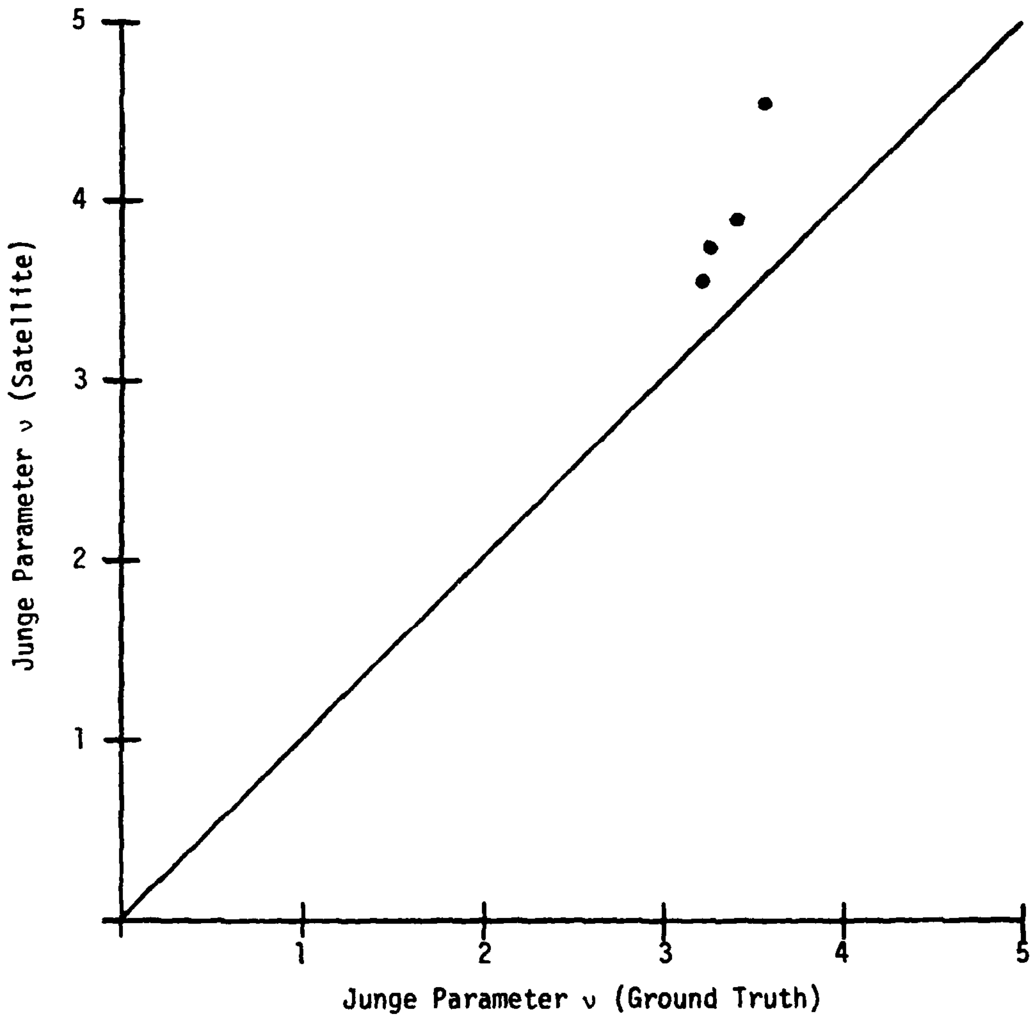

Figure 4. Comparison of AVHRR and Ground Truth Measurements of Aerosol Size Distribution. (USNS Hayes)

Table 1. Comparison of Channel 1 Analysis and Two Channel Analysis at San Diego.

Date	N (Ground Truth)	2 Channel		Channel 1 (Corrected) Only
		N_{Sat}	ν_{Sat}	N_{Sat}
6-13	0.59	0.66	4.0	0.47
6-14	0.85	0.73	3.5	0.68
7-11	0.84	0.65	3.8	0.67
7-15	0.56	0.50	6.0	0.47
7-16	0.64	0.56	3.7	0.57
7-29	1.37	1.13	4.7	1.29
7-30	1.40	1.10	3.6	1.09
9-16	0.86	0.64	4.2	0.67
9-17	0.50	0.54	4.7	0.50
9-18	0.55	0.46	2.3	0.57
10-18	0.53	0.70	5.0	0.98
10-19	0.27	0.46	6.5	0.60 } $\theta_o > 73°$
10-20	0.27	0.64	4.8	0.50 } $\theta_o > 73°$

4.2.1 Water Vapor Correction for Channel 2

The spectral bandpass of AVHRR extends from 0.67 μm to 1.2 μm with 50% response at 0.71 μm and 1.02 μm. This spectral region includes several water vapor absorption bands[6], so that the radiance observed by the AVHRR Channel 2 is influenced by the water vapor in the atmosphere. This problem has previously been addressed for Landsat data since the MSS7 bandpass covers part of the same spectral region. Pitts et al[7] calculated the atmospheric transmission for the MSS7 bandpass as a function of water vapor content, based on high spectral resolution calculations. Griggs[8] showed that these results could be fit to a good approximation by the equation:

$$\tau = \exp(-.094u^{.43}) \qquad (3)$$

where τ is the path transmission and

$$u = w(1 + \sec\theta_0) \qquad (4)$$

where w is the vertical water vapor content in precipitable cm and θ_0 is the sun zenith angle.

The water vapor correction was applied to the MSS7 radiance values by multiplying them by $1/\tau$. This approach, used by Pitts et al is a simplified one, ignoring scattering effects, but is justified since the correction is small. The Landsat study[9] showed that the transmission factor to be applied to the MSS7 radiances, in the absence of water vapor information, is 0.81 with an uncertainty of ±0.1.

For AVHRR Channel 2, using the spectral information given by Koepke and Quenzel[6], the transmission factor is found to be 0.86 ± 0.07, with the actual variation of transmission being approximated by:

$$\tau = \exp(-.069u^{.43}) \qquad (5)$$

The transmission factor in the AVHRR bandpass is higher than in MSS7, even though it includes an additional water vapor band, since the water vapor bands represent a smaller fraction of the broader bandpass.

In the results presented above in this section, the Channel 2 radiances for San Diego were corrected using a transmission factor of 0.86, since water vapor data were not available. For the USNS Hayes data analysis, precipitable water vapor maps of the United States were obtained from the National Climatic Center in Ashville, and used to determine a value of w. For the four USNS Hayes data sets, w varied between 0.94 and 1.24, resulting in τ values of 0.86, 0.87, 0.87 and 0.89, which are close to the fixed value of 0.86 used for the San Diego data.

Thus, it is believed that a water vapor correction factor of 0.86 can be satisfactorily used in future analysis of AVHRR Channel 2 radiances. Based on the calculations on the radiance variation with ν reported previously[2], the uncertainty of ±0.07 in the water vapor correction factor results in an uncertainty of about ±0.15 in ν. A more detailed error analysis of the two channel analysis is required to determine the relative significance of this uncertainty in comparison with those due to errors in the satellite data.

5. CONCLUSIONS

Analysis of the NOAA-6 AVHRR data and the ground-truth measurements at two locations showed that the radiance-aerosol relationship agrees very well with that previously found for Landsat 2. The analysis again revealed a problem in the calibration of the satellite sensor as reported previously for the Landsat and GOES satellites.

A new technique has been developed to infer aerosol size distribution information, in addition to the aerosol optical thickness, from analysis of the AVHRR Channels 1 and 2 radiances. Application of this method to the limited data set from the USNS Hayes in the Atlantic showed excellent agreement between the satellite and ground-truth values of the size distribution parameter. Further ground-truth data are required to validate the technique, and calculations are needed to perform an error analysis.

REFERENCES

1. M. Griggs, "Satellite Measurements of Atmospheric Aerosols," Annual Report, Contract N00014-77-C-0489 (March 31, 1979).

2. M. Griggs, "Satellite Measurements of Atmospheric Aerosols," Annual Report, Contract N00014-77-C-0489 (November 14, 1980).

3. K. Bullrich, "Scattering in the Atmosphere," Advances in Geophysics, 10, 99, 1964.

4. M. Griggs "Tiros-N AVHRR Data for Measurements of Atmospheric Aerosols," Progress Report, NOAA Contract MO-A01-78-00-4092 (November 1978)

5. J. Reagan, University of Arizona, Tucson. (Private Communication)

6. P. Koepke and H. Quenzel, Appl. Opt., 17, 2114, 1978.

7. D. E. Pitts, W. E. McAllum and A. E. Dillinger, 9th Remote Sensing Symposium, Ann Arbor, April 1974.

8. M. Griggs, "Satellite Measurements of Tropospheric Aerosols," Final Report, Contract NAS1-15898, January 1981.

9. M. Griggs, "Determination of Aerosol Content in the Atmosphere from Landsat Data," Final Report, Contract No. NAS5-20899 (January 1978).