High Altitude Hyperspectral Remote Sensing with AVIRIS

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Overview

AVIRIS, the Airborne Visible and InfraRed Imaging Spectrometer, is a world class NASA remote sensing instrument which is supported, calibrated, and maintained by Caltech's Jet Propulsion Laboratory (JPL). A NASA/Lockheed ER-2, (derived from the USAF/Lockheed U-2) is the platform for AVIRIS at its operational altitude of 20 km.

AVIRIS is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 224 contiguous spectral bands from 400 to 2500 nm. This year, AVIRIS is acquiring data for scientific investigations of the land, water, and atmosphere. The common thread in these investigations is the use of the molecular absorption and particle scattering properties expressed in the AVIRIS spectra to pursue advanced quantitative research. Figure 1 shows the AVIRIS concept.

Background

AVIRIS had its maiden flight in the summer of 1987 on a NASA/Lockheed U-2. Initially, the signal-to-noise ratio and spectral and radiometric stability were below expectations. AVIRIS also was susceptible to high ambient humidity, causing gradual deterioration of the IR fibers and mirror surfaces. Improvements during the annual engineering cycle in the electronics, fibers, dewars, and in-flight reference source have brought significant improvements in performance and reliability, Since then, AVIRIS has flown over diverse sites throughout the United States, as well as Canada, Central America, and Europe.

Flight season occupies 6 months of greatest albedo, beginning mid-spring and finishing mid-fall. Between flight seasons, AVIRIS returns to JPL for calibration, maintenance, and upgrade. AVIRIS is an evolving prototype receiving performance improvements annually based on science community consensus, similar instruments, and available resources. Areas of consistent improvement comprise: signal-to-noise ratio; spectral, radiometric, and geometric accuracy; dewar hold time; and data volume capacity.

The standard unit of AVIRIS data is a scene, an area on the ground 11 kilometers wide by 9 kilometers long. This corresponds to 512 scanned lines of 614 spatial pixels. Each scene contains 224 images stacked in a data cube, with each image corresponding to an AVIRIS spectral band. Digitization is 10 bit words. A 10,4 gigabyte S-VHS / T-120 cassette stores 75 minutes of digital data.

Data Collection and Processing

Based at NASA Ames Research Center/ Moffett Federal Airfield, the ER-2 also deploys to other locations when necessary. The decision to fly and science target site selections are made three hours before launch, based on weather and site conditions. Clouds over the site are usually not part of the experiment and considered unacceptable. The science ground team at the site takes ground truth spectrometer measurements and sun photometry measurements. An AVIRIS launch site team pre-flights the instrument to verify that its performance is within acceptable limits.

The flight tape is shipped overnight back to JPL for processing in the AVIRIS Data Facility (ADF). The Experiment Coordinator (EC) confers with the investigators to determine the initial acceptability of the weather and site conditions when the data was collected. Within two days, the first and last science runs on the tape are scanned for instrument performance evaluation. Within two weeks, quicklook images from the runs are stored in an anonymous FTP site for the investigators to examine. When data is deemed acceptable, data products are generated and shipped to the investigators on 4mm DDS tape.

Data is available in three forms: raw, radiance, and reflectance. Raw data is in unitless data numbers (dn) that AVIRIS digitizes from its detectors. Radiance data is radiometrically corrected using various levels of calibration sources and ultimately is traceable to NIST. Reflectance data uses MODTRAN radiative transfer code to back out the estimated effects of the atmosphere and determine the actual reflectance of the target. Figure 2 shows atmospheric transmission and a comparison of AVIRIS spectral channels with Landsat Thematic Mapper bands. Figure 3 shows results from the AVIRIS calibration experiment at the start of the 1994 flight season, comparing AVIRIS measured radiance with MODTRAN predicted radiance from a well characterized site at Lunar Lake, Nevada.

Data Applications

Data from AVIRIS is used in the fields of ecology, geology, snow hydrology, atmospheric research, environmental science and oceanography. Ecology and environmental science study the effects of man made and natural stressors on vegetation. Geologists are developing methods to determine constituents at mineral sites. Snow hydrologists estimate snow pack depth and density. Atmospheric aerosols, particulate, and water vapor content are measurable and determine the spectral absorption characteristics in the optical path between AVIRIS and the earth. Oceanographers estimate concentrations of brine shrimp and phytoplankton, organisms near the very bottom of the food chain. In all of these applications, signal-to-noise ratio and calibration accuracy are critically important for the usefulness of the data. Absolute radiometric accuracy is **7°/0.**

Foreoptics

AVIRIS uses a whiskbroom scanner. The two-sided triangular mirror sweeps across the complete field of view (30°) with 70% efficiency. Scans are taken in only one direction at 12 scans/see with a flyback speed approximately twice the scan speed. An ellipsoidal mirror magnifies the image 1.3 times to achieve the required IFOV of 1 mrad. The foreoptics effective pupil diameter is 14.5cm and throughput is 1.3e-4cm^2·sr. The effective focal length of the foreoptics is 20cm (depth-of-focus is ±0.4cm). A shutter closes during the scan flyback for dark current sampling. and during the calibration sequences at the beginning and end of each data run.

Fiber Optics

Single optical fibers transmit the light from the foreoptics to each of four spectrometers. Optical fibers eliminate the need for optical bench alignment between the foreoptics and spectrometers, allowing more efficient packaging, mass savings, and simpler assembly and alignment. The numerical aperture of the fibers is 0.55. Two fibers in the shorter wavelength subbands use a Nippon SI 200H sheet glass fiber. The two fibers for the longer subbands have a zirconium fluoride core and beryllium fluoride doped cladding. The fibers are thinly cladded (<250μm) for tight packing in the foreoptics focal plane. Figure 4 is an optical component schematic diagram,

Spectrometers

AVIRIS has four off-axis Schmidt spectrometers to cover the required wavelength range at the maximum grating efficiencies. A spherical mirror collimates the light from the fibers and directs it to a diffraction grating where it separates into its spectral components which fall onto a focal plane (linear detector array). The differences among the four spectrometers are the tilt of the grating and the material of the detectors. The A spectrometer uses a silicon array and the B, C, and D spectrometers use IR responsive iridium antimonide arrays. The spectrometers have numerical apertures of 0.45, spectral sampling intervals ≤ 10nm, and average transmittances of 20-30°/0.

On-Board Calibrator

The on-board calibrator (OBC) checks the spectral alignment and radiometric stability of the spectrometers before and after each data run to insure the data's accuracy. A tungsten source is focused on a fiber bundle by a convex metal mirror. An 8-position filter wheel consists of two neutral density filters, five different spectral filters, and a dark position. Light from the OBC shining onto the backside of the closed foreoptics shutter is reflected into the spectrometer fibers.

Conclusion

The Airborne Visible-InfraRed Imaging Spectrometer is a NASA sponsored earth-looking imaging spectrometer, employing a whiskbroom type scanner, grating spectrometers, and solid state detectors to measure upwelling spectral radiance. AVIRIS data are spectrally, radiometrically, and geometrically calibrated in order to: 1) derive geophysical parameters directly from the measured spectral radiance, 2) compare data acquired from different regions and different times and 3) analyze data in conjunction with measurements acquired by different instruments, or generated by radiative transfer and process models.

Browsing on the Web

Documentation and pages on the Web are at the anonymous ftp site. Connect to the ftp site -- ftp://ophelia.jpl. nasa.gov/ -- and then click on README.htm.

Acknowledgements

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Bibliography

Summaries of the Fourth Annual JPL Airborne Geoscience Workshop, Volume 1, AVIRIS Workshop, JPL pub 93-26, Vol. 1, R. Green, editor

Remote Sensing of Environment, Volume 44, Numbers 2/3, May/June 1993, Elsevier

Summaries of the Third Annual JPL Airborne Geoscience Workshop, Volume 1, AVIRIS Workshop, JPL pub 92-14, Vol. 1, R. Green, editor

R. Green, “Remote Sensing Soars to New Heights”, Photonics, p. 81, August 1991

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Titles / Captions:

Figure 1. AVIRIS Concept. Each spatial element (pixel) has a continuous spectrum from 400 to 2500 nm, resulting in 224 spectral images taken simultaneously.

Figure 2. AVIRIS Channels, Landsat Bands, and Atmosphere Transmission, While the six Landsat Thematic Mapper bands cover limited subranges between 400 and 2500 nm, AVIRIS observes the entire range,

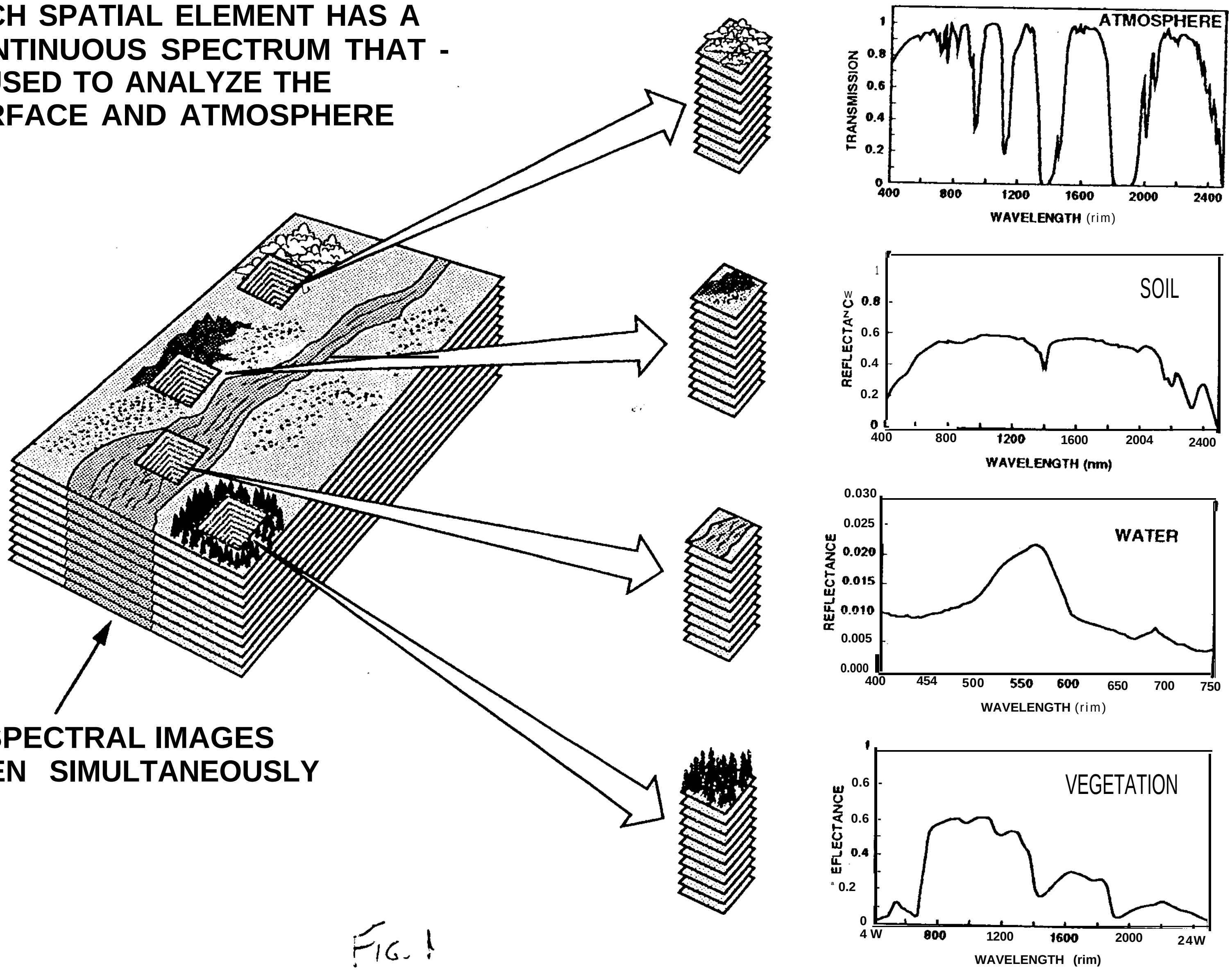
Figure 3. AVIRIS Calibration Experiment: Lunar Lake, NV, 5 April 1994. Average absolute agreement between AVIRIS measured and Modtran predicted values is within 5 percent.

Figure 4. AVIRIS Optical Subsystem. The reciprocating mirror scans at 12 Hz in one direction with 70% efficiency.

Cover/After Image Photo: AVIRIS Image Cube, Boreas Experiment Southern Study Area, Saskatchewan, Cananda. The image is a false color enhancement. Side panels represent 224 channel spectral data corresponding to the line of ground pixels at the top, with increasing wavelength going down the page. Radiance increases going from blue to red, The two black bands indicate atmospheric opacity due to water vapor.

AVIRIS CONCEPT

EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT - IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE



224 **SPECTRAL IMAGES TAKEN SIMULTANEOUSLY**

FIG. 1

JPL

AVIRIS Channels, Landsat Bands and Atmosphere Transmission

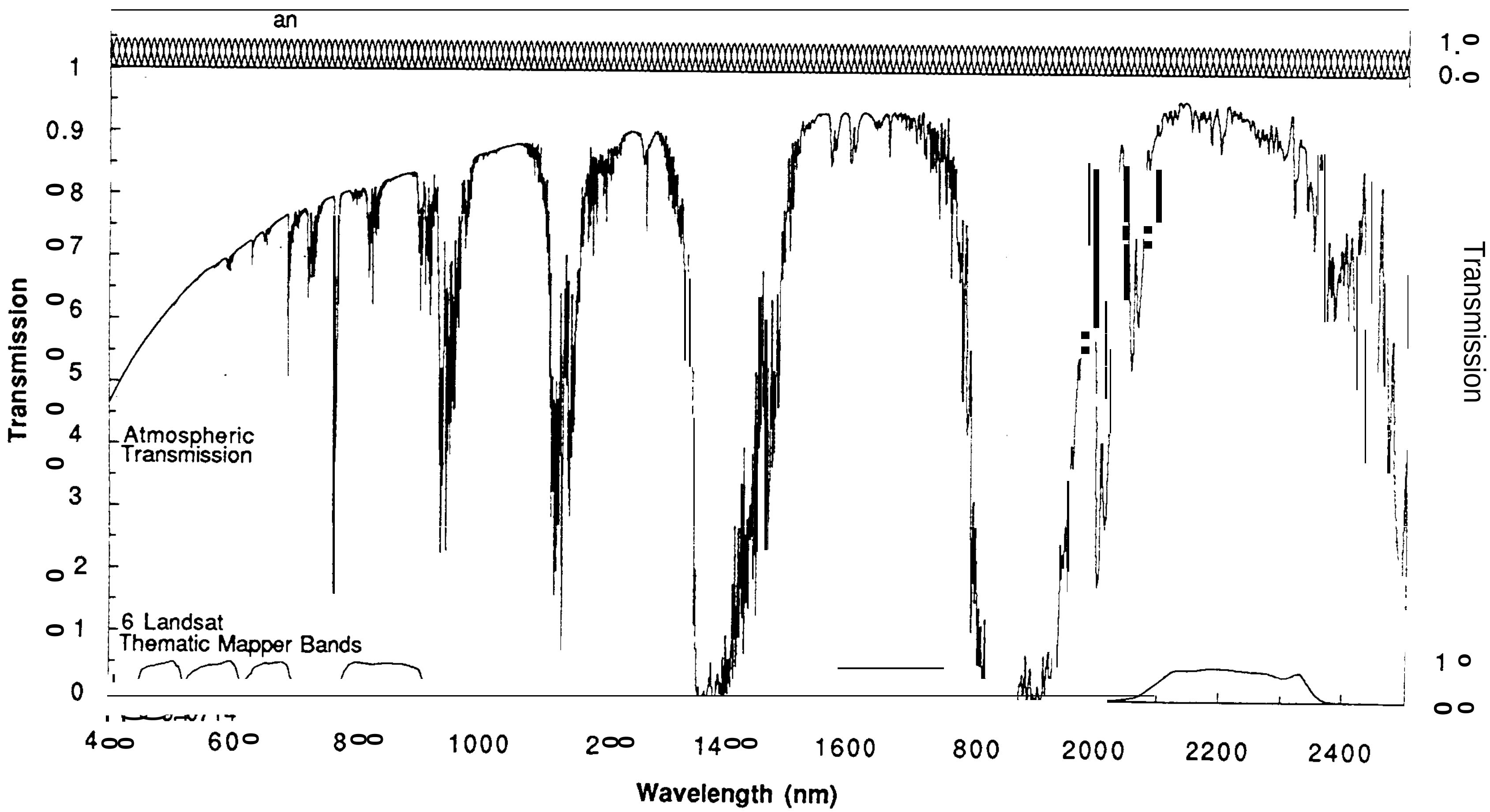


Fig. 2

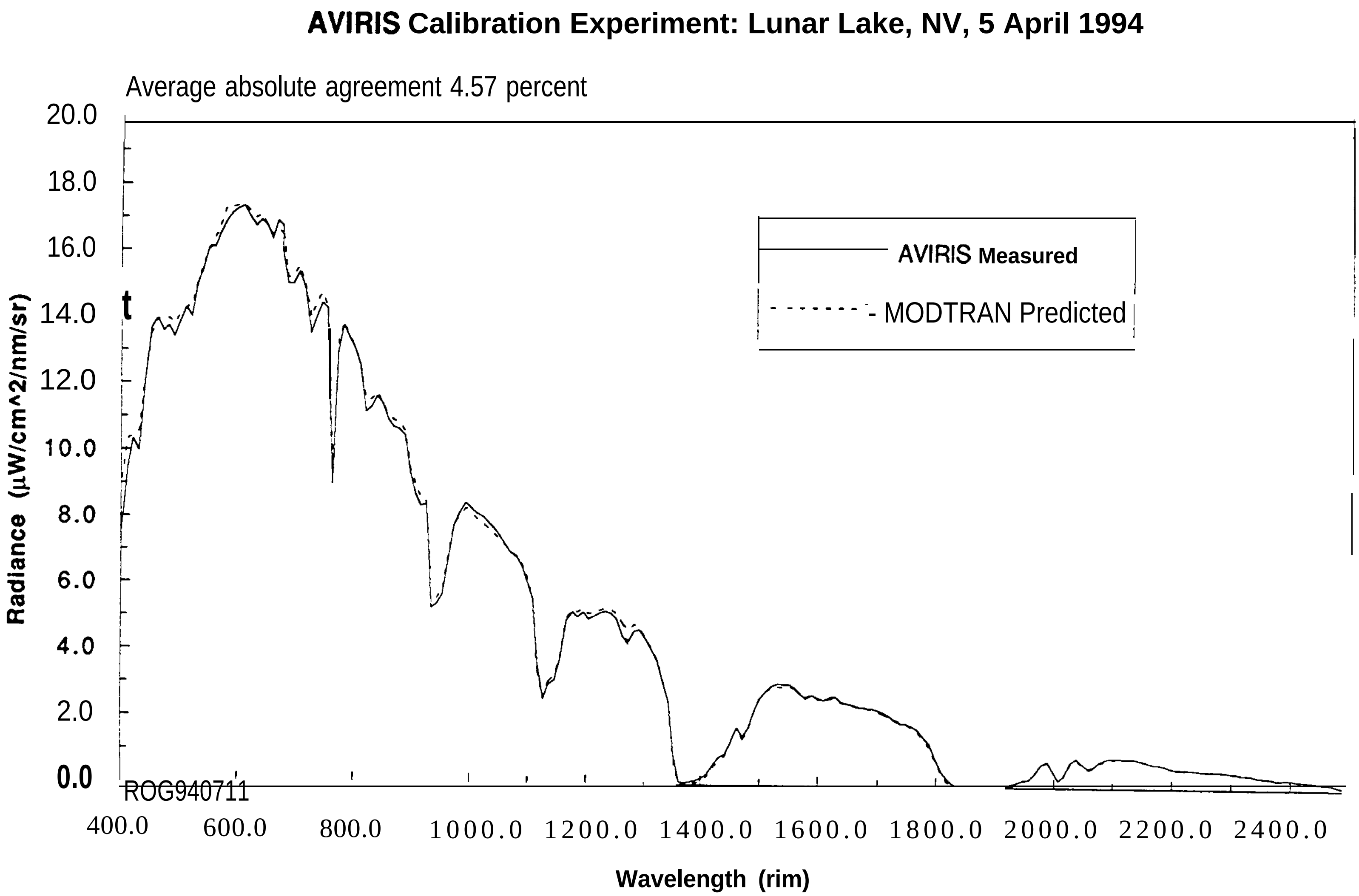

AVIRIS Calibration Experiment: Lunar Lake, NV, 5 April 1994
Average absolute agreement 4.57 percent
AVIRIS Measured
MODTRAN Predicted
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Radiance (µW/cm^2/nm/sr)
ROG940711
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0
2000.0
2200.0
2400.0
Wavelength (rim)

Fig. 3

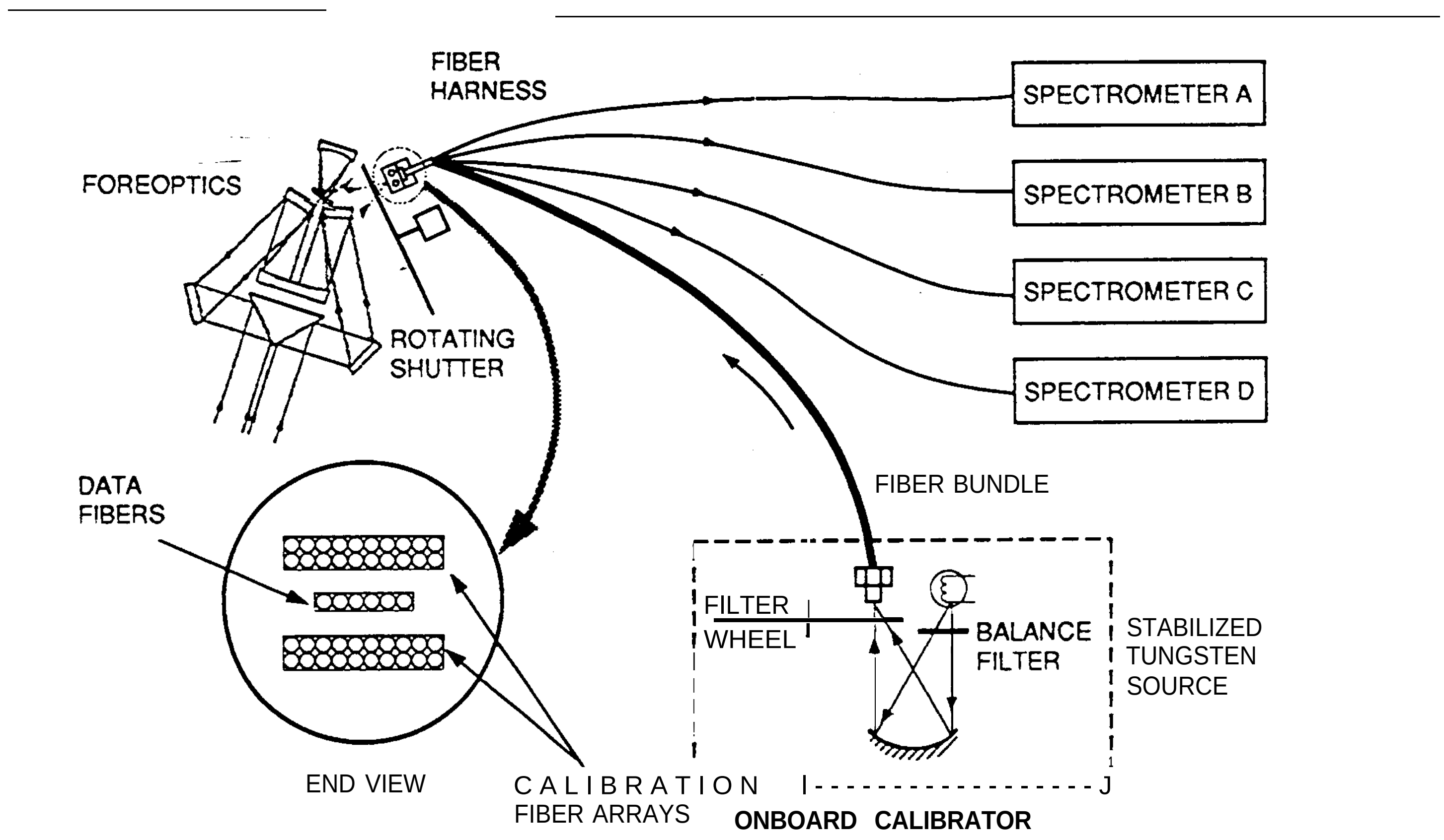
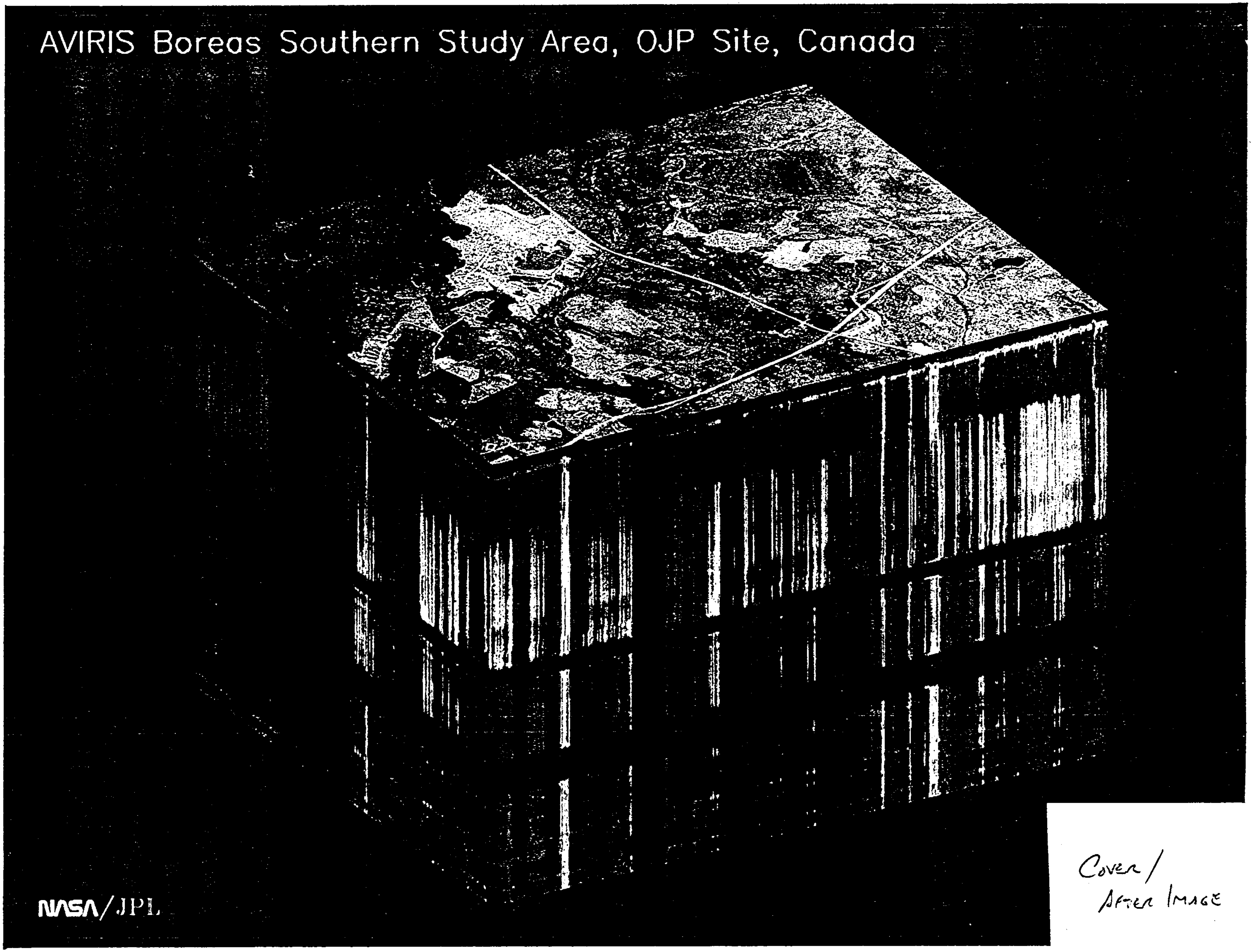

FIBER
HARNESS
FOREOPTICS
ROTATING
SHUTTER
SPECTROMETER A
SPECTROMETER B
SPECTROMETER C
SPECTROMETER D
DATA
FIBERS
FIBER BUNDLE
FILTER
WHEEL
BALANCE
FILTER
STABILIZED
TUNGSTEN
SOURCE
END VIEW
CALIBRATION
FIBER ARRAYS
I
J
ONBOARD CALIBRATOR

Fig. 4



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