Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Recent improvements to the Sensor and Data Facility

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ABSTRACT

AVIRIS operations at the Jet Propulsion Laboratory consist primarily of a sensor task and a data facility task. These two activities are supported by an experiment coordination, a calibration and a management effort. The sensor task is responsible for AVIRIS sensor maintenance, laboratory calibration, and field operations. The AVIRIS data facility is responsible for data archiving, data calibration, quality monitoring and distribution. In this paper we describe recent improvements in these two primary AVIRIS tasks. The inflight performance of AVIRIS in 1992 and 1993 that resulted from these improvements is also presented.

1.() IN"I'RODUCI'1ON

AVIRIS is a NASA-sponsored Earth-looking imaging spectrometer designed, built and operated by the Jet Propulsion Laboratory. AVIRIS acquires flight data at 20 km altitude from the Q-bay of a NASA ER-2 that is operated by the Ames Research Center. The spectral, radiometric and geometric characteristics of the data acquired by AVIRIS are given in Table 1. To demonstrate the imaging spectrometer characteristics of AVIRIS, a plot showing the 224 spectral channels of AVIRIS in conjunction with the 6 visible to short wavelength infrared Thematic Mapper bands is shown in Figure 1. A representative transmission spectrum of the terrestrial atmosphere is shown as well. In Table 1, the operational characteristics of the AVIRIS sensor and data facility are given.

AVIRIS has been operational since 1989, however in each year since 1989 major improvements have been completed in most of the subsystems of the sensor and data facility. As a consequence of these efforts, the capabilities of AVIRIS to acquire and deliver calibrated imaging spectrometer data of high quality have improved significantly over those in 1989. improvements to AVIRIS prior to 1992 have been described previously (Porter et al., 1990, Chrien et ai., 1991, Chrien et al., 1992 and, Hansen et al., 1992). In the following sections of this paper we describe recent and planned improvements to AVIRIS in both the sensor and data facility tasks.

2.() SENSOR IMPROVEMENTS

2.1 1992 Engineering and Maintenance Cycle

A planned replacement of the 1985 vintage high density tape recorder (HDTR) was undertaken during this maintenance cycle. Following environmental testing a thermal control system was integrated into the new 1-11)"1'1< to allow operations at the ER-2 aircraft Q-bay temperatures. Incorporation of this recorder into the

AVIRIS sensor expanded the data capacity from 6 to 10 gigabytes or from 600" to 1000 linear kilometers of airborne data acquisition per flight. This new recorder also provided an order of magnitude reduction in the pcr unit cost of recording media A spare recorder was acquired to allow timely recovery upon HDTR malfunction.

To improve the signal-to-noise performance of AVIRIS, efforts were made to reduce the noise contribution of the pre-amplifier circuitry in each of the AVIRIS spectrometers. This activity resulted in a reduction in noise from approximately 1.8 to 1.1 digitized numbers, Fixed pattern noise was reduced in AVIRIS through increased shielding of the timing and signal chain cables. These noise reduction efforts lead to significant improvements in the signal-to-noise performance shown in Figure 2.

To provide improved AVIRIS absolute radiometric calibration several mollifications were made to the on board calibrator subsystem. Based on failures in 1991, the AVIRIS onboard calibrator bulb was replaced in 1992 with a bulb of longer life and improved stability. An improved color balancing filter was added to provide a more uniform signal across the four AVIRIS spectrometers. Data from the onboard calibrator are recorded with each AVIRIS flight line and provided with all AVIRIS data distributed to investigators.

During the 1992 maintenance cycle a number of the transmissive elements in the AVIRIS sensor were modified. Spectrometer spherical mirrors were recoated to repair accumulated corrosion damage. Anti reflection coatings were added to the hatch window, the fore optics window anti the fore optics termination of the fiber harness. These coatings provided incremental improvements in AVIRIS throughput, At this time, the fore optics window was tilted to minimize the affects of unwanted internal reflections. These efforts to improve signal throughput also contributed to the signal-to-noise gains shown in Figure 2. Prior to fiber harness installation in 1992, a failure was noted in the primary fiber connecting the C spectrometer to the fore optics. The spare infrared fiber previously integrated into the fiber harness was installed. Use of the spare fiber introduced an integer shift of three spatial samples in the C spectrometer data. This shift was compensated in the calibrated AVIRIS data prior to distribution to the investigator. The spare infrared fiber performed nominally throughout the seven month flight season.

Following these modifications to the sensor a calibration experiment was hekl to characterize and validate the performance of AVIRIS. This inflight calibration experiment was held on the 30th of May 1992 at Rogers Dry Lake, California. Surface and atmosphere measurements were acquired at the time of" the AVIRIS overflight. 'l'he MODTRAN2 (Berk et al., 1989) radiative transfer code was constrained by these in situ measurements to predict the radiance arriving at the AVIRIS aperture. In Figure 3 a comparison of the MODTRAN2 predicted radiance and the AVIRIS laboratory calibrated radiance is shown. Agreement between the AVIRIS-measured and MODTRAN2-predicted radiance was better than 7 percent. This close agreement demonstrates that AVIRIS performed as expected based on the sensor improvements achieved in this engineering period.

2.2 1993 Engineering and Maintenance Cycle

Optical elements in the AVIRIS sensor were modified and improved during this time period. A set of new fiber harnesses were procured and one of them installed in AVIRIS. The new fiber material was manufactured to have improved strength and resistance to humidity degradation. Problems with both breakage and humidity damage have been encountered with the previous 1986 vintage fiber material. improvements were made to the fiber optic spectrometer connector to improve repeatability and stability of spectral alignment. The old connector may have been responsible for some change in the spectral calibration of the B spectrometer during the 1992 flight season. To further improve energy throughput, new spectra] order blocking filters were installed in the AVIRIS spectrometers. These filters provided both higher throughput in the band pass and improved blocking of unwanted energy As an example, a piot of the 1992 and 1993 filter transmissions for spectrometer B is shown in Figure 4. 'l'he improvement in spectrometer B ranges between 20 and 50 percent. in the C spectrometer a 5 to 30 percent increase in throughput was achieved. Better long wavelength energy blocking was achieved in spectrometer D. Reduction in this background energy decreased the noise in the D spectrometer by as much as 30 percent.

During calibration and characterization of AVIRIS in 1993, a non linearity in response was discovered for extremely bright targets. The problem was traced to a set of clamping diodes in the pre-amplifiers that are required to compensate for multiplexer switching transients. These diodes have been adjusted to effectively eliminate the nonlinear effects for the imaging of all terrestrial surfaces.

An additional improvement to the onboard calibrator was implemented in this period. In the past, the onboard calibrator signal was reflected into the optical system from one of two sides of a shutter. The side of the shutter measured was an unpredictable function of the flight line acquisition timing. A slight difference in the reflectance of the two sides of the shutter was measured in 1992. A change was implemented in 1993 to measure both sides of the shutter at the beginning and end of each flight line. This eliminates any ambiguity in the measured onboard calibrator signal.

During this engineering cycle, a new automated spectral calibration capability was implemented for AVIRIS. This computer controlled laboratory instrumentation allows direct calibration of each of the 224 spectral channels. During previous years, typically 10 channels of each spectrometer were manually calibrated and the remainder calibrated through interpolation. With this new automated system, AVIRIS was spectrally calibrated with 8 hours of measurements in May of 1993. A plot of the spectral calibration for channel number 32 in the A spectrometer is given in Figure 5.

The inflight determined performance of AVIRIS following this period of engineering, is shown in Figures 6 and 7 respectively. Figure 6 shows the results of an inflight calibration experiment on the 18th of May 1993. An agreement of 6 percent was achieved between the AVIRIS laboratory calibrated measurements anti the radiative transfer code predicted radiance for this experiment. In Figure 7, a comparison is shown between the 1993 and 1992 inflight signal-to-noise performance of AVIRIS.

2.3 Future Engineering and Maintenance Plans

in order to improve reliability and improve AVIRIS performance, a new set of focal planes are pianned to be integrated into AVIRIS prior to the 1994 flight season. These focal planes will be based on current detector and multiplexor technology. Improved reliability is expected as well as a significant decrease in focal plane noise with respect to the current 1986 technology focal planes. As a consequence of the decreased noise anticipated in the new focal planes, the AVIRIS digitization will be increased from 1() to 12 bits to fully encode this improved precision.

in the future, incremental improvements are planned for the onboard calibrator. These improvements will include introduction of an inflight spectral source that will be used to fully monitor the inflight spectral calibration of AVIRIS. Direct viewing of the downwelling solar irradiance by the AVIRIS spectrometers is also being considered as an additional inflight calibration source.

Consideration has been given to improving the position and pointing telemetry encoded with the AVIRIS data. A goal of 5 to 10 m knowledge has been proposed for AVIRIS X, Y and Z and 0.25 to ().5 milliradians for roil, pitch and yaw. This improvement is essential for quantitative geometric analysis of the AVIRIS data and if AVIRIS is flown in the future on lower altitude aircraft in the more turbulent portion of the atmosphere.

Additional modifications will be proposed and implemented in the AVIRIS sensor and support instrumentation as they are *shown* to improve the quality of AVIRIS data delivered to the science investigators.

3.0 AVIRIS DATA FACILITY IMPROVEMENTS

3.1 1992 Data Facility Modifications

in 1992, with the upgrade of the high density tape recorder in the AVIRIS sensor, a new high density tape recorder was installed in the AVIRIS data facility. Since installation, a sophisticated software interface has been developed between the HDTR and the AVIRIS archiving software. This allows rapid downloading as well as detailed monitoring of the AVIRIS data transferred from the high density data tape.

Prior to the 1992 flight season, a complete rewrite of the software to archive, calibrate and distribute AVIRIS data was undertaken, Typically 200 gigiabytes of laboratory and flight AVIRIS data pass through this code each year. All data (distributed to investigators has the calibration algorithms (Green et al., 1992) applied in this code as well. A limited augmentation to the data facility computer hardware was undertaken in conjunction with the software upgrade. Sensor performance and data quality monitoring were designed into this new code as core capabilities. The upgrade was completed in 1992 and resulted in a quadrupling of the data archiving, calibration and distribution performance of the data facility.

As part of the AVIRIS software upgrade, a relational database was integrated into the AVIRIS data facility software to control and record AVIRIS data activities. This data base has significantly improved levels of data trend analysis as well as data acquisition, calibration and distribution tracking.

A policy was established in 1992, with the support of the AVIRIS NASA sponsors, to offer data acquired in previous years to investigators for the marginal cost of reproduction. This has resulted the exploration of the uses of imaging spectrometry data by additional university, industry and government investigators.

3.2 1993 Data Facility Modifications

An extensive effort has been undertaken to eliminate potential single point failures in the AVIRIS data facility system in 1993. Removal of single point failure has been motivated by the desire to minimize interruptions in data delivery to the AVIRIS investigators. This effort has been largely successful with most of the AVIRIS software capable of operating on two or more computer hardware platforms. At present, the single HDTR at the dam facility remains the dominant potential single point of failure.

in 1993, a software subsystem has been pursued to automate the generation of AVIRIS calibration files. This software allows rapid reduction of the gigabytes of radiometric calibration data acquired in the laboratory before and after each flight season. A number of analysis tools have been developed to monitor and validate this process of radio metric calibration file generation.

To allow use of AVIRIS data in calibrating and modeling current and future spaceborne sensors, software has been developed to offer AVIRIS data convolved to the spectral characteristics of a number of satellites. Currently weighted spectral convolution software has been completed for the Optical Sensor (OPS) on board the Japanese Earth Resources Satellite 1. For this spaceborne sensor, AVIRIS data are being used to establish the on orbit calibration of OPS (Green et a]., 1993a). In future, weighted spectral convolution AVIRIS imagery will be available in the AVIRIS spectral range for Landsat TM, Landsat MSS, AVHRR. EOS ASTER, EOS MODIS, EOS MISR, etc.

An improved capability for the monitoring of encoded sensor telemetry has been developed in 1993. The software allows the rapid extraction and trend analysis of telemetry stored in the AVIRIS database. Monitoring and assessment of the sensor telemetry encoded on the high density data tape is required prior to authorizing subsequent airborne acquisitions of AVIRIS data.

All AVIRIS data are archived, calibrated and distributed through the AVIRIS data facility. Based on this modifications described, the capability of the data facility to fulfill this role has kept pace with the growing demand for calibrated AVIRIS data. A summary of the recent and projected acquisition and distribution of AVIRIS data are given in Table 3. At present, an archive of approximately one terabyte of AVIRIS data acquired since test flights in 1987 is maintained under the cognizance of the data facility.

3.3 Data Facility Future Plans

In 1994 a new archive server computer is planned to be acquired in the AVIRIS data facility. This machine will replace hardware acquired in 1989 that is becoming unmaintainable. With this hardware upgrade, further improvements in data archiving rates and data quality monitoring will be possible. Compatibility with future system and network software releases will also be ensured. in conjunction with the archive server upgrade, [he data facility plans to maintain AVIRIS quicklook images on-line for a one year period after acquisition. Maintaining these images on-line will allow investigators to retrieve and examine quicklook data as soon as they are available across the ethernet. These improvements are consistent with the current goals of the AVIRIS data facility: 1) to deliver quicklook images to investigators within one week of acquisition, and 2) to calibrate and distribute data to investigators within two weeks of request. To exceed these performance goals in the future, on-line storage and direct network distribution of AVIRIS data is being investigated.

Finally, the data facility hopes to pursue the delivery of AVIRIS derived geophysical parameters in addition to the instrument measured signal and calibrated upwelling radiance currently offered. Geophysical parameters that are currently being considered arc apparent surface reflectance (Green et al., 1993b), atmosphere water wiper, surface leaf water, cirrus cloud maps, surface oxygen pressure height, etc. Some of these parameter may be offered in the 1994 and 1995 time frame.

4.0 CONCLUSION

Since AVIRIS first became operational in 1989 the AVIRIS system has been undergoing incremental improvements. These improvements have occurred in both the sensor and the data facility components of AVIRIS project. In all cases, the driver for these modifications and upgrades has the quality of data provided to the science investigators. As a consequence, virtually all of the AVIRIS subsystems have been modified and improved since 1989. The important modifications in 1992 iind 1993 have. been descri bcci.

Plans are to continue to improve AVIRIS performance through the future. For the AVIRIS sensor, significant improvements may be achieved in the focal planes, on board calibrator and platform pointing and position telemetry. In the data facility efforts will continue to improve data delivery rates and take advantage of growing network connectivity. In addition, geophysical parameters may be offered directly from the AVIRIS data facility to the investigator. By pursuing these improvements and upgrades, AVIRIS will continue to have an important role in providing calibrated imaging spectrometer data to researchers across the Earth science disciplines.

5.() ACKNOWLEDGMENTS

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6.0 REFERENCES

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8.() TABLES

Table 1. AVIRIS Data Characteristics

SPECTRAL	
Wavelength range	400 to 2.500 nm
Sampling	<= 10 nm
Spectral response (fwhm)	10 nm nominal
Calibration	<= 1 nm
RAII1OME'1'R1C	
Radiometric range	O to maximum lambertian
Sampling	-1 dn noise rms
Absolute calibration	<= 7 %
Intra flight calibration	<= 2 %
Precision/noise	exceeding NEdl ./SNR requirement
GEOMETRIC	
Field of view (FOV)	30 degrees (11 km)
Instantaneous FOV	1.0 mrad (20 m)
Calibration	<= ().2 mrad
Flight line length	Up to ten 100 km flight lines

Table 2. AVIRIS Operational Characteristics

SENSOR	
Imager type	Whiskbroom scanner
Cross track samples	614 elements
Scan rate	12 scans/second
Dispersion	Four grating spectrometers (A, B,C,D)
Detectors	224 detectors(32,64,64,64) Si & InSb
Digitization	10 bits (planned 12 bits in 1994)
Data rate	17 mbits/second
Spectrum rate	7300 spectra/second
Data capacity	>10 gigabytes (>1 0,000 km^2)
Onboard calibration	Radiometric and spectral
Position & pointing	X, Y, Z and roll, pitch, yaw
Launches	~30 per year
DATA FACILITY	
Performance monitoring	48 hours from acquisition
Archiving	One week from acquisition
Quicklook distribution	One week from acquisition
Calibration	Two weeks from request
Quality monitoring	Prior to distribution
Distribution	Two weeks from request
Engineering analysis	High priority as required

'1'able 3. Recent and plan AVIRIS data acquisition

	1991	1992	1993*
Months of operations	7	8	7
Aircraft bases	5	4	4
Principle investigators supported	52(Europe)	32	35
investigator sites flown	137	172	200
Launches	36	34	35
Inflight calibration experiments	3	3	3
Square kilometers flown	115,000	127,300	140,000"
Flight scenes	1150	1273	1400
Gigabytes archived	161	178	196
Data scenes calibrated/distributed	498	847	1000"
Approximate data turnaround(months)	5	2.5	1

*projected

9.0 FIGURES

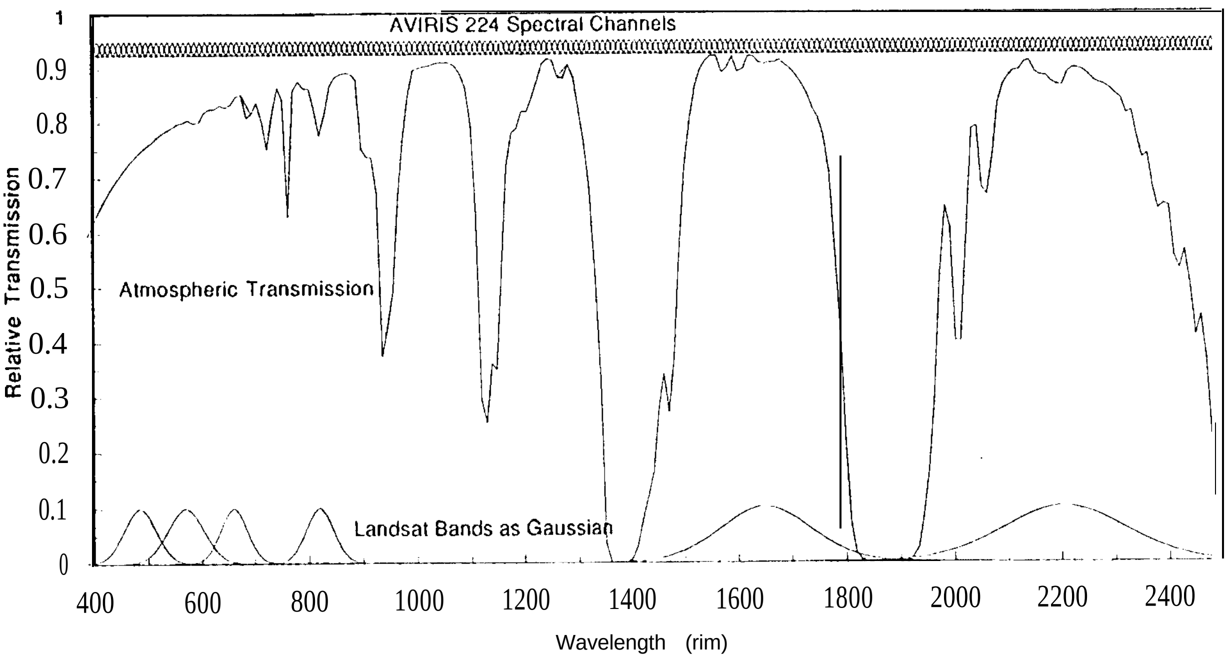

Figure 1. Comparison of AVIRIS 224 spectra] channels with the Thematic Mapper bands modeled as gaussian functions with a terrestrial atmosphere transmission spectrum,

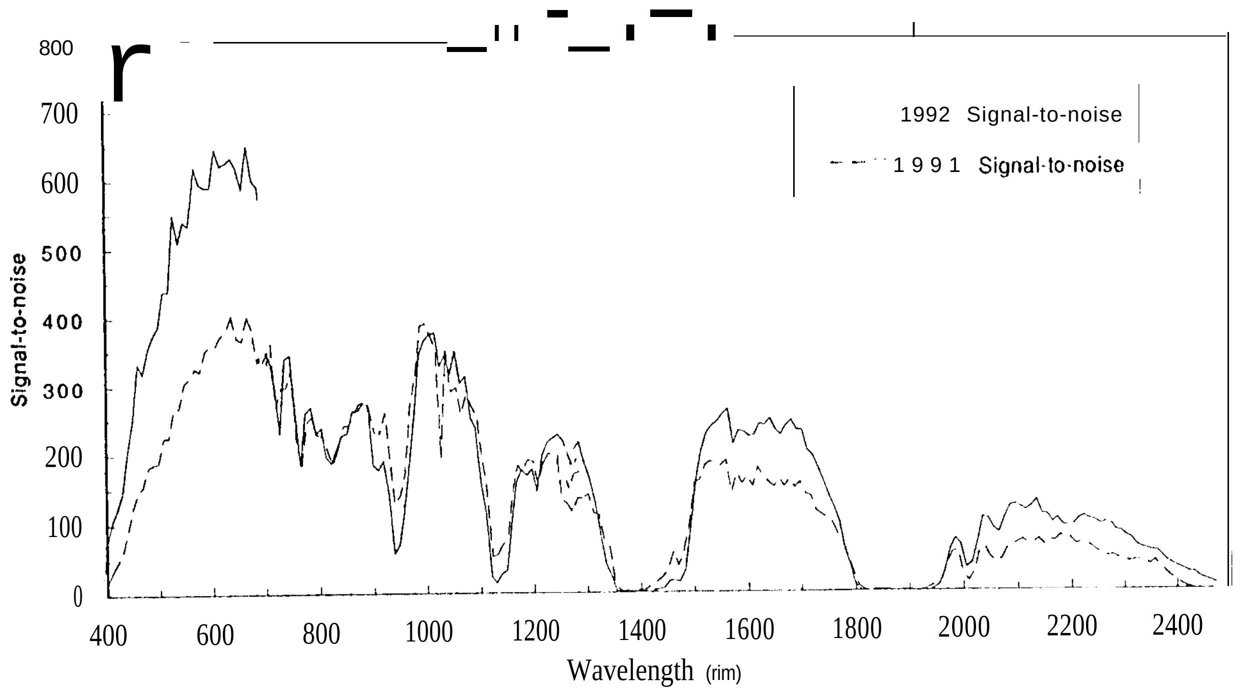

Figure 2. AVIRIS 1992 inflight signal-to-noise in comparison to the performance at the beginning of the 1991 flight season. These signal-to-noise ratios are scaled to the AVIRIS reference radiance which is a 0.5 reflectance target illuminated by the sun at 23.5 degrees through the MODTRAN2 mid latitude summer atmosphere.

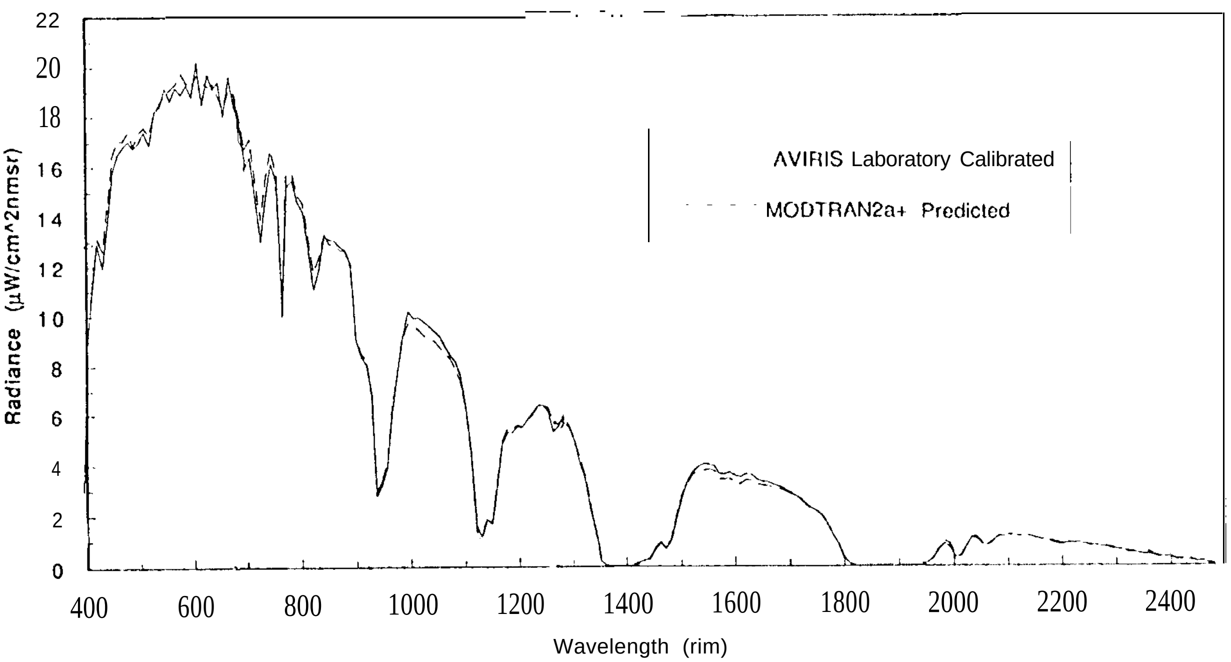

Figure 3. Results of the AVIRIS inflight calibration experiment on the 30th of May 1992. A comparison of the AVIRIS-measured and MODTRAN2-predicted radiance.

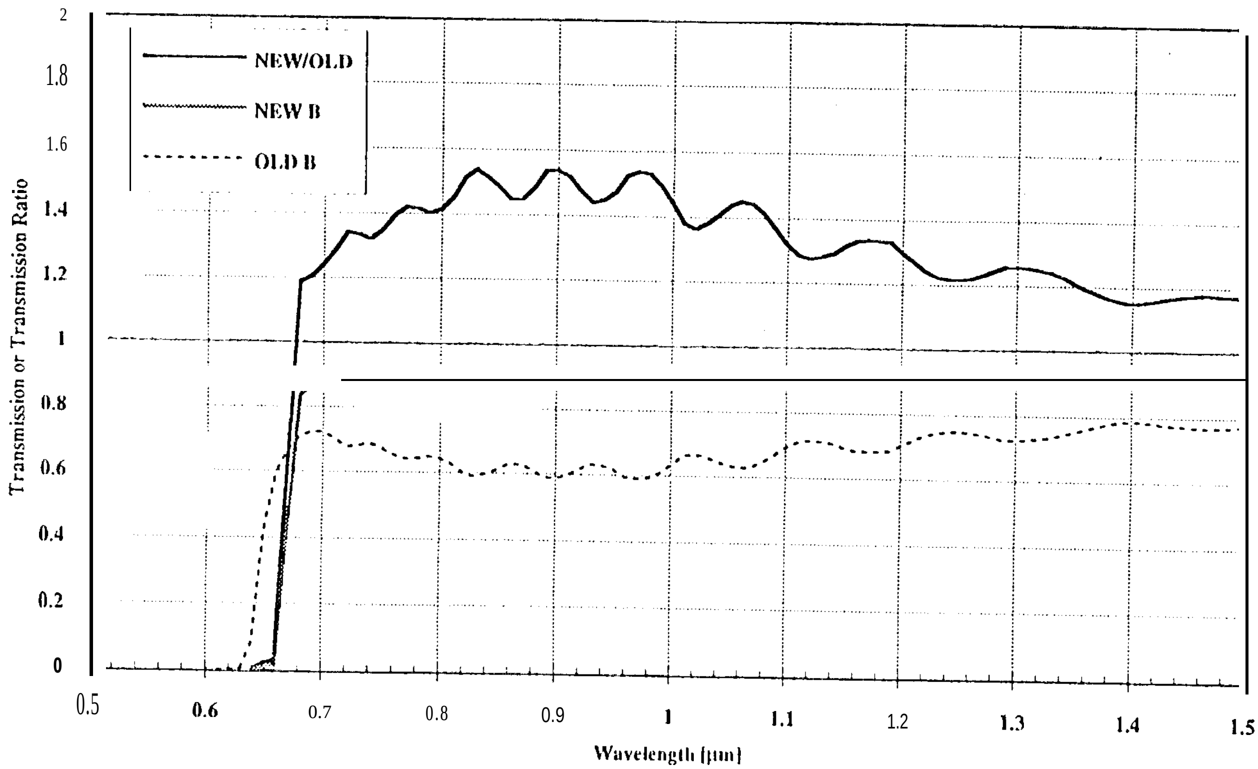

Figure 4. A plot of the 1992 and 1993 filter transmission spectra and ratio for spectrometer B.

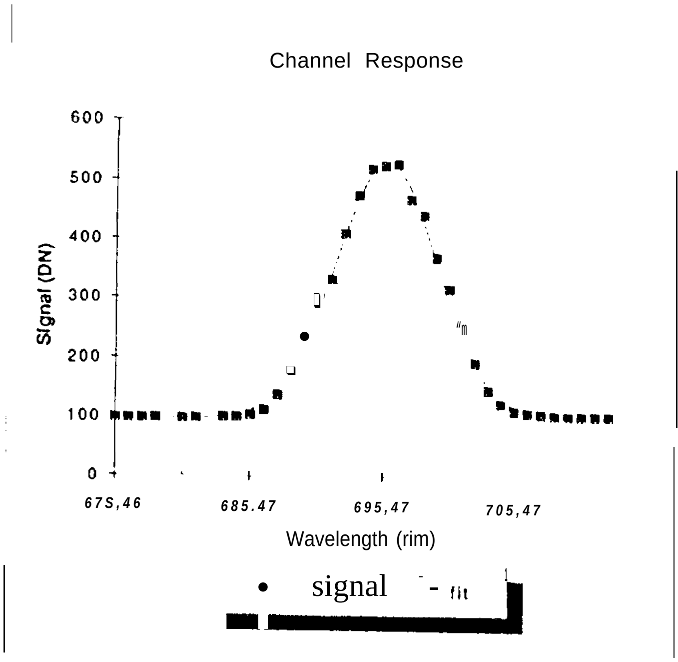

Figure 5. Results from the automated spectral calibration for AVIRIS channel 32. The monochrometer measured points and gaussian model of the channel are shown.

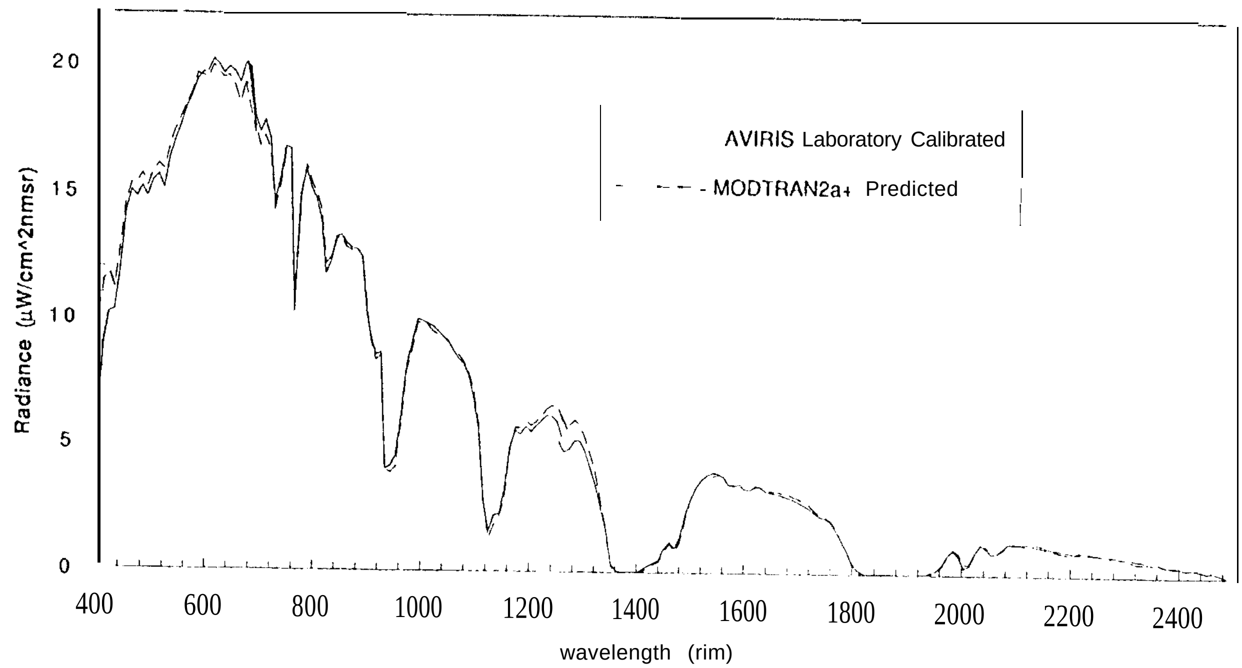

Figure 6. Results of the May 18,1993 AVIRIS inflight calibration experiment comparing measured and radiative transfer predicted radiance at the AVIRIS aperture.

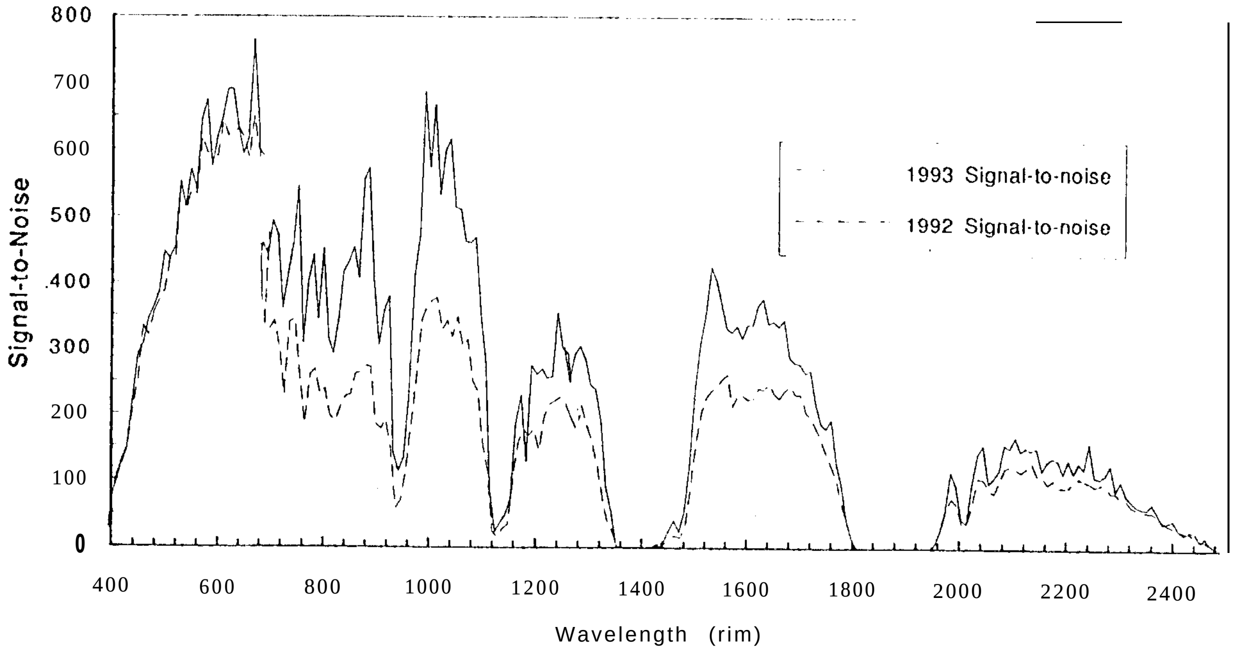

Figure 7. Inflight signal-to-noise for AVIRIS in 1992 and 1993. These signal-to-noise ratios are scaled to the AVIRIS reference radiance.