AVIRIS USER'S GUIDE*

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1. Introduction

This paper serves as a brief overview of the AVIRIS instrument (Airborne Visible/Infrared Imaging Spectrometer) and its role in the field of imaging spectrometry. Mission planning and flight operations are discussed, and recommendations are given regarding the deployment of ground truth experiments.

1.1 Objectives of imaging spectrometry with AVIRIS

The AVIRIS sensor collects data that can be used for quantitative characterization of the Earth's surface and atmosphere from geometrically coherent spectroradiometric measurements. This data can be applied to studies in the fields of oceanography, environmental science, snow hydrology, geology, volcanology, soil and land management, atmospheric and aerosol studies, agriculture, and limnology. Applications under development include the assessment and monitoring of environmental hazards such as toxic waste, oil spills, and land/air/water pollution.

1.2 Description of sensor system

The AVIRIS instrument, built and operated by the Jet Propulsion Laboratory (JPL), is a nadir-viewing whiskbroom scanner that operates unattended in the instrument bay of a NASA ER-2 high altitude aircraft. AVIRIS measures upwelling ground radiance from a nominal altitude of 20 kilometers. With proper calibration and correction for atmospheric effects, the measurements are converted to ground reflectance data which can then be used for quantitative characterization of surface features.

The spatial response of AVIRIS is 1.0 mrad, forming a "pixel" 20m by 20m on the ground. The image width (swath) is 11 km wide, and the image length is typically 10 to 100km. The spectral response ranges from blue-green to near-infrared (400 to 2450 nm). The light entering the instrument is divided between four grating spectrometers and is broken down into 224 contiguous spectral channels approximately 10 nm wide using linear arrays of InSb and Si detectors. Data quantization is 10 bits (upgrading to 12 bits in 1995 - see Sarture et al., 1995). Data from the 4 spectrometers is interleaved with instrument telemetry and aircraft navigation data, then sent out at a rate of 17 Mbits/sec (20 Mbits/sec in 1995). The data is stored on a 10-gigabyte Metrum high density tape storage unit. This allows AVIRIS to collect about 850 km of ground track data per flight.

Calibration of the sensor is maintained by several methods. First is an onboard calibrator that provides a continuous spectral and radiometric reference during data collection. Second is an intensive laboratory calibration that is performed twice each year whereby spectral, radiometric, and geometric aspects of AVIRIS data are compared with laboratory standards. Finally, an in-flight calibration is performed three times each year whereby performance is compared to theoretical predictions based on atmospheric measurements, surface reflectance measurements, and radiative transfer models.

An engineering field team monitors instrument health by performing preflight and postflight diagnostics. All data produced by the sensor is sent to the AVIRIS data processing facility at JPL. This facility performs the functions of monitoring instrument performance, archiving the data, applying instrument-specific calibration, transforming the data into a user-compatible format, and distributing the data products to investigators. Distribution of data more than one year old is handled by the EROS data center (Earth Resource Observation System) through an agreement with JPL.

The ER-2 aircraft, the airborne platform used for AVIRIS data collection, is a high altitude aircraft with a ground speed of 734 km/h, an altitude of 20 km, and a range of about 2200 km. It seats a crew of one person who serves as pilot, navigator, and instrument operator. The ER-2 is operated by the Ames Research Center in Mountain View, CA.

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1.3 Project management

Operation of the AVIRIS instrument and collection of AVIRIS data aboard the ER-2 is funded primarily through the project office of Mission to Planet Earth at NASA Headquarters in Washington, D.C. This office also reviews experiment proposals and selects the experiments which it will fund. The High Altitude Missions Branch of NASA-Ames Research Center receives flight requests for experiments requiring AVIRIS/ER-2 data collection and, in collaboration with NASA Headquarters, drafts aircraft deployment schedules. The AVIRIS project operates under the Observational Systems Division of the Jet Propulsion Laboratory. In addition to operating and maintaining the sensor, the AVIRIS project works to insure that experiment requirements are met for each flight and that users are satisfied with data quality and the level of service provided.

2. The data collection process

All groups and agencies interested in acquiring AVIRIS data must submit an experiment proposal to NASA headquarters and a flight request to Ames Research Center. These items should be submitted well in advance of the time period for which data collection is desired. Each experiment must designate a Principal Investigator who will serve as a single point of contact for headquarters, Ames, and JPL.

Experiment proposals are reviewed by headquarters, and selections are made based on merit and the program goals of the Mission to Planet Earth office. Once the selection process is completed, the High Altitude Missions Branch at Ames Research Center iteratively designs an aircraft schedule that best accommodates the geographic and seasonal requirements for the suite of approved experiments. An alternative to seeking Headquarters funding for an AVIRIS/ER-2 flight is to contract directly with Ames Research Center on a cost-reimbursable basis. Such arrangements, however, must be approved by NASA headquarters individually.

After the aircraft schedule is drafted, it is distributed to all Principal Investigators. One month prior to the beginning of their experiments, investigators will be contacted by the AVIRIS experiment coordinator to verify experiment requirements and to discuss schedules and arrangements for calibration/validation activities that will accompany data collected during flight operations. The experiment coordinator will also assist investigators in fine-tuning experiment requirements and logistics to insure the likelihood of a successful mission.

3. Flight operations

3.1 Mission planning and execution

AVIRIS experiment requirements are transformed into flight plans by the ER-2 operations team. This team integrates AVIRIS requirements with requirements of other sensors being used by the ER-2 platform. Whenever possible, multiple experiments are combined into a single mission. The personnel involved in a typical AVIRIS mission include two pilots, a NASA representative, a 7-person aircraft ground crew, an AVIRIS experiment coordinator, two AVIRIS engineers, and engineers for any other instruments onboard the ER-2.

During flight operations, the primary contact for investigators will be the experiment coordinator. The duty of the experiment coordinator is to route all pertinent and time-critical information from/to ER-2 operations to/from the community of AVIRIS investigators. All changes to experiment requirements must be submitted in writing to the experiment coordinator and/or pilot at least 24 hours before they can be implemented. Late submission of requirements changes could result in missed flight opportunities for an experiment.

The day before a flight, a nominal set of target sites is selected. This selection is based on weather predictions, experiment requirements, ground team status, and other operational considerations. The ground teams involved with these experiments are alerted to the possibility of a flight, and the requirements for these experiments are frozen. The launch time is determined from the timing requirements and geographic locations of all experiments considered.

On flight day, three hours before the scheduled launch, a team of key people gathers to make the launch decision. This team consists of the pilot, the ER-2 ground crew chief, the AVIRIS experiment coordinator, the NASA representative, and one or more engineers representing each instrument on the ER-2. The pilot then makes a launch decision based on immediate considerations of weather, aircraft readiness, instrument readiness, and experiment ground team readiness. The pilot also considers long term factors such as weather patterns, ground team logistical problems, and schedules of other observation platforms used by the investigators.

Occasionally, a conflict arises whereby two different experiments have good flight conditions, but due to their geographic separation they cannot both be flown on the same day. In this situation the priority of the experiment, designated by NASA headquarters or other sponsoring agency, will be taken into account. In the absence of a designated priority, logic will dictate which site gets flown - i.e., the site that has a short time window, a large and expensive field team, or rare opportunities for good weather. ER-2 Operations and the Experiment Coordinator go to great lengths to head off potential conflicts and to insure that all experiments receive equal consideration. Investigators can take comfort in the knowledge that, in the vast majority of cases, the factors of weather and experiment timing requirements eliminate all conflict between experiments.

After the launch decision is issued, the affected ground teams are notified, and preparation is begun on the aircraft and instruments. The pilot drafts a flight plan and files it with Air Traffic Control. One hour before launch, the pilot dons a pressure suit and breathes oxygen to purge nitrogen from his or her body. If the launch is aborted due to aircraft/instrument anomalies or new weather information, the affected ground teams are again notified. Ground teams will receive confirmation at the time of launch, if so requested. Coordination of multiple NASA aircraft (DC-8, C-130) is handled by the NASA representative. All other aircraft coordination should be handled by the investigator or designated field contact.

During the flight, the experiment coordinator gathers information from unaffected ground teams regarding ground conditions and operational readiness. Investigators are also contacted to discuss deployment status and any operational concerns of the experiment coordinator. After the flight is completed, the pilot briefs the experiment coordinator on the significant events of the mission, emphasizing any anomalous conditions of weather, aircraft performance, instrument performance, or any other conditions that would affect a data run. The experiment coordinator then fills out the AVIRIS flight log based on information from the flight plan and the post-flight briefing. The data tape and flight log are then shipped by express courier to JPL for processing.

3.2 Ground truth experiments: recommendations

The chief purpose of ground truth data collection for AVIRIS experiments is to provide input parameters to radiative transfer or other models that remove the effects of atmospheric absorption and scattering, ultimately converting the radiance data measured by AVIRIS into reflectance data. The ground truth data can also be used to validate the results of AVIRIS data analysis. This section discusses logistics and management issues of ground truth experiments; it is not intended as a guide for designing such experiments. For this information, the reader is referred to the literature (Green et al., 1990, Bruegge et al., 1990, Conel et al., 1988).

Experiment teams are advised to establish reliable pathways of communication and to test these pathways prior to the start of operations. If the experiment site is in a remote location, it is well worth investing in a portable phone or a radio with phone-patch access. One person or one telephone number should be designated as the central point of contact for the group. A regular call-in schedule for key team members is also recommended, especially during initial deployment and during rotation of field personnel.

A time window of at least two weeks' duration is recommended for each experiment to allow for uncertainties in weather patterns and possible equipment failures. In addition to weather, aircraft, and AVIRIS, there are other factors including air traffic control problems, investigator instruments (damaged, lost, or borrowed), and investigator observation platforms such as ships, balloons, and low-altitude aircraft.

Each team should secure a core set of instruments for which it has exclusive use during the entire deployment, especially those instruments used for simultaneous ground truth (e.g., radiometer, sun photometer, radiosonde). For various reasons, an investigator will have to shift or extend the experiment time window. This can create a serious conflict between groups sharing the same instrument if their time windows suddenly overlap.

Creating separate teams for simultaneous and non-simultaneous measurements can reduce personnel costs, thereby allowing a longer experiment window. Typically, the team performing simultaneous measurements is small and operates the set of instruments described in the preceding paragraph. Once the overflight has occurred, the rest of the team travels to the site to perform non-simultaneous ground truth measurements. Costs may reduce the simultaneous measurement team to a single person with one radiometer; however, this is preferable to missing a flight opportunity simply because nobody was in the field.

Accepting early data also helps insure a successful experiment. A compromise in data quality that results from flying at a different time of the month or a different hour of the day is preferable to the possibility of no data at all. An investigator who insists on ideal conditions often ends up, out of desperation, accepting data with 50% cloud cover on the last day of the deployment. Note: this sudden relaxation of requirements is referred to as the "data panic curve."

Field team members should recognize that weather appearing to be clear from the ground may still be unacceptable to an airborne sensor, due either to cloud shadow, near-invisible cirrus, or haze. The ER-2 operations team has full access to satellite images and terminal forecast networks and is very experienced at making weather decisions. Casual observations of the sky by field teams ("It's really clearing up - you people better fly over here!") are generally not useful due to the limited horizon of a ground-based observer. Field teams can, however, assist the weather decision process by providing information on local diurnal weather patterns.

4. Data processing and distribution

All AVIRIS data is processed by the AVIRIS Data Facility at JPL. After data is collected and a flight log is prepared, the data tape and flight log are sent by overnight courier to the data facility. Two hours after receipt of the tape (19 hours after data collection), the data facility generates a performance evaluation of the sensor based on preliminary analysis of the data. This performance evaluation will reveal any anomalies that were not detected by the preflight and postflight diagnostics performed in the field.

Within 72 hours of data collection, the data facility will have archived the data and generated quick-look data products. An assessment of data quality (i.e., cloud cover) can also be performed during this period if arrangements have been made through the AVIRIS Experiment Scientist or the Experiment Coordinator. Every Friday, the quick-look data is placed online via an anonymous FTP (File Transfer Protocol) server. An e-mail message is sent to the Principal Investigator announcing the availability of the data and describing the procedure for downloading it via FTP. If needed, the quick-looks can be sent as hard copy through the mail.

After inspecting the quick-looks, the investigator can place an order for the portions of data he/she would like retrieved from the archive. The data can be delivered as raw or calibrated radiance (this is the instrument-specific calibration, not an atmospheric calibration). In either case, a file is provided that describes the calibration parameters. The investigator has a choice of three mediums: 8 millimeter, 4 millimeter, or 9-track tape. At the present time, data processing is performed on a set of SUN workstations capable of processing 1000 AVIRIS scenes per year. The data volume produced by AVIRIS in 1994 was on the order of 2000 scenes, resulting (unfortunately) in significant lag times for data delivery. A hardware upgrade is scheduled for 1995 that should provide at least a partial remedy to this situation.

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