AVIRIS Investigator's Guide for High- and Low-Altitude Experiments

By Jessica Faust, Chris Chovit, Michael Eastwood, Chuck Sarture,
Betina Pavri, and Howell Johnson
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Introduction

This guide serves as a brief overview of the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) instrument 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.

Objectives of Imaging Spectrometry with AVIRIS

The AVIRIS sensor collects data that can be used for characterization of 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. With proper calibration and correction for atmospheric effects, the measurements can be converted to ground reflectance data that can then be used for quantitative characterization of surface features.

Description of Sensor System

- Scanner type: nadir-viewing, whiskbroom
- Image width (swath): 11 km (high altitude), 1.9 km (low altitude)
- Typical image length: 10 - 100 km
- Spatial response: 1.0 mrad, corresponding to a "pixel" 20 m x 20 m (high altitude) or 4 m x 4 m (low altitude) on the ground
- Spectral response: visible to near-infrared (400 to 2500 nm), with 224 contiguous channels, approximately 10 nm wide
- Data quantization: 12 bits
- Data capacity: 10 gigabytes, corresponding to about 850 km of ground track data, per flight

Description of Airborne Platforms

- **ER-2**
  - Nominal ground speed: 734 km/hr
  - Nominal altitude: 20 km
  - Maximum range: 2200 km
  - Maximum flight time: 6.5 hours *
  - Standard deployment sites: Dryden Flight Research Center, CA; Wallops Island, VA

- Other deployment sites include: Texas, Florida, Kansas, Alaska, Hawaii
    * Flights up to 8 hours (2800 km) may be authorized if required.

- **Twin Otter**
  - Nominal air speed: 80 to 160 knots
  - Altitude range: 6,000 to 17,500 feet
  - Maximum range: 560 nautical miles
  - Maximum flight time: 5 hours
  - Flexible deployment sites

Project Management

Operation of the AVIRIS instrument and collection of AVIRIS data aboard the ER-2 and the Twin Otter are funded primarily through the Office of Earth Science at NASA Headquarters in Washington, D.C. This office also reviews experiment proposals and selects the experiments that it will fund. The Airborne Science Directorate of NASA-Dryden Flight Research Center receives flight requests for experiments requiring AVIRIS/ER-2/Twin Otter 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 ensure that experiment requirements are met for each flight and that users are satisfied with data quality and the level of service provided.

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 Dryden Flight Research Center. These items should be submitted by July 1st for the following fiscal year. Each experiment must designate a principal investigator who will serve as a single point of contact for Headquarters, Dryden Flight Research Center, and JPL.

NASA Headquarters reviews experiment proposals, and selections are made based on merit and the program goals of the Office of Earth Science. Once the selection process is completed, the Airborne Sciences Directorate at Dryden Flight 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 Dryden Flight Research Center on a cost-reimbursable basis. Reimbursable funding is also an option for the Twin Otter, with the funds being sent through Dryden Flight Research Center. Such arrangements must be approved individually by NASA headquarters. Help with the process can be sought through the Airborne Sciences Directorate at NASA Dryden Flight Research Center (http://www.dfrc.nasa.gov/Projects/airsci/general/SciProg/contacts.html).

After the aircraft schedule is drafted, it is distributed to all principal investigators. At least one month prior to the beginning of their experiments, investigators will be contacted by the AVIRIS experiment coordinator. This contact is essential for verification of experiment requirements and to discuss schedules and arrangements for any 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 increase the likelihood of a successful mission. Investigators will be asked to check their requirements on the AVIRIS website and to e-mail an affirmation that the information is correct or a correction if it is not correct. It is critical for investigators to confirm that the data that the AVIRIS team is using to plan the flights is correct. Latitude/longitude target coordinates are especially critical to confirm.

Mission Planning and Execution

ER-2

Operations and Responsibilities

AVIRIS experiment requirements are transformed into flight plans by the ER-2 operations team. This team integrates AVIRIS requirements with those 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 mission manager, a 7-person aircraft ground crew, an AVIRIS experiment coordinator, an AVIRIS engineer/technician, and engineers for any other instruments aboard the ER-2.

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 to/from ER-2 operations from/to the community of AVIRIS investigators. All changes to experiment requirements must be submitted in writing (e-mail preferred) to the experiment coordinator and/or pilot *at least* 24 hours before they are to be implemented. Late submission of requirement changes could result in missed flight opportunities for an experiment.

The investigator must provide the following information:

- Flight line coordinates, in one of three forms:
  1. Start/stop points: Latitude and longitude coordinates are given for the starting and ending points of each flight line.
  2. Center point: Latitude and longitude coordinates are given for the center of the line. Flight direction and the length of the flight line must also be specified.
  3. Box area: Latitude and longitude coordinates are given for the four corners of a "box" whose area needs total coverage. The pilots will use this information to draft appropriate flight lines.

  Note: Please specify coordinates using deg-minutes.decimal-minutes format (e.g., 34-48.6 North, 119-29.0 West)
- Weather conditions desired (default is n/a)
- Maximum cloud cover, (nominally between 5 and 20%; default is 10%)
- Sun angle limits (may be expressed as a Sun angle limit or a "time of day" window). Please specify times in GMT (e.g., 1900 GMT +/- 1 hr.) or with reference to solar noon (default is solar noon +/- 2 hrs.). *Please do no not use local times.*
- Ground conditions, if any (default is n/a)
- Other conditions, such as simultaneous satellite overpass, tidal or sea states, etc. (defaults are n/a)

Default parameters will be used for any that remain unspecified.

If any parts of the target line or box area are of critical importance to the experiment, i.e., calibration targets or essential areas, it is recommended that the line or box be designed such that the area is not near the start/end points or box edge. The closer to the center of the area they are, the less likely they will be cropped due to unforeseen events during data collection.

Flights over foreign soil or U.S. military restricted areas must be given approved clearance. It is the responsibility of the NASA mission manager to obtain this clearance from the appropriate authorities and provide the experiment coordinator and/or pilot with the corresponding clearance number at least 24 hours in advance of the flight. On approach to the restricted area, the pilot will use this number to confirm entry into the area. Please note that flight lines that are near to or adjacent to restricted areas may also require clearance in order to be flown.

The day before a flight, a nominal set of target sites is selected. The 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 the experiments considered.

On the day of the flight, three and one-half hours before the scheduled launch, the AVIRIS experiment coordinator provides the NASA mission manager with the list of possible targets for the day. This list is assembled based on the availability of ground truth teams and scientific considerations. Three hours prior to 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 mission manager, 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 and aircraft readiness.

Occasionally, a conflict arises whereby two different experiments have good flight conditions, but due to their geographic separation or data requirements, they cannot 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, taking into account the experiments' flight windows, ground team efforts, coordination with other platforms, and rare opportunities for good weather. However, 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 files a flight plan with air traffic control. If the launch is aborted due to aircraft/instrument anomalies or new weather information, the affected ground teams will be notified. The ground teams will also receive confirmation at the time of launch, if so requested. The NASA mission manager handles coordination of multiple NASA aircraft (DC-8, C-130). The investigator or designated field contact should handle all other aircraft coordination.

After the flight is completed, the pilot briefs the experiment coordinator on the significant events of the mission, emphasizing any anomalous conditions of the weather, aircraft performance, instrument performance, or any other conditions that would affect data acquisition. The experiment coordinator then fills out an 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.

Twin Otter

Operations and Responsibilities

The personnel involved in the low-altitude data acquisition are two Twin Otter pilots, an AVIRIS experiment coordinator, and an AVIRIS engineer/technician. The primary contact for investigators will be the experiment coordinator. The primary mode of contact for the experiment coordinator should be e-mail sent to avec@spectra.jpl.nasa.gov. Urgent messages can be left on the voicemail pager, 888-415-4547 (option 2). However, the experiment coordinator will not be able to listen to the voicemail in flight, so investigators may not receive a response for several hours and should leave an evening contact telephone number with these messages.

The duty of the experiment coordinator is to make sure that the pilots have the proper flight line coordinates for each day's experiment and that the investigator's requirements are met. The pilots enter the flightline coordinates into their Global Positioning System (GPS) database several days before the lines are planned to be flown. For this reason, requests for new sites should be submitted one month in advance of the deployment. All changes in experiment requirements must be submitted by e-mail to the experiment coordinator one week prior to the first flight of a deployment. Late submission of requirement changes could result in missed flight opportunities for an experiment.

Because the weather determines when the Twin Otter will arrive at each site, the experiment coordinator is responsible for providing notice to the investigators as to when the acquisition might take place, *but* the investigator is responsible for being ready at any time during the deployment. Our goal is to be able to give the investigators notice a night or two before the acquisition is planned. For this reason, providing both day and evening telephone numbers for ground team contacts is extremely important. If the investigator will not be available for the entire deployment period, including a secondary contact is also strongly recommended.

Depending upon weather and locality, the pilots and experiment coordinator will determine what targets are feasible for the next day and then spend the night at a location that will allow them to acquire data at those targets the next day. The number of days spent waiting for a clear weather window at any given site is dependent upon the number of targets left, their locations, and the number of days left in the deployment.

On the day of the flight, the AVIRIS experiment coordinator and the pilots will determine if the weather conditions are favorable for acquiring the sites that had been decided upon, and the ground teams will be notified. If the ground team has information that is pertinent to the decision-making process, then they should make contact with the experiment coordinator via the AVIRIS pager (888-415-4547).

The investigator must provide the same information as for ER-2 flights except for the flight line coordinate information. *The flight line coordinate information should always take the form of start/stop end points for the center of each line (giving the latitude and longitude coordinates in degrees-minutes.decimal-minutes: ddd:mm.mm).* The pilot cannot check the

accuracy of these coordinates; therefore, investigators need to check the AVIRIS website and confirm that their lines have been accurately entered into the database. This confirmation should be in the form of e-mail to the experiment coordinator.

The PI will also need to specify the altitude at which data shall be collected. In order to achieve adequate sampling in the along-track direction at typical Twin Otter ground speeds, an altitude of at least 12,500 ft above *ground* level is recommended. However, investigators should also consider the following: FAA regulations require the pilots to use supplemental oxygen at 12,500 ft (above *sea* level) - if they're there for more than 30 minutes, and at all times above 14,000 ft. All passengers must be equipped with oxygen above 15000 ft (above sea level). The higher the plane flies, the faster the oxygen gets used, and oxygen has been a limiting factor in data collection in the past (when we're out of oxygen, we're done for the day). For sites at high altitude, PIs may want to consider trading some undersampling (i.e., lower altitude) for more areal coverage.

Restricted and Military Operations Areas

Restricted areas and military operations areas (MOAs) are depicted on airspace charts, and investigators are encouraged to plan their lines outside of these areas, if at all possible. For flights requiring access to military areas or over foreign soil, investigators are responsible for making contact with the appropriate authorities and providing the experiment coordinator with the clearance number or code and the controlling agency's radio frequency. On approach to the restricted area, the pilot will use this information to confirm entry into the area. When obtaining a clearance, investigators should inform the controlling authorities that the data might be collected at any time during the low-altitude deployment window, and find out when the areas will be closed to non-military traffic. It is helpful to remember that many restricted areas will not allow access during the week, but might be accessible on weekends. In addition, flight lines that are near or adjacent to restricted areas may also require clearance in order to be flown. (This is less of an issue with the Twin Otter than it is with the ER-2 but it is still important to remember.) Finally, investigators should be aware that clearances could be revoked at any time. The Twin Otter pilots also have the authority to decide that military operations in the area make flight there too hazardous even with the clearance, thus canceling the collection. Therefore, lines within restricted airspace are much less likely to be flown given all of the other constraints of a mission.

Ground Truth

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.

Experiment teams are advised to establish reliable pathways of communications and to test these pathways well before the start of operations. If the experiment site is in a remote location, it is well worth investing in a portable telephone 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, air-traffic control problems, and other factors. Accepting early data also helps ensure 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 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.

Field team members should recognize that weather's 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-related decisions. Casual observations of the sky by field teams ("It's really clearing up - you people should fly!") are generally not useful due to the limited horizon of a ground-based observer. However, field teams can assist the weather decision process by providing information on local diurnal weather patterns.

Data Processing and Distribution

The AVIRIS Data Facility at JPL processes all AVIRIS data. Two hours after AVIRIS data is received at the data facility, (approximately 20 hours after data collection), a sensor performance evaluation is generated, based on preliminary analysis of the data. This performance evaluation will reveal any anomalies that were not detected by the preflight and post-flight diagnostics performed in the field.

Within 72 hours after data collection, the data facility will have archived the data and generated quick-look data products. An assessment of data quality (e.g., cloud cover) can also be performed during this period if arrangements have been made through the AVIRIS experiment coordinator. "Quicklook" data will be generated and placed on-line via the AVIRIS anonymous FTP server. An email message is sent to the principal investigator announcing the availability of the data and describing the procedure for downloading it via FTP, or viewing it with a web browser.

After inspecting the quicklooks, the investigator can place an order for the portions of data that he/she would like retrieved from the archive. The data can be delivered as raw, or calibrated for radiance (this is an 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 media: 8-millimeter, 4-millimeter, or 9-track tape. Delivery times vary, based on the current volume of data being processed at the data facility, but generally range from 1 - 4 months after data collection.

Acknowledgements

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.