FLAASH Module User's Guide

ENVI FLAASH Version 4.2
August, 2005 Edition

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Contents

Chapter 1
Introduction

This chapter covers the following topics:

Introduction to Atmospheric Correction and ENVI FLAASH

The nature of remote sensing requires that solar radiation pass through the atmosphere before it is collected by the instrument. Because of this, remotely sensed images include information about the atmosphere as well as information about the surface. For those interested in quantitative analysis of surface reflectance, removing the influence of the atmosphere is a critical pre-processing step. To compensate for atmospheric effects, properties such as the amount of water vapor, distribution of aerosols, and scene visibility must be known. Because direct measurements of these atmospheric properties are rarely available, there are techniques that infer them from their imprint on hyperspectral radiance data. These properties are then used to constrain highly accurate models of atmospheric radiation transfer to produce an estimate of the true surface reflectance. Moreover, atmospheric corrections of this type can be applied on a pixel-by-pixel basis because each pixel in a hyperspectral image contains an independent measurement of atmospheric water vapor absorption bands.

ENVI's atmospheric correction module, FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes), is a first-principles atmospheric correction modeling tool for retrieving spectral reflectance from hyperspectral radiance images. With FLAASH, you can accurately compensate for atmospheric effects. FLAASH corrects wavelengths in the visible through near-infrared and short-wave infrared range, up to 3 microns (for thermal regions, use the **Basic Tools → Preprocessing → Calibration Utilities → Thermal Atm Correction** option). Unlike many other atmospheric correction programs that interpolate radiation transfer properties from a pre-calculated database of modeling results, FLAASH incorporates the MODTRAN4[1] radiation transfer code. You may choose any of the standard MODTRAN model atmospheres and aerosol types to represent the scene, and a unique MODTRAN solution is computed for each image.

FLAASH also includes:

- A correction for the adjacency effect (pixel mixing due to scattering of surface-reflected radiance)

- An option to compute a scene-average visibility (that is, aerosol/haze amount), and uses the most advanced techniques for handling particularly stressing atmospheric conditions (such as the presence of clouds)

- A cirrus and opaque cloud classification map

- Adjustable spectral polishing for artifact suppression.

FLAASH supports both hyperspectral sensors (such as HyMAP, AVIRIS, HYDICE, HYPERION, Probe-1, CASI, and AISA) as well as multispectral sensors (such as Landsat, SPOT, IRS, and ASTER). Water vapor and aerosol retrieval are only possible when the image contains bands in appropriate wavelength positions (see "Input Data Requirements" on page 10 for details). In addition, FLAASH can correct images collected in either vertical (nadir) or slant viewing geometries.

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1. The version of MOTRAN4 incorporated into ENVI FLAASH was modified to correct errors in the HIT-RAN-96 water line parameters. See Matthew et al, 2000 for details.

FLAASH was developed by Spectral Sciences, Inc., a world leader in optical phenomenology research, under the sponsorship of the U.S. Air Force Research Laboratory. Spectral Sciences has been an integral part in the development of modern atmospheric radiation transfer models, and has worked extensively on MODTRAN since the model's inception in 1989.

References

For detailed scientific descriptions of the model employed by FLAASH, see the following references:

Adler-Golden, S. M., M.W. Matthew, L. S. Bernstein, R. Y. Levine, A. Berk, S. C. Richtsmeier, P. K. Acharya, G. P. Anderson, G. Felde, J. Gardner, M. Hoke, L. S. Jeong, B. Pukall, A. Ratkowski and H.-H Burke. *Atmospheric Correction for Short-wave Spectral Imagery Based on MODTRAN4*. SPIE Proc. Imaging Spectrometry, V. 3753. pp. 61-69. 1999.

Berk, A., L. S. Bernstein, G. P. Anderson, P. K. Acharya, D. C. Robertson, J.H. Chetwynd and S. M. Adler-Golden. *MODTRAN Cloud and Multiple Scattering Upgrades with Application to AVIRIS*. Remote Sens. Environ., Vol. 65. pp. 367-375. 1998.

Berk A., L. S. Bernstein and D. C. Robertson. *MODTRAN: a moderate resolution model for LOWTRAN7. GL-TR-89-0122*. Air Force Geophys. Lab., Hanscom AFB, MA. p. 38. 1989.

Matthew, M.W., S.M. Adler-Golden, A. Berk, S.C. Richtsmeier, R.Y. Levine, L.S. Bernstein, P.K. Acharya, G.P. Anderson, G.W. Felde, M.P. Hoke, A. Ratkowski, H.-H. Burke, R.D. Kaiser, and D.P. Miller. *Status of Atmospheric Correction Using a MODTRAN4-based Algorithm*. SPIE Proceeding, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI. 4049. pp. 199-207. 2000.

The ENVI FLAASH Model

This section is a brief overview of the atmospheric correction method used by FLAASH. For more thorough details, see "Introduction to Atmospheric Correction and ENVI FLAASH" on page 6.

FLAASH starts from a standard equation for spectral radiance at a sensor pixel, *L*, that applies to the solar wavelength range (thermal emission is neglected) and flat, Lambertian materials or their equivalents. The equation is:

$$L = \left(\frac{A\rho}{1 - \rho_e S}\right) + \left(\frac{B\rho_e}{1 - \rho_e S}\right) + L_a \tag{1}$$

where:

   ρ is the pixel surface reflectance

   ρ_e is an average surface reflectance for the pixel and a surrounding region

   S is the spherical albedo of the atmosphere

   L_a is the radiance back scattered by the atmosphere

   A and B are coefficients that depend on atmospheric and geometric conditions but not on the surface.

Each of these variables depends on the spectral channel; the wavelength index has been omitted here for simplicity. The first term in Equation (1) corresponds to radiance that is reflected from the surface and travels directly into the sensor, while the second term corresponds to radiance from the surface that is scattered by the atmosphere into the sensor. The distinction between ρ and ρ_e accounts for the adjacency effect (spatial mixing of radiance among nearby pixels) caused by atmospheric scattering. The adjacency effect correction may be ignored by setting $\rho_e = \rho$. However, this correction can result in significant reflectance errors at short wavelengths, especially under hazy conditions and when strong contrasts occur among the materials in the scene.

The values of A, B, S and L_a are determined from MODTRAN4 calculations that use the viewing and solar angles and the mean surface elevation of the measurement, and assume a certain model atmosphere, aerosol type, and visible range. The values of A, B, S and L_a are strongly dependent on the water vapor column amount, which is generally not well known and may vary across the scene. To account for unknown and variable column water vapor, the MODTRAN4 calculations are looped over a series of different column amounts, then selected wavelength channels of the image are analyzed to retrieve an estimated amount for each pixel. Specifically, radiance averages are gathered for two sets of channels: an absorption set centered at a water band (typically the 1130 nm band) and a reference set of channels taken from just outside the band. A two-dimensional look-up table for retrieving the water vapor from these radiances is constructed.

After the water retrieval is performed[2], Equation (1) is solved for the pixel surface reflectances in all of the sensor channels. The solution method involves computing a spatially averaged radiance image L_e, from which the spatially averaged reflectance ρ_e is estimated using the approximate equation:

$$L_e \approx \left(\frac{(A + B)\rho_e}{1 - \rho_e S} \right) + L_a \qquad (2)$$

Spatial averaging is performed using a point-spread function that describes the relative contributions to the pixel radiance from points on the ground at different distances from the direct line of sight. For accurate results, cloud-containing pixels must be removed prior to averaging. The cloudy pixels are found using a combination of brightness, band ratio, and water vapor tests, as described by Matthew et al., 2000.

The FLAASH model includes a method for retrieving an estimated aerosol/haze amount from selected dark land pixels in the scene. The method is based on observations by Kaufman et al., 1997, of a nearly fixed ratio between the reflectances for such pixels at 660 nm and 2100 nm. The aerosol amount is retrieved by iterating the Equation (1) and (2) calculations over a series of visible ranges, for example, 17 km to 200 km. For each visible range, the scene-average 660 nm and 2100 nm reflectances for the dark pixels are retrieved, and the best estimate of the visible range is interpolated by matching the ratio to the average ratio of ~0.45 that was observed by Kaufman et al. Using this visible range estimate, a second and final MODTRAN4 calculation loop over water is performed.

Reference

Kaufmann, Y. J., Wald, L. A. Remer, B.-C. Gao, R.-R. Li, and L. Flynn. *The MODIS 2.-μm Channel-Correlation with Visible Reflectance for Use in Remote Sensing of Aerosol*. IEEE Transactions on Geoscience and Remote Sensing. Vol. 35. pp. 1286-1298. 1997.

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2. For images that do not contain bands in the appropriate wavelength positions to support water retrieval (for example, Landsat or SPOT), the column water vapor amount is determined by the user-selected atmospheric model (see "Using Water Retrieval" on page 21 for details).

Input Data Requirements

The input image for FLAASH must be a radiometrically calibrated radiance image in BIL or BIP interleave. The data type may be floating-point, 4-byte signed integers, 2-byte signed integers, or 2-byte unsigned integers. In order to perform water retrieval, the image's bands must span at least one of the following ranges at 15 nm spectral resolution or better:

- 1050-1210 nm

- 770-870 nm

- 870-1020 nm

Additional wavelength coverage is required for aerosol retrieval (see "Using Aerosol Retrieval" on page 22). For hyperspectral sensors, wavelengths and full width half maximum (FWHM) values must be provided either in the image's ENVI header file or as separate ASCII files. Known multispectral sensors require only wavelength values, while unknown (custom) multispectral sensors also require spectral response filter functions (see "Multispectral Settings" on page 26). If the input radiance image is not already in floating-point, you must also know the scale factor (or factors) used to convert radiance data into floating-point values in units of $\mu\dot{W}/(cm^2 \bullet nm \bullet sr)$. The scale factors are a division factor that satisfies the following relationship:

$$\left(\frac{\text{integer radiance image}}{\text{scale factor}} \right) = \text{floating point radiance image } [\mu W/(cm^2 \bullet nm \bullet sr)]$$

If the scale factor is not a constant for all bands, a scale factor for each band must be provided in an ASCII file. An example of a scale factors file that is appropriate for 1995-2002 AVIRIS data can be found in `\envidata\flaash\hyperspectral\input_files\` `AVIRIS_1998_scale.txt` on ENVI tutorial data CD number 3.

Installing and Licensing FLAASH 4.2

The FLAASH Module is automatically installed when you install ENVI 4.2. However, to use the FLAASH Module, you must purchase a FLAASH license. If you do not have an FLAASH license, contact RSI or your ENVI distributor.

For information about entering a new ENVI license, refer to your *Installing & Licensing ENVI 4.2* manual.

Before You Begin

Before using ENVI FLAASH 4.2, make sure you check the following:

- **OS Version** — Ensure you are running on one of the supported Windows versions or UNIX versions (see Table 1-1), or a UNIX version that is binary-compatible with one of the UNIX versions.

- **ENVI 4.2** — Verify ENVI 4.2 is installed. FLAASH for ENVI 4.2 is automatically installed with ENVI 4.2. For more information on installing ENVI, see the *Installing & Licensing ENVI 4.2* manual.

  Note ——————————————————————————————
  ENVI FLAASH 1.*x* is not compatible with ENVI 4.2.

  FLAASH 4.2 is not backward compatible with previous versions of ENVI.
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- **Disk space** — To process images in FLAASH, you must have 25 MB of free disk space plus enough free disk space to store four times the size of your input radiance image.

ENVI FLAASH 4.2 supports the following platforms and operating systems:

Platform	Supported Versions	Operating System	Hardware
Microsoft Windows	2000, XP	Windows	Intel x86, 32-bit
UNIX[a]	Red Hat Enterprise 3.x + Fedora Core 3[c]	Linux[b]	x86 32-bit x86_64, 64-bit
	SGI 6.5.1	IRIX	Mips 32-bit Mips 64-bit
	SUN	Solaris 8, 9	SPARC 32-bit SPARC 64-bit

Table 1-1: System Requirements for ENVI FLAASH 4.2

[a] For UNIX, the supported versions indicate that ENVI FLAASH 4.2 was either built on the lowest version listed or tested on that version. You can install and run ENVI FLAASH 4.2 on other versions that are binary compatible with those listed.

[b] ENVI FLAASH 4.2 was built on the Linux 2.4 kernel with `glibc` 2.2 using Red Hat Linux 7.1. If your version of Linux is compatible with these, it is possible that you can install and run ENVI FLAASH 4.2 on your version.

[c] For Red Hat Enterprise users: Some functions in IDL 6.2 and ENVI 4.2 require the `libstdc++` compatibility libraries to be installed. To check if these libraries are already installed, issue the following command:

```
rpm -qa | grep compat
```

and look for `compat-libstdc++-<`*version_number*`>`. If this is not listed, install the appropriate RPM for your distribution (from your ENVI installation CD-ROMs).

Contacting RSI

If you have problems with installing or licensing this software product, contact RSI technical support for assistance:

- E-mail: `support@RSInc.com`

- Phone: (303) 413-3920

- Fax: (303) 786-9909

- Web page: `http://www.RSInc.com` — Visit the Tech Tips section in the Support section of our Web page for Frequently Asked Questions.

International customers should contact their local RSI office or distributor for technical support.

Chapter 2
Using ENVI FLAASH

This chapter describes how to use ENVI FLAASH, including detailed descriptions of the parameters and instructions for setting them are included. This chapter covers the following topics:

Standard FLAASH Input Parameters

The parameters for ENVI FLAASH include selecting an input radiance image, setting output file defaults, entering information about the collecting sensor and the collected scene, selecting an atmosphere and aerosol model for the correction, and setting options for the atmosphere correction model.

Advanced settings, such as setting the azimuth and zenith for instruments that use a non-nadir viewing geometry and entering a CO_2 mixing ratio are described in "FLAASH Advanced Settings" on page 30.

1. From the ENVI main menu bar, select one of the following:

   • **Basic Tools → Preprocessing → Calibration Utilities → FLAASH**

   • **Spectral → FLAASH**.

   The FLAASH Atmospheric Correction Model Input Parameters dialog appears (Figure 2-1).

2. Set the input parameters as described in the following sections.

Figure 2-1: FLAASH Atmospheric Corrections Model Input Parameters Dialog

Specifying Input and Output File Information

In the top portion of the FLAASH Atmospheric Corrections Model Input Parameters dialog, select the input radiance image and provide output image settings.

The input radiance image should contain calibrated radiance data in a floating-point, long integer (4-byte signed), or integer (2-byte signed or unsigned) data type, and the interleave must be BIL or BIP.

> **Tip** ———————————————————————————————————————
> To convert between different interleaves, select **Basic Tools → Convert Data (BSQ, BIL, BIP)** from the ENVI main menu bar.
>
> If you select a spatial subset, you can make adjustments to it later by using the FLAASH Advanced Settings dialog (see"FLAASH Advanced Settings" on page 30).
> ———————————————————————————————————————

To select the input radiance image:

1. In the FLAASH Atmospheric Corrections Model Input Parameters dialog, click **Input Radiance Image** to open the FLAASH Input File dialog.

   • Select the input file and any spatial subsetting (see the *ENVI User's Guide* for subsetting instructions), then click **OK**.

      If wavelengths are not defined in the input image header file, FLAASH prompts you to read these values from an ASCII file using ENVI's Input ASCII File dialog.

      The ASCII file should contain its data in columns (for example, the wavelengths are in one column). Be sure to correctly specify the wavelength column and units when reading the ASCII file.

   • The Radiance Scale Factors dialog appears (Figure 2-2).

2. In the Radiance Scale Factors dialog, select whether to enter a single scale factor (a constant) for all bands, or to read an array of scale factors (one per band) from an ASCII file.

   • If you select **Read array of scale factors (1 per band) from ASCII file**, a file selection dialog appears. Select the input ASCII file.

   • If you select **Use single scale factor for all bands**, the **Single scale factor** text box appears. Enter a scale factor.

   Be sure to specify the correct column for the scale factor. For convenience, a multiplication factor and/or inverse can be applied. If both are specified, the multiplication factor is applied before the inverse. If necessary, you can redefine the scale factors later using the FLAASH Advanced Settings dialog (detailed in "FLAASH Advanced Settings" on page 30). An example of an appropriate scale factors file for 1995-2002 AVIRIS data can be found in `\envidata\flaash\hyperspectral \input_files\AVIRIS_1998_scale.txt` on ENVI tutorial data CD number 3.
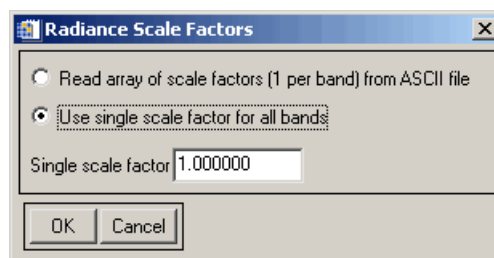

Figure 2-2: Radiance Scale Factors Dialog

Note

Choose scale factors such that the input pixel values divided by these factors converts the data into floating-point radiance values in units of $\mu W/(cm^2 \bullet nm \bullet sr)$.

If you are familiar with ATREM, the scale factors that FLAASH uses are identical to those expected by ATREM. If the input image is already in floating-point radiance in the correct units, then set the scale factors to one for all bands.

After you select the input file and radiance scale factors, the top three text boxes are populated with the input file name and directory information, the default output file name and path, and the default output directory.

To set file output parameters:

1. To change the output file name, in the FLAASH Atmospheric Corrections Model Input Parameters dialog, click **Output Reflectance File**.

   • When the file selection dialog appears, navigate to the desired output directory and enter the new file name in the text box.

   • Click **Open**. The new directory and output name appears in the **Output Reflectance File** text box.

     Alternatively, you can enter the path and file name directly into the text box. If you choose to enter a filename, but do not enter a directory path, the reflectance file output is saved in the directory that is designated in the **Output Directory for FLAASH Files** text box.

2. To change the output directory, click **Output Directory for FLAASH Files**. This setting is the location where all FLAASH files (except the output reflectance file) are written. The FLAASH files that are output to this directory include the column water vapor and cloud map images, the journal file, and optionally the template file.

   • When the output directory selection dialog appears, navigate to the desired output directory and click **OK**. The new directory information appears in the **Output Directory for FLAASH Files** text box.

     Alternatively, you can enter the path directly into the text box. Be sure to include the full directory path.

3. In the **Rootname for FLAASH Files** text box, enter the prefix to add to each FLAASH file produced during a FLAASH session. Do not include a directory path.

   The root name is the prefix that is appended to the output FLAASH filenames. ENVI automatically adds an underscore character to the rootname. For example, a rootname of `MyHymapImage` produces a cloud map output image called `MyHymapImage_cloudmask.dat`.

Entering Scene and Sensor Information

Scene and sensor information include the scene center location (lat/lon), the average ground elevation of the scene, the sensor type, the sensor altitude, and the flight date and time. These data let FLAASH determine where the sun was in the sky and the path the sun's light took through the atmosphere to the ground and back to the sensor.

1. In the **Lat** and **Lon** text boxes, enter the latitude and longitude of the scene center, using negative values for the Southern and Western Hemispheres.

    To toggle between decimal degrees and degrees-minutes-seconds, click on the **DD <-> DMS** button.

2. From the **Sensor Type** button menu, select the name of the sensor that collected the input radiance image. The input parameters dialog changes slightly when switching between **Multispectral** and **Hyperspectral** sensor types. For spaceborne sensors, a default **Sensor Altitude (km)** is automatically set according to the sensor type.

    Note ───
    For multispectral sensors, the sensor type is used to automatically assign the correct spectral response functions for the image bands. FLAASH uses ENVI's filter functions for the named multispectral sensors.
    ──

3. In the **Sensor Altitude (km)** text box, enter the altitude of the sensor when the image was collected, in kilometers above sea level. For spaceborne sensors, the sensor altitude is automatically set when the sensor type is selected.

4. In the **Ground Elevation (km)** text box, enter the average scene elevation, in kilometers, above sea level.

5. In the **Pixel Size (m)** text box, enter the image pixel size in meters. The pixel size value is used for the adjacency effect correction. An approximate value is adequate. For non-nadir looking sensors (or any sensor with non-square pixels) enter the largest pixel dimension.

6. From the **Flight Date** drop-down lists, select the month and date the scene was collected. Use the arrow increment buttons to select a year, or enter the four-digit year in the text box.

7. In the **Flight Time** text boxes, enter the Greenwich Mean Time at which the scene was collected, in HHMMSS, or use the arrow increment buttons to set the time.

Selecting Atmospheric Model Settings

Use the **Atmospheric Model** drop-down list to choose one of the standard MODTRAN model atmospheres.

For the best results, select a model whose standard column water vapor amount is similar to, or somewhat greater than, that expected for the scene. The standard column water vapor amounts (from sea level to space) for each model atmosphere are given in Table 2-1. If no water vapor information is available, select an atmosphere according to the known or expected surface air temperature, which tends to correlate with water vapor. If the

temperature is unknown, select an atmosphere from Table 2-2, which is based on a seasonal-latitude surface temperature model.

Model Atmosphere	Water Vapor (std atm-cm)	Water Vapor (g/cm^2)	Surface Air Temperature
Sub-Arctic Winter (SAW)	518	0.42	-16 °C or 3 °F
Mid-Latitude Winter (MLW)	1060	0.85	-1 °C or 30 °F
U.S. Standard (US)	1762	1.42	15 °C or 59 °
Sub-Arctic Summer (SAS)	2589	2.08	14 °C or 57 °
Mid-Latitude Summer (MLS)	3636	2.92	21 °C or 70 °
Tropical (T)	5119	4.11	27 °C or 80 °

Table 2-1: Column Water Vapor Amounts and Surface Temperatures for the MODTRAN Model Atmospheres

Latitude (°N)	Jan.	March	May	July	Sept.	Nov.
80	SAW	SAW	SAW	MLW	MLW	SAW
70	SAW	SAW	MLW	MLW	MLW	SAW
60	MLW	MLW	MLW	SAS	SAS	MLW
50	MLW	MLW	SAS	SAS	SAS	SAS
40	SAS	SAS	SAS	MLS	MLS	SAS
30	MLS	MLS	MLS	T	T	MLS
20	T	T	T	T	T	T
10	T	T	T	T	T	T
0	T	T	T	T	T	T
-10	T	T	T	T	T	T
-20	T	T	T	MLS	MLS	T
-30	MLS	MLS	MLS	MLS	MLS	MLS
-40	SAS	SAS	SAS	SAS	SAS	SAS
-50	SAS	SAS	SAS	MLW	MLW	SAS
-60	MLW	MLW	MLW	MLW	MLW	MLW
-70	MLW	MLW	MLW	MLW	MLW	MLW
-80	MLW	MLW	MLW	SAW	MLW	MLW

Table 2-2: Selection of MODTRAN Model Atmospheres Based on Latitudinal/Seasonal Dependence of Surface Temperature

Using Water Retrieval

To solve the radiative transfer equations that allow apparent surface reflectance to be computed, the column water vapor amount for each pixel in the image must be determined. FLAASH includes a method for retrieving the water amount for each pixel. This technique produces a more accurate correction than using a constant water amount for the entire scene. To use this water retrieval method, the image must have bands that span at least one of the following ranges at a spectral resolution of 15 nm or better:

  - 1050-1210 nm (for the 1135 nm water feature)

  - 870-1020 nm (for the 940 nm water feature)

  - 770-870 nm (for the 820 nm water feature)

For most of the multispectral sensor types, the **Water Retrieval** setting is **No** because these sensors do not have the appropriate bands to perform the retrieval.

The **Water Retrieval** options are:

  - **Yes** — To perform water retrieval. Then, in the **Water Absorption Feature** drop-down list, select the water feature you wish to use. The 1135 nm feature is recommended if the appropriate bands are available. If the 1135 nm or the 940 nm feature is selected, and the feature is saturated due to an extremely wet atmosphere, then the 820 nm feature is automatically used in its place if bands spanning this region are available.

    Tip ————————————————————————————————————
    When performing a water retrieval on multispectral image data, use the Multispectral Settings dialog to manually set the water bands (see "Multispectral Settings" on page 26 for details).
    ——

  - **No** — To use a constant column water vapor amount for all pixels in the image. In this case, the column water vapor amount is determined according to the standard column water vapor amount for the selected Atmospheric Model, multiplied by an optional **Water Column Multiplier**. See Table 2-1 for the standard column water vapor amounts for each Atmosphere Model. Use the **Water Column Multiplier** to adjust the water amount.

Selecting an Aerosol Model

Use the **Aerosol Model** drop-down list to select one of the standard MODTRAN aerosol/haze types.

Note ——————————————————————————————————————
The choice of model is not critical if the visibility is high (for example, greater than 40 km).
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The model choices are:

  - **Rural** — Which represents the aerosol found in areas not strongly affected by urban or industrial sources. The particle sizes are a blend of two distributions, one large and one small.

  - **Urban** — Which is a mixture of 80% rural aerosol with 20% soot-like aerosols, and is appropriate for high-density urban/industrial areas.

- **Maritime** — Which is representative of the boundary layer over oceans, or continents under a prevailing wind from the ocean. It is composed of two components, one from sea spray and another from rural continental aerosol (that omits the largest particles).

- **Tropospheric** — Which applies to calm, clear (visibility greater than 40 km) conditions over land, and consists of the small-particle component of the rural model. For more details on MODTRAN aerosol models, see Abreu and Anderson, 1996.

Using Aerosol Retrieval

FLAASH includes a method for retrieving the aerosol amount and estimating a scene average visibility using a dark pixel reflectance ratio method based on work by Kaufman et al., 1997. The dark-land pixel-retrieval method requires the presence of sensor channels around 660 nm and 2100 nm. A dark-land pixel is defined to be one with a 2100 nm reflectance of 0.1 or less and a 660:2100 reflectance ratio of approximately 0.45. If the input image contains bands near 800 nm and 420 nm, an additional check is performed, requiring the 800:420 radiance ratio to be 1 or less, which eliminates pixels likely to be shadows and water bodies.

Choose one of the following from the **Aerosol Retrieval** drop-down list:

- **No** — To use the value in the **Initial Visibility (tm)** text box method for the aerosol model (described in the following section).

- **2-Band (K-T)** — To use the aerosol retrieval method. If no suitable dark pixels are found, then the value entered in the **Initial Visibility** text box is used.

Tip ───

When performing an aerosol retrieval on multispectral image data, use the Multispectral Settings dialog to manually set the aerosol bands (see "Multispectral Settings" on page 26 for details).

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Entering an Initial Visibility Value

In the **Initial Visibility** text box, enter an estimate of the scene visibility in kilometers. The initial visibility value is assumed for the atmospheric correction if the aerosol is not being retrieved.

Table 2-3 lists approximate values based on weather conditions.

Weather Condition	Scene Visibility
Clear	40 to 100 km
Moderate Haze	20 to 30 km
Thick Haze	15 km or less

Table 2-3: Approximate Scene Visibility Values

The visibility, *V* is defined as the 550 nm meteorological range and is related to extinction coefficient β (base *e*) by the equation V = 3.912/β.

Note ───

Enter a value even if you have set the **Aerosol Retrieval** parameter to **Yes**, as FLAASH uses the **Initial Visibility (tm)** value if the aerosol cannot be retrieved.

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Using Spectral Polishing

Polishing is a term used by Boardman [1998] for a linear renormalization method that reduces spectral artifacts in hyperspectral data using only the data itself. The basic assumptions are as follows:

- The artifacts may be removed by applying a uniform linear transformation (that is, channel-dependent gain factors and offsets) to the spectra.

- Spectrally smooth reference pixels (for example, soil or pavement) can be found within the scene from which the transformation can be derived.

- The true spectra of the reference pixels can be approximated by applying a spectral smoothing operation.

The gains and offsets are generated from the reference pixels by performing a linear fit of the smoothed spectra to the original spectra. Boardman's original algorithm, which smooths by Legendre polynomial fitting, is found in the ENVI main menu bar under **Spectral →
EFFORT Polishing**.

The FLAASH polishing algorithm yields similar results with less input data. The smoothing is performed with a running average over *n* adjacent channels (where *n* is defined as the polishing width). Spectrum endpoint and missing-channel complications are limited if only a modest amount of smoothing is desired (*n* is low). For example, a polishing width of 2 is useful for removing residual sawtooth noise caused by a dark current offset between odd-numbered and even-numbered channels, as seen in early AVIRIS data. A wider polishing width (for example, 5-11) is better for removing larger-scale artifacts such as atmospheric absorption band residuals.

1. Select one of the following from the **Spectral Polishing** arrow buttons:

   - **Yes** — To spectrally polish the reflectance image.

   - **No** — To output the unaltered modeled reflectance.

2. In the **Width (number of bands)** text box, enter the width (in bands) of the smoothing window to be used in the FLAASH spectral polishing algorithm.

The reference pixels are selected as follows:

1. For each pixel a smoothed spectrum is calculated.

2. The difference between the smoothed spectrum and the unsmoothed spectrum is calculated for each measured wavelength.

3. The RMS of the smoothed-unsmoothed difference at each wavelength is calculated, and normalized by dividing by the mean reflectance over all wavelengths for the pixel.

4. The pixels with the lowest ten percent of normalized RMS differences are selected from among the cloud-free, non-blank, and non-vegetated pixels.

5. The normalized RMS differences for the selected pixels are histogrammed and the pixels that fall into the lower half of the histogram are selected to be reference pixels for the calculation of the gain factor. This eliminates artifacts often found using EFFORT with a vegetated scene.

6. The gain factor for the linear transformation is computed as the ratio of the RMS smoothed to RMS un-smoothed spectrum for these pixels. There is no offset in the transformation. For this reason, very dark pixels such as water are essentially unaffected by the FLAASH polishing.

A larger number generates more smoothing. A value of 9 is recommended for typical 10 nm-resolution hyperspectral sensors (such as AVIRIS). A value of 2 provides minimal smoothing but removes odd-even spectral band imbalances. Odd polishing widths are slightly more computationally efficient. Spectral polishing requires hyperspectral input data, and is therefore disabled when a multispectral sensor type is selected.

Recalibrating the Input Wavelengths

An accurate wavelength calibration is critical for atmospherically correcting hyperspectral data. Even slight errors in the locations of the band center wavelengths can introduce significant errors into the water retrieval process, and reduce the overall accuracy of the modeled surface reflectance results. To minimize such errors, FLAASH includes a method for identifying and correcting wavelength miscalibrations.

Wavelength recalibration choices are:

- **Yes** — To automatically adjust the wavelength calibration prior to computing the water retrieval.

- **No** — To use the input file's wavelengths.

AVIRIS, HYDICE, HYMAP, HYPERION, CASI, and AISA sensors are automatically supported for wavelength recalibration. All other hyperspectral sensors require a spectrograph definition file (see the "Selecting a Spectrograph Definition File" on page 30 for more details).

When a wavelength recalibration is performed, an additional output file is created which summarizes the results. The output file is saved to the FLAASH output directory and named *rootname + wl_recalibration.txt*. In addition, a message summarizing each spectrograph's wavelength correction is written in the journal file under the heading "Determined Wavelength Shift Using NODD Algorithm." One shift and variance value exist for each spectrograph. The shift value indicates the average wavelength shift in channels, as computed from a number of pixels near the centerline of the image; the variance value indicates the uncertainty in the shift determination. In some cases, both the shift and variance are zero. This can occur when wavelength calibration errors are not present, or when no absorption feature is available within the spectral range of the spectrograph, preventing a wavelength correction from being performed. The FLAASH reflectance output file contains the new wavelength assignments.

Tip ———

If you find that the corrected wavelengths are an improvement after the FLAASH processing is completed, you may want to apply them to the original input radiance image. To do this, select the ENVI main menu bar **File → Edit ENVI Header → Edit Attributes → Wavelengths** option. You can automatically import the new wavelengths using the FLAASH output file called *rootname + wl_recalibration.txt*. If you choose to do this, then any further processing of the radiance file in FLAASH should be done with the **Wavelength Recalibration** toggle button set to **No**, which speeds processing time.

For algorithm details, see:

Felde, G. W., G. P. Anderson, S. M. Adler-Golden, M. W. Matthew, and A. Berk. *Analysis of Hyperion Data with the FLAASH Atmospheric Correction Algorithm.* Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery IX. SPIE Aerosense Conf., Orlando. 21-25 April 2003.

Hyperspectral Settings

The **Hyperspectral Settings** button appears at the bottom of the FLAASH Atmospheric Correction Model Input Parameters dialog when you select a hyperspectral sensor from the **Sensor Type** button menu. This option allows you to choose how bands are selected for water vapor and/or aerosol retrieval.

Note ——

If the input data is from a named hyperspectral sensor (listed under the **Sensor Type** button menu on the FLAASH Atmospheric Corrections Model Input Parameters dialog), and neither water nor aerosol is being retrieved, it is unnecessary to check the hyperspectral settings before applying FLAASH.

Select one of the following options in the Hyperspectral Settings dialog:

- **File** — To specify a channel definition file. Click **Channel Definition File**, navigate to the desired channel definition file, and select it. The correct format for a channel definitions file is described in "Hyperspectral Channel Definitions File" on page 26.

- **Automatic Selection** — To have FLAASH automatically select the channel definitions. Channel definitions are automatically assigned by FLAASH based on the spectral characteristics of the data. This is the default setting and is recommended.

Hyperspectral Channel Definitions File

The channel definition file follows a simple format where each line contains one channel definition in the form:

```
channel_type = band_number
```

The valid `channel_types` are listed below, and must be included in the file verbatim:

```
water channels reference
water channels absorption
cirrus channel
KT upper channels
KT lower channels
alternate water channels absorption
alternate water channels reference
```

The alternate water channels are used in case the selected water channels are saturated.

The first band in the file is referred to as band number 1. If more than one band is appropriate for a `channel_type`, the bands should be enclosed in curly brackets `{}` and separated with white space. Comments can be included as long as they are preceded with a semi-colon character. You only need to include channel definitions for those processing steps that are being requested.

The following text is an example channel definition file for an AVIRIS sensor:

```
; Standard AVIRIS channels
; Channels are counted starting at 1.

water channels reference = {73 74 75 87 88 89} ; wings must be
        ; symmetric on absorption center channel
water channels absorption = {80 81 82} ; absorption band
cirrus channel = 109 ; no {} needed for single number

; optional channels. Can leave these out, but will lose some
; functionality. KT is needed for automatic visibility
; determination.

; Kaufman-Tanre method channels
KT upper channels  = { 184 185 186 187 188 }
KT lower channels  = { 29 30 31 32 33 34 }

alternate water channels absorption = { 49 50 } ; 0.82 micron band
alternate water channels reference =  { 44 45 54 55 }
```

FLAASH produces a channel definition file for each processing run (both multispectral and hyperspectral). The file, named *rootname*_channel_definition.txt, is saved when the **Output Diagnostic Files** option is set to **Yes** in the FLAASH Advanced Settings dialog.

Multispectral Settings

The **Multispectral Settings** button appears at the bottom of the FLAASH Atmospheric Correction Model Input Parameters dialog when you select a multispectral sensor from the **Sensor Type** button menu. When applying the FLAASH atmospheric correction model to a multispectral dataset, it is critical to properly choose the bands that are used for water vapor and/or aerosol retrieval. In addition, if the input data is from an unknown multispectral sensor, it is necessary to define the sensor's spectral response functions.

Use the FLAASH Multispectral Settings dialog to define the bands for water vapor and aerosol retrieval.
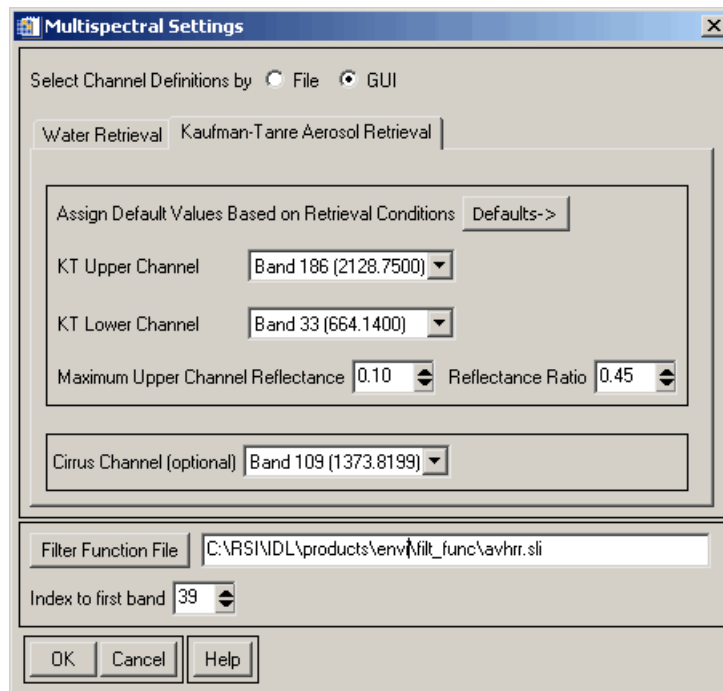

Figure 2-3: Multispectral Settings Dialog

Note ───

If the input data is from a named multispectral sensor (listed under the **Sensor Type** button menu on the FLAASH Atmospheric Corrections Model Input Parameters dialog), and neither water nor aerosol is being retrieved, it is unnecessary to check the multispectral settings before applying FLAASH.

───

The channel definitions are used to assign bands from the input file for use in the water and aerosol retrieval process. If a FLAASH template file was restored before opening the Multispectral Settings dialog, then the channel definitions are set according to the information saved in the template file. Otherwise, FLAASH selects default bands according to pre-defined wavelength ranges (defined below). If bands within the pre-defined ranges are not available, then the channel is left undefined.

Select from the following options in the Multispectral Settings dialog:

- **File** — To specify a channel definition file. Click **Channel Definition File**, navigate to the desired channel definition file, and select it. The correct format for a channel definitions file is described in "Multispectral Channel Definitions File" on page 29.

- **GUI** — To select the channels interactively using the FLAASH GUI. In the GUI view:

    A. Select either the **Water Retrieval** or the **Kaufman-Rate Aerosol Retrieval** tabs to choose the retrieval category (water or aerosol).

B. Within each active retrieval category, use the drop-down lists to select the desired band.

C. In the **Kaufman-Rate Aerosol Retrieval** tab, set the **Maximum Upper Channel Reflectance** and the **Reflectance Ratio** values. These settings identify dark pixels used for the visibility estimate. Recommended values are assigned automatically by choosing one of the options under the **Defaults** pull-down menu. For more information about the Aerosol Retrieval algorithm and these settings, see "The ENVI FLAASH Model" on page 8 or the following reference:

Y. J. Kaufmann, A. E. Wald, L. A. Remer, B.-C. Gao, R.-R. Li, and L. Flynn. *The MODIS 2.-μm Channel-Correlation with Visible Reflectance for Use in Remote Sensing of Aerosol*. IEEE Transactions on Geoscience and Remote Sensing. Vol. 35. pp. 1286-1298. 1997.

Note ———————————————————————————————————————

If using the Over-Water Retrieval default settings, the KT Upper and Lower bands are reversed. This is done by design. Applying a maximum reflectance threshold to the 880 nm band tends to better discriminate clear water from turbid or wet areas, leading to more accurate visibility retrievals.

———

You only need to define channels for the processing that is being requested. For example, if you are requesting an aerosol retrieval, but not a water retrieval, then you may leave the water channels undefined, but both the KT Upper and KT Lower channels have to be defined.

The recommended wavelength ranges for each channel are:

Water Retrieval	1135 nm	absorption	1117 - 1143 nm
		reference upper wing	1184 - 1210 nm
		reference lower wing	1050 - 1067 nm
	940 nm	absorption	935 - 955 nm
		reference upper wing	870 - 890 nm
		reference lower wing	995 - 1020 nm
	820 nm	absorption	810 - 830 nm
		reference upper wing	850 - 870 nm
		reference lower wing	770 - 790 nm
Aerosol Retrieval	KT upper		2100 - 2250 nm
	KT lower		640 - 680 nm
Cloud Masking	cirrus clouds		1367 - 1383 nm

Table 2-4: Recommended Wavelengths for Channel Definitions

D. If the input image is from an unknown multispectral sensor type, the sensor's spectral response functions must be defined using a filter function file. Click **Filter Function File** and use standard ENVI methods to navigate to the multispectral sensor's filter function file. The filter function file must be an ENVI spectral library format file, and contain the sensor's filter functions consecutively, one for each band in the sensor. However, the filter function for the sensor's first band need not be the first function in the file.

E. In the **Index to first band** text box, enter the index into the filter function file (beginning at zero) where the sensor's filter functions begin.

Note

When using a known multispectral sensor (i.e., one whose name is listed under the **Sensor Type** button menu), the filter function file and index are automatically set properly to use the filter function files included in the ENVI distribution.

Multispectral Channel Definitions File

The channel definition file follows a simple format where each line contains one channel definition in the form:

```
channel_type = band_number
```

The valid `channel_types` are listed below, and must be included in the file verbatim:

```
water channels reference
water channels absorption
cirrus channel
KT upper channels
KT lower channels
KT band cutoff
KT band ratio
```

The first band in the file is referred to as band number 1. If more than one band is appropriate for a `channel_type`, the bands should be enclosed in curly brackets `{}` and separated with white space. Comments can be included as long as they are preceded with a semi-colon character. You only need to include channel definitions for those processing steps that are being requested. For example, a channel definition file for applying FLAASH to Landsat TM with aerosol retrieval but a fixed water vapor amount could include the following text:

```
; FLAASH channel definition for Landsat TM
KT upper channels = 6
KT lower channels = 3
```

FLAASH produces a channel definition file for each processing run (both multispectral and hyperspectral). The file, named *rootname*`_channel_definition.txt`, is saved when the **Output Diagnostic Files** option is set to **Yes** in the FLAASH Advanced Settings dialog.

FLAASH Advanced Settings

The FLAASH advanced settings are arranged into three categories: modeling parameters, viewing geometry, and FLAASH processing controls. Use the Advanced Settings dialog to modify the defaults, enter additional data, or to make changes to previous settings.

To access the advanced settings, click **Advanced Settings** in the lower right corner of the FLAASH Atmospheric Correction Model Input Parameters dialog.
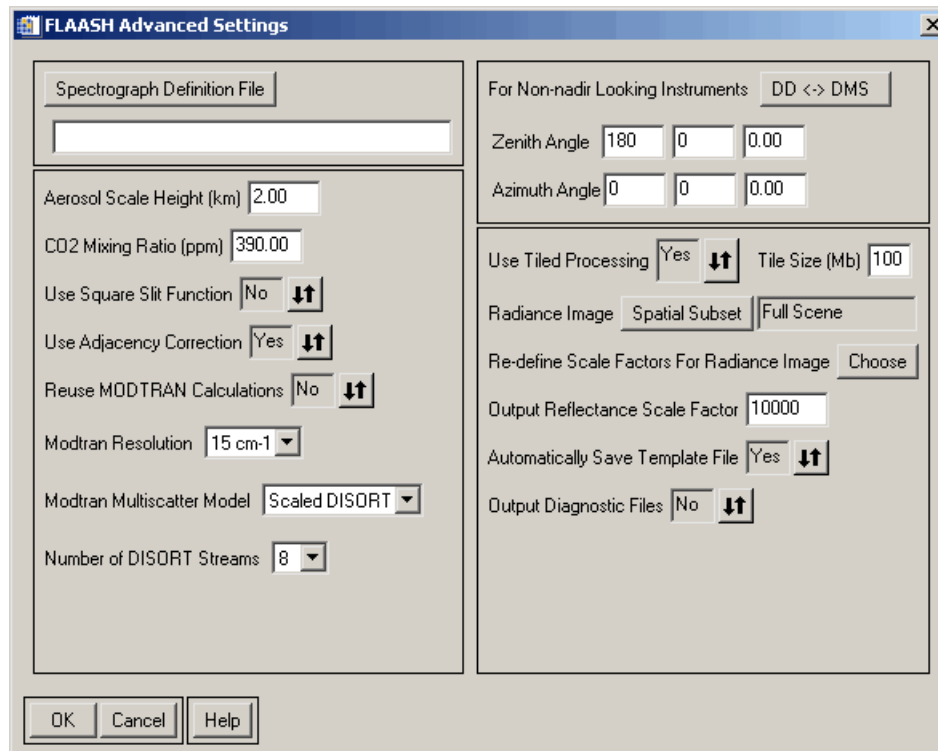

Figure 2-4: FLAASH Advanced Settings Dialog

Selecting a Spectrograph Definition File

The spectrograph definition file is used to assign the spectral features that are used to correct the wavelength calibration for hyperspectral input images. FLAASH includes built-in spectrograph definitions for the AVIRIS, HYMAP, HYDICE, HYPERION, CASI, and AISA sensors. If the input image is from another hyperspectral sensor, or you wish to customize the built-in spectrograph definitions you must provide your own spectrograph definition file.

To select a file, click **Spectrograph Definition File** and navigate to the file on disk.

The Spectrograph Definition file is an ASCII text file which contains one line for each spectrometer in the sensor. Each spectrometer's line contains the following information:

- The wavelength (in nanometers) of the reference absorption feature being used to correct the wavelength calibration. If no reliable absorption feature is contained within the span of the spectrometer, then no correction can be made and this value should be set to zero.

- The full-width half-maximum (FWHM) factor for the reference absorption feature. A wavelength span equal to:

  ```
  4*(FWHM factor)*(mean FWHM)
  ```

  on each side of the reference absorption feature is used to find the bands needed for identifying the feature. The exact value of the FWHM factor is not critical for a successful wavelength recalibration. Values between 0.5 and 1.5 tend to work well for hyperspectral sensors with critical sampling (where the FWHM is approximately equal to the band spacing). If no reference absorption feature exists for the spectrometer, then set this factor to zero.

- The first band number in the spectrometer relative to the first band in the sensor (starting at band number 1).

- The last band number in the spectrometer relative to the first band in the sensor.

The required format of the file is illustrated in the following example, which depicts the default Spectrograph Definition File for the AVIRIS sensor:

```
; FLAASH spectrograph definition for AVIRIS
spectrograph = {0., 0., 1, 32}
spectrograph = {760.17, 0.6, 33, 96}
spectrograph = {0., 0., 97, 160}
spectrograph = {2058.7, 1.5, 161, 224}
```

The first line in the file is a comment (comments can be placed anywhere in the file, but must be preceded with the semi-colon character). Each of the next four lines contain a spectrograph definition for one of the AVIRIS instrument's four spectrometers.

The first spectrometer contains instrument bands 1-32, but does not span any known absorption feature that can be used to recalibrate the wavelengths (so the first 2 values are set to zero). The second spectrometer contains instrument bands 33-96, and the oxygen feature at 760.17 nm is used as the reference absorption feature, with a FWHM factor of 0.6. The third spectrometer contains instrument bands 97-160, but does not contain any reliable features. The fourth spectrometer contains bands 161-224, and the CO_2 feature at 2058.7 nm is used, also with a FWHM factor of 1.5.

Note

For CASI and AISA, the built-in spectrograph definition file assumes that the collected bands span the 760 nm oxygen feature.

Setting Modeling Parameters

Set the following modeling parameters:

1. In the **Aerosol Scale Height (km)** text box, specify the effective $1/e$ height of the aerosol vertical profile in km. Typical values are 1 to 2 km.

   Note ───
   The aerosol scale height is used only for the calculation of the adjacency scattering range.
   ──

2. In the **CO2 Mixing Ratio (ppm)** text box, specify the carbon dioxide (CO_2) mixing ratio in parts per million by volume. In 2001, the value was approximately 370 ppm. For best results, add 20 ppm to the actual value.

3. In the **Use Square Slit Function** text box, set this toggle button to **Yes** for images that were derived by averaging together adjacent bands (for example, LASH). This better models the spectral response of the derived bands.

4. Use the **Use Adjacency Correction** toggle button to specify whether or not to use adjacency correction. Unlike most atmospheric correction models, the FLAASH model accounts for both the radiance that is reflected from the surface that travels directly into the sensor and the radiance from the surface that is scattered by the atmosphere into the sensor. The distinction between the two accounts for the adjacency effect (spatial mixing of radiance among nearby pixels) caused by atmospheric scattering. More accurate reflectance retrievals result when adjacency is enabled; however, there may be occasions when it is desirable to ignore this effect. Turning adjacency correction off sets $\rho_e = \rho$ in Equation (1) (see "The ENVI FLAASH Model" on page 8 for more information).

5. Use the **Reuse MODTRAN Calculations** toggle button to specify whether or not to reuse previous MODTRAN calculations. Reusing previous MODTRAN calculations is useful for rapidly processing multiple images taken under essentially identical conditions—the identical illumination, viewing geometries and visibility are assumed, but the water vapor retrieval is performed again. It is also useful for rapidly generating images with and without polishing, or with different polishing widths. Choose either:

   No — To have FLAASH compute a new set of MODRTRAN radiative transfer calculations for the selected image and model parameters

   Yes — To have FLAASH perform the atmospheric correction using the MODTRAN calculations from the *previous* FLAASH run. This change causes FLAASH to perform a water retrieval; therefore, the **Water Retrieval** toggle button on the main FLAASH Input Parameters dialog is automatically set to **Yes**. You cannot reset **Water Retrieval** to **No** until **Reuse MODTRAN Calculations** is set to **No**.

> **Note** ————————————————————————————————
>
> Following each FLAASH run, the MODTRAN calculations are stored in a file called `acc_modroot.fla`, and a copy is saved in both the FLAASH output directory as well as in ENVI's temporary directory (defined in the ENVI preferences file). If **Reuse MODTRAN Calculations** is set to **Yes**, ENVI first looks in the current FLAASH output directory for the `acc_modroot.fla` file. If the file is present, it is used. Otherwise, ENVI uses the copy that is in the temporary directory. Therefore, you can force FLAASH to use the MODTRAN calculations from any previous run by copying the desired `acc_modroot.fla` from the desired run into the FLAASH output directory for the current run.
>
> ——

6. In the **Modtran Resolution** drop-down list, select a resolution. The **Modtran Resolution** setting controls the MODTRAN spectral resolution and the trade-off of speed versus accuracy for the MODTRAN4 portion of the calculation. Lower resolution yields proportionally better speed but less accuracy. The main differences in accuracy are be seen near 2000 nm and beyond. The 5 cm^{-1} resolution is generally recommended, but the 15 cm^{-1} resolution gives similar results when polishing is used. If aerosol is being retrieved, there are two MODTRAN4 runs performed at 15 cm^{-1} resolution followed by one MODTRAN4 run at the resolution you select. If aerosol is not being retrieved, the first two runs are omitted.

7. In the **Modtran Multiscatter Model** drop-down list, select a multiple-scattering algorithm to be used by MODTRAN4. FLAASH offers three options for multiscatter models: **Isaacs**[1], **Scaled DISORT**, and **DISORT**[2]. The default is **Scaled DISORT** with 8 streams.

    The DISORT model provides the most accurate short-wave (less than ~ 1000 nm) corrections, however it is very computationally intensive. The Isaacs 2-stream method is fast but oversimplified. The Scaled DISORT method provides near-DISORT accuracy with almost the same speed as Isaacs. In the Scaled DISORT model, DISORT and Isaacs calculations are performed at a small number of atmospheric window wavelengths. The multiple scattering contributions in each method are identified and ratios of the DISORT and Isaacs methods are computed. This ratio is interpolated over the full wavelength range, and finally, applied as a multiple scattering scale factor in a spectral radiance calculation performed with the Isaacs method. This procedure yields near-DISORT accuracy at window wavelengths, and also improves the accuracy in absorbing regions.

8. If you select **DISORT** or **Scaled DISORT** as the multiscatter model, specify the number of streams: 2, 4, 8, or 16. The number of streams is related to the number of scattering directions evaluated by the model. Calculations with 2 or 4 streams are not recommended, as they dramatically increase computation time (over **Isaacs**) with little or no improvement. Increasing the number of streams for the Scaled DISORT model should not significantly increase processing time.

---

1. K. Stamnes, S.-C. Tsay, W. Wiscombe, and K. Jayaweera. *Numerically Stable Algorithm for Discrete-Ordinate-Method Radiative Transfer in Multiple Scattering and Emitting Layered Media*. Applied Optics. Vol. 27. 1988. pp. 2502-2509.
2. R. G Isaacs, W. C. Wang, R. D. Worsham, and S. Goldenberg. *Multiple Scattering LOWTRAN and FAS-CODE Models*. Applied Optics. Vol. 26. 1987. pp. 1272-1281.

Tip
Use of the DISORT multiscatter model dramatically increases FLAASH processing time, and is rarely necessary for accurate atmospheric corrections. The magnitude of multiple scattering in any scene is dependent on the amount of haze (water vapor and aerosols) that are present. Moreover, scattering preferentially affects the shorter (visible) wavelengths; longer (near infrared) wavelengths are minimally affected. You should only consider using the DISORT model in the most severe cases, when haze is very strong and critical correction of the shortest wavelengths is required. Computation times vary with system resources, but typical relative computation times are:

Isaacs: DISORT-2: DISORT-4: DISORT-8: DISORT-16 = 1: 22: 24: 30: 60.

That is, running DISORT with 8 streams usually takes about 30 times longer than using Isaacs. In addition, a combination of DISORT (with any number of streams) and a MODTRAN resolution of 1 cm^{-1} is extremely computationally intensive.

Setting Viewing Geometry Parameters

For instruments that use a non-nadir viewing geometry, you must specify the zenith and azimuth angles. The zenith angle is defined as the angle between the line of sight and the zenith (180 for nadir-viewing sensors). Zenith angles must be positive and between 90 and 180 degrees. The azimuth angle is defined as the angle between the line of sight and due North (arbitrary for nadir-viewing sensors).

In the **Zenith Angle** and **Azimuth Angle** fields, enter the correct angles.

Note
To toggle between degrees-minutes-seconds and decimal degrees, click the **DD <-> DMS** button.

Setting FLAASH Processing Controls

Set the following parameters for processing:

1. Use the **Use Tiled Processing** toggle button to specify whether or not to use tiled processing. Like all ENVI processing routines, FLAASH processes the input data in pieces (called tiles), then reassembles the tiles after processing is complete to produce the final result. Using tiled processing allows FLAASH to run on images of any size, regardless of system resources (that is, available memory).

   The default setting in FLAASH is to use tiled processing (**Yes**). Tiled processing is highly recommended; however, some cases occur when FLAASH runs faster without tiling.

   If set to **Yes**, then enter a value (in megabytes) in the **Tile Size** text box. The default tile size is set to the larger of your ENVI Preferences Cache Size or 100 MB. When processing, FLAASH ensures that the largest piece of the image that is read into memory at any time never exceeds the tile size. It is recommended that the tile size be set to the largest value that does not leave the rest of the computer system deprived of

memory for essential functions. For single user machines, a reasonable estimate is about 75% of the installed RAM.

2. Click **Spatial Subset** to re-define the spatial subset you selected during original input file selection. You can also use the information displayed in the **Spatial Subset** field to verify the spatial subset that was defined when the input image was selected.

3. Click **Choose** to re-define the scale factors you selected during the original input file selection. When the Radiance Scale Factors dialog appears, select a scale factor method (see "Specifying Input and Output File Information" on page 16 for details).

4. In the **Output Reflectance Scale Factor** text box, enter the value used to scale the output reflectance image from floating-point into 2-byte integer data space.

   Signed integers have an absolute data range between -32768 and +32767. The recommended scale factor is 10,000. This value is stored as the Reflectance Scale Factor Attribute in the header file of the output image.

5. Use the **Automatically Save Template File** toggle button to specify if you want to automatically save FLAASH parameters to a template file in the FLAASH output directory. For details about template files, see "Saving and Restoring FLAASH Run Parameters (Templates)" on page 37. The file name is `template.txt` appended to your defined root name.

   Tip ───
   RSI recommends leaving this setting at **Yes** (the default), as it can be helpful to retain a copy of each run's parameters for later reference.
   ───

6. Use the **Output Diagnostic Files** toggle button to specify whether or not to create intermediate data files, including the channel definition files used for both hyperspectral and multispectral corrections. The intermediate files can be helpful in diagnosing runtime problems.

   In most cases, leave this setting at **No** (the default) unless instructed by RSI Technical Support to change it, or if you want to see the channel definition file used by FLAASH.

Starting the Processing

When all FLAASH parameters are set, click **Apply** in the FLAASH Atmospheric Model
Input Parameters dialog to begin processing.

Saving and Restoring FLAASH Run Parameters (Templates)

You can save a complete set of FLAASH run parameters, including input and output file names, to a template file. You can then use the FLAASH template to restore the run settings at a later date. This can be quite useful for quickly re-defining the model settings, or for checking to see how the parameters were set in a previous run. For convenience, the template file is in an ASCII format, so it can easily be read outside of ENVI using any text editor. Template files can also be used to share FLAASH run details with colleagues who also have FLAASH—just send the template file to them to restore.

Saving the Template

To save the FLAASH run settings to a template file at any time, click **Save** in the lower right corner of the FLAASH Atmospheric Model Input Parameters dialog.

Note

If the **Automatically Save Template File** parameter is set to the default of **Yes**, in the FLAASH Advanced Settings dialog, a template file is automatically saved into the FLAASH output directory when you click **Apply**.

Restoring a Template File

To restore a FLAASH template file, click **Restore** at the bottom right-hand corner of the FLAASH Atmospheric Model Input Parameters dialog.

The template file stores the full path names of the input and output files (that is, the file names include the directory names). If the input file is not already opened in the current ENVI session, it is automatically opened. If any of the files or directories cannot be located on the computer where FLAASH is running, the corresponding fields in the FLAASH dialogs will not be filled in, but ENVI reads the rest of the parameters. This process allows template files to be shared between users working in different locations.

FLAASH Output Files

The FLAASH atmospheric correction model produces the output files described in the following sections.

Surface Reflectance

An image of retrieved surface reflectance, scaled into two-byte signed integers using the scale factor defined in the FLAASH Advanced Settings dialog. (To set the scale factor, see "Setting FLAASH Processing Controls" on page 34.) The name and location for this output file is defined in the FLAASH Atmospheric Correction Model Input Parameters dialog, in the **Output Reflectance File** text box. The reflectance image bad bands are set according to the bad bands defined for the input radiance image, as well as those for which the atmospheric transmission, as determined by FLAASH, is too low for an accurate reflectance calculation.

Water Vapor

An image of retrieved column water vapor in units of (atm • cm). This file is written to the FLAASH output directory with the name `water.dat` appended to your specified root name.

Cloud Map

A cloud map classification image is written to the FLAASH output directory with the name `cloudmask.dat` appended to your specified root name. The cloud determinations are used during FLAASH processing to refine the estimate of ρ_e in equation (1). This quantity defines the magnitude of the adjacency effect.

Log File

The log file is an ASCII file containing a detailed description of the FLAASH processing. This file is written to the FLAASH output directory with the name `journal.txt` appended to your specified root name.

FLAASH Template File (Optional)

If the FLAASH Advanced Settings dialog parameter **Automatically Save Template File** is set to **Yes**, then the FLAASH parameters are saved to a template file in the FLAASH output directory with the name `template.txt` appended to your specified root name.

Index

ENVI Tutorials:
Atmospherically Correcting Hyperspectral Data Using the FLAASH Module

Table of Contents

Overview of This Tutorial

This tutorial provides an introduction to using FLAASH to atmospherically correct a hyperspectral image. You will display the radiance image, applying an atmospheric correction, and examine the results.

Files Used in This Tutorial
CD-ROM: Tutorial Data CD #3
Path: `envidata\flaash\hyperspectral\input_files` (radiance image, scale factors file, and template file)
    `Envidata\flaash\hyperspectral\flaash_results` (sample reflectance image)

The image used in this exercise was collected by the AVIRIS sensor (Airborne Visible Infrared Imaging Spectrometer), which is a research instrument operated by NASA. The sample image covers a portion of the Jasper Ridge Biological Preserve, located in the eastern foothills of the Santa Cruz Mountains at the base of the San Francisco Peninsula, nine kilometers west of the main Stanford University campus in San Mateo County, CA. The AVIRIS data were provided courtesy of the Jet Propulsion Laboratory (JPL) in Pasadena, CA. For more information about the sample data, see the FLAASH_Sample_Data_Readme.txt file in the `envidata\flaash\hyperspectral\ancillary_data` directory. This image contains approximately the same area as the Landsat TM image used for the multispectral tutorial; however the pixel size, image orientation, and collection dates are different.

File	Description
JasperRidge98av.img	Jasper Ridge Biological Preserve AVIRIS radiance image
AVIRIS_1998_scale.txt	Scale factors file for 1998 AVIRIS data
JasperRidge98av_template.txt	Template file
JasperRidge98av_flaash_refl.img	Reflectance image sample file

Note

The FLAASH Module requires an additional license in your installation; contact your RSI sales representative to obtain a license. If you are not licensed for the FLAASH Module, the tool will be disabled.

## Opening the Raw Landsat Image in ENVI

This exercise will demonstrate how to use FLAASH to produce an apparent surface reflectance image.

1. From the ENVI main menu, select **File → Open Image File**.

2. Navigate to the `envidata\flaash\hyperspectral\input_files` directory, select the **JasperRidge98av.img** file and click **Open**. The Available Bands List is displayed.

3. From the Available Bands List right-click on the **JasperRidge98av.img** file and select **Load True Color**. The image is loaded into the display.

   You may recognize several features in the scene, including a vertically oriented lake in the top center of the image, various types of vegetation on the left hand side of the image, and urban areas on the right-hand side. This image is a standard AVIRIS data product that has been processed by JPL. It contains calibrated at-sensor radiance that has been scaled into two-byte signed integers.

4. Right-click in the Image window and select **Z Profile (Spectrum)** to display the Spectral Profile.

5. Click and drag in the middle part of the image and note the shape of the radiance curves.

6. Right-click in the Image window and select **Pixel Locator**.

7. Move the Pixel Locator window so that you can see it and the Spectral Profile window at the same time.

8. In the Pixel Locator, enter **366** and **179** in the **Sample** and **Line** text boxes, respectively. Click the **Apply** button to center on the pixel location. This pixel location illustrates some of the common atmospheric features seen in hyperspectral data (see image below).
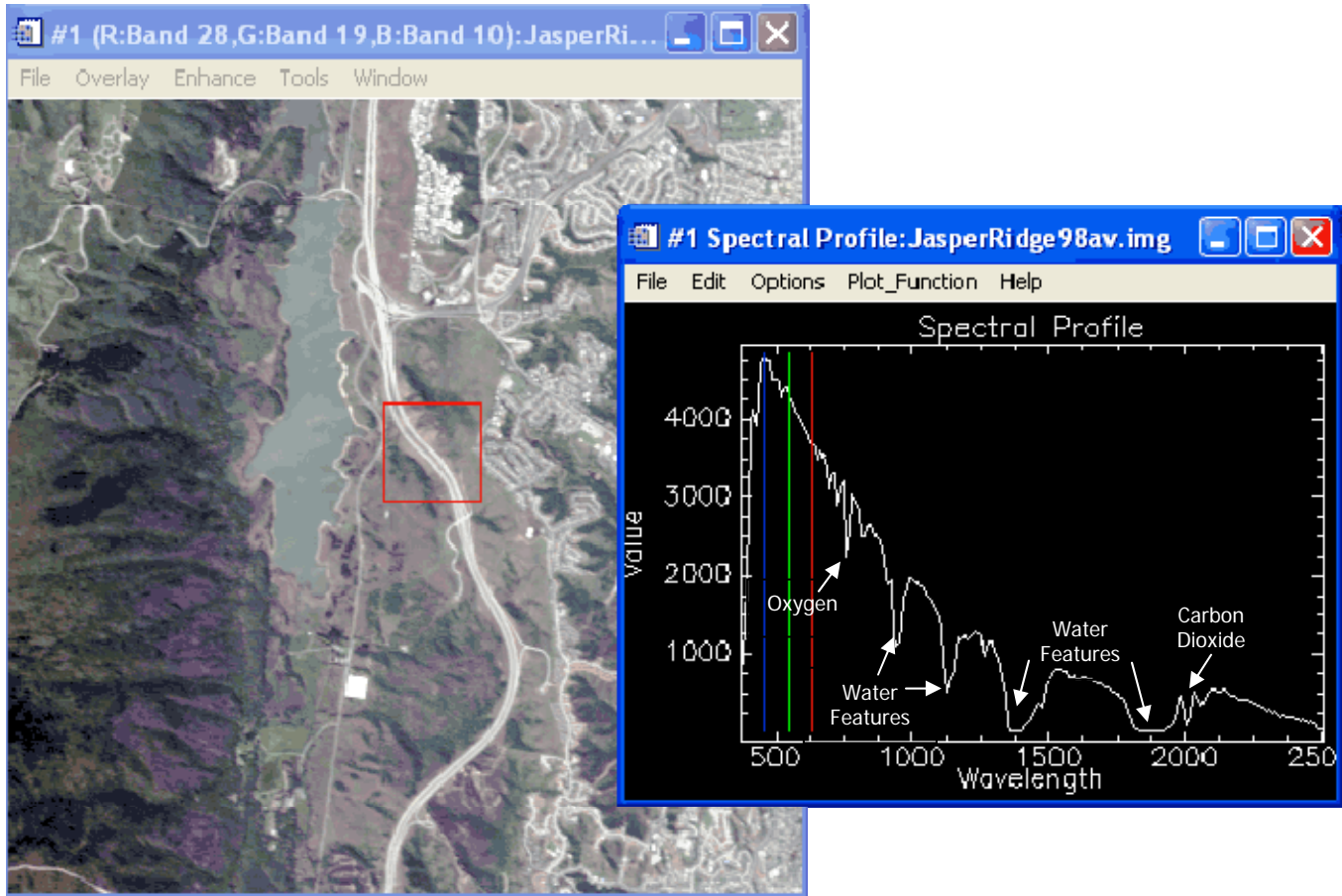
9. Click and drag the cursor in the Spectral Profile window along the radiance spectrum and locate the water vapor absorption features at approximately 760 nm, 940 nm, and 1135 nm. Note also the opaque atmospheric regions around 1400 nm and 1900 nm where virtually no signal is recorded at the instrument. You can also see a common CO2 signature that consists of two absorption features near 2000 nm.

Atmospherically Correcting the AVIRIS Image Using FLAASH

1. From the ENVI main menu bar, select **Spectral → FLAASH**. The FLAASH Input File dialog appears.

2. Click on the **Input Radiance Image** button, select the **JasperRidge98av.img** file, and click **OK**. The Radiance Scale Factors dialog appears.

3. Select the **Read array of scale factors (1 per band) from ASCII file** radio button then click **OK**. The file selection dialog appears

4. Navigate to the `envidata\flaash\hyperspectral\input_files` directory, select the **AVIRIS_1998_scale.txt** file, and click **Open**. The Input ASCII File dialog appears.

5. Accept all of the default values and click **OK**.

6. The input radiance image has been scaled into two-byte signed integers. In order for FLAASH to compute the atmospheric correction, these data must be converted into floating-point radiance values in units of:
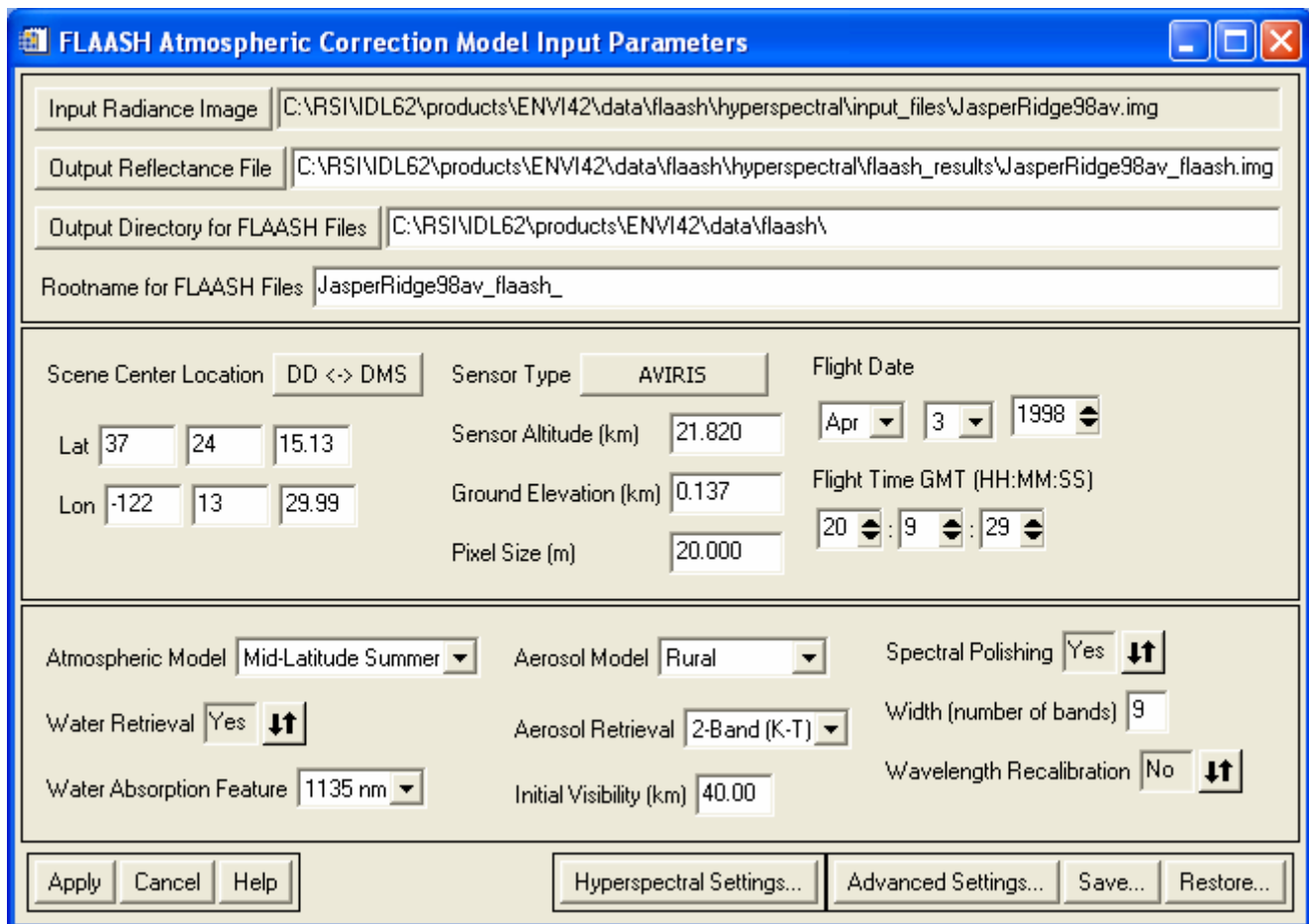   `W/(cm2 • nm • sr)`

   The 1998 AVIRIS scale factors (which are valid for all AVIRIS data collected between 1995 and 2003) are 500 for the first 160 bands and 1000 for the remainder.

In the FLAASH Atmospheric Correction Model Input Parameters dialog, the default path and output reflectance file name for the FLAASH-corrected reflectance result are displayed in the **Output Reflectance File** text box.

7. In the Output Reflectance File field, type a name for the FLAASH-corrected output reflectance file. To navigate to the desired output directory before defining the output file name, click the **Output Reflectance File** button.

8. In the Output Directory for FLAASH Files field, type the full path of the directory where you want to have all other FLAASH output files written. You may also click the **Output Directory for FLAASH Files** button to navigate to the desired directory.

9. In the Rootname for FLAASH Files field, type the name you want to use as a prefix for the FLAASH Output Files. In the next step, ENVI will automatically add an underscore character to the rootname that you enter.

    The FLAASH output files consist of the column water vapor image, the cloud classification map, the journal file, and (optionally) the template file. All of these files are written into the FLAASH output directory and use the rootname as a prefix to their individual standard file names.

10. Click the **Restore** button (located on the bottom right of the FLAASH Atmospheric Correction Model Input Parameters dialog.

11. Navigate to the `envidata\flaash\hyperspectral\input_files` directory, select the **JasperRidge98av_template.txt** file, and click **Open**. This file provides the FLAASH model parameters for the Jasper Ridge image. Review the scene collection details and model parameters for the Jasper Ridge AVIRIS image (see image below). If a message appears, warning you that the paths don't exist, click **OK** to dismiss it.

12. Click the **Advanced Settings** button at the bottom of the dialog window to explore the available advanced settings options. The parameters in the Advanced Settings dialog allow you to adjust additional controls for the FLAASH model. The default setting for Automatically Save Template File is **Yes** and Output Diagnostic Files is **No**. While you may find it excessive to save a template file for each FLAASH run, this file is often the only way to determine the model parameters that were used to atmospherically correct an image after the run is complete,

and access to it can be quite important. The ability to output diagnostic files is offered solely as an aid for RSI Technical Support engineers to help diagnose problems.

13. Click **Cancel** to dismiss this dialog and return to the previous dialog.

14. In the FLAASH Atmospheric Model Input Parameters dialog, click **Apply** to begin the FLAASH processing. You may cancel the processing at any point, but be aware that there are some FLAASH processing steps that can't be interrupted, so the response to the Cancel button may not be immediate.

Viewing the Corrected Image

When FLAASH processing completes, the output reflectance image, as well as the column water vapor image and the cloud classification map, will be entered into the Available Bands List. You should also find the journal file and the template file in the FLAASH output directory.

1. Click **Cancel** on the FLAASH Atmospheric Correction Model Input Parameters dialog to dismiss the dialog.

2. Examine then close the FLAASH Atmospheric Correction Results dialog.
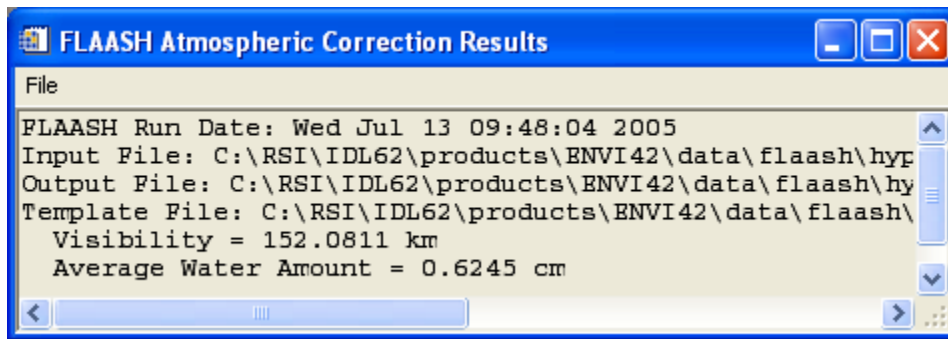
3. From the Available Bands List right-click on the **JasperRidge98av_flaash.img** file and select **Load True Color to <New>**. The image is loaded into a new display.

4. Right-click in the new Image window and select **Z Profile (Spectrum)** to display the Spectral Profile.

5. Click and drag around the image and note the shape of the radiance curves. Note that some bands in the reflectance image have been designated as ENVI bad bands and are not displayed in the plot window. The bad bands list in the ENVI header file is automatically set by FLAASH according to the strength of the radiance signal.

Verifying the Model Results

The results you produce with the sample Jasper Ridge files should be identical to the data found in the `envidata\flaash\hyperspectral\flaash_results` directory.
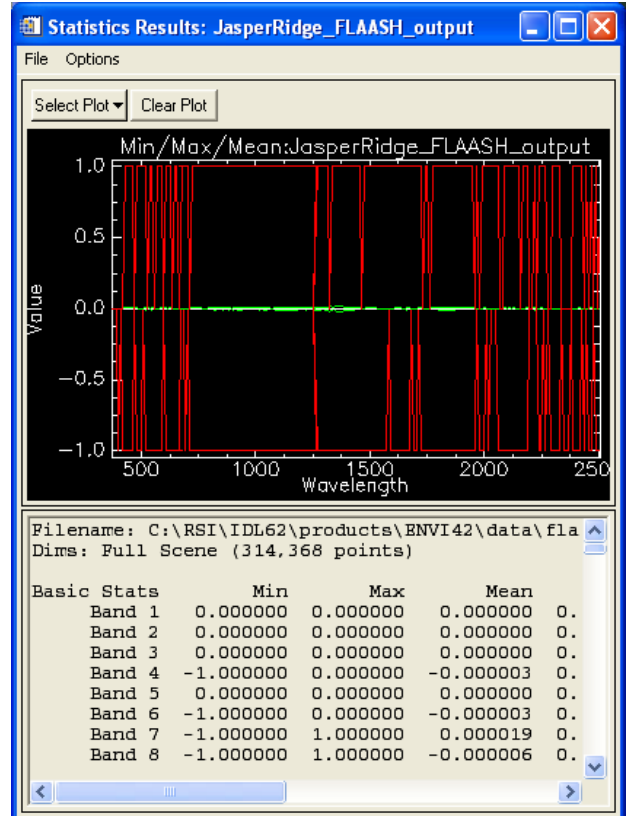
Comparing Images

1. From the ENVI main menu bar, select **File → Open Image File**.

2. Navigate to the `envidata\flaash\hyperspectral\flaash_results` directory, select the **JasperRidge98av_flaash_refl.img** file and click **Open**. The Available Bands List is displayed.

3. From the Available Bands List right-click on the **JasperRidge98av_flaash_refl.img** file and select **Load True Color to <New>**. The image is loaded into a new display.

4. From the Image window menu bar, select **Tools → Link → Link Displays**. You can also right-click in the image and select **Link Displays**.

5. Toggle the **Dynamic Overlay** option **Off** and click **OK** in the Link Displays dialog to establish the link.

6. Double-click in one of the Image windows to display the Cursor Location/Value window.

7. Move your mouse cursor around in one of the images and note the data values in the Cursor Location/Value window. You should see that the data values are identical for corresponding bands in both images.

Computing a Difference Image Using Band Math

For a more quantitative verification of the reflectance results, you will compute a difference image using Band Math.

1. From the ENVI main menu bar, select **Basic Tools → Band Math**. The Band Math dialog appears.

2. In the **Enter an Expression** field, type the following expression:
   float(b1) – b2
   then click **OK**. The Variables to Bands Pairings dialog appears.

3. Click on **B1** to select it then click the **Map Variable to Input File** button. The Band Math Input File dialog appears.

4. Select the **JasperRidge98av_flaash_refl.img** file and click **OK**.

5. Click on **B2** to select it then click the **Map Variable to Input File** button. The Band Math Input File dialog appears.

6. Select the **JasperRidge98av_flaash.img** file and click **OK**.

7. In the **Enter Output Filename** field, type or choose a file name for the output result and click **OK**. Note that the file size for this difference image will be twice as large as the FLAASH reflectance image file, so be sure you have sufficient disk space for this Band Math result.

8. Every value in the difference image should be zero. To ensure that the results are identical, select **Basic Tools → Statistics → Compute Statistics** from the ENVI main menu bar to calculate the basic statistics for the difference image.

9. Note the Max and Min columns in the statistics report window. Due to differences in computer machine precision, your FLAASH reflectance image result may differ from those in the verification directory by approximately 1-5 DNs, or 0.0001 to 0.0005 reflectance units.

References

L. W. Abreu and G. P. Anderson, eds. The MODTRAN 2/3 Report and LOWTRAN 7 Model. Air Force Research Laboratory, Hanscom AFB, MA. 01731-3010. prepared by Ontar Corp. under Contract No. F19628-919C-0132. January 1996.

J.W. Boardman. Post-ATREM Polishing of AVIRIS Apparent Reflectance Data using EFFORT: a Lesson in Accuracy versus Precision. Summaries of the Seventh JPL Airborne Earth Science Workshop. JPL Publication 97-21, Vol. 1. p. 53. 1998.

Kaufman, Y.J., A.E. Walk, L.A. Refer, B.-C. Gao, R.-R. I, and L. Fling. The MODIS 2.1-mm Channel—Correlation with Visible Reflectance for Use in Remote Sensing of Aerosol. IEEE Transactions on Geoscience and Remote Sensing, Vol. 35. pp. 1286-1298. 1997.

Ending the ENVI Session

You can quit your ENVI session by selecting **File → Exit** (**Quit** on UNIX) from the ENVI main menu.

ENVI Tutorials:
Atmospherically Correcting Multispectral Data Using the FLAASH Module

Table of Contents

Overview of This Tutorial

This tutorial provides an introduction to using the ENVI FLAASH Module to atmospherically correct a multispectral image. You will display the radiance image, prepare the data for use in FLAASH, apply an atmospheric correction, and examine the results.

Files Used in This Tutorial
CD-ROM: Tutorial Data CD #1
Path: `envidata\flaash\multispectral\input_files` (radiance image, scale factors file, and template file)
  `envidata\flaash\multispectral\flaash_results` (sample reflectance image)

The image used in this exercise was collected by the Landsat 7 ETM+ sensor on April 3, 1997. It is a standard L1G product. It is a spatial subset of a full Landsat TM scene for path 44 row 34. The image covers a portion of the Jasper Ridge Biological Preserve, located in the eastern foothills of the Santa Cruz Mountains at the base of the San Francisco Peninsula, nine kilometers west of the main Stanford University campus in San Mateo County, CA. The Landsat image was provided courtesy of the USGS EROS Data Center. The full scene is available at http://glovis.usgs.gov. This image contains approximately the same area as the AVIRIS image used for the FLAASH hyperspectral tutorial, however the pixel size, image orientation, and collection dates are different.

File	Description
LandsatTM7_Subset_JasperR_B10.FST	
LandsatTM7_Subset_JasperR_B20.FST	
LandsatTM7_Subset_JasperR_B30.FST	
LandsatTM7_Subset_JasperR_B40.FST	FLAASH input images
LandsatTM7_Subset_JasperR_B50.FST	(Landsat 7 ETM+ fast format Level 1G data product)
LandsatTM7_Subset_JasperR_B70.FST	
LandsatTM7_Subset_JasperR_HRF.FST	
JasperRidgeTM_template.txt	FLAASH template file
JasperRidgeTM_flaash_refl.img	FLAASH reflectance result

Note

The FLAASH Module requires an additional license in your installation; contact your RSI sales representative to obtain a license. If you are not licensed for the FLAASH Module, the tool will be disabled.

Opening the Raw Landsat Image in ENVI

This exercise will demonstrate how to use FLAASH to produce an apparent surface reflectance image.

1. From the ENVI main menu bar, select **File → Open External File → Landsat → Fast**.
2. Navigate to the `envidata\flaash\multispectral\input_files` directory, select the **LandsatTM_JasperRidge_HRF.FST** header file from the list, and click **Open**. The Available Bands List is displayed.
3. From the Available Bands List right-click on the **LandsatTM_JasperRidge_HRF.FST** file and select **Load True Color**. The image is loaded into the display.

   You may recognize several features in the scene, including a long lake oriented NW-SE in the middle of the image, various types of vegetation on the left hand side of the image, and urban areas on the right-hand side.

   This image is a standard Landsat 7 L1G data product, except that it has been spatially subsetted to a small area around Jasper Ridge. The data type is byte (8 bits per pixel) and the image contains uncalibrated digital numbers (or DN).

4. From the Image window menu bar, select **Enhance → [Image] Gaussian** to enhance the display.

Preparing the Image for Use in FLAASH

Before the TM image can be corrected using FLAASH, it must be calibrated into the proper radiance units and converted into a BIP or BIL interleave.

Calibrating the TM Image into Radiance

FLAASH requires that the input image be calibrated into radiance in units of [microWatts/(cm2*sr*nm)]. This can be accomplished in two simple steps using standard ENVI utilities.

1. From the ENVI main menu bar, select **Basic Tools →
   Preprocessing → Calibration Utilities → Landsat TM**. The TM Calibration Input File dialog appears.

2. Select the **LandsatTM_JasperRidge_hrf.fst** file and click **OK**. The TM Calibration Parameters dialog appears.

3. Select the **Radiance** Calibration Type radio button.

4. Select the **Memory** radio button, and click **OK.** The new bands are loaded into the Available Bands List.
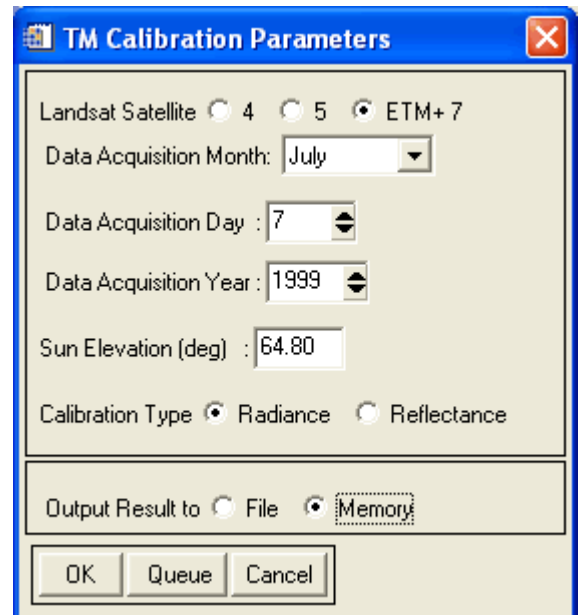
Adjusting the Radiance Units

ENVI's TM calibration utility outputs data with radiance units of [w/(m^2*sr*um)]. However, FLAASH requires radiance in units of [microWatts/(cm2*sr*nm)]. These two units differ by a factor of 0.1, so an additional step is required to convert the units. This exercise uses Band Math to adjust the radiance units. You could instead apply a multiplication factor of 0.1 to the Radiance Scale factors when specifying the FLAASH input file.

1. From the ENVI main menu bar, select **Basic Tools → Band Math**.

2. In the **Enter an expression** field, type the expression:
   ```
   b1 / 10.0
   ```

3. Click **OK**. The Variables to Bands Pairings dialog appears.

4. Click the **Map Variable to Input File** button. The Band Math Input File dialog appears.

5. Select the **Memory** file result and click **OK**.

6. In the **Enter Output Filename** field, type **JasperRidgeTM_radiance.img** and click **OK**. The new bands are loaded into the Available Bands List.

Converting the Interleave

The Band Math result from the previous step has a BSQ interleave, but FLAASH requires the input radiance image to be in either BIL or BIP interleave.

1. From the ENVI main menu bar, select **Basic Tools → Convert Data (BSQ, BIL, BIP)**. The Convert File Input File dialog appears.

2. Select the **JasperRidgeTM_radiance.img** file and click **OK**. The Convert File Parameters dialog appears.

3. Select the **BIL** Output Interleave radio button.

4. Toggle the Convert in Place option to **Yes**, click **OK** to start processing, and answer **Yes** to the warning message.
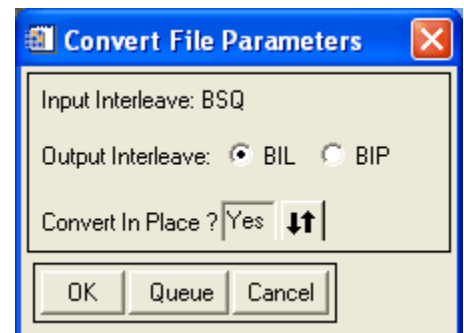
   For relatively small files such as this, it is faster to perform the interleave conversion In Place. For larger images, such as a full Landsat TM scene, it will be considerably faster to write the new interleave file to disk.

Atmospherically Correcting the TM Image Using FLAASH

1. In the Available Bands List, right-click on the **JasperRidgeTM_radiance.img** file and select **Load True Color to <current>**.

2. From the Image window menu bar, select **Enhance → [Image] Gaussian** to enhance the display.

3. Right-click in the Image window and select **Z Profile (Spectrum)** to display the Spectral Profile.

4. Click and drag in the bottom middle part of the image, over the vegetated areas, and note the shape of the radiance curves. The most prominent atmospheric feature in these spectra is the consistent upward trend in the blue and green bands. This is likely caused by atmospheric aerosol scattering, or what is often referred to as 'skylight'. An accurate atmospheric correction should compensate for the skylight to produce spectra that more truly depict surface reflectance.
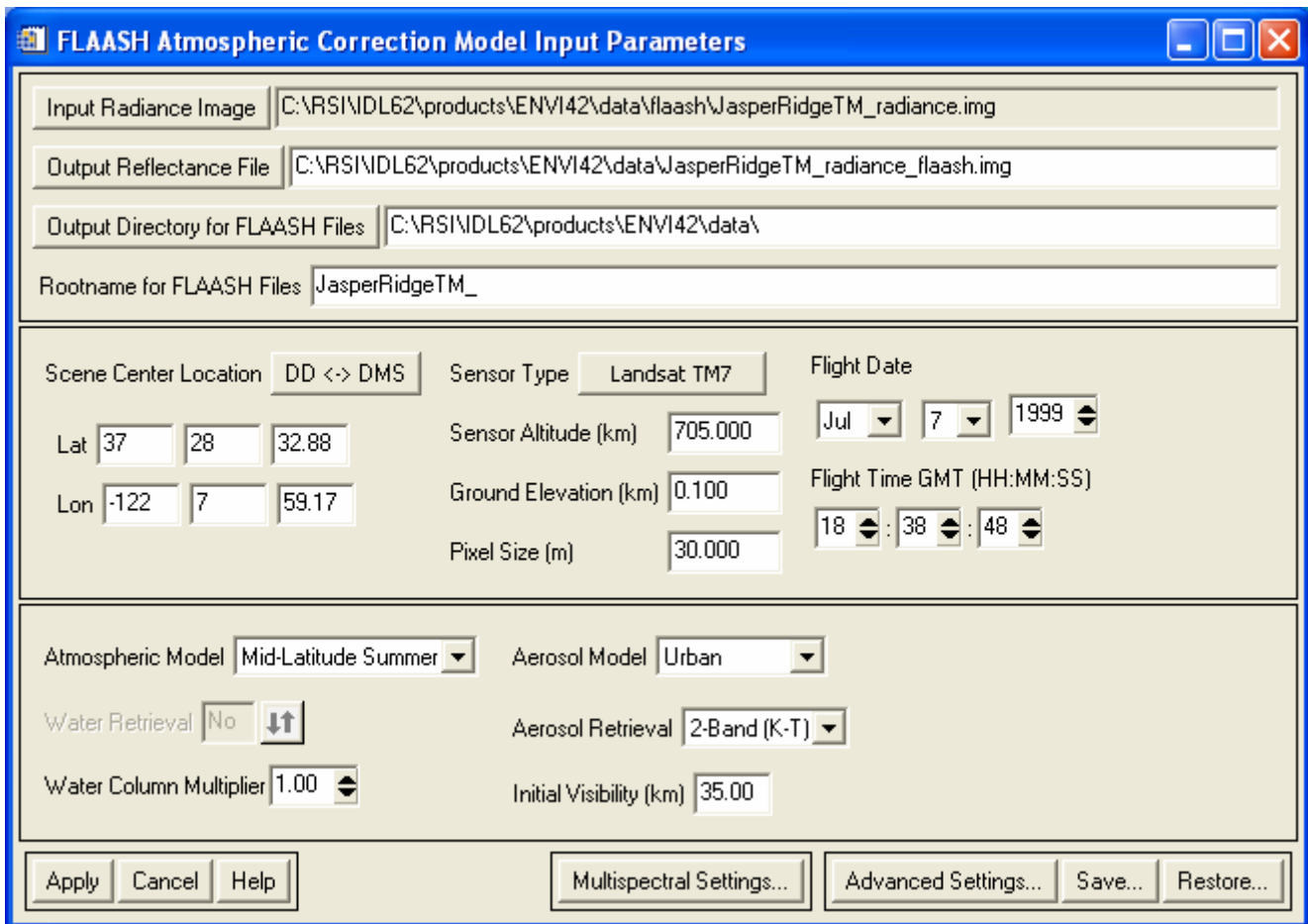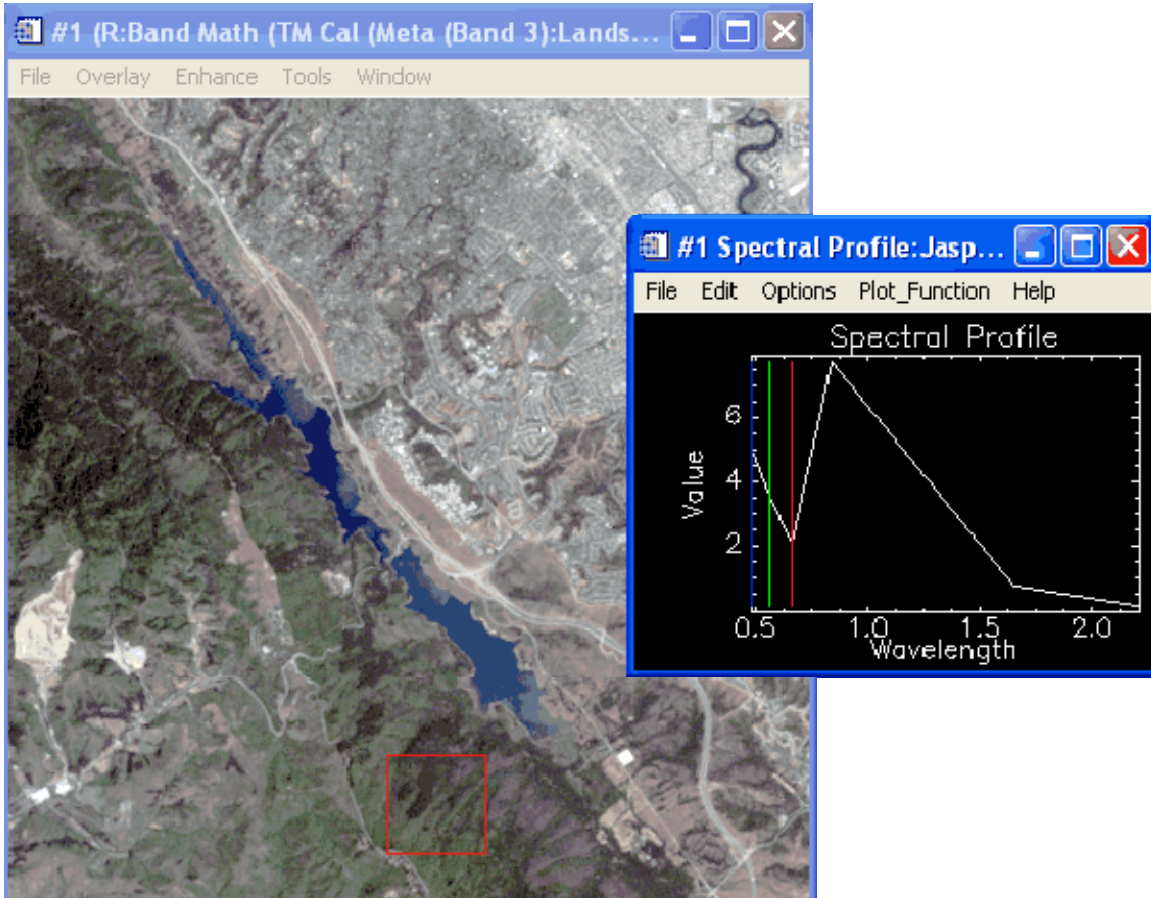

5. From the ENVI main menu, select **Spectral → FLAASH**.

6. Click the **Input Radiance Image** button, select the **JasperRidgeTM_radiance.img** file, and click **OK**. The Radiance Scale Factors dialog appears.

7. Select the **Use single scale factor for all bands** radio button. Since the input image units have already been correctly scaled (see the exercise "Adjusting the Radiance Units"), the Single Scale Factor default value of 1 is acceptable. If the units had not already been scaled, the Single Scale Factor setting could have been used to apply the correct scale factor of 0.1. Click **OK**.

8. In the Output Reflectance File field, type a name for the FLAASH-corrected output reflectance file. To navigate to the desired output directory before defining the output file name, click the **Output Reflectance File** button (see image on following page).

9. In the Output Directory for FLAASH Files field, type the full path of the directory where you want to have all other FLAASH output files written. You may also click the **Output Directory for FLAASH Files** button to navigate to the desired directory (see image on following page).

10. In the Rootname for FLAASH Files field, type the name you want to use as a prefix for the FLAASH Output Files. In the next step, ENVI will automatically add an underscore character to the rootname that you enter.

    If Water Retrieval is selected, the FLAASH output files will consist of the column water vapor image, the cloud classification map, the journal file, and (optionally) the template file. All of these files are written into the FLAASH output directory and use the rootname as a prefix to their individual standard filenames.

11. Click the **Restore** button (located on the bottom right of the FLAASH Atmospheric Correction Model Input Parameters dialog.

12. Navigate to the `envidata\flaash\multispectral\input_files` directory, select the **JasperRidgeTM_template.txt** file, and click **Open**. This file provides the FLAASH model parameters for the Jasper Ridge image. Review the scene collection details and model parameters for the Jasper Ridge TM image (see image below).

    In this example, the Water Retrieval toggle is set to No because the Landsat TM sensor does not have bands in the water absorption regions that can be used to compute the atmospheric water vapor. As is common for multispectral sensors, a fixed water amount based on a typical atmosphere must be used instead.


13. Click the **Multispectral Settings** button at the bottom of the dialog window to explore the multispectral settings available. The Multispectral Settings dialog is used to select a filter function file and define the bands which are used for various FLAASH processing steps. The water retrieval bands are left undefined because water retrieval is not possible with Landsat TM data. However, the Landsat TM sensor does contain bands that can be used to estimate the aerosol concentration.

14. Click the **Aerosol Retrieval** tab to see which bands were selected.

15. Click **Cancel** to dismiss this dialog and return to the previous dialog.

16. Click the **Advanced Settings** button at the bottom of the dialog window to explore the available advanced settings options. The parameters in the Advanced Settings dialog allow you to adjust additional controls for the FLAASH model. The default setting for Automatically Save Template File is **Yes** and Output Diagnostic Files is **No**. While you may find it excessive to save a template file for each FLAASH run, this file is often the only way to determine the model parameters that were used to atmospherically correct an image after the run is complete, and access to it can be quite important. The ability to output diagnostic files is offered solely as an aid for RSI Technical Support engineers to help diagnose problems.

17. Click **Cancel** to dismiss this dialog and return to the previous dialog.

18. In the FLAASH Atmospheric Model Input Parameters dialog, click **Apply** to begin the FLAASH processing. You may cancel the processing at any point, but be aware that there are some FLAASH processing steps that can't be interrupted, so the response to the Cancel button may not be immediate.
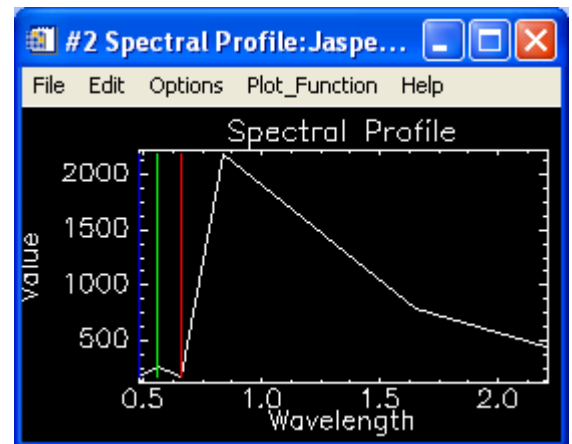
Viewing the Corrected Image

When FLAASH processing completes, the output reflectance image will be entered into the Available Bands List. You should also find the journal file and the template file in the FLAASH output directory.

1. Click **Cancel** on the FLAASH Atmospheric Correction Model Input Parameters dialog to dismiss the dialog.

2. Examine then close the FLAASH Atmospheric Correction Results dialog.
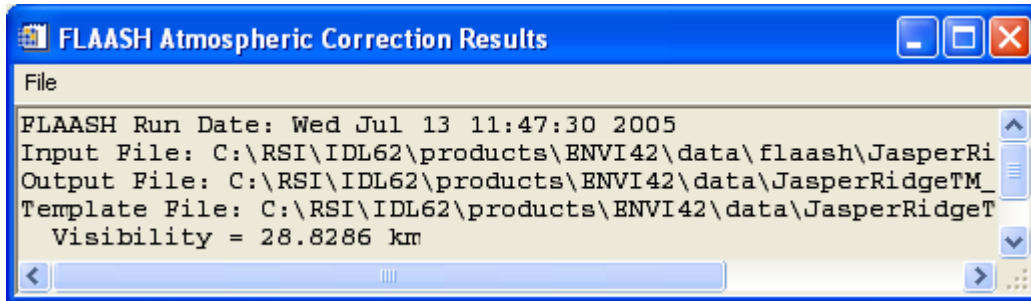
3. From the Available Bands List right-click on the **JasperRidgeTM_radiance_flaash.img** file and select **Load True Color to <New>**. The image is loaded into a new display.

4. Right-click in the new Image window and select **Z Profile (Spectrum)** to display the Spectral Profile.

5. Click and drag around the image and note the shape of the radiance curves. The vegetation reflectance curves now display a more characteristic shape, with a peak in the green, a chlorophyll absorption in the red, and a sharp red edge leading to higher near infrared reflectance.

Verifying the Model Results

The results you produce with the sample Jasper Ridge files should be identical to the data found in the `envidata\flaash\multispectral\flaash_results` directory.
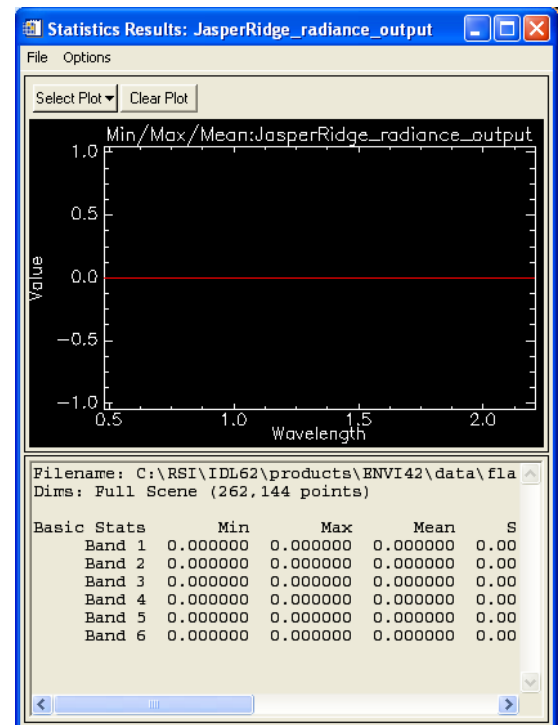
Comparing Images

1. From the ENVI main menu bar, select **File → Open Image File**.

2. Navigate to the `envidata\flaash\multispectral\flaash_results` directory, select the **JasperRidgeTM_flaash_refl.img** file and click **Open**. The Available Bands List is displayed.

3. From the Available Bands List right-click on the **JasperRidgeTM_flaash_refl.img** file and select **Load True Color to <New>**. The image is loaded into a new display.

4. From the Image window menu bar, select **Tools → Link → Link Displays**. You can also right-click in the image and select **Link Displays**.

5. Toggle the **Dynamic Overlay** option **Off** and click **OK** in the Link Displays dialog to establish the link.

6. Double-click in one of the Image windows to display the Cursor Location/Value window.

7. Move your mouse cursor around in one of the images and note the data values in the Cursor Location/Value window. You should see that the data values are identical for corresponding bands in both images.

Computing a Difference Image Using Band Math

For a more quantitative verification of the reflectance results, you will compute a difference image using Band Math.

1. From the ENVI main menu bar, select **Basic Tools → Band Math**. The Band Math dialog appears.

2. In the **Enter an Expression** field, type the following expression:
    float(b1) – b2
    then click **OK**. The Variables to Bands Pairings dialog appears.

3. Click on **B1** to select it then click the **Map Variable to Input File** button. The Band Math Input File dialog appears.

4. Select the **JasperRidgeTM_flaash_refl.img** file and click **OK**.

5. Click on **B2** to select it then click the **Map Variable to Input File** button. The Band Math Input File dialog appears.

6. Select the **JasperRidgeTM_radiance_flaash.img** file and click **OK**.

7. In the **Enter Output Filename** field, type or choose a file name for the output result and click **OK**. Note that the file size for this difference image will be twice as large as the FLAASH reflectance image file, so be sure you have sufficient disk space for this Band Math result.

8. Every value in the difference image should be zero. To ensure that the results are identical, select **Basic Tools → Statistics → Compute Statistics** from the ENVI main menu bar to calculate the basic statistics for the difference image.

9. Note the Max and Min columns in the statistics report window. Due to differences in computer machine precision, your FLAASH reflectance image result may differ from those in the verification directory by approximately 1-5 DNs, or 0.0001 to 0.0005 reflectance units.

Ending the ENVI Session

You can quit your ENVI session by selecting **File → Exit** (**Quit** on UNIX) from the ENVI main menu.