Processing of Hyperspectral Remote Sensing Data

Book · December 2013

DOI: 10.13140/RG.2.1.1642.9609

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Printed : February, 2013

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TB-ICN : 111/2013

Correct Citation
Sahoo R. N., Pargal, S., Pradhan, S., Krishna, G. and Gupta, V.K. 2013. Processing of Hyperspectral Remote Sensing Data, Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi-110 012, India, Pp. 72.

Published by the Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi – 12, India and Printed at M/s. Venus Printers and Publishers, B-62/8, Naraina Industrial Area, Phase-II, New Delhi – 110 028, Ph. : 45576780, 9810089097; E-mail: pawannanda@gmail.com

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Foreword

Ever since satellite remote sensing emerged as potential technology for better managing natural resources, Indian Agricultural Research Institute took the lead role in establishing a successful programme to harness this technology for agriculture. The Division of Agricultural Physics, IARI, New Delhi has been involved for more than five decades in conducting research and developing human resources in the country on Remote Sensing and their various applications in Natural Resource Management. Over the years Division has developed expertise on hyperspectral Remote Sensing and demonstrated various potential applications of this technique in agriculture. As well Division has contributed significantly for human resource development on remote sensing and other geospatial technologies through its Post-Graduate teaching Programme and by conducting series of training programmes.

With the continued strength and expertise, Division is conducting in series 2nd short course on "Hyperspectral Remote Sensing for Agriculture" (HYPERAGRI-2013) during Feb 18-27, 2013 funded by Natural Resource Data Management System (NRDMS), Department of Science and Technology, Government of India. The training programmed is well composed by Dr. Rabi N Sahoo, Senior Scientist & Course Director, and Dr. Sanatan Pradhan, Scientist & Course Coordinator, supported by experienced faculties from the Institute and other associated organizations. This publication under the title 'Processing of Hyperspectral Remote Sensing Data' describes in details processing of data from both spectroradiometer and satellite is a welcome contribution of the Division of Agricultural Physics. I am pleased to record my appreciation to whole team who have contributed to this publication which will be a useful reference source for many researchers working or intending to work in the field of hyperspectral remote sensing applications.

(Ravender Singh)

Preface

Multispectral remote sensing data have been potentially explored in India for various applications. A major limitation of multispectral broadband remote sensing products is that they use average spectral information over broadband widths resulting in loss of critical information available in specific narrow bands. The narrow spectral channels that constitute hyperspectral sensors enable the detection of small spectral features that might otherwise be masked within the broader bands of multi-spectral scanner systems. However, use of hyperspectral remote sensing is still in nascent stage. Keeping in view, recent rapid advances in imaging spectroscopy and opportunities for unique applications hitherto thought to be infeasible using broad-band remote sensing, second short course under the aegis of DST-NRDMS initiative on hyperspectral remote sensing is being organized during Feb 18-27, 2013 to develop trained human resource on hyperspectral remote sensing and its application in agriculture. The publication on "Processing of Hyperspectral Remote Sensing Data" will be a guide book to process and analyze the hyperspectral data collected through spectroradiometer, Fourier Transform Infrared Spectroscopy (FTIR) and EO-1 Hyperion sensor. This includes spectral signature collection through both ground held instruments and their analysis, hyperspectral image processing – pre-processing, classification, spectral library generation and spectral matching etc.

We are grateful to the Director and Joint Directors (Research, Education and Extension) for bestowing responsibility on us for conducting this training course and their encouragement and support to bring out this publication. We are grateful to the NRDMS, Department of Science & Technology, Government of India for the financial support. We are thankful to Venus Printers and Publishers, Naraina Industrial Area, New Delhi for bringing out the publication to our expected form.

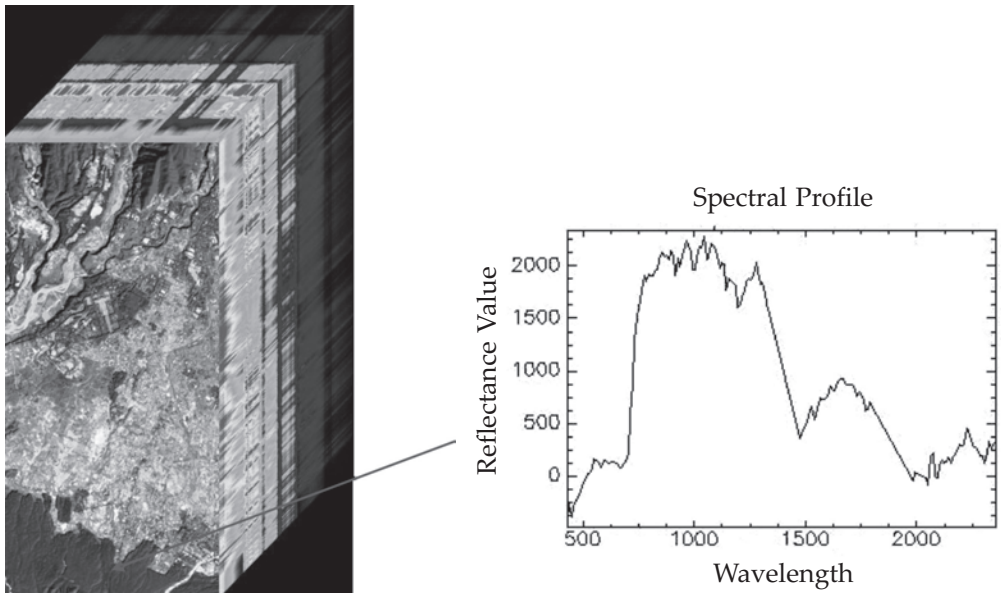
New Delhi

Rabi N Sahoo
Sourabh Pargal
Sanatan Pradhan
Gopal Krishna
Vinod K. Gupta

Contents

Introduction

Remote Sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation [1]. This is usually in the form of an image acquired at a distance from the surface. Multispectral remote sensing data have been potentially explored worldwide for various applications. One of the major limitations of the multispectral data is that the sensors operate in broad wavelength bands thus limiting the amount of spectral information available [2]. Hyperspectral sensors record reflected electromagnetic energy from the Earth surface across the electromagnetic spectrum extending from the visible wavelength region through the near-infrared and mid-infrared region (0.3µm to 2.5µm) in tens to hundreds of narrow (in the order of 10nm) contiguous bands [1]. Such narrow bandwidths results in an almost continuous and detailed spectral response for each pixel providing accurate and precise information about its constituents and is clearly an advantage over multispectral imaging. The high spectral resolution of a hyperspectral sensor allows us to capture small deviations in the spectral response of the materials thus aiding in their identification. Figure below depicts a typical Hyperspectral data cube and the spectrum of a single pixel.



Hyperion Image cube and reflectance spectrum

Hyperspectral imaging or reflectance spectrometry techniques are now in use for over a decade and come as a rapid and inexpensive mode for taking spectral reflectance measurements. This course will introduce the participants to the state-of-the-art techniques in hyperspectral image processing and interpretation with a focus on satellite based and ground based sensors. The participants will be exposed to the complete hyperspectral processing chain starting from data acquisition with emphasis on agricultural applications.

Chapter

1

Spectral Signature Collection Using FieldSpec® 3 Hi-Res Portable Spectroradiometer and Its Analysis

1. Introduction to Spectroradiometer

Spectrometer is an optical instrument that uses detectors other than photographic film to measure the distribution of radiation in a particular wavelength region. A spectroradiometer is a special kind of spectrometer that can measure radiant energy (radiance and irradiance). The FieldSpec® 3 Spectroradiometer is a general-purpose spectrometer useful in many application areas requiring the measurement of reflectance, transmittance, radiance, or irradiance. It is specifically designed for field environment remote sensing to acquire visible near-infrared (VNIR) and short-wave infrared (SWIR) spectra. While the most highly regarded features of the FieldSpec spectroradiometer are performance and field-portability, this instrument also performs well in the laboratory. The FieldSpec spectroradiometer is a compact, field portable and precision instrument with a spectral range of 350-2500 nm and a rapid data collection time of 0.1 second per spectrum. The FieldSpec spectroradiometer offers spectral data collection in various subsections of the spectral range as listed in Table 1.1.

Table 1.1 FieldSpec Wavelength Configuration

Wavelength Name	Wavelength Range
VNIR-SWIR1-SWIR2	350 - 2500 nm
VNIR only	350 - 1050 nm
VNIR-SWIR1	350 - 1800 nm
SWIR1 only	1000 - 1800 nm
SWIR1-SWIR2	1000 - 2500 nm
SWIR2 only	1800 - 2500 nm
VNIR & SWIR2	350 - 1050 nm & 1800 - 2500 nm

The spectral resolution is:

- 3 nm (Full-Width-Half-Maximum) at 700 nm.
- 10 nm (Full-Width-Half-Maximum) at 1400 nm.
- 10 nm (Full-Width-Half-Maximum) at 2100 nm.

The sampling interval is:

- 1.4 nm for the spectral region 350-1000 nm.
- 2 nm for the spectral region 1000-2500 nm.

The series of figures below show the **FieldSpec® 3 Hi-Res Portable Spectroradiometer** and its various accessories and enhancements.

Figure 1. FieldSpec spectroradiometer front-view showing fiber connection and power output.

Figure 2. FieldSpec spectroradiometer power supply and cables and power output.

Figure 3. Portable battery pack (one on each side of hip belt) output.

Figure 4. FieldSpec power connector which plugs into the instrument output.

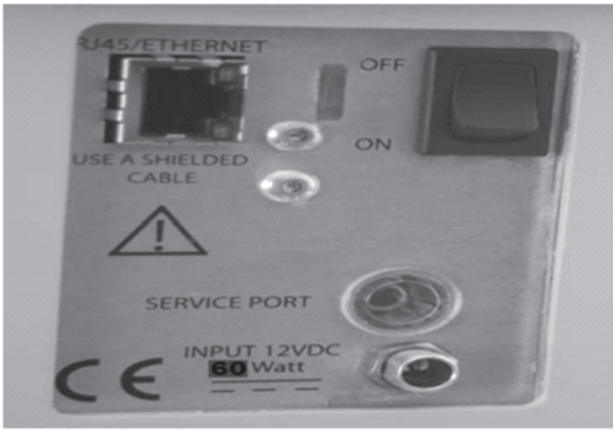


Figure 5. FieldSpec back panel with Ethernet connection, power switch, and power input jack.

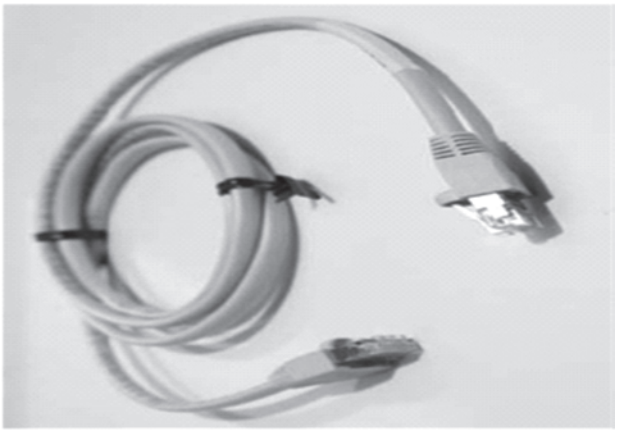


Figure 6. Shielded cross-over Ethernet cable.

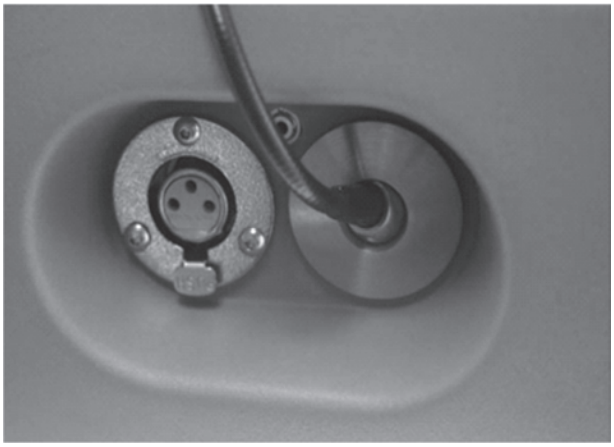


Figure 7. Enhanced view of the front panel with the fiber optic cable connector, port for remote trigger, and accessory power port for probe.

Figure 8. Cable connecting FieldSpec accessory power port to Contact Probe or other authorized ASD accessory.

Figure 9. Pistol grip with red-dot scope, Ten degree field-of-view and trigger (standard) attached.

Figure 10. Laptop Carrier attached to shoulder straps of the Ergonomic Pro-Pack.

Figure 11. The FieldSpec 3 strapped into the Ergonomic Pro-Pack.

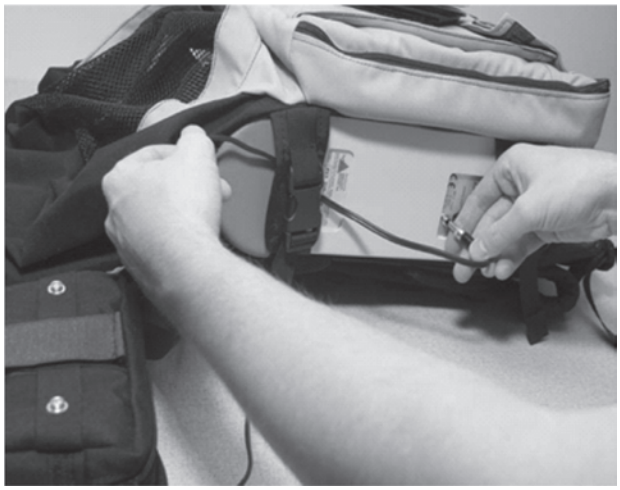


Figure 12. Routing the battery cable to the FieldSpec spectroradiometer.

Figure 13. FieldSpec 3 in Ergonomic Pro-Pack and instrument controller on the laptop carrier.

2. Theory of Operation and Spectral Data Collection

The FieldSpec spectroradiometer measures the optical energy that is reflected by, absorbed into, or transmitted through a sample. Optical energy refers to a wavelength range that is greater than just the visible wavelengths, and is sometimes called electromagnetic radiation or optical radiation. In its most basic configuration, the spectroradiometer views and detects the form of radiant energy defined as radiance. With accessories, various set-ups, and built-in processing of the radiance signal, the FieldSpec spectroradiometer can measure:

- Spectral Reflectance,
- Spectral Transmittance,
- Spectral Absorbance,
- Spectral Radiance, and
- Spectral Irradiance.

Field spectrometry is the quantitative measurement of radiance, irradiance, reflectance or transmission in the field. It involves the collection of accurate spectra and requires an awareness of the influences of:

- Sources of illumination.
- Atmospheric characteristics and stability.
- Winds.
- Instrument field-of-view.
- Sample viewing and illumination geometry.
- Instrument scanning time.
- Spatial and temporal variability of the sample characteristics

In order to determine the reflectance or transmittance of a material, two measurements are required:

- The spectral response of a reference sample.
- The spectral response of the target material.

The reflectance or transmittance spectrum is then computed by dividing the spectral response of the target material by that of a reference sample. Using this method, all parameters which are multiplicative in nature and present in both the spectral response of a reference sample and the target material, are ratio-ed out, such as:

- The spectral irradiance of the illumination source.
- The optical throughput of the field spectrometer.

Note: An inherent assumption when determining the reflectance or transmittance of a material in the field is that the characteristics of the illumination are the same for the reference and target materials. Variability of the illumination characteristics between the time the reference and target materials are measured will result in errors in the resultant spectra.

2.1. Dark Current Measurement

Dark Current (DC) refers to current generated within a detector in the absence of any external photons. DC is the amount of electrical current that is inherent in the spectrometer's detectors and other electrical components and is additive to the signal generated by the measured external optical radiation.

As Noise is the uncertainty in a given measurement, one channel at a time and noise by definition is random it can be reduced by using more samples and averaging the signal. Dark Current is different from noise, because it is relatively stable and can be characterized. DC is a property of the detector and the associated electronics (not the light source). DC varies with temperature. In the VNIR region, DC also varies with integration time.

Whenever DC is taken, a mechanical shutter is used to block off the entrance slit of the VNIR spectrometer so the signal can be measured. This signal is subtracted from each subsequent spectrum until another DC is taken. The SWIR spectrometers take and subtract DC on every scan. The DC measurement can be updated at any time, but should be updated more frequently in the beginning of a given session while the instrument warms up.

2.2. White Reference

A material with approximately 100% reflectance across the entire spectrum is called a white reference panel or white reference standard or spectralon. The raw measurement made by the spectroradiometer is influenced by both the sample and the light source. An independent measure of the light source illumination on a reference of known reflectance is required to calculate the reflectance of the sample. The use of a white reference standard with near 100% reflectance simplifies this calculation.

Reflectance and transmittance are inherent properties of all materials and are independent of the light source. Reflectance is the ratio of energy reflected from a sample to the energy incident on the sample. Spectral Reflectance is the reflectance as a function of wavelength. Transmittance is the ratio of the radiant energy transmitted through a sample to the radiant energy incident on the surface of the sample. Spectral Transmittance is the transmittance as a function of wavelength.

Relative reflectance is computed by dividing the energy reflected from the sample by the energy reflected off a white reference panel or standard. Absolute reflectance is computed by multiplying the relative reflectance by the known reflectance of the white reference panel. With the reflectance of the reference standard available and known, the ASD RS3 or Indico applications can compute the absolute reflectance or transmittance for the material being sampled.

2.3. Collection of Spectral Signature

Before starting to take reading the instrument should be allowed to warm up enough. The warm-up time of the instrument depends on the environment in which it is used. Minimum one hour of warm-up time is recommended for radiometric work. Radiometer battery and laptop battery should be fully charged before use.

Follow the instructions for plugging in the instrument and starting the **RS³** software

Step 1: Attach required fore-optic accessories (pistol grip) to fore-optic.

Step 2: Click on **Start > All Program > ASD Programs > RS³**

RS3 Software opens

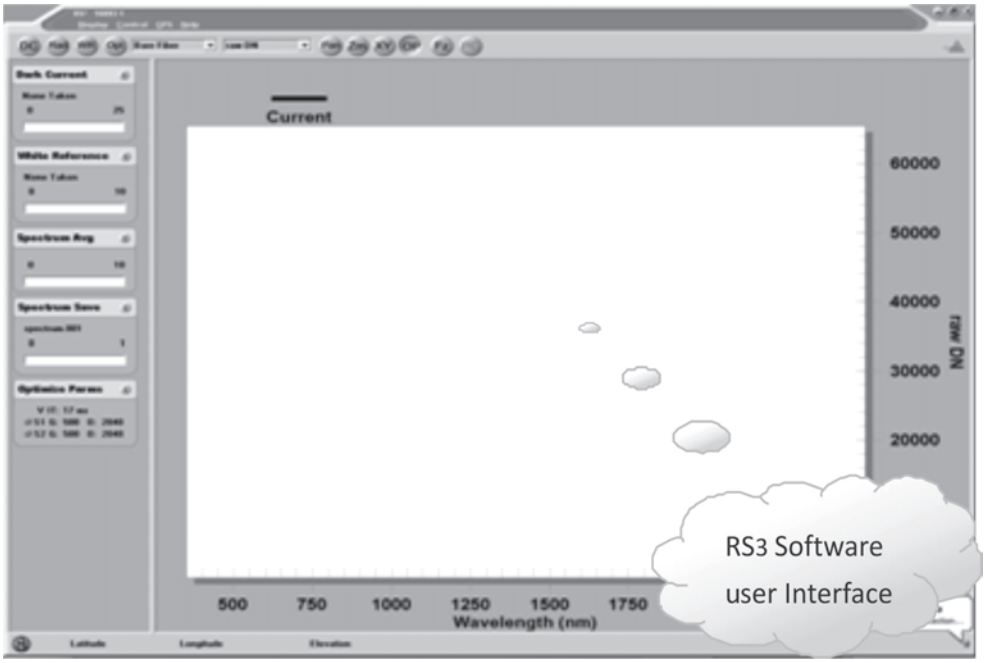


Figure 14. RS³ Software user Interface

Step 3: Open the Control Configuration in the RS3 application**.**

Click on **Control > Spectrum Save** (Give the output Spectrum Name and Path where files are to be saved).

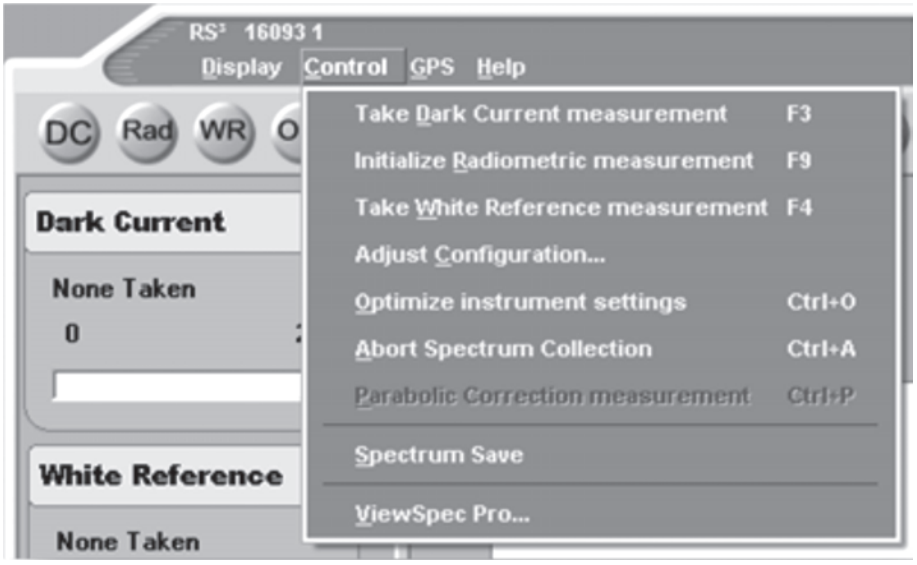


Figure 15. Set the sample, white reference, and dark current averages to 10 **scans**

Step 4: Keep the attached accessory (Contact Probe etc) over Spectralon (white reference)

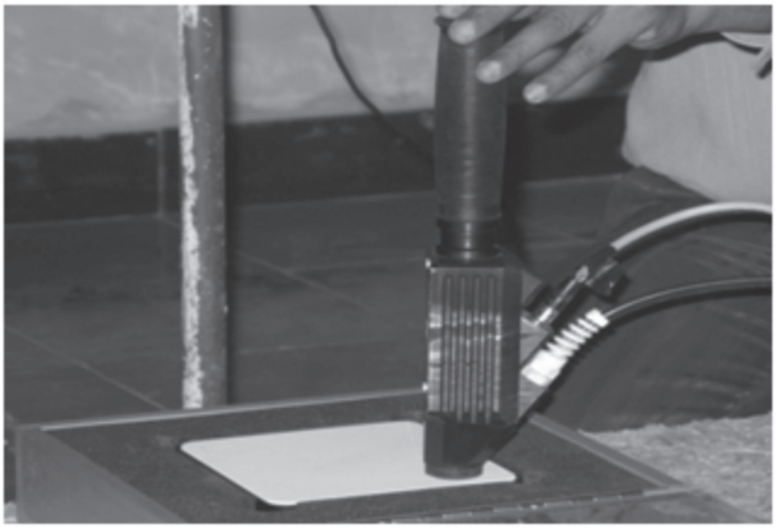


Figure 16. White Reference measurement

Step 5: Click **Opt** option on the RS3 menu bar

Clicking on Opt button perfprms following actions;

- Optimizes the detector sensitivities for the probe and light source currently being used.
- The dark offset and white reference will also be measured and saved.
- Status bars will indicate each process.
- Graph will be displayed as below once optimization is done.

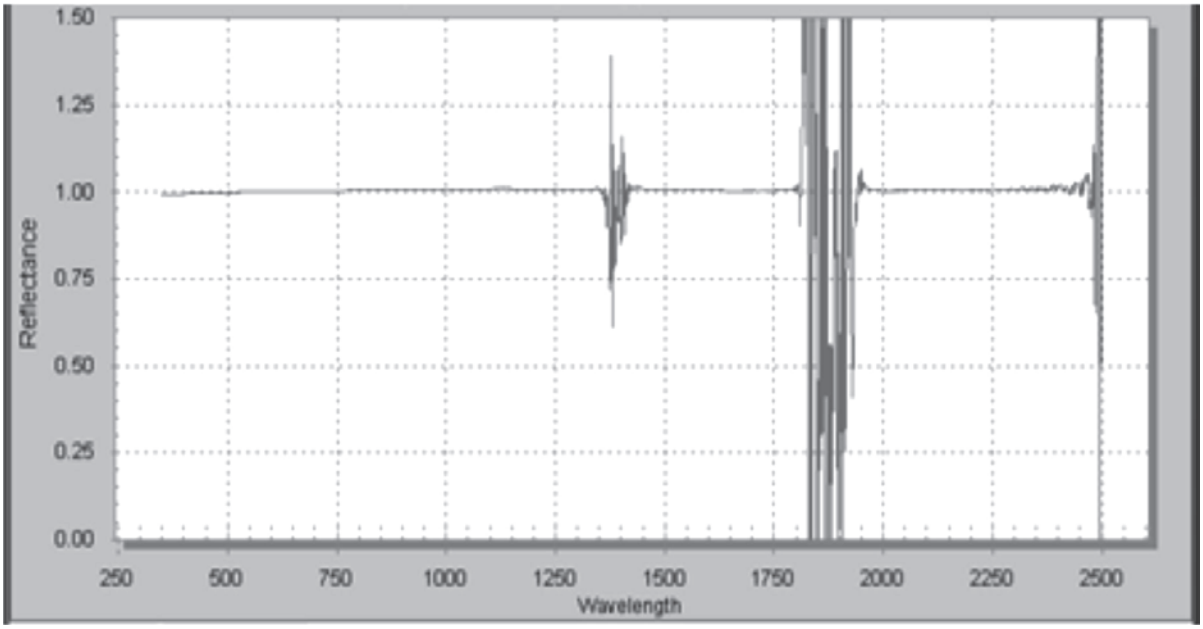


Figure 17. Spectralon reflectance after optimization

Step 6: Now save this optimized file by pressing SPACE BAR.

The FieldSpec 3 spectroradiometer must be re-optimized for:

- Light changes.
- Any atmospheric changes.
- Outdoor solar changes at least every 10 to 15 minutes.
- Indoor use every 30 minutes.
- Changes in temperature.

Note: Conditions can change rapidly or slowly. It all depends on clouds, wind (affecting temperature), instrument warm up time, etc.

It is important that the position of the reference sample when taking a white reference is as similar as possible to the position for capturing data from the samples. When saving reflectance data, point the probe at the Spectralon once every few measurements for a minute or two with the same viewing geometry. If the relative reflectance of the Spectralon is less than or greater than one, a new white reference may be needed. If the relative reflectance of the Spectralon is greater than one, re-optimization is recommended.

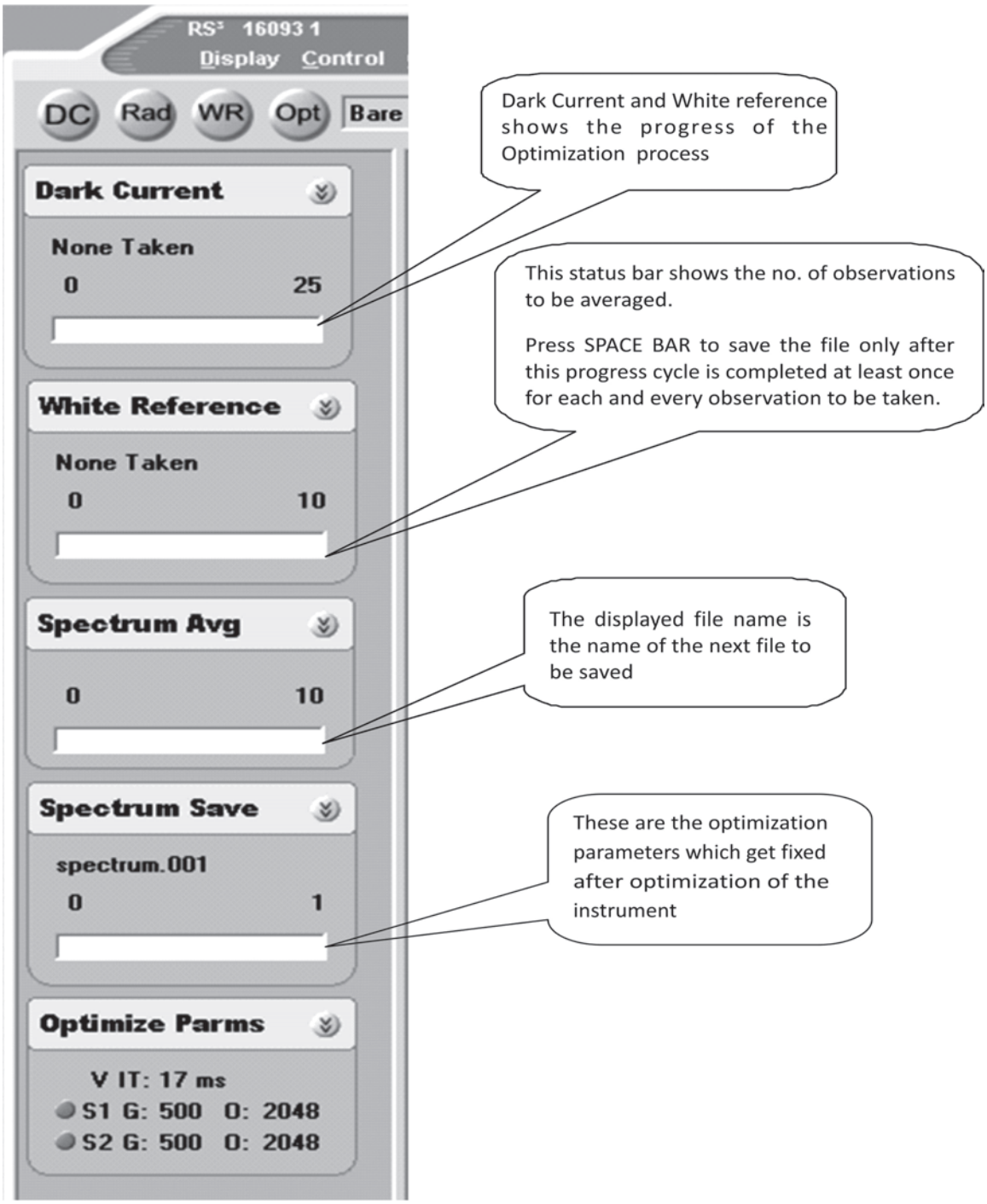


Figure 18. Different Status bars on the User Interface

Step 7: Go on taking the signature of desired samples and save it by pressing SPACE BAR

Note: The actual spectrum average will be determined by striking a compromise between noise reduction through averaging the spectra and the time desired for each spectrum collection. For instance, if you are using the instrument in the field, are walking a large area, and are making frequent spectral readings, you will want a shorter average setting than if you are collecting spectra in-situ and desire the cleanest spectra possible.

3. Analysing/ Post-Processing the Observed Spectra

ViewSpec is one of many applications that can post-process the observed data. The spectral data can be imported into many different applications. When using the RS3 application, ViewSpec can be used to convert spectral data to ASCII text files. Conversion can be done one file at a time. Or, several files can be merged into a single text file, which is a useful feature when inputting data into other analysis programs. ViewSpec also permits viewing large groups of files.

To reduce the effects of low-frequency noise conditions like those found outdoors it is recommended to take multiple spectra with spectrum averaging set to 10-25, and then further averaging of those spectra can be done in post processing using the ViewSpec pro software.

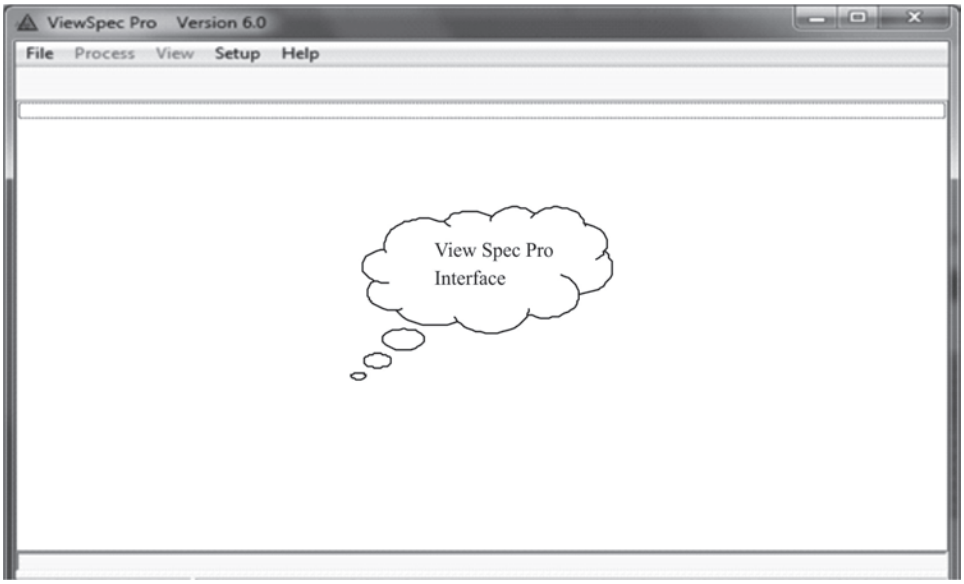


Figure 19. View Spec Pro Interface

The input directory from where the software picks up the spectra, as well as the directory where the outputs can be saved is selected from the **Setup** tab, as shown below:

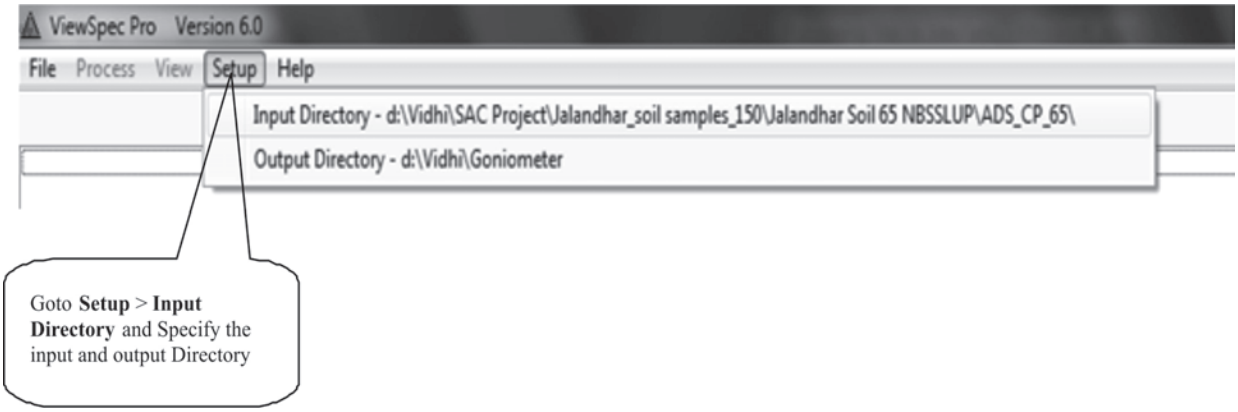


Figure 20. ViewSpec Pro Menu Bar

From the Process pull-down menu, an applicable post-processing option for the selected spectra file(s) can be selected.

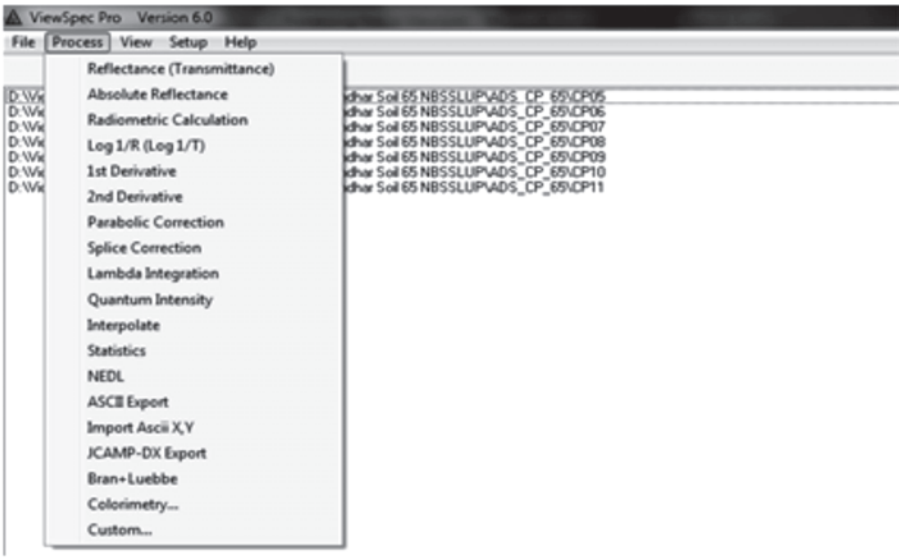


Figure 21. Process pull-down menu.

3.1. Viewing Graphs of the data:

Using this application, one can view the data graphically.

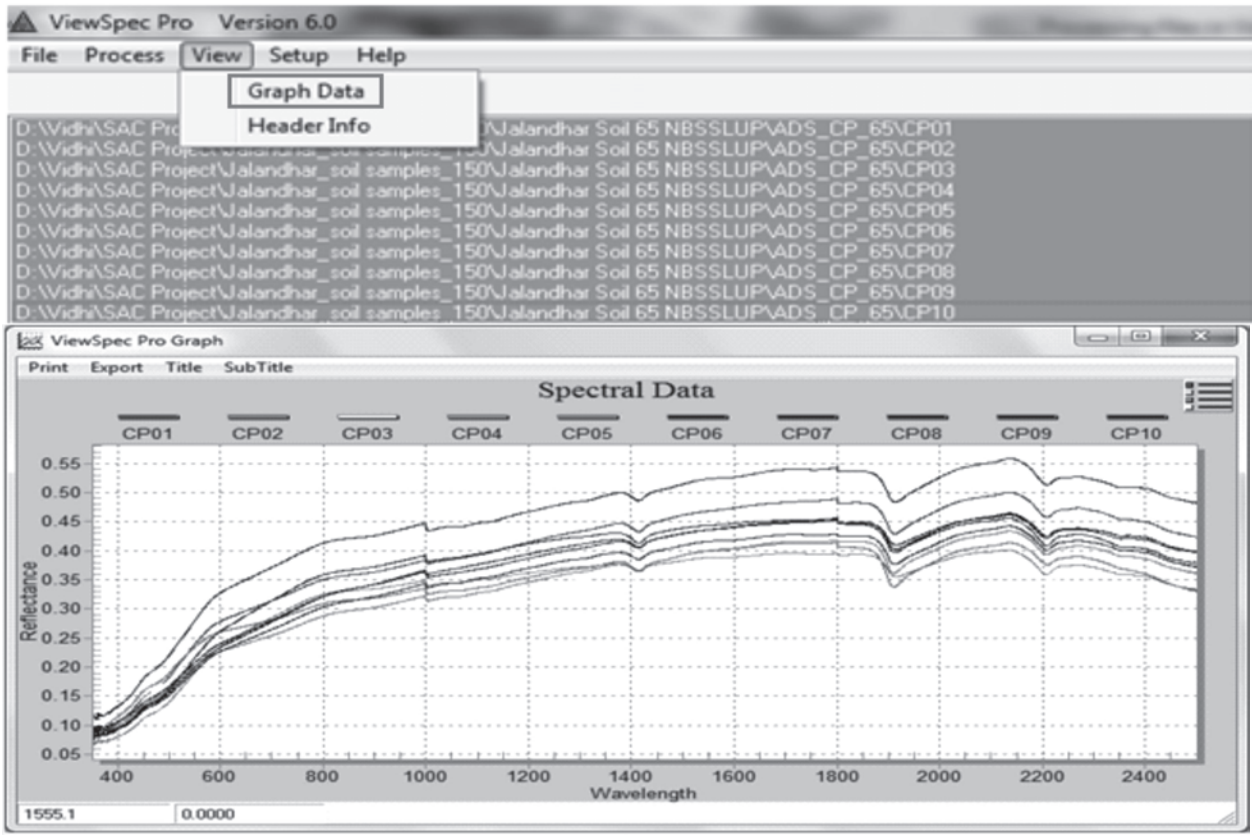


Figure 22. Example of Graph generated for spectral data

3.2. Log 1/R (1/T):

Converts reflectance or transmittance to absorbance.

Absorbance = log (1/Transmittance)

A commonly used math pretreatment, useful for linearizing reflectance data. This expression is often abbreviated as log(1/R). In most cases it is possible to find a linear correlation of log(1/R) data to concentration of an analyte in the target matrix. However, a general derivation relating reflectance to concentration cannot be rigorously derived, such as, the Bouguer-Lambert-Beer law for transmittance.

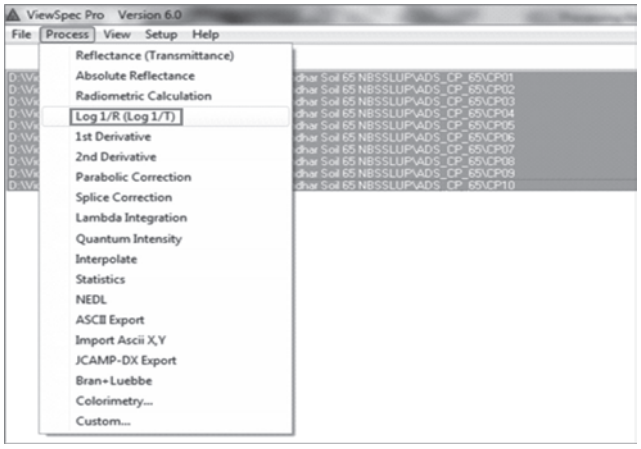


Figure 23.

3.3. 1st Derivative:

Takes the first derivative of the data. The algorithm uses a specified gap distance to skip that number of points to take the differences instead of adjacent data points.

The derivative gap dialog box is displayed wherein; the user is required to give a derivative gap for calculating the 1st derivative.

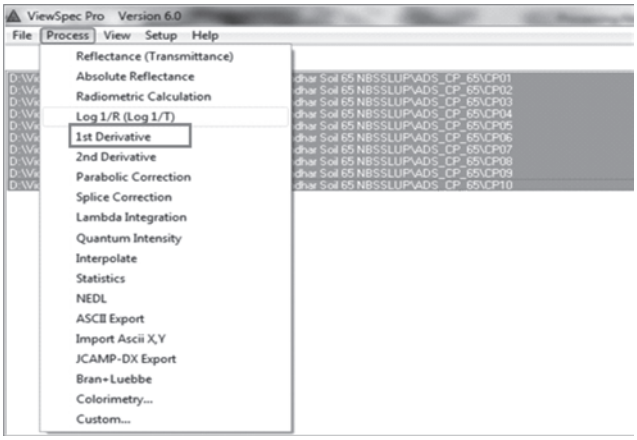


Figure 24.

3.4. 2nd Derivative:

Takes the second derivative of the data.

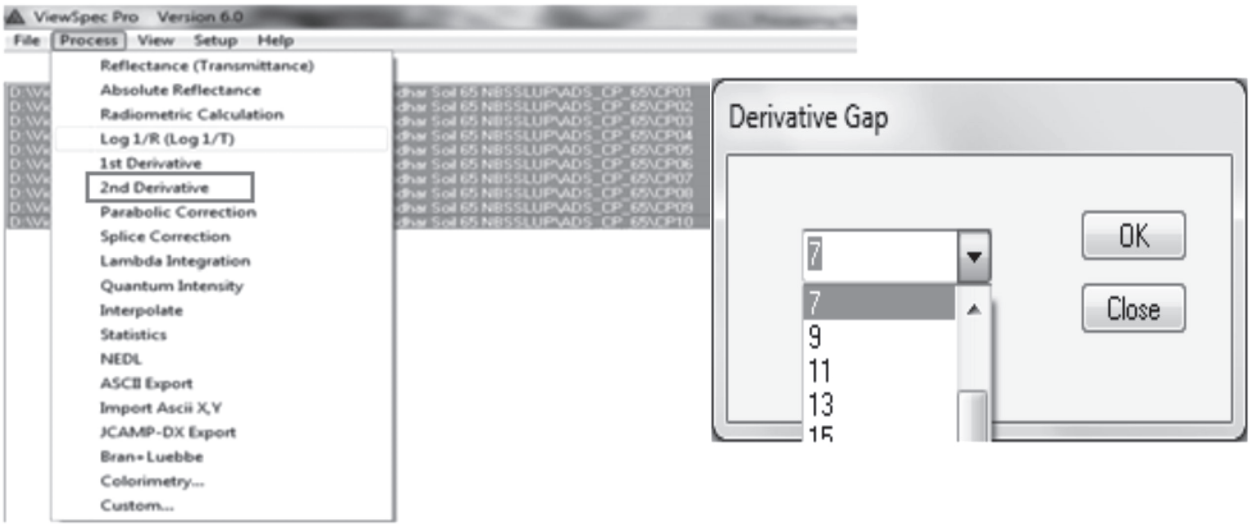


Figure 25.

3.5. Lambda Integration:

Integrates or averages wavelengths over a certain area that is set by the end user. The lambda Integration Inputs window is displayed wherein; the user determines the intervals for integration. The user is required to enter a start and end wavelength of a range and integrate or average the spectra as per application.

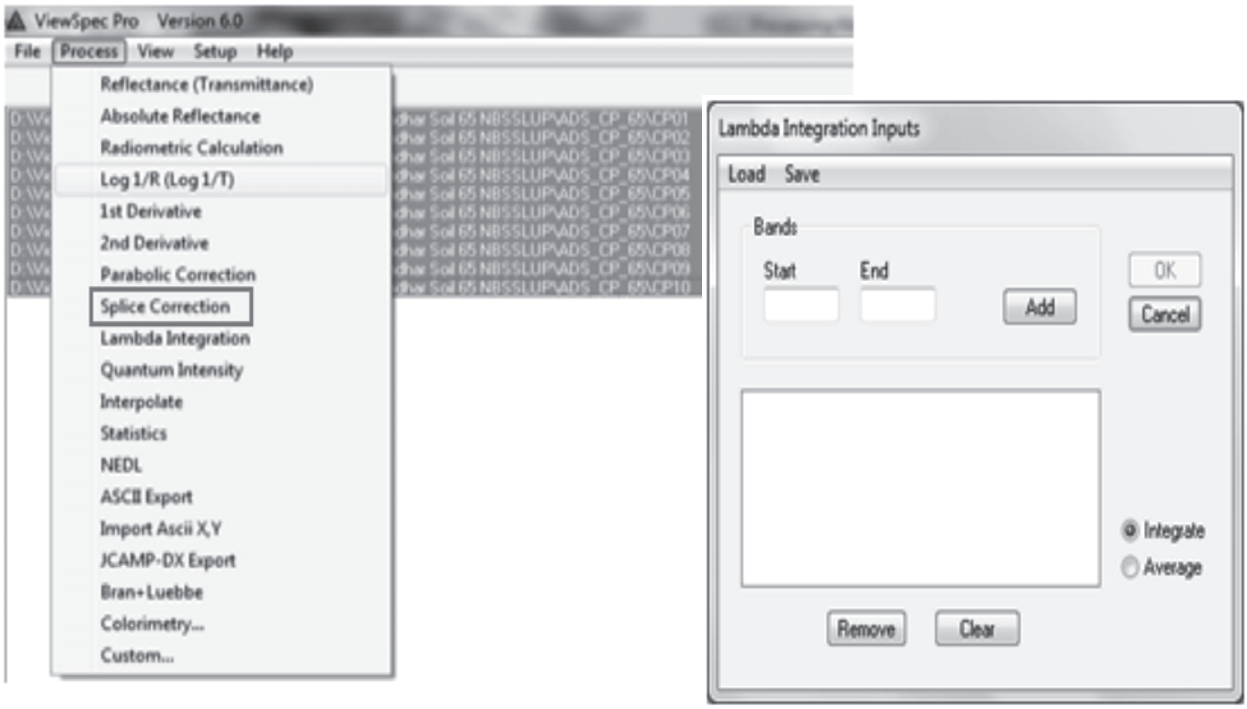


Figure 26.

3.6. Statistics:

This process applies standard statistical functions: Mean, Median and Standard Deviation to the selected files. Mean, Standard Deviation, and Median distinguishes the noise of each spectrometer. These statistical operations cannot be performed on single files.

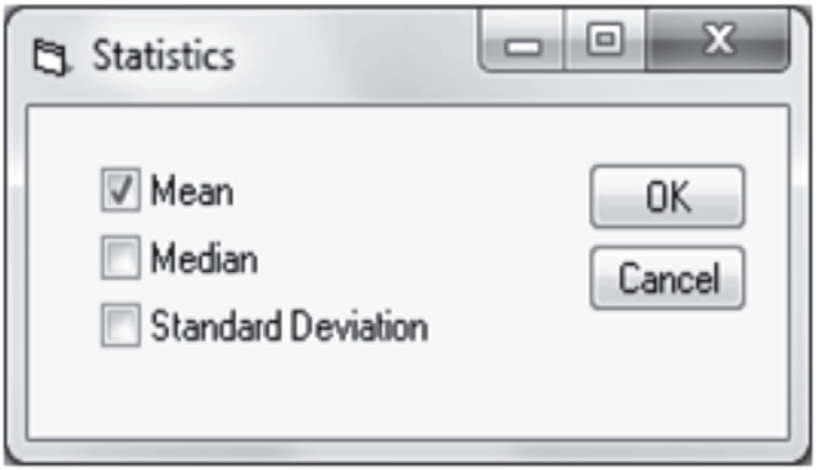


Figure 27. Statistics window

3.7. ASCII Export:

This process converts data files into ASCII text files. Files can be exported individually or similar files can be combined into an array and conveniently output as a single file. Header data can also be included with the data files or exported independently. Files exported with this utility can be imported into many analysis, spreadsheet or database programs.

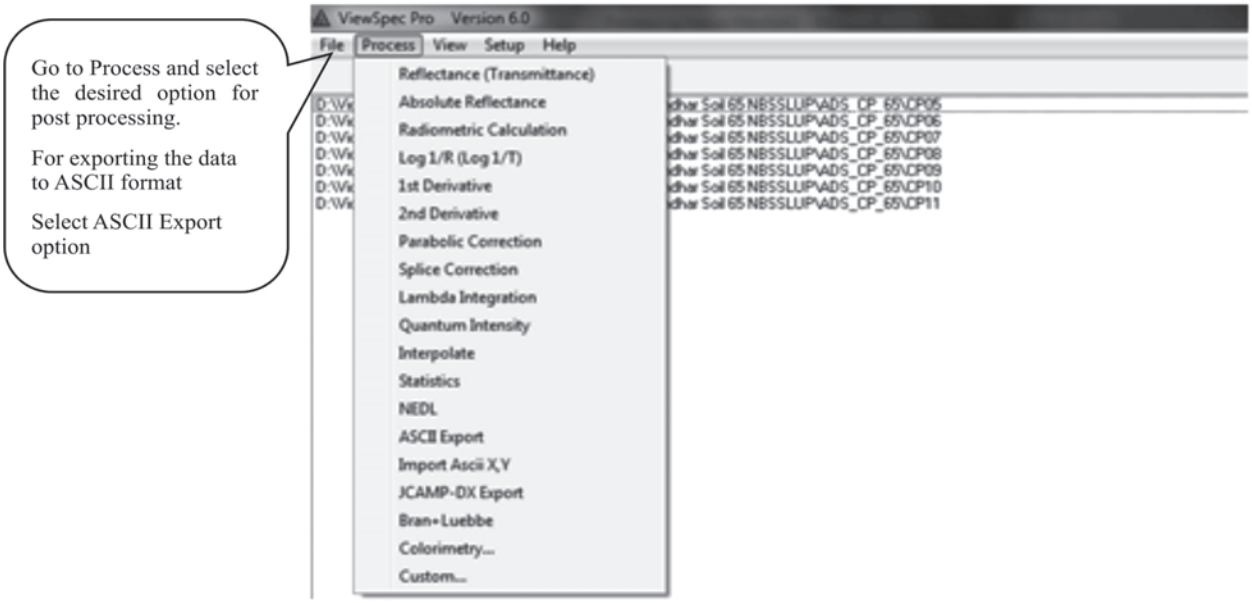


Figure 28. ASCII Export

When ASCII Export is selected, the following Dialog Box is displayed:

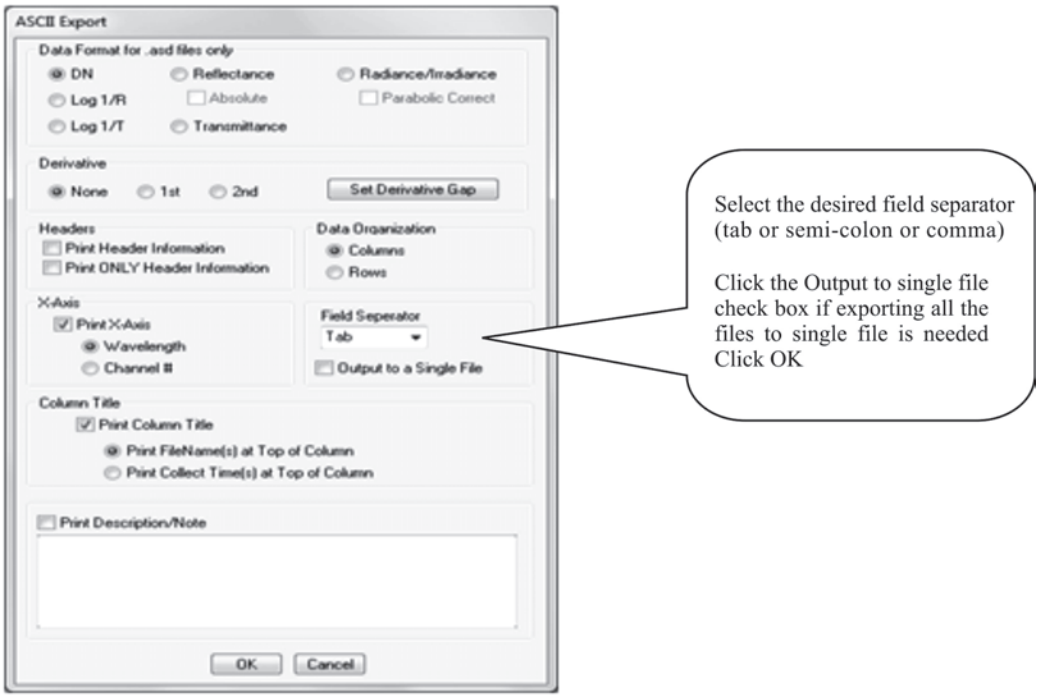


Figure 29. ASCII Export window

4. Post-processing the observed spectra using ENVI

The composition of the spectral signature taken from the spectroradiometer can be identified using pure spectra of the probable constituents of the composition. Methodology adopted for identification of unknown combination of spectral signatures through spectral analysis using Spectral Angle Mapper (SAM), Spectral Feature Fitting (SFF) and Binary Encoding (BE) is as shown below in figure 30.

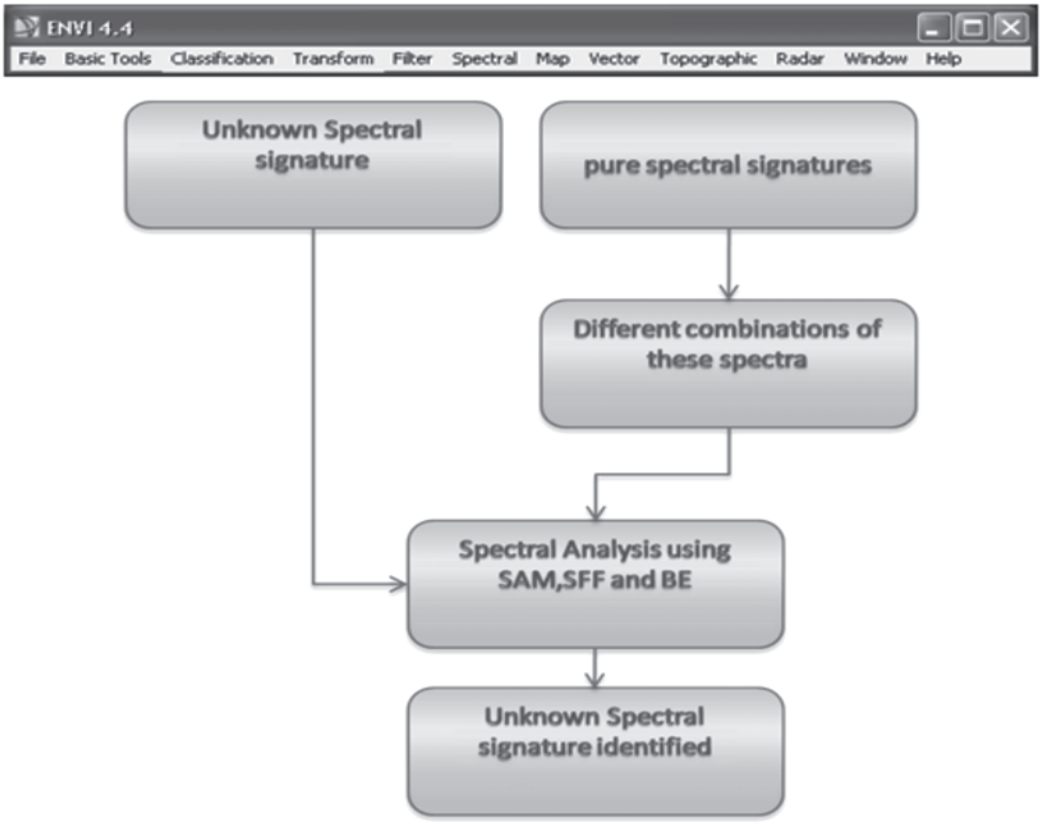


Figure 30.

The mixing of pure spectra of different features is done at an interval of 5% i.e. spectral mixture of 0%A with 100%B, 5%A with 95%B ….100%A with 0%B. Where A is Target and B is pure spectra of different materials.

Now the unknown spectra is compared and analyzed with the above mentioned spectral mixtures using Spectral angle Mapper (SAM) method, Spectral Feature Fitting (SFF) method and the Binary Encoding method.

4.1. Building Spectral Library

Use the Spectral Library Builder to create ENVI spectral libraries from a variety of spectra sources, including ASCII files, spectral files produced by ASD spectrometers, other spectral libraries, ROI and spectral profiles and plots. The procedure for building spectral library from ASCII files is described below;

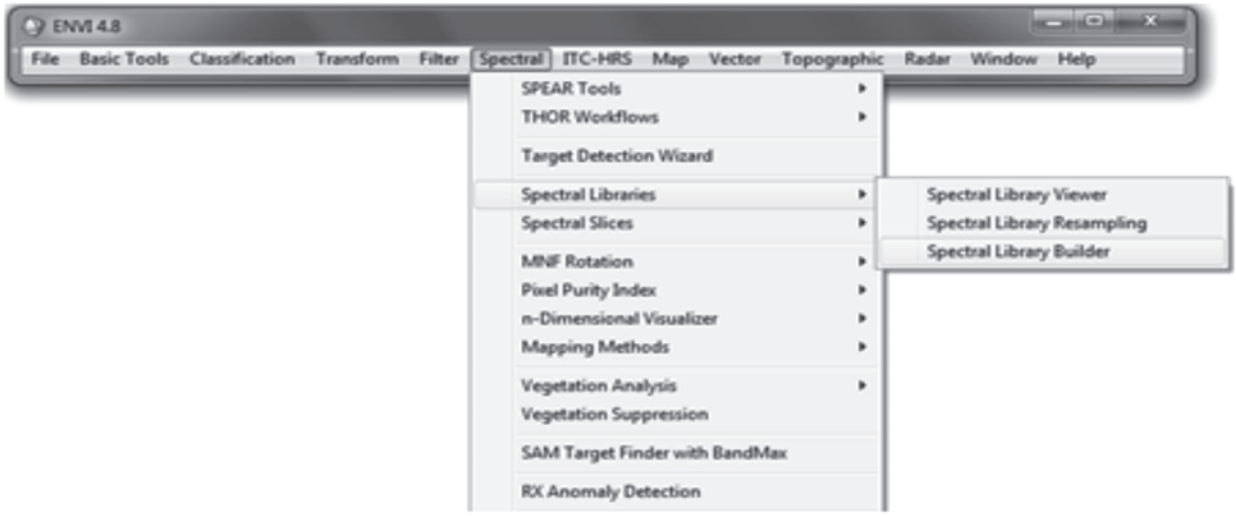


Figure 31.

The Spectral library Builder window opens. Choose the ASCII file option to give ascii data file as input.

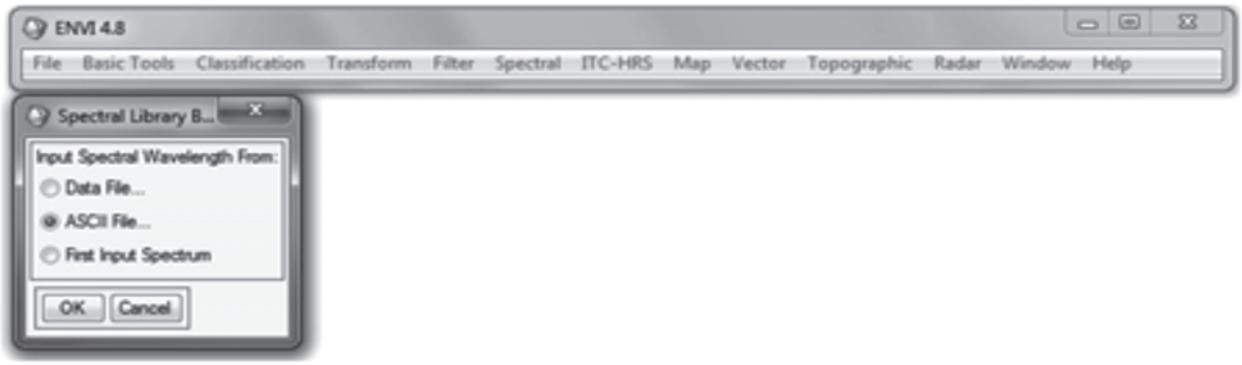


Figure 32.

A new window opens asking for the file containing the output wavelength region across which you want to build the library. Choose the ascii file exported from ViewSpe Pro. The first column of the ASCII file is the wavelength column. Choose the ASCII file and click on Open.

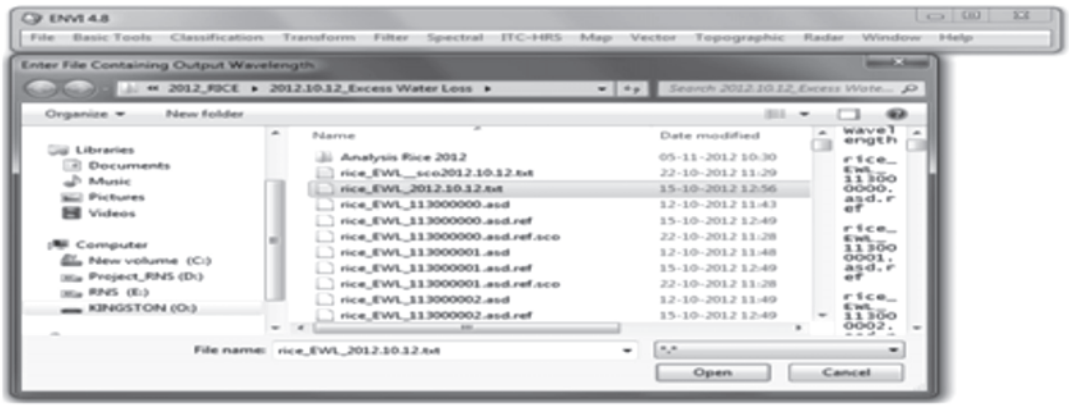


Figure 33.

The Input ASCII File window opens. Enter the Wavelength column as '1'. Wavelength units as 'nanometers' and y scale factor as '1.0000'. Click OK

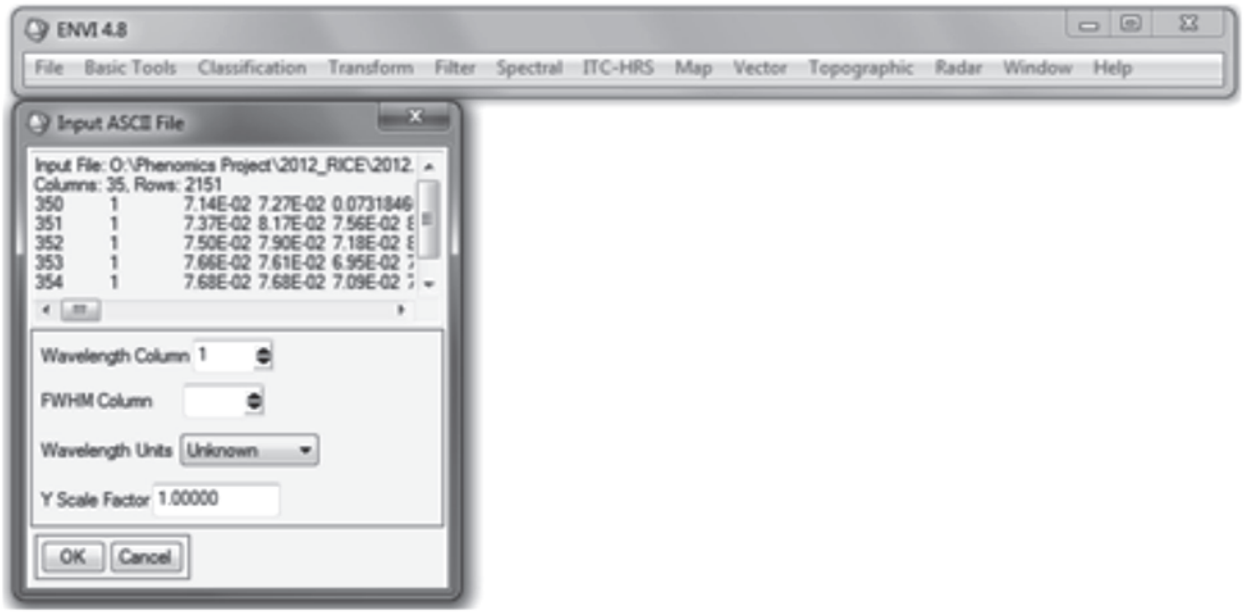


Figure 34.

The Spectral Library Builder window opens. Click on Importà from ASCII file

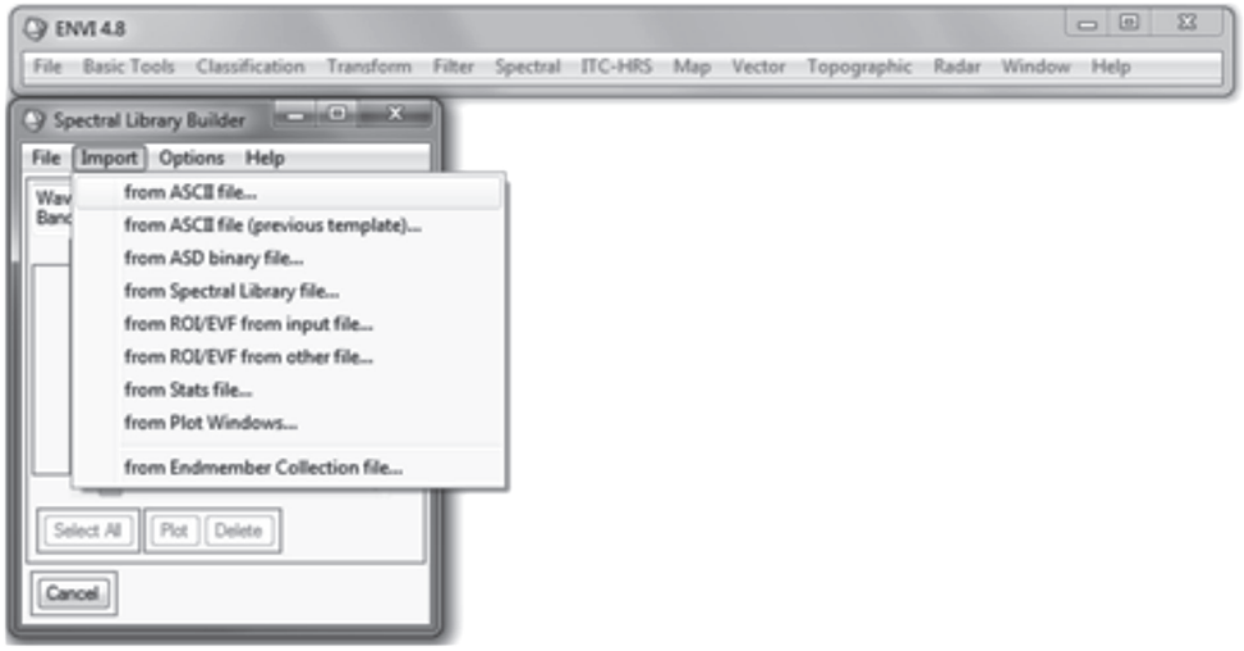


Figure 35.

Select the ASCII file again and click **open**. Import the file and you will see in the Spectral Library builder window a number of files are listed. These are the individual spectra of different plant varieties. You can select individual spectra and click on **Plot.** You can also

plot all the spectral profiles in the same window as well by selecting all the spectra and click on Plot. The spectra will be displayed as shown in the figure 36.

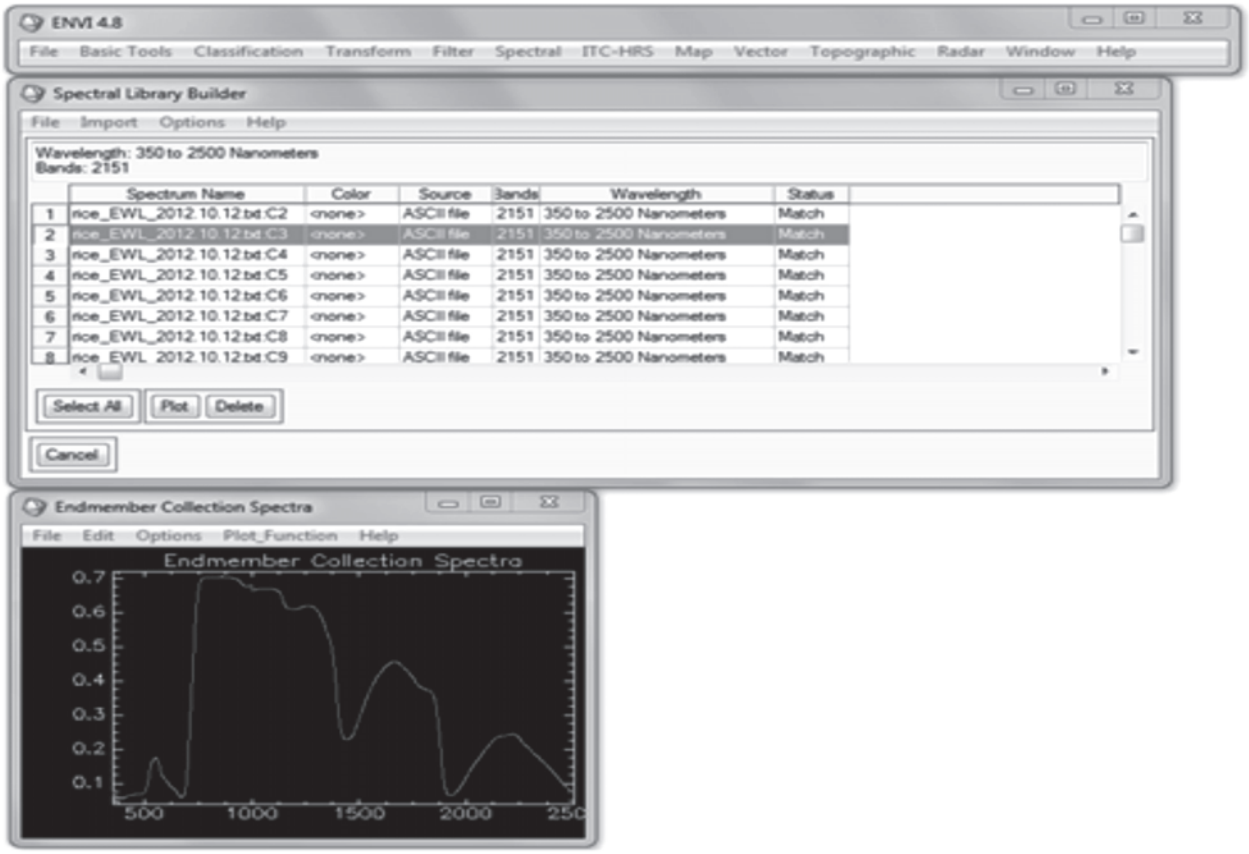


Figure 36.

Under the **options menu**, there are options for importing spectrum names for all the spectra from a different ascii file or you can rename them individually. Under the **File** menu, there is option for saving the spectra as Spectral Library file.

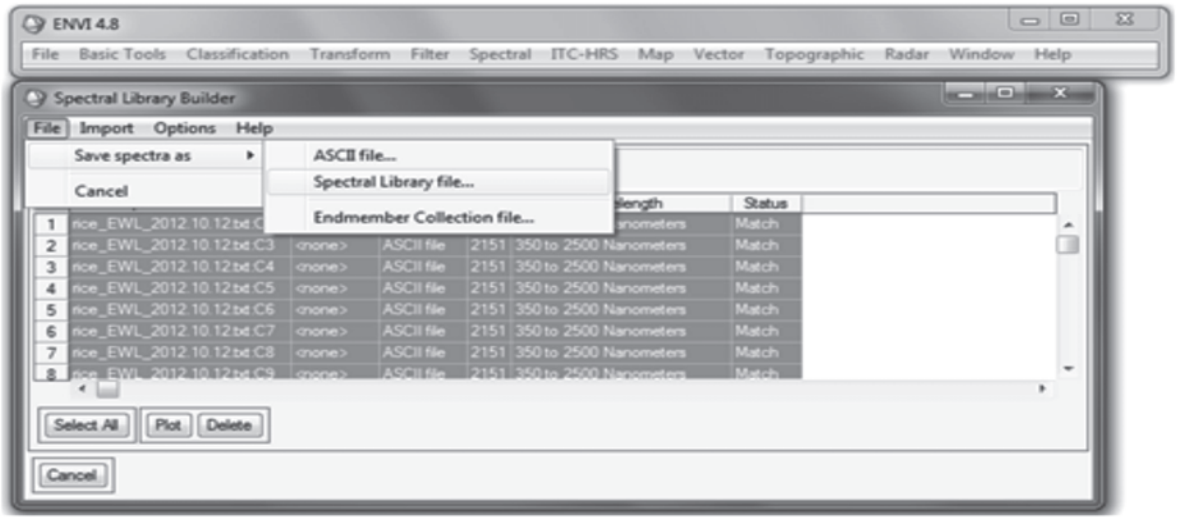


Figure 37.

The **Output spectral library** window opens. Enter the required information and then enter the output file name and click **OK.** The spectral library is created and can be viewed from Spectralà Spectral Librariesà Spectral LibraryViewer.

4.2 Procedure for Spectral mixing

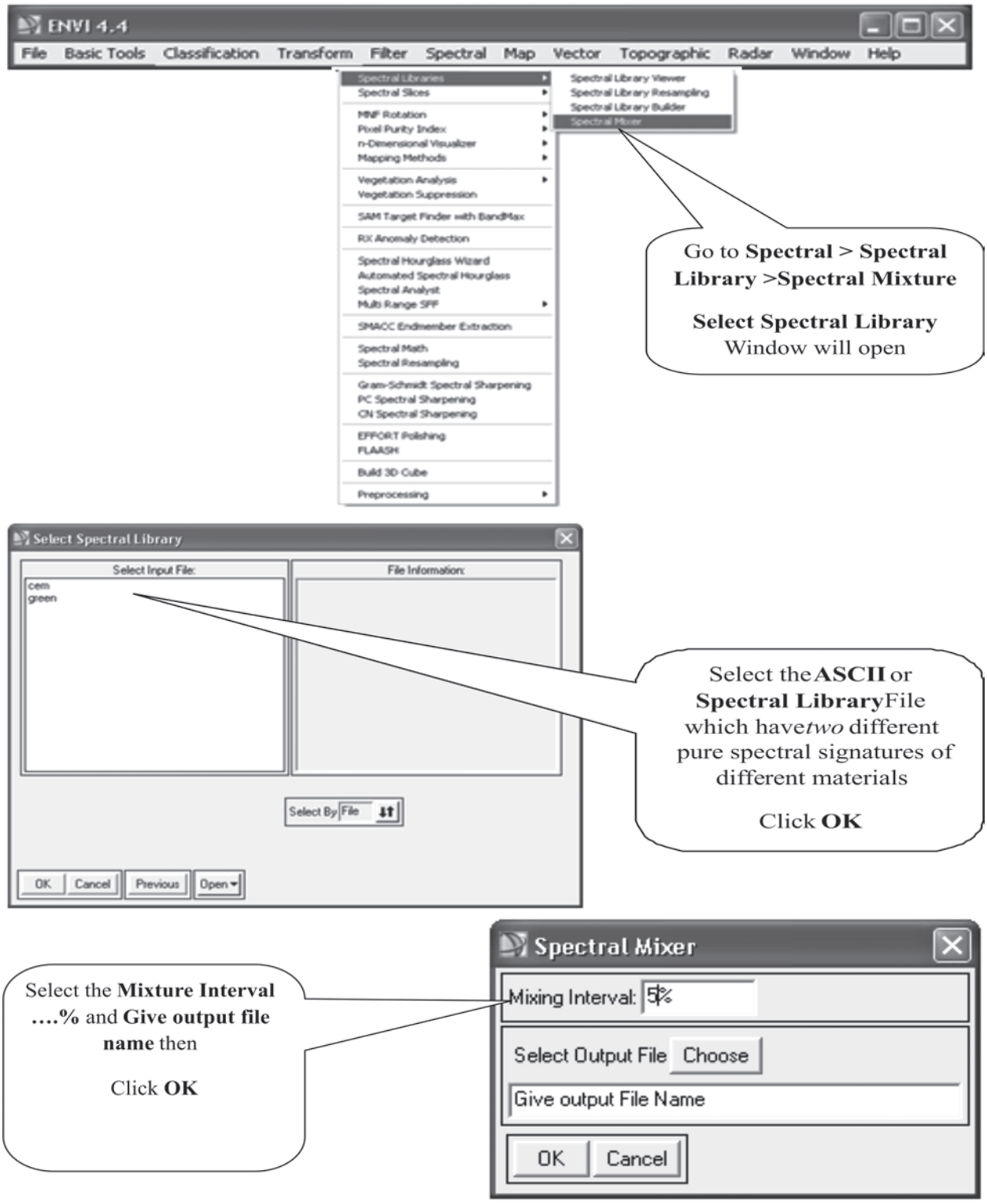


Figure 38.

For viewing the saved Spectral mixture Go to **Spectral > Spectral Libraries > Spectral Library Viewer**

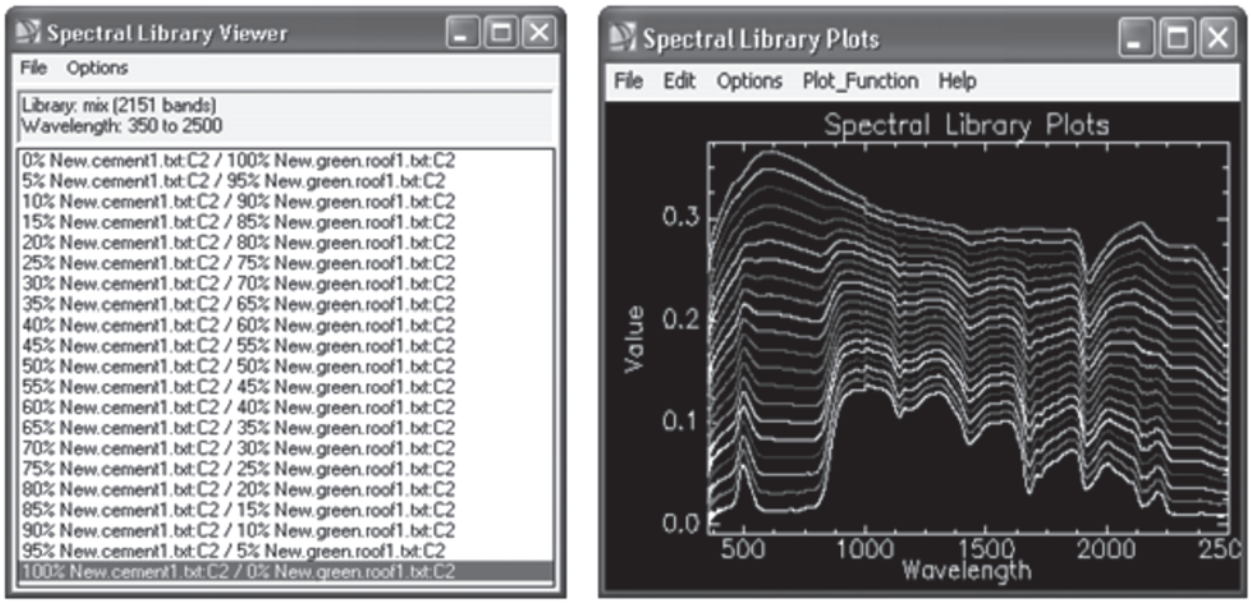


Figure 39.

4.3 Spectral Analyst

For identification of the composition of the observed spectra with pure spectra of the library go to **Spectral > Spectral Analyst.** Before going for Spectral Analyst open your observed data in spectral library viewer and follow the procedure –

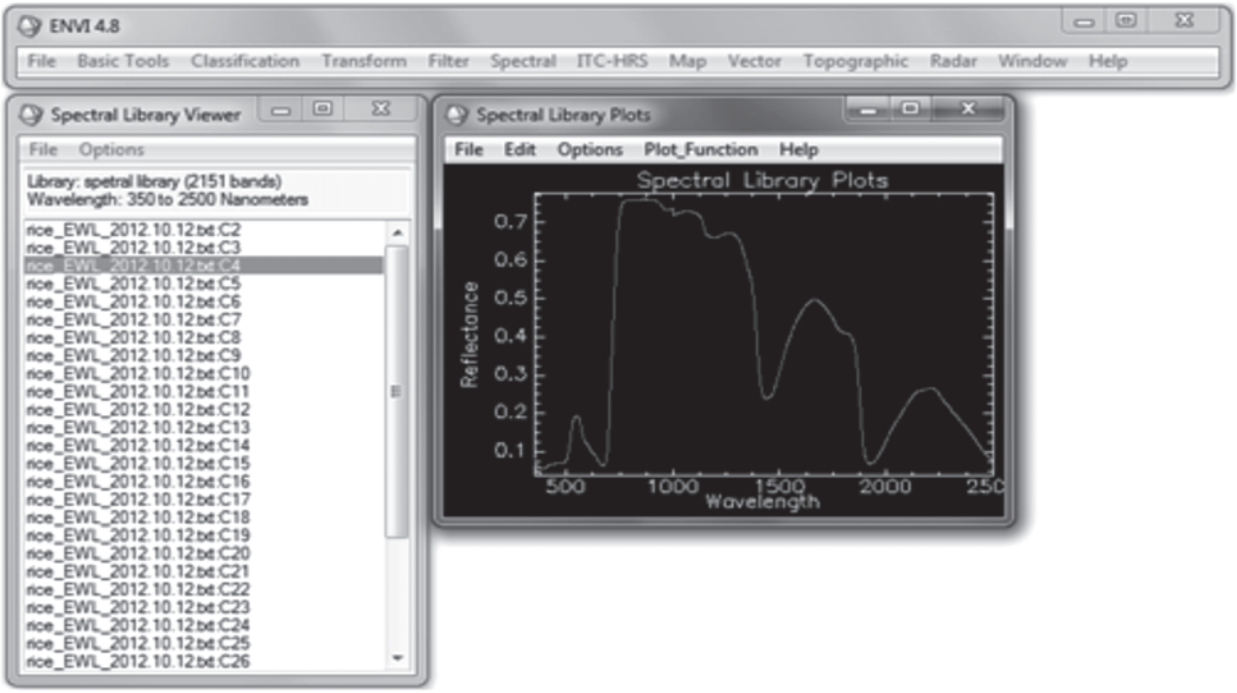


Figure 40.

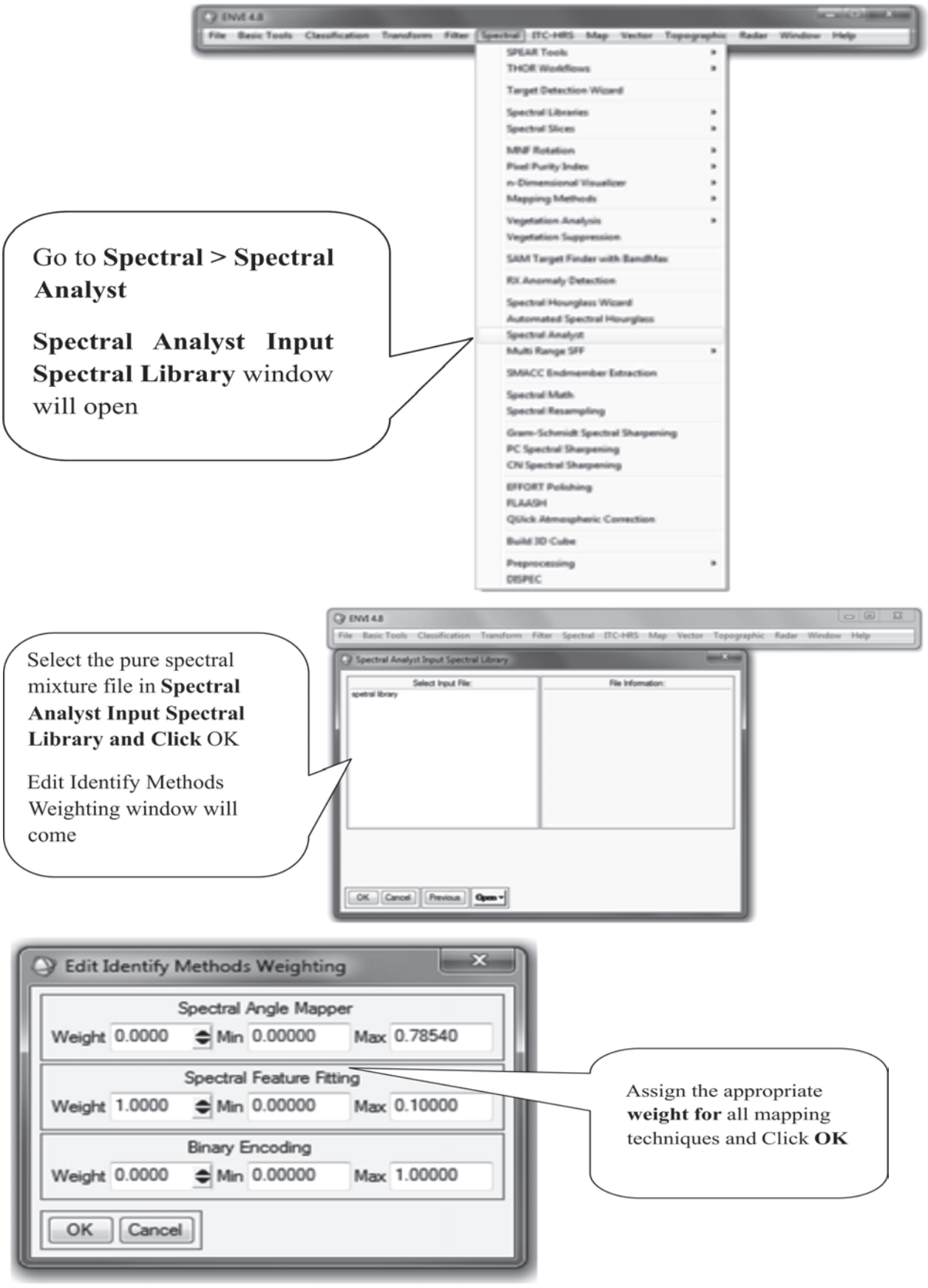

Go to **Spectral > Spectral Analyst**
Spectral Analyst Input Spectral Library window will open
Select the pure spectral mixture file in **Spectral Analyst Input Spectral Library and Click** OK
Edit Identify Methods Weighting window will come
Assign the appropriate **weight for** all mapping techniques and Click **OK**
Edit Identify Methods Weighting
Spectral Angle Mapper
Weight 0.0000 Min 0.00000 Max 0.78540
Spectral Feature Fitting
Weight 1.0000 Min 0.00000 Max 0.10000
Binary Encoding
Weight 0.0000 Min 0.00000 Max 1.00000
OK
Cancel

Figure 41.

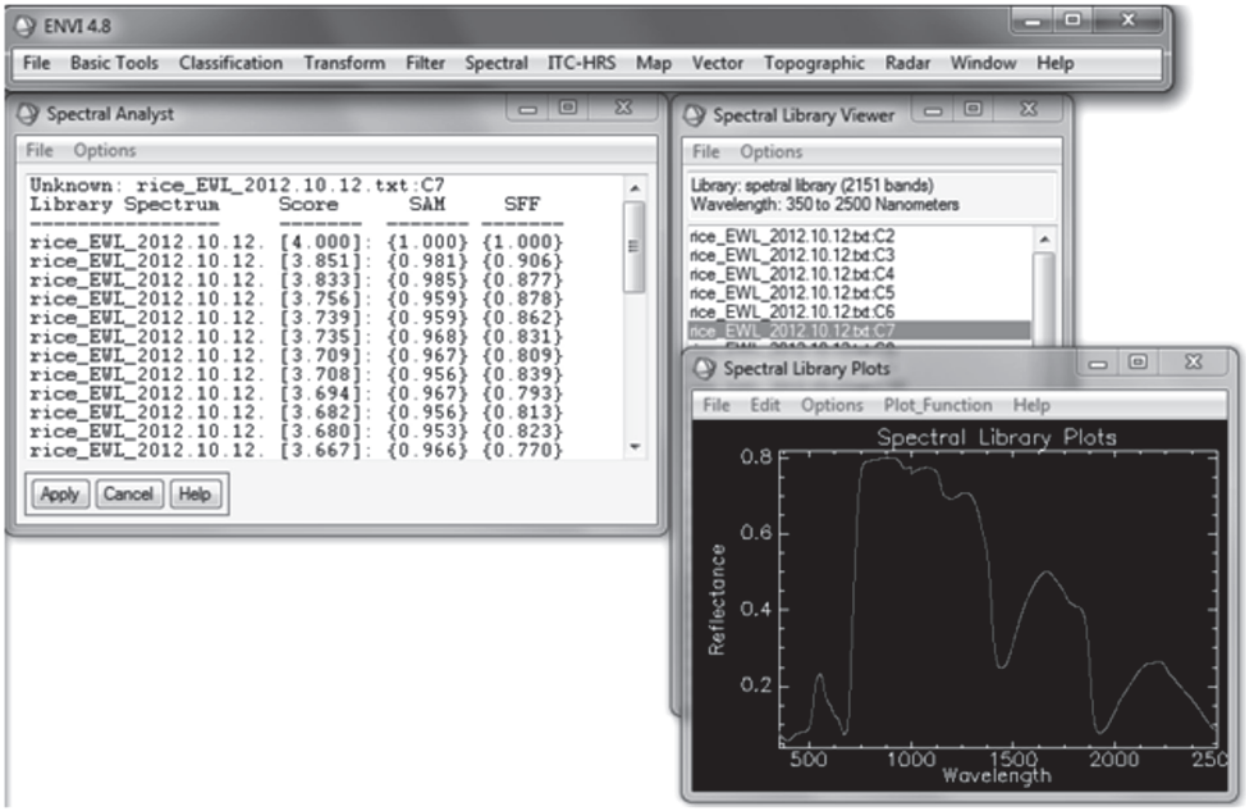


Figure 42. Spectral Analyst Window

The analysis is done on the basis of score derived from these three methods. The score ranges from 0 to 1. Higher is the score nearer is the composition of unknown spectra to the known mixture. On spectral analysis we can identify that the unknown spectra which has the maximum matching with the spectral mixture corresponding to the highest score of SAM, SFF and BE method. A spectral library can be prepared using spectral database collected from field as well as lab which can further be used to identify the composition of any unknown spectra. But there is a limitation with this database is that it will be able to identify only limited no. of samples, otherwise it will result to wrong interpretation.

Chapter

2

Fourier transform Infrared (FTIR) Spectroradiometer

Fourier Transform Infrared spectroscopy is a technique which is used to obtain an infrared spectrum of absorption, emission from a solid, liquid or gas. The term Fourier transform infrared spectroscopy originates from the fact that a Fourier (a mathematical algorithm) is required to convert the raw data into the actual spectrum. The Hand Portable FT-IR spectrometer manufactured by D&P instruments is a hand portable, remote sensing field and industrial instrument designed for field measurement of spectral radiance from the Earth's surface and atmosphere in the 3–5-μm and 8–14-μm atmospheric windows, with a 6-cm21 spectral resolution [3]. The instrument is packaged in a small case as shown in figure 36. Portable spectrometers were originally developed for the battlefield detection of chemical agents. These instruments have also been used to monitor atmospheric composition, particularly pollution. Small FTIR spectrometers have also been developed as spaceborne instruments. The use of spectrometers in space has, in turn, spurred a need for measurements of radiance from the ground, i.e., the so-called ground-truth measurements, to verify calibration, provide atmospheric correction data, and to measure the emissivity of terrestrial surface materials that cannot be measured in the laboratory.

1. Features & Specifications

- Thermally Stabilized Interferometer
- Embedded Pentium® PC Computer
- USB, Ethernet, and VGA ports
- Calibrated Output with Optional Thermally Stabilized Blackbody
- "Through-the-Lens" Viewing of Targets
- High Sensitivity and Throughput
- Full sun readable LCD screen
- Real-Time On-Screen Spectra and Math Processing
- Runs on compact battery, 12 volt, or worldwide universal AC supply.

The Specifications of the field portable FT-IR Spectrometer are given in Table 2.

Figure 43.

Table 2. Specifications of Hand Portable FT-IR Spectrometer

Item	Paramter	Value	Units	Comments
1	Spectral Range	2 - 16	micrometers	Standard IR
2	Spectral Resolution (FWHH)	4	wavenumbers	@ 2 μm, Standard, 1 sec. scan
3	Size (WxDxH)	36x20x23	centimeters	(14"x8"x9")
4	Weight	< 7	kilograms	(<15 pounds)

1.1. Standard Equipment

- Optical/Electronic module, including interferometer, drive & sampling electronics, embedded Pentium® PC computer, WinFT™ processing software running on Windows XP™, USB, Ethernet, VGA, parallel and serial connections
- Liquid nitrogen (LN2) cooled dual InSb/MCT detector and preamp (2-16 μm)
- 1" Ø, 4.8° field-of-view (FOV) and 2", 2.4° FOV fore-optics with through-the-lens viewing
- AC supply and dual battery charger
- 12 volt, 7 A-hr battery pack
- Thermoelectrically stabilized blackbody (1" or 2" diameter)
- Diffuse gold plate for down-welling radiance measurements
- Pouring dewar, tripod

2. Working Principle and Operational Considerations

2.1. Michelson interferometer

The core of the spectrometer is the Michelson interferometer. This contains infrared optics, beam splitter, and a scanning mirror assembly. The high-throughput advantage of the Michelson interferometer spectrometer resulted in the compact and lightweight development of the D&P FTIR spectroradiometer. Figure 44 shows the gives the outer and crossectional view of the Michelson interferometer used inside this spectrometer.

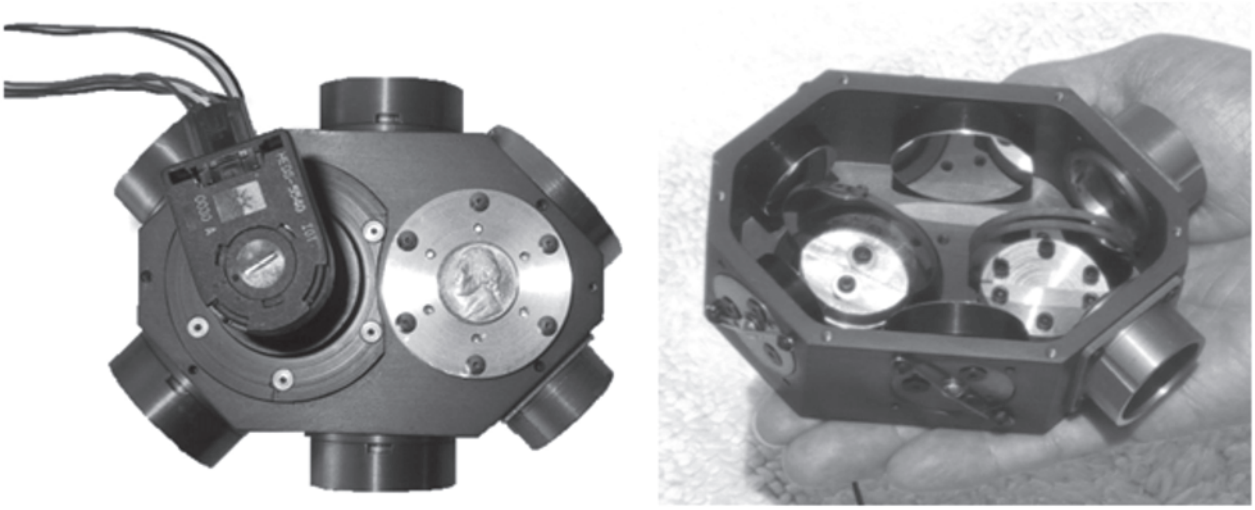


Figure 44.

Input light passes through the fore optics, an aperture, and a lens (which also seals the unit) into the interferometer. The internal mirrors are servo driven at a constant speed, producing the interference patterns. The output light passes through a focusing lens (which also seals the unit) onto an infrared detector in a liquid nitrogen (LN2) dewar. The standard detector is a dual sandwich type, consisting of Indium Antimonide (InSb) over Mercury Cadmium Telluride (HgCdTe, or MCT). This detector has a spectral range of approximately 2 to 16 micrometers. This must be filled with liquid nitrogen before use. A temperature controlled laser diode (LD) provides the reference for the servo and sampling electronics, and wavelength calibration for the spectrum. Figure 45 shows a schematic of the FTIR and its accessories.

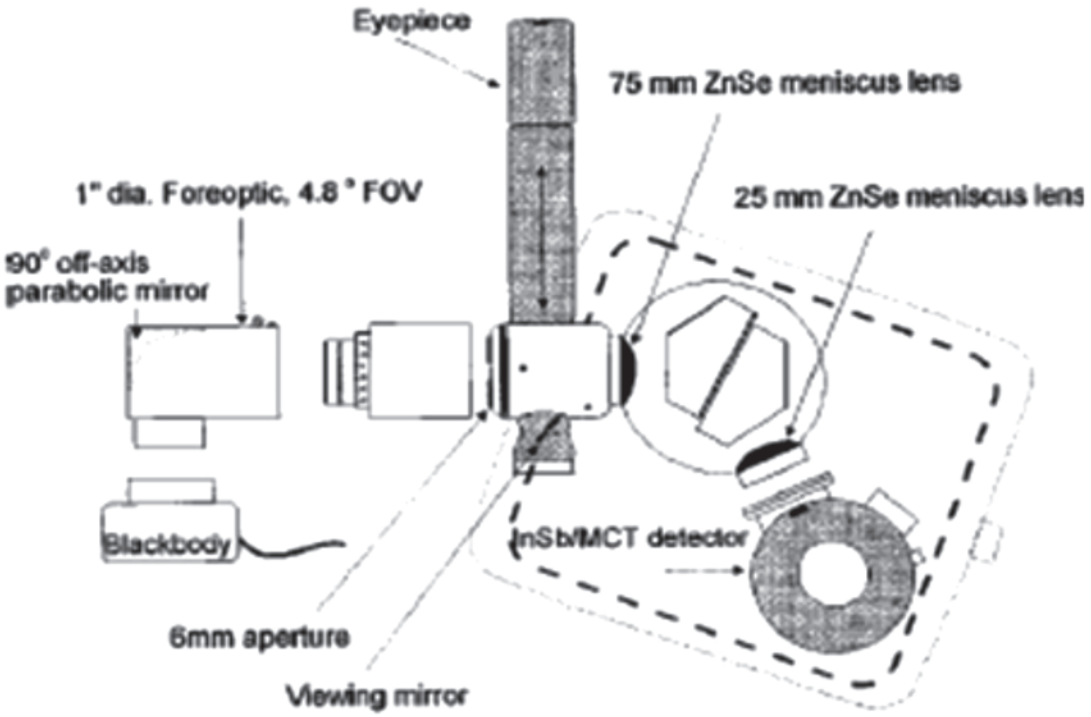


Figure 45.

2.2. Operational Considerations

Removal of environmental factors such as reflected downwelling atmospheric and background radiance from the measured signal are of paramount importance. Proper separation of temperature and spectral emissivity is also a key factor in obtaining spectra of accurate shape and magnitude. The environmental conditions, under which one is collecting spectra, the time of day, and the target's thermodynamic properties, will all have a profound influence on the quality of the collected data.

For the reasons stated above it is imperative that an organization that routinely collects spectral ground truth data in the field has a protocol to follow that will allow investigators to produce a spectral library of consistent and repeatable quality. A few of the considerations are listed below;

2.2.1. Instrument Considerations

- **Warm-up** - If possible, let the instrument run for as long as possible, prior to making measurements. This "warm-up" period allows ample time for the instrument components within the enclosure to come to thermal equilibrium.
- An instrument should be controlled to within 0.1°C between calibration and actual target measurements.
- **Black Body** - A blackbody calibration should be conducted for every target measured, or at least every 10 minutes, to reduce the effect of instrument temperature drift.
  - ✓ In general the **cold blackbody** should be set just below ambient (being careful that condensation does not form on its surface).
  - ✓ The **warm blackbody** should be set just above the sample temperature anticipated.
- **Field of View -** Be sure to overfill the field-of-view of the device. Samples should be measured at a distance of no more than 1 meter if possible to minimize the effects of atmosphere.
- **Downwelling radiance** should always be measured immediately following the sample measurement by collecting the reflected radiance off of a diffuse reflective plate, usually InfraGold or crinkled aluminum foil.
  - ✓ Orientation should be the same as the target/sample
  - ✓ Direct solar reflection should be avoided (no surface is truly diffuse)
- **Time of Measurement -** Measurements are best made in the early morning or late afternoon to avoid the rising thermal currents at the hottest point of the day.
- Instrument and operator must not cast a shadow on the sample
- Any contributing background source must not move or change during the sample and downwelling scans
  - ✓ Operator, other people in the scene
  - ✓ Vehicles, other movable objects
  - ✓ Clouds, atmospheric conditions

2.2.2. Target / Sample Considerations

- Is the target uniform in composition and makeup?
  - ✓ Color
  - ✓ Consider why you are collecting the spectra
  - ✓ Compositional elements compared to ground and aircraft sensor FOV
  - ✓ Individual components may have distinct spectral signatures
- Is the surface multi-faceted?
  - ✓ Trees, vegetation
  - ✓ Soil/gravel surface
- Is the surface rough or smooth relative to the frequency that measurements are being made at?

- ✓ Painted steel/rusted steel

- Can the background be seen through the target?
  - ✓ Transparency
  - ✓ Porosity
- Will the sample change temperature during scans?
  - ✓ Thermal inertia

3. Software Operation and Spectral Data Collection

The FTIR software WIN^{FT} runs on Windows XP platform. All the functions can be easily accessed by the keyboard, however a USB mouse is also provided to make the operation quicker. The main menu items are across the top of the screen, and are accessed using the mouse or using the <Alt> key and the first (underlined) letter of the title,. They are:

File **Instrument** **Display** **Process** **Help**

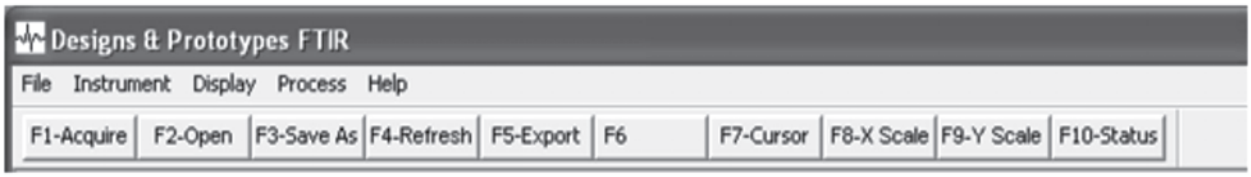


Figure 46. WinFT Menu Bar

There are also 10 function keys assigned for the most commonly used repetitive operations. Their functions are listed in a row of boxes located just below the main menu titles at the top of the screen. Either the function key or mouse click on the box activates them. The Function key assignments are:

F1-Acquire	F2-Open	F3-Save As	F4-Refresh	F5-Export
F6- TBD	F7-Cursor	F8-X scale	F9-Y scale	F10-Status
<alt>F9-Disable Temp Alarm		<Alt>F10-Factory Setup		

There are quite a few file types used in the software. Raw binary data is saved in one of six types of files, with distinct extensions. They are:

- Setup File (.INI) used to store instrument setup
- Sample (.SAM) used in all types of processing
- Reference (.REF) used in ratio, difference, absorbance processing
- Cold Blackbody (.CBB) used in radiance and emissivity processing
- Warm Blackbody (.WBB) used in radiance and emissivity processing
- Downwelling Radiance (.DWR) used in emissivity processing

3.1. File Menu

The File menu has 9 items in its submenu, selected by mouse, arrow key, or underlined letter. They are:

Open	Save As	Save Settings	Data File Name and Directory		
AutoName	Reverse Video	Auto Calibrate	A-to-D	Print	Exit

3.2. Instrument Menu

The Instrument menu has 5 items in its submenu, selected by mouse, arrow key, or underlined letter. They are:

Coadds	Resolution	Zero Fill	FFT Apodization	Temperatures

Coadds: sets the number of spectra to be averaged

Resolution: is used to specify the size of the FFT performed, and thus the resolution of the resulting spectrum. The number of points collected is not changed, and all interferogram data is stored in the raw data file, so any spectrum can be reprocessed later at a different resolution.

Zero Fill: is used to generate higher plot resolution at any spectral resolution.

- **None** no zero filling
- **2X** interferogram filled out with two times the number of points
- **4X** interferogram filled out with four times the number of points
- **8X** interferogram filled out with eight times the number of points

FFT Apodization: sets the weighting function to be used to window the interferogram data before performing the FFT.

Temperatures: is where all instrument and blackbody temperatures are set and their respective controllers can be turned on and off manually.

3.3. Display Menu

The Display menu has 3 items in its submenu, selected by mouse, arrow key or underlined letter. They are:

Plot Type	Display Units	Plot Scales

Plot Type specifies what type of display to use for data. The choices are:

- **Interferogram** displays the interferogram full screen in one window
- **Spectrum** displays the spectrum full screen in one window
- **Both** displays the interferogram in one window at the top of the screen, and the spectrum in a separate window at the bottom of the screen.

Display Units is used to set the X and Y axis units for all displays. There are three choices for the X units:

- **Micrometers** The X scale is displayed and exported in micrometers (um)
- **Nanometers** The X scale is displayed and exported in nanometers (nm)

- **Wavenumbers** The X scale is displayed and exported in wavenumbers (cm-1)

Display Scales is used to set the display limits for interferogram and spectral plots. When this item is activated, a dialog box appears to select Spectrum or Interferogram scales to set. When displaying a plot, the F9 function key can be used to toggle between Y-axis auto scaling and the manual limits set here.

3.4. Process Menu

The Process menu normally has 1 item in its submenu, selected by mouse, arrow key, or underlined letter. If Radiance or Emissivity math is selected, a second item to calibrate a sample appears. Once a sample has been calibrated, a third item to fit a Planck function to a calibrated radiance appears. If a Planck function has been fitted to a calibrated radiance, a fourth menu item appears to remove the Planck function. The four functions are:

Math Calibrate Instrument Fit Planck to Radiance Remove Planck Plot

Math is used to set which math, if any, is to be done on acquired or restored data files. The choice of Math function also determines what types of data will be acquired or restored when any of those functions are used. When the Math item is selected, a dialog box appears with a choice of none, or six different math operations. They are:

• **None**		no math performed, raw data displayed
• **Ratio**	Sam/Ref	the Sample file is divided by the Reference file
• **Difference**	Sam-Ref	the Reference file is subtracted from the Sample file
• **Difference**	Ref-Sam	the Sample file is subtracted from the Reference file
• **Inverse**	1-Sam/Ref	the ratio function is subtracted from 1
• **Absorbance**	-log (Sam/Ref)	the logarithm of the ratio is calculated and negated
• **Radiance**	f (cbb,wbb,sam)	calibrated Radiance in (Watts/(m2*microns*sr))
• **Emissivity**	f (cbb,wbb,dwr,sam)	a calibrated radiance is corrected for sky reflected energy and divided by a Planck at the estimated sample temperature

Calibrate Instrument appears under the Process menu if either Radiance or Emissivity is chosen as the Math function. This operation requires two blackbody data files (a Cold and a Warm) to be acquired or restored. The calibration function generates a slope and offset correction at each wavelength, which is then used to take out the instrument function when displaying sample Radiance or Emissivity. The units of Radiance will be in [Watts/m2*um*sr]. Selecting this menu item brings up a submenu with three choices:

Acquire Data and Calibrate	to acquire new BB data
Open BB Files and Calibrate	to restore previously acquired BB data
Calibrate Now with Open Data Files	to use current data in memory

Selecting the first option, Acquire Data and Calibrate, will open a dialog box for the Autocalibrate function. From this screen, the instrument's blackbody can be controlled, data acquired, and instrument calibration performed.

3.5. Function Keys

The function keys are linked to frequently used operations. There are 10 function key assignments listed across the top of the screen, just below the menu bar. Their assignments are:

- **F1-Acquire** starts the acquisition of a data set
- **F2-Open** brings up the File Dialog box to open a file (same as menu File-Open)
- **F3-Save As** brings up the File Dialog box to save a file (same as menu File-Save As)
- **F4-Refresh** used to refresh the screen after making changes
- **F5-Export** used to start the ASCII File export process
- **F6-** TBD
- **F7-Cursor** puts a cursor on interferogram or spectral plots
- **F8-X Scale** toggles the X scale between ALL X and USER X scales
- **F9-Y Scale** toggles the Y scale between AUTO Y and USER Y scales
- **F10-Status** brings up a status screen showing currently loaded files
- **<Alt>F9** turn off audible temperature alarm
- **<Alt>F10** factory setup, used to set up instrument operating parameters

3.6. Measuring Emissivity

The instrument has specialized software for the measurement of surface emissivity of targets in the field. For this, four raw data files are required; three are for calibration and one is the sample itself. Of the three calibration measurements, two are blackbodies and one is a measurement of downwelling radiance. The blackbodies are used to calibrate the target and downwelling radiances. The downwelling radiance sample is collected from a diffuse reflector placed in the field of view of the instrument. Samples are then placed in the same location as the diffuse reflector when they are measured. In this way, the reflected downwelling radiation off the target samples can be subtracted out to give the absolute emissivity. The algorithm used to compute the emissivity is given by:

es(l) = [Ls(l)-Ldwr(l)]/[B(l,Ts)-Ldwr(l)]; where

es(l)	is the surface emissivity of the sample as a function of wavelength;
Ls(l)	is the calibrated radiance of the sample;
Ldwr(l)	is the calibrated radiance of the downwelling radiance;
B(l, Ts)	is a Planck function at the sample temperature.

The downwelling radiance term must be corrected for the emissivity of the diffuse reflector and its temperature. These two parameters are prompted for as part of the data acquisition process for a downwelling radiance file. The sample temperature is derived

by fitting a Planck function to the calibrated sample radiance. Two methods are provided in the software for doing this; a manual fit or an automatic fit. When the proper Planck function is found, this is used in the computation and display of the final emissivity curve.

A step by step procedure for measuring emissivity is discussed below;

- FOUR measurements are required.
- Connect blackbody cable
- Set Math to Emissivity
- Fit blackbody onto fore-optic (twist lock)
- Set Auto-calibrate temperatures under Instrument-Temperature function (10 and 40 to start)
- Go to Process-Calibrate-Acquire Data
- Set Cold, wait for BB Temp to reach set point, then Acquire and Store Cold BB data
- Set Warm, wait for BB Temp to reach set point, then Acquire and Store Warm BB data
- Sight on diffuse gold plate
- Take a "downwelling" spectra
- Sight object to be measured
- Take a "sample" spectra

Collected dpectra of a raw quartz sample is shown in the figures below:

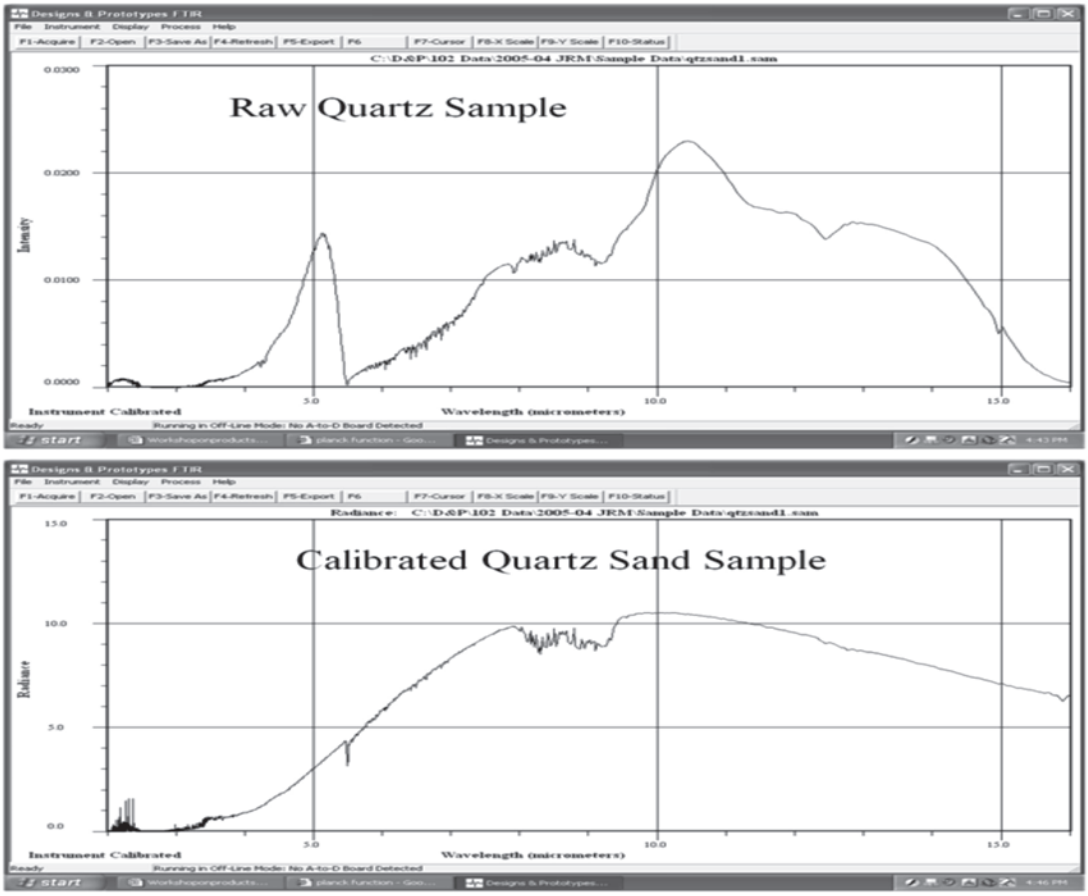


Figure 47.

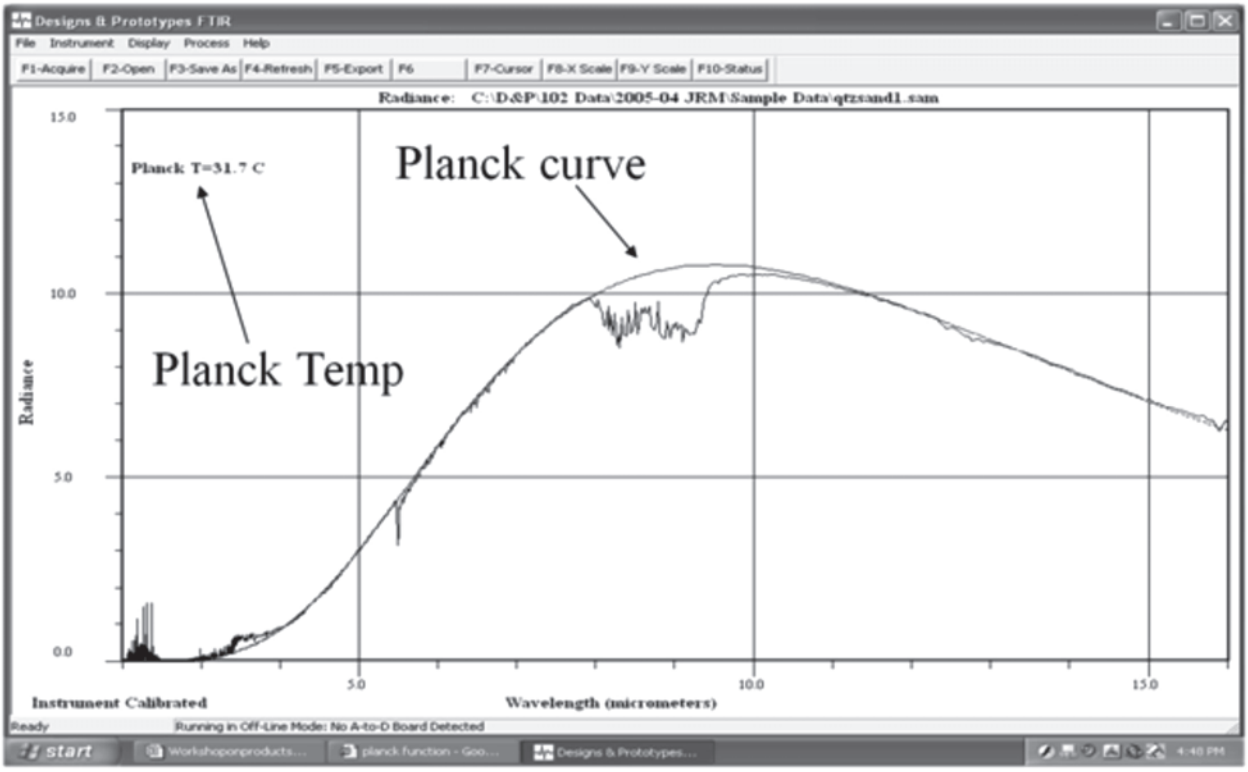


Figure 48. Calibrated Quartz Sand with Planck fit and temperature

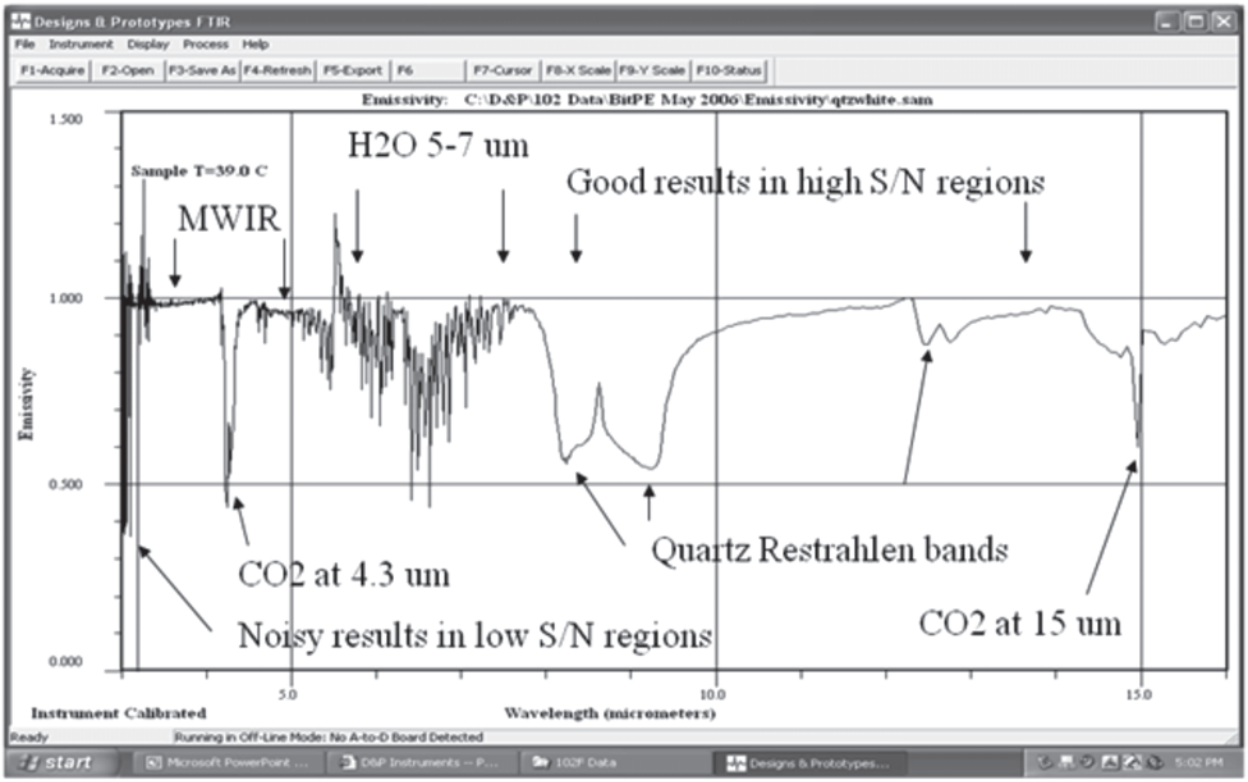


Figure 49. Quartz Sand Emissivity 2-16 microns

Chapter 3

Hyperspectral Satellite Image Processing

1. Hyperspectral Datasets

The availability and use of airborne hyperspectral data has been well studied and documented with a number of airborne sensors in operation since early eighties. With the launch of NASA's Earth Observing 1(EO-1) Hyperion instrument in the year 2000, a platform was created for exploiting the spaceborne hyperspectral imaging capabilities. Hyperion was the first hyperspectral sensor to provide a continuous spectral profile across the broad electromagnetic spectrum ranging from 400nm to 2500nm. The comparison of an airborne sensor, such as Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Hyperion datasets in terms of spectral information provide comparable results under optimum acquisition conditions viz. illumination, dark targets etc. [3]. The spatial resolution of airborne sensors (2-20 m depending upon flight altitude and sensor resolution) is however comparatively higher than that of space borne sensors (30 m in the case of Hyperion). The low spatial resolution of the hyperion sensor causes a problem of mixed pixels, a pixel which is formed when spectra of different underlying substances are combined into a mixture spectrum. In spite of the limitations on the spatial resolution there are quite a few arguments which go in favour of space borne sensors. Firstly, they allow regular and repeated coverage over wider and restricted areas. Secondly, variations and distortions arising due to aircraft motion are reduced [4].

Due to the continuous spectrum for each pixel, the high-dimensional data space generated by hyperspectral sensors poses challenges in image processing and data analysis and is quite different from multispectral processing where there are only a few discrete bands. Also the space borne hyperspectral remote sensing images are more affected by noise due to the narrow bandwidths, which can hamper the image interpretation and information extraction processes. Hyperspectral datasets are spectrally overestimated and there is a lot of redundant information present. So there is need for exploration of dimensionality reduction (DR) and end member extraction (EE) methods which can effectively reduce noise in hyperspectral datasets and aid in the spectral unmixing.

1.1 EO-1 Hyperion Sensor

Hyperion instrument onboard NASA's Earth Observation-1 (EO-1), launched on 21st November 2000 as part of NASA's New Millennium Program, is the first space borne Hyperspectral sensor for Earth Observation studies. It orbits the Earth in a sun-

synchronous orbit at an altitude of 705km. The Hyperion is a Push-broom scanner with a high spectral resolution. It has 242 spectral bands spanning a spectral range from 0.4 to 2.5 μm, with a sampling interval of 10nm. The Spatial resolution is 30m with a swath width of 7.7 km and covers an area of 7.7 × 100 square km per image with high radiometric resolution (16 bit).

The Hyperion sensor has two spectrometers operating over different spectral ranges. One operates in Visible and near Infrared region (VNIR) i.e. 0.355 μm to 1μm having 70 bands and the other operates in Shortwave Infrared region (SWIR) i.e. 0.9 to 2.5μm having 172 bands. The overlap region between the two spectrometers between 0.9 to 1μm allows for cross calibration between two spectrometers. Figure 50 shows an image of the Hyperion Sensor onboard EO-1.

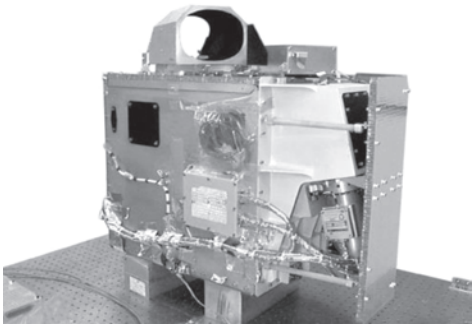


Figure 50. Hyperion Sensor

1.2. EO-1 Hyperion Data Products

The data in the form of cubes is put into Hierarchical Data Format (HDF) format written as band-interleaved-line (BIL) files stored as 16-bit signed integer radiance values. The SWIR bands have a scaling factor of 80 and the VNIR bands have a scaling factor of 40 applied. The actual radiance values vary from zero to approximately 32,767. The various formats in which the Hyperion sensor data is made available by USGS to the users are listed below [5]:

- **Level 1R (L1R)**

The Level 1 Radiometric product is only radiometrically corrected and not geometrically resampled. The L1R product ia available only in HDF format. The data product consists of the HDF data file (.L1R), a metadata file (.MET), a header file (.hdr and a auxiliary file (.AUX).

- **Level 1Gs (L1Gst)**

The Level 1 Gs product is radiometrically corrected and geometrically resampled and is registered to a geographic map projection. The image is also terrain corrected i.e. ortho-rectified using digital elevation models (DEM) for correcting parallax error due to topographic relief. Each image band in the L1G product is provided in a separate file. The L1Gst product is available in two formats: HDF v 4.1 and GeoTIFF.

- ✓ **L1Gst (HDF)**

  The Hyperion product includes a metadata file (_MTL.L1T), an HDF header file (_HDF.L1T), a Federal Geographic Data Committee (FGDC) metadata file (.fgdc) and multiple image bands (_B###.L1T).

- ✓ **L1Gst (GeoTIFF)**

  GeoTIFF defines a set of public domain TIFF tags that describe all cartographic and geodetic information associated with geographic TIFF imagery. This Hyperion

product includes a metadata file (_MTL_L1T.TIF), an FGDC metadata file (.fgdc) and multiple image bands (_B###_L1T.TIF).

The USGS products are packaged in Hierarchical Data Format (HDF) with the datasets being image data, spectral center wavelengths, spectral bandwidths, gain coefficients and a flag mask. The file naming convention utilizes an entity ID with acquisition target. In this course work we will be using the L1R product for hands on practical classes. Table 3.1 describes the naming convention for Hyperion datasets and Table 3.2 lists the scene characteristics of the Hyperion L1R image of Jalandhar area, to be used in this course work.

Table 3.1: Data File Name Description

EO1SPPPRRRYYYYDDDXXXML_GGG_VV	
EO1	Earth Observing 1 mission
S	Sensor, A = ALI, H = Hyperion
PPP	Target WRS path of the product
RRR	Target WRS row of the product
YYYY	Acquisition year of the image
DDD	Acquisition Julian day of year
X	Hyperion, ALI, Atmospheric Corrector (AC), (1 = sensor on, 0 = sensor off)
M	Pointing Mode, P = Pointed within path/row, K = Pointed outside path/row, N = Nadir
L	Scene identifier which may be 0-9 or an upper or lower case alpha character.
GGG	Ground/ Receiving Station
VV	Version Number

Table 3.2: Scene Characteristics of Hyperion Image of Jalandhar Area (Source: http://edcsns17.cr.usgs.gov/NewEarthExplorer)

Data Attribute	Attribute Value	Data Attribute	Attribute Value
Entity ID	EO1H1480382008133110PW_PF1_01	Scene Start Time	2008:133:05:19:04.228
Acquisition Date	5/12/2008	Scene Stop Time	2008:133:05:19:20.228
Site coordinates		Date Entered	5/13/2008
NW Corner	31°41′01.22"N, 75°36′50.63"E	Target Path	148
NE Corner	31°40′06.36"N, 75°41′26.14"E	Target Row	38
SW Corner	30°46′41.15"N, 75°22′15.21"E	Sun Azimuth	115.528803
SE Corner	30°45′46.71"N, 75°26′48.18"E	Sun Elevation	64.876435
Cloud Cover	0 to 9% Cloud Cover	Satellite Inclination	98.13
Receiving Station	PF1	Look Angle	3.3236

Data Description

Samples	*1041*
Lines	*3531*
Bands	*242*
Header offset	*0*
File type	*HDF Scientific Data*
Data type	*2*
Interleave	*BIL*
Sensor type	*HYPERION*
Byte order	*1*
Read procedures	*HDF read spatial*
Subset procedure	*HDF read scroll*

Hyperion Sensor Characteristics

EO-1 SATELLITE-HYPERION DATA CHARACTERISTICS

Sensor altitude	*705 Km*
Spatial resolution	*30 m*
Radiometric resolution	*16 Bits*
Swath	*7.2 Km*
IFOV (mrad)	*0.624 degrees (256 pixels)*
Imaging Technology	*Pushbroom*
(Samples) No. of rows	*1041*
(Lines) No. of columns	*3531*
VNIR range	*0.35-1.35 μm*
SWIR	*1.40-2.48 μm*
No. of Bands	*242*
Scaling factor (VNIR)	*40*
Scaling factor (SWIR)	*80*
Band width	*10 nm*

More about E01-Hyperion

- The Hyperion sensor on board the EO-1 satellite is the first Hyperspectral sensor to operate from space.
- The Hyperion provides high resolution Hyperspectral data having 242 spectral bands (from 0.35 to 2.5 μm) with a 30-meter resolution.
- Hyperion data is initially processed by the EO-1 product generation system (EPGS) and distributed in different processing levels (.L1R & .L1T)
- Hyperion is a push broom type sensor; characteristically these sensors have poorly calibrated detectors. These detectors cause high frequency errors in the VNIR or SWIR regions, which can be identified as vertical strips in the image bands.

- Due to poorly calibrated detectors, mean and slandered deviation of the data values for particular band will be effected.
- During this realignment, actual SWIR bands are shifted across track by -1 (FOV) in X direction and +1 pixel down track in Y direction.
- The digital values of the Level-1 products are in 16-bit radiances and stored as a 16-bit signed integer.
- The Level 1 radiometric (L1R) product used in the study has 242 bands; only 198 of them are calibrated (band 8 to 57 for visible-to-near-infrared (VNIR) and 77 to 242 in shortwave-infrared (SWIR) regions).

Disadvantages

- Large volume,
- Band selection,
- Computational complexities

2. Introduction to ENVI

ENVI (Environment for Visualizing Images) is a software tool for image visualization, analysis and interpretation. The whole package includes advanced state of the art of image processing tools for spectral analysis, geometric correction, terrain analysis, radar image analysis, vector and raster GIS capabilities and much more. This section will discuss about some of the basic concepts of image processing in ENVI software and few of its key features with emphasis on Hyperspectral Remote Sensing. ENVI includes a full suite for Hyperspectral Image analysis and Interpretation.

2.1. Getting Started

2.1.1. Starting ENVI

- For running ENVI in Windows machines select ***Startà Programs → ENVI v.v → ENVI***

(where v.v is the version number)

2.1.2. Opening an Image file

1. From theENVI menu bar, select ***File → Open Image File***
2. Locate the Hyperspectral Image file and click ***Open***
3. The ***HDF Dataset Selection Window*** will open, select the file (.L1R) and click ***Open***
4. Select the data format (BSQ, BIL and BIP) and click ***OK***
5. To load a Gray scale image, From the available band list select radio button ***Gray Scale*** and select a band and then click ***Load Band***
6. To load a colour image select ***RGB Color*** radio button along with the desired band combination.
7. Click **Display#1** and select **New Display** and then click ***Load Band*** to load RGB image.

As you click on Load Band a group of windows will open allowing you to analyse the image. The group of windows is collectively referred to as **"Display Group"** and consists of an Image Window, a Scroll Window and a Zoom Window as shown in Figure 51.

You can choose which combinations of windows should appear on the screen by right-clicking on any image window and selecting a style from the **Display Window Style** submenu.

From the ENVI main menu bar select **File** → **Preferences** → **Display Defaults** tab to change the default settings for which windows you wish to display and where you wish to position them. A wide variety of other types of ENVI windows may also be displayed, such as scatter plots, spectral profiles, spectral plots, and vector windows.

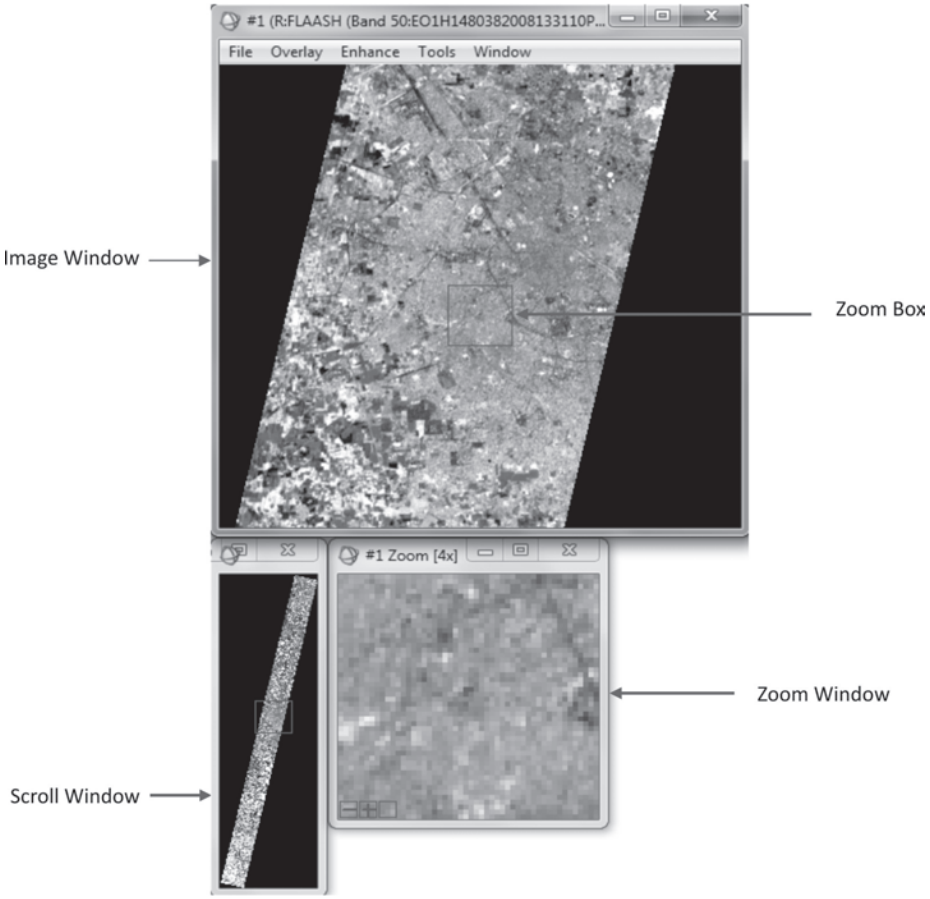


Figure 51. Display Group

2.1.3. The Available Band List

The available band list as shown in Figure 52 is an ENVI dialog box containing a list of image bands available from all open files or any associated map information. The available band list dialog box can be for loading both colour and gray scale images into multiple displays simultaneously.

The File and Options menu at the top in the Available Band List dialog box provides various functionalities such as Opening and closing the Image files or bands, wavelength

locator, show currently displayed band. By right clicking on the available band list or on a file displays a range of functions for editing the header file, computing statistics of the image, and for loading true colour and colour infrared images into the display.

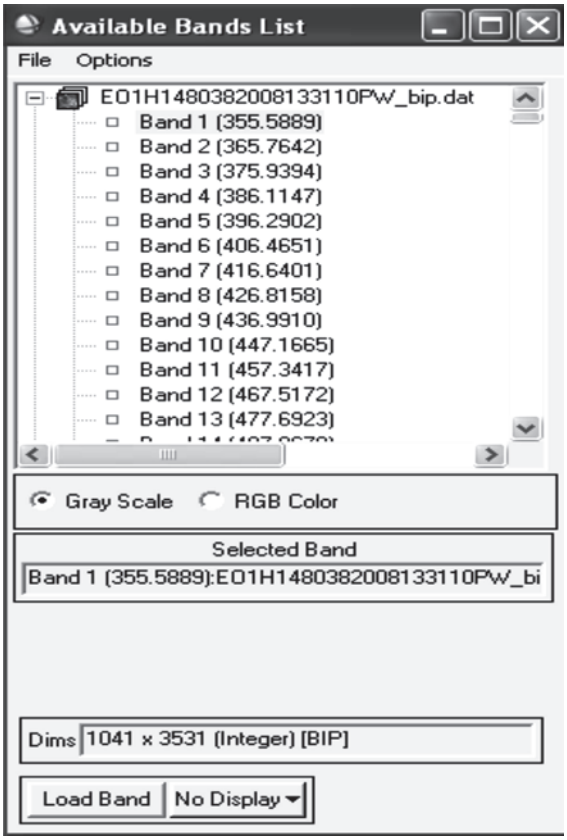


Figure 52. Available Band List

2.1.4. ENVI File Formats

The ENVI uses a general raster data format consisting of a simple flat-binary file and an associated ASCII header file. This file format permits ENVI to use nearly any image file, including those that contain their own embedded header information. The general raster data is stored in ENVI Flat Binary Format as a binary stream of bytes either in Band Sequential Format (BSQ), Band Interleaved by Pixel Format (BIP), or Band Interleaved by Line Format (BIL) formats.

- **BSQ** is the simplest format, with each line of data followed immediately by the next line of the same spectral band. BSQ format is optimal for spatial (x,y) access to any part of a single spectral band.
- **BIP** format provides optimal spectral processing performance. Images stored in BIP format have the first pixel for all bands in sequential order, followed by the second pixel for all bands, followed by the third pixel for all bands, etc., interleaved up to the number of pixels. This format provides optimum performance for spectral (z) access of the image data.

- **BIL** format provides a compromise in performance between spatial and spectral processing and is the recommended file format for most ENVI processing tasks. Images stored in BIL format have the first line of the first band followed by the first line of the second band, followed by the first line of the third band, interleaved up to the number of bands. Subsequent lines for each band are interleaved in similar fashion.

ENVI also supports a number of generic image formats such as ASCII, BMP, HDF, JPEG, JPEG 2000, PICT, PNG, TIFF (GeoTIFF), TIFF world (.tfw), SRF, XWD. Also it supports a variety of data types such as byte, integer, unsigned integer, long integer, unsigned long integer, floating-point, double-precision floating-point, complex, double-precision complex, 64-bit integer, and unsigned 64-bit integer.

2.1.5. ENVI Header

The ENVI Header file contains information about the dimensions of the image, data format or any other information which ENVI uses to read the image data file. The Header file can be created the first time a particular data file is read by ENVI. It can also be created or edited manually by the user itself.

1. From the ENVI menu bar, select **File** → **Edit Envi header** or alternatively right click on file name in **Available band List** → select **Edit Header**
2. Header Info: dialog box will appear as shown in Figure 53.
3. Click the **Cancel** button to close the header file.

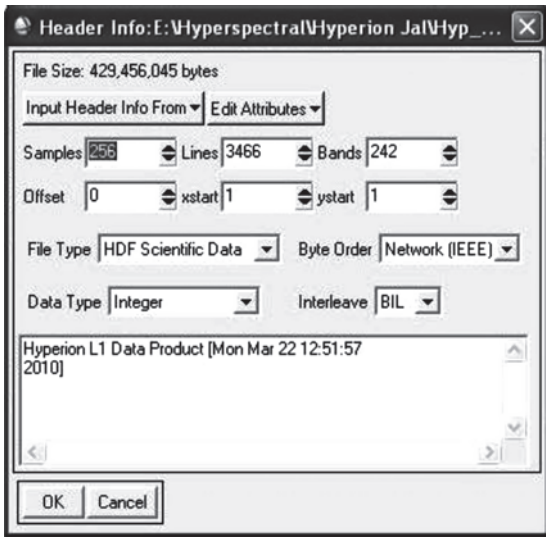


Figure 53. Header Info Dialog Box

2.2. Basic ENVI Functions

This section will discuss about some of the basic functions which we can perform in ENVI.

2.2.1. Opening External Files

This option is used for opening a number of standard file types including some sensor specific formats, military formats and other generic image formats.

1. From the ENVI menu bar, select **File** → **Open External File** → **file_type** → **file_format**.

   (where: **file_type** is the type of external file (for example, **Landsat**; **file_format** is the format of the external file (for example, **HDF**)
2. Select a file to open.
3. Click **Open.** ENVI automatically extracts the necessary header information, including the associated georeferencing information, and places the filename and bands in the Available Bands List.

2.2.2. Display Cursor Location and Value

1. To display the cursor location and value, select **Window à Cursor Location/Value** from either the ENVI main menu bar or the Display group menu bar. You can also right-click in the Image window and select **Cursor Location/Value**.
2. Double-click in the Image window to display or to hide the Cursor Location/Value dialog

2.2.3. Linking Two Displays

Link the two displays together for comparison. When you link two displays, any action you perform on one display (scrolling, zooming, etc.) is echoed in the linked display. To link the two displays on your screen, do the following.

1. From the Display group menu bar, select **Tools → Link → Link Displays**. You can also right-click in the Image window and select **Link Displays**.
2. The Link Displays dialog box opens
3. Select the displays to be linked and click **OK** in the Link Displays dialog to establish the link.
4. Scroll and zoom in on display group and observe as the changes are mirrored in the second display.

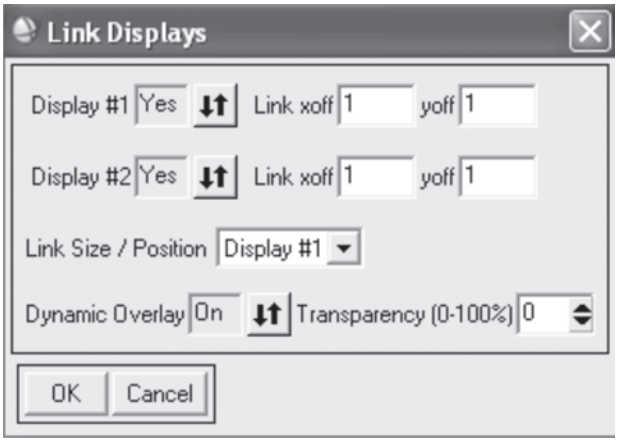


Figure 54. Link Displays

2.2.4. Displaying Spectral Profiles

1. From the Display group menu bar, select **Tools → Profiles → Z Profile** to display a spectral plot. You can also open a Z profile from the right-click menu in any **Image window**.
2. The spectral profile window will open as shown in Figure 55.

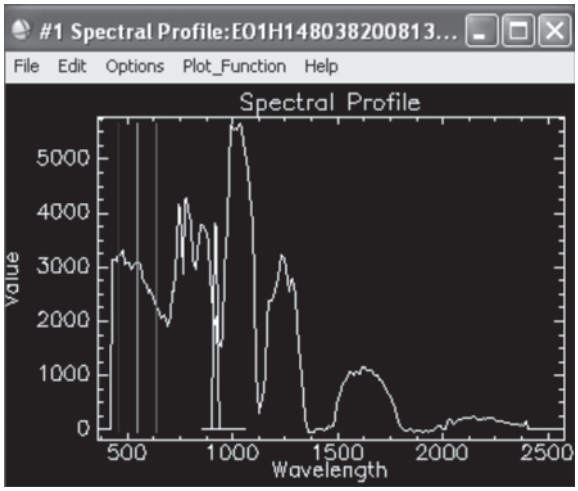


Figure 55. Spectral Profile of a Pixel

2.2.5. Selecting Regions of Interest

ENVI lets you define regions of interest (ROIs) in your images. ROIs are typically used to extract statistics for classification, masking, and for deriving average spectra from a group of pixels. You can define as many ROI's as you want in a displayed image.

1. From the Display group menu bar, select **Overlay** → **Region of Interest** or right-click in the Image window and select **ROI Tool**.
2. Draw a polygon that represents the region of interest by clicking the left mouse button in the Image window to establish the first point of the ROI polygon, then selecting further border points in sequence by clicking the left button again. Close the polygon by clicking the right mouse button, then accept the polygon by clicking the right mouse button again. The middle mouse button deletes the most recent point, or (if you have closed the polygon) the entire polygon.

   ROIs can also be defined in the Zoom and Scroll windows by selecting the appropriate window radio button in the ROI Tool dialog.

   When you have finished defining an ROI, it is shown in the dialog table, with the name, region color, number of pixels enclosed, and other ROI properties. ROIs can also be defined as polylines or as a collection of individual pixels by selecting the desired ROI type from the ROI_Type pull-down menu in the ROI Tool as shown in Figure 2.6.
3. Click the **New Region** button.
4. Select an ROI by clicking in a cell of the far left column of the ROI Tool table. An ROI is selected when its entire row is highlighted. An asterisk next to the row also signifies the currently active ROI. Multiple ROIs can be selected by using **Shift**-click or **Ctrl**-click. All the ROIs can be selected by clicking the **Select All** button. Click and type to edit the values in the cells of the ROI Tool table. Change the name for the region and select a new color.

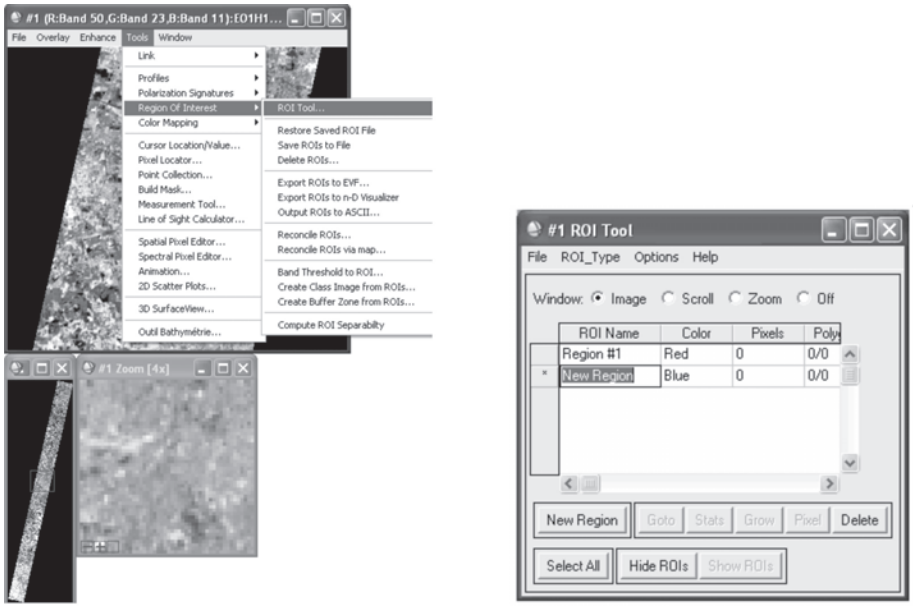


Figure 56. ROI Tool

5. Hide ROIs by selecting them in the table and clicking the **Hide ROIs** button. Use the **Show ROIs** button to re-display these hidden ROIs.
6. Go to an ROI in the ENVI display by selecting it and clicking the **Goto** button.
7. View the statistics for one or more ROIs by selecting them in the table and clicking the **Stats** button.
8. Grow an ROI to its neighboring pixels within a specified threshold by selecting it and clicking the **Grow** button.
9. Pixelate polygon and polyline ROIs by selecting them in the table and clicking the **Pixel** button. Pixelated objects become a collection of editable points.
10. Delete ROIs by selecting them in the table and clicking the **Delete** button.

    The ROI Tool table also allows you to view and edit various ROI properties, such as name, color, and fill pattern. Menu options available at the top of the ROI Tool dialog let you perform other various tasks, such as calculate ROI means, save your ROI definitions, and load saved definitions. ROI definitions are retained in memory after the ROI Tool dialog is closed, unless you explicitly delete them. ROIs are available to other ENVI functions even if they are not displayed.
11. Close the ROI Tool using the menu at the top of the table, select **File** → **Cancel**.

3. Hyperspectral Data Preprocessing

This section discusses about the various pre-processing steps which are applied on the Hyperion dataset. The dataset used in this research work is the Hyperion level L1R dataset of the Jalandhar area and its surroundings. The Hyperion is a push-broom sensor with 242 contiguous, narrow bandwidth bands. Because of the huge volume of spectral data available, and the noise present the spaceborne hyperspectral dataset, it requires careful pre-processing for managing the noise. The pre-processing of dataset can be considered as the first step towards further interaction with the dataset.

The pre-processing approach adopted in this thesis involves:

- Bad band removal i.e. removing the bands with no information,
- Along track destriping and
- Atmospheric corrections to convert the radiance to reflectance.

3.1. Bad Band Removal

Hyperion level L1R data has 242 bands out of which only 198 are nonzero i.e. a few were intentionally left unused (Bands 1 to 7 and 225 to 242) and others fall in the overlap region of the two spectrometers (Bands 58 to 76). Among the non zero bands, four band are still in the overlap region of the two spectrometers i.e. bands 56, 57 and 77, 78 out of which bands 77 and 78 were eliminated because of the higher noise levels present in those bands [6], which left us with 196 unique bands.

Then there are water vapour absorption bands which needs to be eliminated and are identified as bands120 to 132 (1346nm to 1467 nm), bands 165-182 (1800 to 1971 nm) and

bands 221 (above 2356) and higher. Water vapour absorption bands absorb all the incident solar energy and can be easily identified visually. The number of bands to be used for further analysis is decided by the user based on the application. However, the list of bands which are eliminated including the water absorption bands is given below in Table 3.3.

Table 3.3: List of Unused Bands of the Hyperion Sensor, L1R product

Bands	Description
1 to 7	Not Illuminated
58 to 78	Overlap Region
120 to 132	Water Vapour Absorption Band
165 to 182	Water Vapour Absorption Band
185 to 187	Identified by Hyperion Bad Band List
221 to 224	Water Vapour Absorption Band
225 to 242	Not Illuminated

3.1.1. Band Selection Using Spectral Subsetting

The steps for band selection are given below and are also illustrated in Figure 57.

1. From the ENVI menu bar select **Basic Tools** → **Resize Data(Spatial Spectral)**
2. In the **Resize Data Input File** window select the File and click **Spectral Subset**
3. In the **File Spectral Subset** dialog box Select the desired bands manually or click **Apply BBL** and then click **OK**
4. Click **OK** in **Resize Data Input File** window and give the output filename.

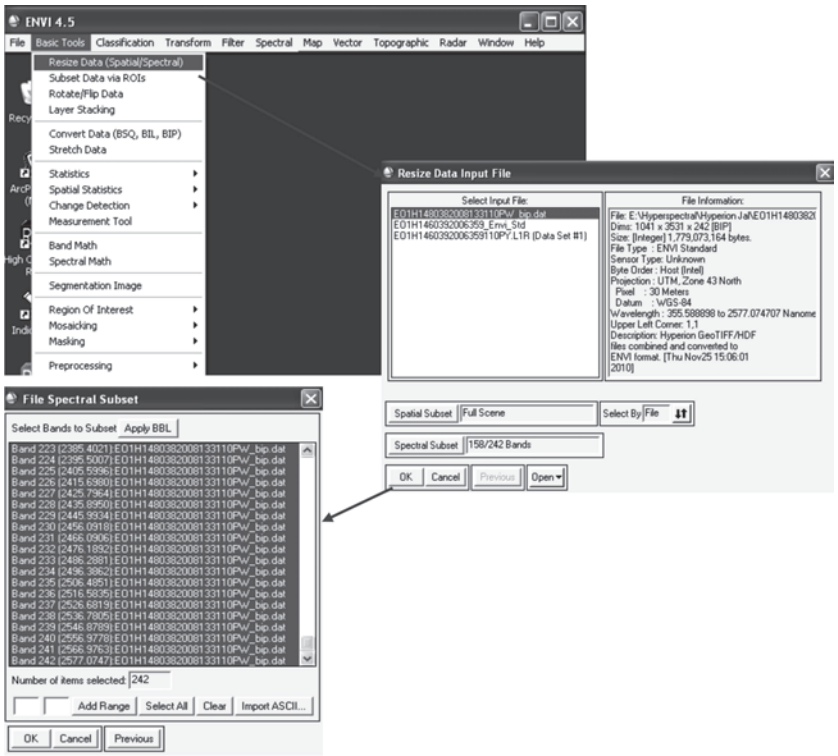


Figure 57. Spectral Subset

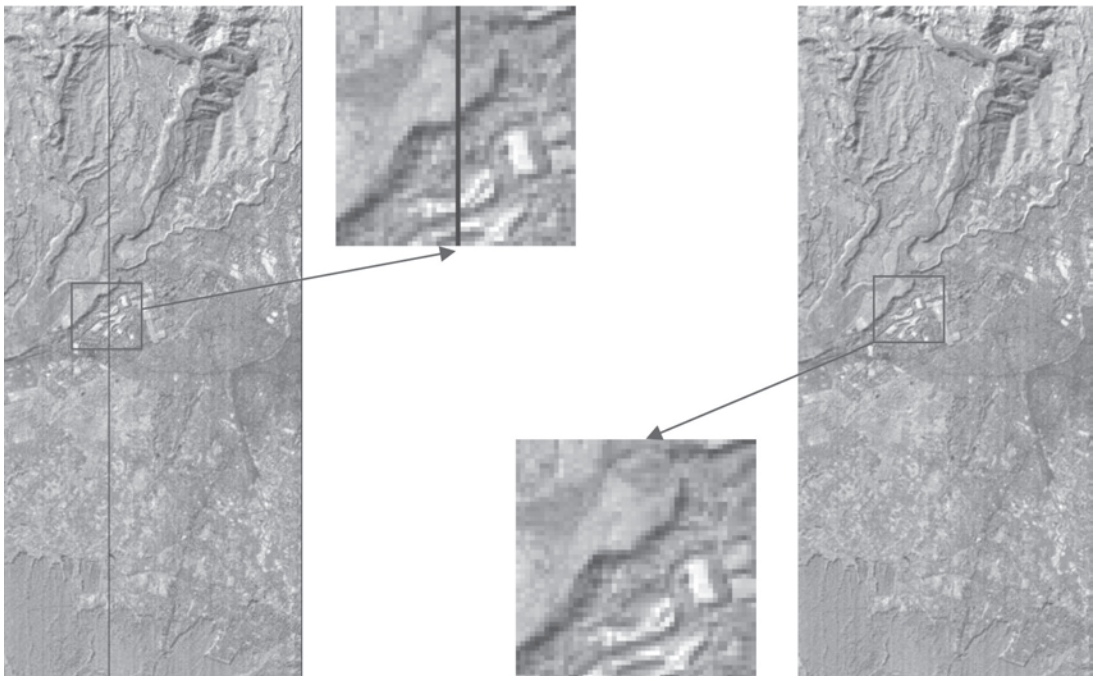
3.2. Along Track Destriping

There are a number of corrupted pixels and dark vertical stripes in the Hyperion datasets that are caused by calibration differences in Hyperion detector array and temporal variations in the detector response [7]. The vertical stripes are in the along-track direction and appear as a series of stripes either along the whole length of the image or intermittently and are also referred to as striping noise. These vertical stripes and the corrupted pixels are referred to as abnormal pixels [8]. These abnormal pixels must be accounted for and corrected before further processing.

According to *Han et al.* [8] majority abnormal pixels in the Hyperion images appear as vertical stripes and can be classified into 4 categories:

- Class1 - continuous with atypical DN values - extremely small DN values, usually zero
- Class2 - continuous with low DN values - low DN values compared to adjacent columns
- Class3 - intermittent with atypical DN values - extremely small DN values
- Class4 - intermittent with lower DN values - low DN values compared to neighbouring pixels

The figures below show examples of different types of abnormal pixels in the Hyperion data. Figure 58. a) shows the Class 1 type of abnormal pixels by taking a spatial subset from the Hyperion image and Figure 58. b) shows the corrected image after correcting the image using Hyperiontools.sav.



(a) Original Band (b) Band after correction

Figure 58. a) Class 1 Abnormal pixels: Continuous with atypical DN values, Band 99 and b) Band after correction using Hyperion tools.sav

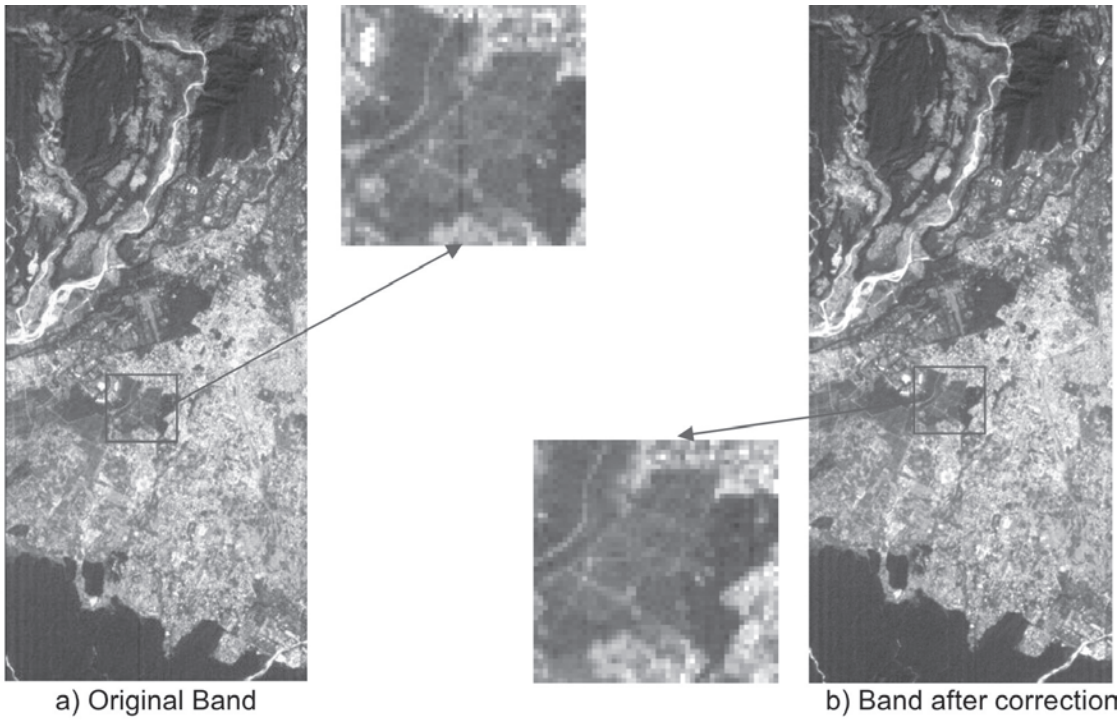


Figure 59. a) Class 4 Intermittent pixels: Intermittent with atypical DN values, Band 14 and b) Band after correction using Hyperion tools.sav

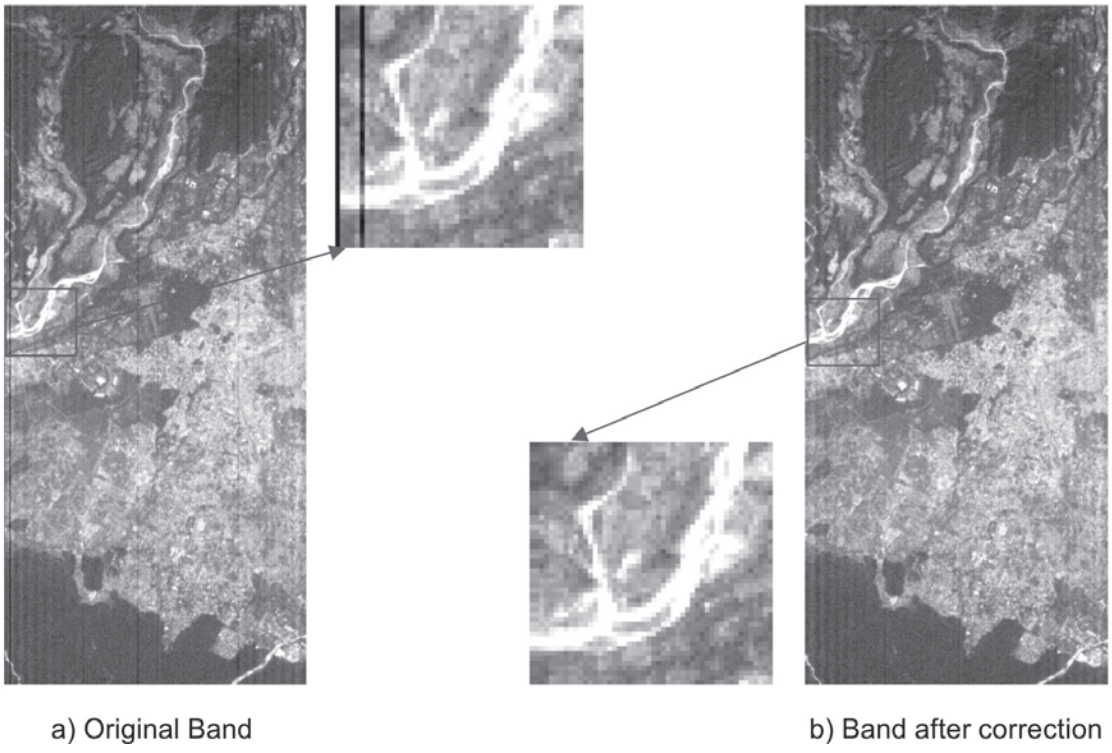


Figure 60. a) Class 2 Abnormal pixels: Continuous with low DN values, Band 10, b) Band after correction using Hyperion tools.sav

The level L1R Hyperion dataset contains a number of bands containing a series of vertical stripes which are left for the user to correct according to its convenience. While generating the bad band list the hyperiontools.sav utility of ENVI uses the flag mask correction for detecting and correcting the continuous vertical stripes and the abnormal pixels with atypical values. Figures 58 (b), 59 (b) and 60 (b) show the output of the hyperiontools.sav utility, for band number 99, 14 and 10 respectively.

3.3. Atmospheric Corrections – Converting Radiance to Reflectance

The electromagnetic signals recorded by the space borne or airborne hyperspectral sensors are a combination of the signals from earth's surface, atmospheric constituents and sensor errors. Thus for quantitative analysis of earth reflectance, these atmospheric effects need to be removed from the acquired signal and the procedure is called atmospheric correction or compensation. Atmospheric corrections transform the hyperspectral data to apparent surface reflectance. Atmospheric corrections are required for matching the image endmember spectra with the reference spectral libraries or ground data.

The choice of atmospheric correction method depends upon various factors such as nature of the problem, type of the sensor and data available, historical atmospheric information of the area, etc. Different atmospheric correction techniques which are available to process hyperspectral datasets are listed in Table 3.4.

Table 3.4: Atmospheric correction: Methods and Models

Empirical Approaches (Statistical Based)	Atmospheric Models (Physics Based)
Empirical line	FLAASH
IARR	ATREM
Flat Field	ATCOR
Output = relative reflectance	**Output = absolute reflectance**

3.3.1. Empirical Line Correction (ELC)

The Empirical Line correction methods involves computing a empirical relation between the radiance and reflectance using a dark and bright target from the study area, both of which are well defined by field as well as image spectra. For an optimal representation these targets should be acquired in the field during the over flight of satellite. A linear regression is applied for all wavelengths which equates DN to reflectance.

First, the radiance spectrum is derived from a dark and a bright target from the scene by either using the ROI tool or by selecting a single pixel.

1. From the ENVI main menu bar, select **Basic Tools** → **Preprocessing** → **Calibration Utilities** → **Empirical Line** → **Compute Factors and Calibrate**.
2. The **Empirical Line Input** File dialog appears.

3. Select the input hyperion file and click **OK**.
4. Empirical Line Spectra dialog box opens.
5. In the Empirical Line Spectra dialog, click **Data Spectra → Import Spectra**.
6. The **Data Spectra Collection** dialog box opens.
7. Collect spectra using the **Import** menu
8. After the data spectra are selected, click **Apply**. The spectra names are entered into the Empirical Line Spectra dialog.
9. In the Empirical Line Spectra dialog, click **Field Spectra → Import Spectra.**
10. Collect spectra using the **Import** menu
11. Click **Apply** to enter the spectra names
12. In the Empirical Line Spectra dialog, select the data spectrum name at the top list.
13. In the bottom list, select the corresponding field spectrum name.
14. Click **Enter Pair** to associate the two spectra. The paired spectra are listed in the **Selected Pairs** field.

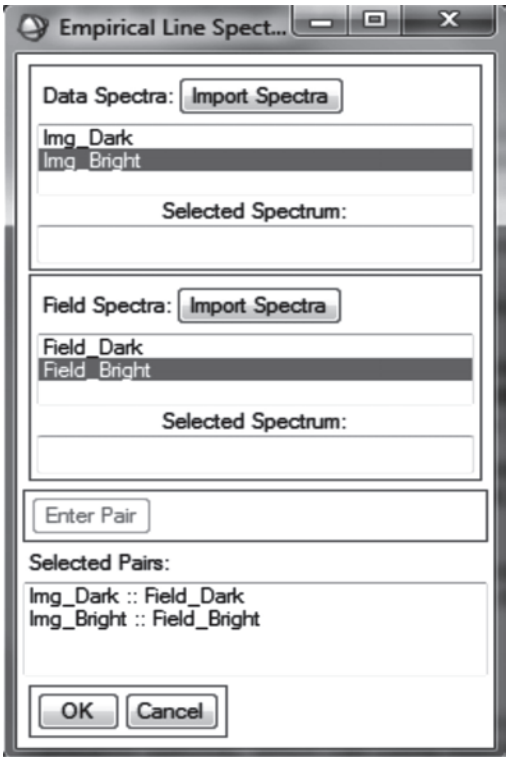


Figure 61.

15. Repeat the selection process for as many data and field spectra pairs as desired.
16. Click **OK**. The **Empirical Line Calibration Parameters** dialog appears.
17. Enter filename in **Output Calibration Filename** field and clock **OK**.
18. The calibration factors are plotted in a plot window and ENVI adds the resulting output to the **Available Bands List**.

3.3.2. Internal Average Relative Reflectance (IARR)

The Internal Average Relative Reflectance (IARR) calibration technique is used to normalize images to a scene average spectrum. This is particularly effective for reducing imaging spectrometer data to "relative reflectance" in an area where no ground measurements exist and little is known about the scene. It works best for arid areas with no vegetation. The IARR calibration is performed by calculating an average spectrum for the entire AVIRIS scene and using this as the reference spectrum. Apparent reflectance is calculated for each pixel of the image by dividing the reference spectrum into the spectrum for each pixel. IARR requires no user input.

1. From the ENVI menu bar select **Spectral → Preprocessing → Calibration Utilities → IAR Reflectance** or **Basic tools → Preprocessing → Calibration Utilities → IAR Reflectance**
2. The **Calibration Input File** dialog box will open
3. Select the **Hyperion file** and take a spectral subset of 158 bands and click **OK**

4. **IARR Calibration Parameters** dialog box opens
5. Enter **Output Filename** and click **OK**

3.3.3. Flat Field Correction

Flat field calibration produces relative reflectance by dividing the mean spectrum of a user-defined ROI into the spectrum of each pixel in the image. ROIs you define should be a spectrally flat material within the wavelength range of the sensor. Beach sand and concrete are popular choices. Materials with spectral features, such as vegetation, are a poor choice. Since the mean spectrum of the ROI is divided into each pixel, the relative reflectance for pixels within the ROI will be flat and have a value around 1.0.

1. To perform flat field calibration, first define a **region of interest**.
2. In the ENVI display window select **Tools → Region of Interest à ROI Tool**
3. The ROI Tool dialog box opens.
4. Set in the ROI tool the target window to the **Zoom Window** and **ROI_TYPE** as **Polygon.**
5. Draw a polygon in the **Zoom Window** over settlement area of the Image.
6. When satisfied with your polygon, close the polygon by clicking the right mouse button. Click again with the right mouse button to capture the pixels inside the polygon.
7. Save the ROI **(File → Save** in ROI tool) to disk and exit the ROI tool.
8. From the ENVI menu bar select **Spectral → Preprocessing → Calibration Utilities → Flat Field** or **Basic tools → Preprocessing → Calibration Utilities → Flat Field**
9. The **Calibration Input File** dialog box will open
10. Select the **Hyperion file** and take a spectral subset of 158 bands and click **OK**
11. **Flat Field Calibration Parameters** dialog box opens
12. Enter **Output Filename** and click **OK**.

3.3.4. FLAASH (Fast Line-of-Sight Atmospheric Analysis of the Spectral Hyper cubes)

ENVI's FLAASH module is a model for retrieving spectral reflectance from hyperspectral radiance images and was developed by Spectral Sciences, Inc., under the sponsorship of the U.S. Air Force Research Laboratory. It compensates for atmospheric effects and corrects wavelengths in the visible region of electromagnetic spectrum through NIR and SWIR region. FLAASH has inbuilt support for hyperspectral sensors such as Hyperion, AVIRIS, HYDICE, HYMAP,Probe-1, CASI and multispectral sensors such as Landsat, SPOT, IRS, AVHRR, ASTER etc.

3.3.4.1. Data Requirements

- The input to FLAASH atmospheric correction module must be a radiometrically calibrated radiance image in BIL or BIP format.
- For water retrieval the image bands must cover at least one of the following ranges at 15nm or better spectral resolution:
  - 770 – 870 nm (for the 820 nm water feature)

- 870 – 1020 nm (for the 940 nm water feature)
- 1050 – 1210 nm (for the 1135 nm water feature)

- Wavelengths, FWHM values must be available in ENVI header files or as separate ASCII files.
- Scale factors in ASCII format to convert radiance image into floating point values (units: $\mu W/cm^2$ nm sr) which is the required FLAASH input data format

3.3.4.2. Conversion to BIP/BIL Format

1. From ENVI main menu bar select Basic **Tools → Convert Data (BSQ, BIL, BIP)**
2. **Convert File Input File** window opens.
3. Select the Hyperspectral Image file (ENVI Format) and click **OK**
4. **Convert File Parameters** Window Opens
5. Select **BIL or BIP** option in Output Interleave, enter the **output filename** and click **OK**

3.3.4.3. FLAASH Input parameters and Settings

1. From the ENVI menu bar select either
   - **Spectral → FLAASH**
   - **Basic tools → Preprocessing → Calibration Utilities → FLAASH**
   - The FLAASH Atmospheric Correction Model Input Parameters dialog box appears as shown in Figure 62.

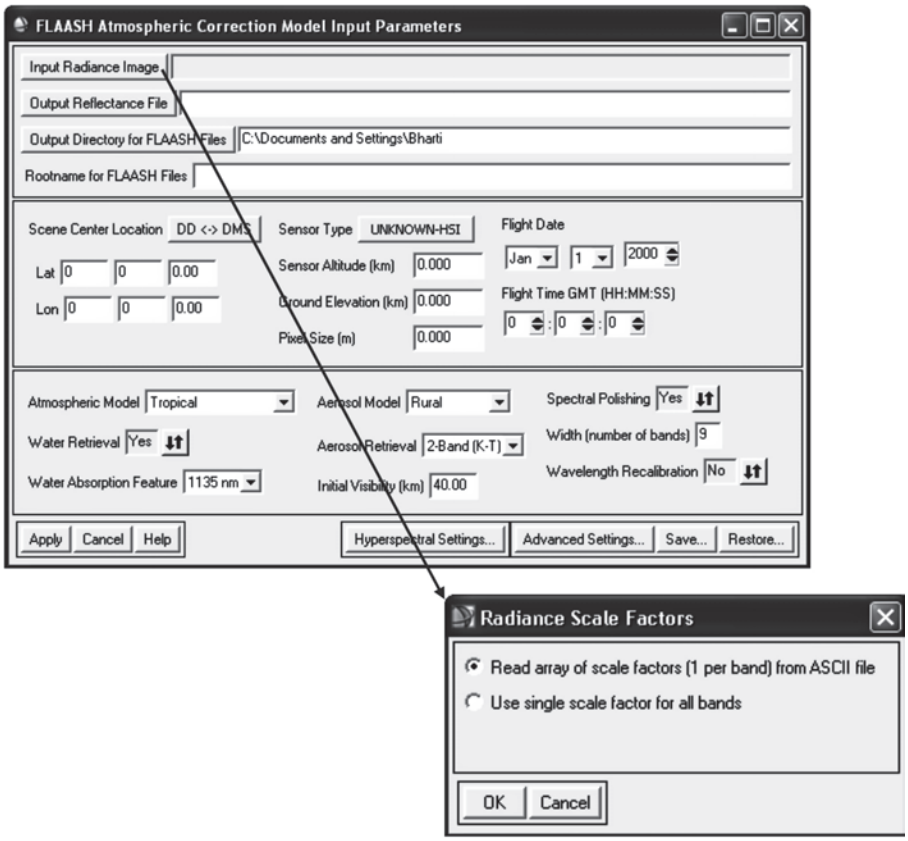


Figure 62. FLAASH Atmospheric Correction Model Input Parameters dialog box

2. In the FLAASH Atmospheric Correction Model Input Parameters dialog box, to select the input radiance image, click **Input Radiance Image and** select the **Hyperion (BIL/ BIP)** image file.
3. Select the option, **Read array of scale factors (1 per band) from ASCII file**, from the **Radiance Scale Factors** dialog box. Then Locate the scale factor file.
4. The various Input and Output parameters required to be entered are listed below
   - **Input radiance image** (in BIL or BIP format)
   - **Output filename**
   - **Output directory** – Directory to which FLAASH results are stored
   - **Root name** – prefix which is appended to all the output FLAASH filenames
   - **Latitude and Longitude of the centre of the scene**
   - **Sensor type** – select the name of the sensor which acquired the radiance data
   - **Sensor altitude (km)** – altitude of the sensor when the image was collected,
   - **Ground elevation (km**) of the area – average scene elevation
   - **Pixel size (m) –** image pixel sixe used for adjacency effect correction
   - **Flight date and Time GMT (HH:MM:SS)**
   - **Atmospheric Model –** The Atmospheric Model is selected is selected based on seasonal latitude surface temperature model as shown in Table 3.5.

Table 3.5: Atmospheres Based on Latitudinal/Seasonal Dependence of Surface Temperature

Latitude (°N)	January	March	May	July	September	November
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

Where,

SAW	-	Sub-Arctic Winter
MLW	-	Mid-Latitude Winter
SAS	-	Sub-Arctic Summer
MLS	-	Mid-Latitude Summer
T	-	Tropical

- **Water Retrieval -** 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 as follows:–
  - **Yes:** Perform water retrieval.

    The 1135 nm feature is recommended if the appropriate bands are available. If you select 1135 nm or 940 nm, 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.
  - **No:** 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. Set the Water Column Multiplier value accordingly.
- **Aerosol Model -** The model choices are as follows:
  - **Rural:** Represents aerosols 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:** A mixture of 80% rural aerosol with 20% soot-like aerosols, appropriate for high-density urban/industrial areas.
  - **Maritime:** Represents 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:** Applies to calm, clear (visibility greater than 40 km) conditions over land and consists of the small-particle component of the rural model.

- **Aerosol Retrieval**
  - **None:** When you select this option, the value in the Initial Visibility (tm) field is used for the aerosol model (described in the following section).
  - **2-Band (K-T):** Use the aerosol retrieval method. If no suitable dark pixels are found, then the value in the Initial Visibility field is used.
- **Initial Visibility (Km)**
  - In the Initial Visibility field, enter an estimate of the scene visibility in kilometers. An estimate of visibility during different conditions is given in Table 3.6.

Table 3.6: Scene Visibility options

Weather Conditions	Scene Visibility
Clear	40 – 100 Km
Moderate Haze	20-30 Km
Thick Haze	15 km or less

- **Spectral Polishing -** Polishing is a term 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.
  - Click the **Spectral Polishing** toggle button to select one of the following options:

    Yes : Spectrally polish the reflectance image.

    No : Output the unaltered modeled reflectance.
  - In the **Width (number of bands)** field, enter the width of the smoothing window to be used in the FLAASH spectral polishing algorithm.

  The reference pixels are selected as follows:
  - For each pixel, a smoothed spectrum is calculated.
  - The difference between the smoothed spectrum and the unsmoothed spectrum is calculated for each measured wavelength.
  - 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.
  - The pixels with the lowest ten percent of normalized RMS differences are selected from among the cloud-free, non-blank, and non-vegetated pixels.

- 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.
- 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.

- **Wavelength Recalibration -** 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. AVIRIS, HYDICE, HYMAP, HYPERION, CASI, and AISA sensors are automatically supported for wavelength recalibration.
  - **Yes:** Automatically adjust the wavelength calibration prior to computing the water retrieval.
  - **No:** Use the input file's wavelengths.

3.3.4.4. FLAASH Advanced Settings

The FLAASH advanced settings are arranged into three categories: modeling parameters, viewing geometry and FLAASH processing controls.

1. Click on **Advanced Settings** in **FLAASH Atmospheric Correction Model Input Parameters** window.
2. **FLAASH Advanced Settings** window opens as shown in Figure 63.
3. **FLAASH Advanced Parameters**
   - In the **Aerosol Scale Height (km)** field, enter the effective 1/*e* height of the aerosol vertical profile in km. Typical values are 1 to 2 km. The default value is 1.5 km.
   - In the **CO2 Mixing Ratio (ppm)** field, enter 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.
   - Click the **Use Square Slit Function** toggle button to select **Yes** for images that were derived by averaging together adjacent bands (for example, LASH). This better models the spectral response of the derived bands.
   - Click the **Use Adjacency Correction** toggle button to specify whether or not to use adjacency correction. Unlike most atmospheric correction models, the

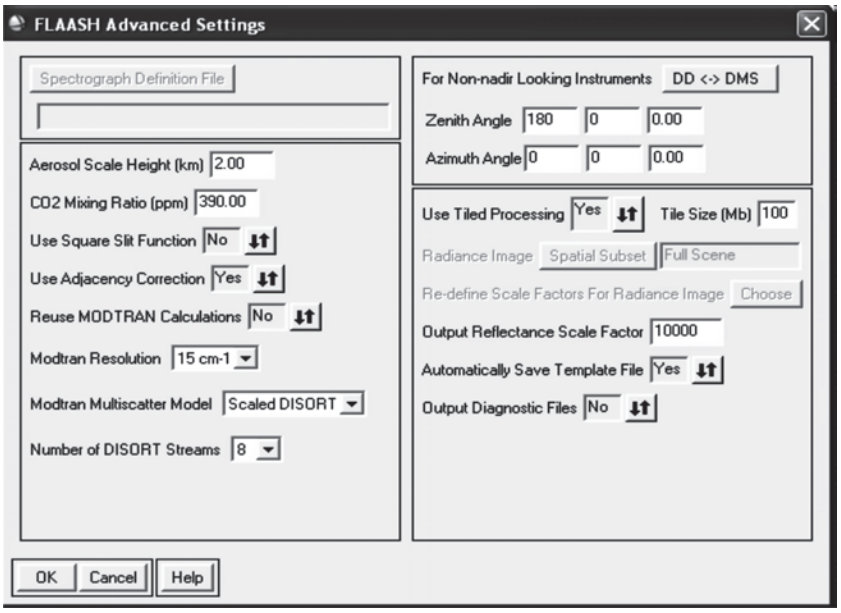


Figure 63. FLAASH Advanced Settings

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.

- Click 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. Following is an explanation of the options:
  - **No**: FLAASH computes a new set of MODRTRAN radiative transfer calculations for the selected image and model parameters
  - **Yes**: FLAASH performs 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 you set **Reuse MODTRAN Calculations** to **No**.
- 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

seen near 2000 nm and beyond. The 5 cm^{-1} resolution is the default value when you select a hyperspectral sensor as input, but it changes to 15 cm^{-1} when you select a multispectral sensor. 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 aerosols are not being retrieved, the first two runs are omitted.

- 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 :** The Isaacs 2-stream method is fast but oversimplified.
  - **Scaled DISORT :** The Scaled DISORT method provides near-DISORT accuracy with almost the same speed as Isaacs.
  - **DISORT :** The DISORT model provides the most accurate shortwave (less than ~ 1000 nm) corrections, however it is very computationally intensive. DISORT multiscatter model dramatically increases FLAASH processing time, and is rarely necessary for accurate atmospheric corrections. DISORT with 8 streams usually takes about 30 times longer than using Isaacs.
  - **The default is Scaled DISORT with eight streams**.
  - In the Scaled DISORT model, DISORT and Isaacs calculations are performed at a small number of atmospheric window wavelengths.

4. After entering all the required parameters click on **Apply.** Now, the Radiance Hyperion Data is converted into Reflectance Image. The final output will be listed on the Available Band List Dialog Box.
5. Display and compare the Reflectance and the Radiance spectral profiles of the same features in separate windows before and after atmospheric corrections as shown in Figure 64.

The data specific parameters used in the FLAASH atmospheric correction module for the Jalandhar Hyperion data can be found in the table given in Appendix A.

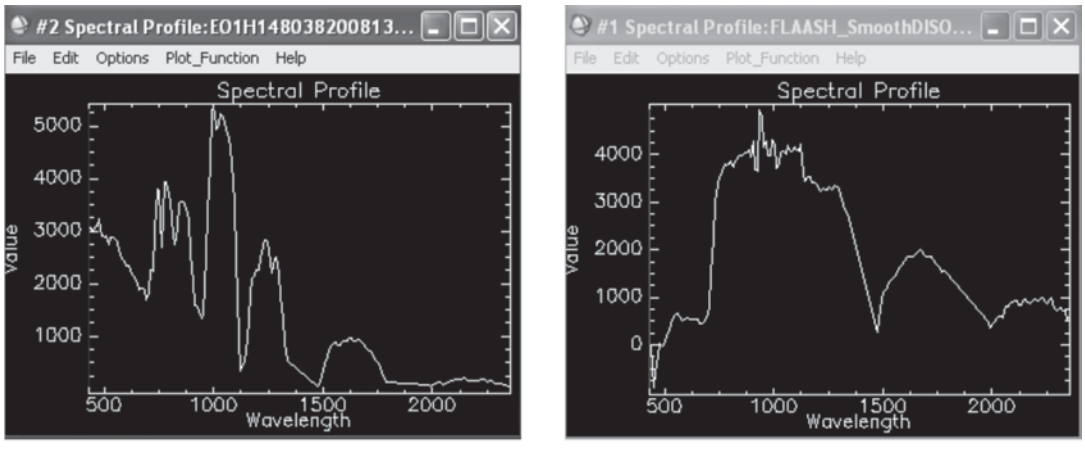


Figure 64. Spectral profile (Z-profile) of a randomly selected pixel, a) before Atmospheric corrections and b) after Atmospheric corrections

3.4. Spatial Subsetting

The spatial subset of the image is usually taken to extract the area of interest of the user from the Hyperion Image.

1. From ENVI mail menu bar select Basic **Tools** → **Resize Data (Spatial/Spectral)**
2. **Resize Data Input File** dialog box will open
3. Select the Hyperion file and click **Spatial Subset**
4. **Select Spatial Subset** dialog box opens.
5. The spatial subset can be selected by using one the following methods:
   - Entering samples and line values
   - Selecting interactively from the image
   - Entering map coordinates
   - Using the same spatial subset that was previously used on another file
   - Using the image shown in the meta scroll window
   - Using the bounding box around a region of interest
6. Choose one of the methods for Subsetting the data and click **OK**
7. Choose the **Resampling** technique in the **Resize Data Parameters** dialog box.
8. Enter the **Output Filename** and click **OK.**

4. Advanced Hyperspectral Analysis

In this section the user will be introduced to the advanced concepts and procedures for the analysis of hyperspectral data starting from dimensionality reduction techniques to spectral unmixing. We will use the Hyperion data of Jalandhar, India for our analysis.

4.1. Minimum Noise Fraction (MNF) Transform

Switzer & Green [9] *, and Green et. al.* [10] proposed the MNF transform which chooses the new components to maximize the SNR and orders them according to increasing image quality or decreasing noise. Minimum noise fraction (MNF) [10] computes the noise statistics information for effectively removing the noise from the dataset and for determining the inherent dimensionality of the dataset. MNF can be treated as two cascaded Principal Component Transformations; the first is the transformation of the noise covariance matrix to an identity matrix also called as the noise whitening step. The second is the standard principal component transformation of the noise whitened dataset maximizing the signal to noise ratio (SNR) and thus segregating the signal from the noise. The noise statistics are calculated using the shift difference method also known as nearest neighbour difference [10].

MNF splits and projects the input image into two subspaces based on visual analysis of the images and associated eigenvalues: The first one is the Signal Subspace (signal plus noise) corresponding the largest eigenvalues and the second is the noise subspace corresponding to the lower eigenvalues. MNF images (eigen images) are used to evaluate

the dimensionality of the data. Eigenvalues for bands that contain information will be an order of magnitude larger than those that contain only noise. The corresponding images will be spatially coherent, while the noise images will not contain any spatial information. In ENVI, MNF transform is used to remove noise from data by performing a forward MNF transform. ENVI assumes that each pixel contains both signal and noise, and that adjacent pixels contain the same signal but different noise. The best noise estimate is gathered using the shift-difference statistics from a homogeneous area rather than from the whole image.

1. From the ENVI menu bar, select either **Transform** → **MNF Rotation** → **Forward MNF** → **Estimate Noise Statistics From Data** or **Spectral** → **MNF Rotation** → **Forward MNF** → **Estimate Noise Statistics From Data**
2. The input File dialog box appears
3. Select an input file and perform optional Spatial Subsetting, Spectral Subsetting, and/or Masking, then click **OK**. The **Forward MNF Transform Parameters** dialog appears.
4. Click **Shift Diff Subset** to select a spatial subset or an area under an ROI/EVF/and so forth on which to calculate the statistics. You can then apply the calculated results to the entire file (or to the file subset if you selected one when you selected the input file).
5. In the **Enter Output Noise Stats Filename [.sta]** field, enter a filename for the noise statistics.
6. In the **Output MNF Stats Filename [.sta]** field, enter an output file for the MNF statistics. Be sure that the MNF and noise statistics files have different names.
7. Select output to **File** or **Memory**.
8. To select the number of output bands without examining the eigenvalues, select **No** from the **Select Subset from Eigenvalues** toggle button, then set the **Number of Output MNF Bands**.
9. To select the number of output MNF bands by examining the eigenvalues, use the following steps:
   - Select **Yes** from the **Select Subset from Eigenvalues** toggle button.
   - Click **OK**. ENVI calculates the statistics and the Select Output MNF Bands dialog appears, with each band listed with its corresponding eigenvalue. Also listed is the cumulative percentage of data variance contained in each MNF band for all bands.
   - Set the **Number of Output MNF Bands**. For the best results, and to save disk space, output only those bands with high eigenvalues. Images with eigenvalues close to 1 are mostly noise.
10. Click **OK**. When ENVI finishes processing, the MNF Eigenvalues plot window appears as shown in Figure 65 and the MNF bands are added to the Available Bands List.

Display the MNF bands from the Available Bands List and compare with the MNF Eigenvalue plot to determine which bands contain data and which bands contain predominantly noise. In subsequent processing of this data, spectrally subset the MNF bands to only include those bands where the images appear spatially coherent and the

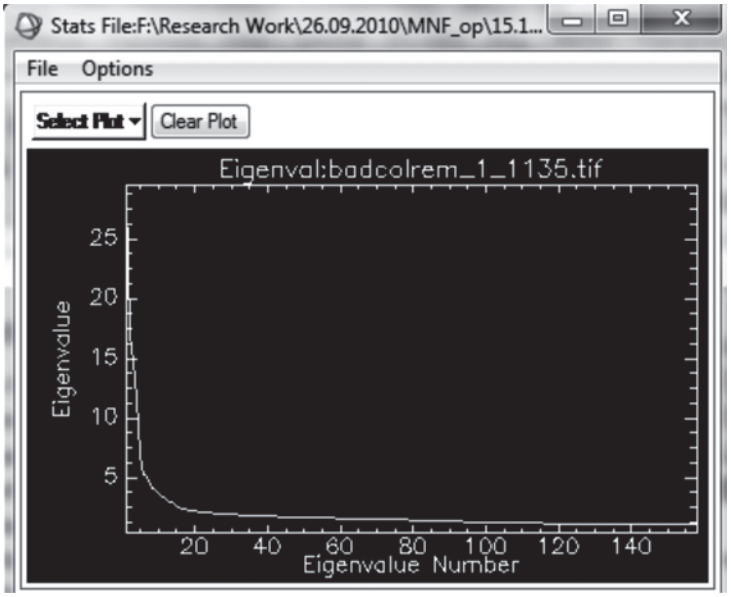


Figure 65. MNF Eigenvalue Plot

eigenvalues are above the break in slope of the MNF Eigenvalue plot. We should only include the first ten to twelve MNF bands because these bands contain 95% of the total information.

4.2. Pixel Purity Index

Pixel purity index (PPI) [11] algorithm, is one of the most widely endmember extraction algorithm used for hyperspectral image analysis. PPI is a means of finding the most "spectrally pure," or extreme, pixels in the hyperspectral images. First the dataset is transformed onto lower dimensions by using either PCA or MNF as the assumption here is that the endmembers lie in the first few principal components. The endmember pixels are obtained by repeatedly projecting the transformed data onto randomly projected vectors (k) in n-dimensional space. As the vectors are randomly generated the results depend upon the number of random projections. Pixels lying at the extremes of a random vector are assigned a purity value. The values are updated after each projection and the pixels having values more than a set threshold (t) are considered as "pure" pixels. The extreme pixels in each projection are recorded and the total number of times each pixel is marked as extreme is noted. A Pixel Purity Index (PPI) image is created in which the DN of each pixel corresponds to the number of times that pixel was recorded as extreme. ENVI employs a FAST PPI method which the image data into memory and performs the computations in memory, which is much faster than the disk-based PPI.

1. From the ENVI main menu bar, select **Spectral** → **Pixel Purity Index** → **New Output Band** or **[FAST] New Output Band**.
2. The Input File dialog appears.
3. Select the input file (**PCA or MNF transform file**) and perform optional Spatial Subsetting, Spectral Subsetting, then click **OK**.

4. Click **OK**. The **FAST Pixel Purity Index Parameters** dialog appears, as shown in Figure 66.
5. Enter a **Number of Iterations** value.

The iterations in the PPI Parameters dialog designate the number of times the data will be projected onto the random vector. After a certain number of iterations, the PPI result will stabilize.

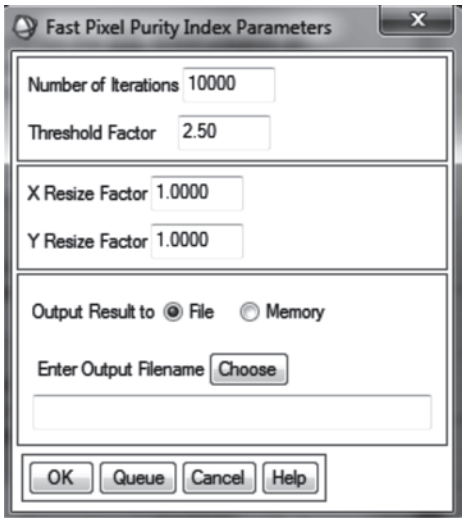


Figure 66. PPI Parameters

6. Enter a **Threshold Factor** value in data units for extreme pixel selection.

   The threshold is a measure for the extremeness of the pixels. For example, a threshold of 2 marks all pixels greater than two digital numbers (DN) from the extreme pixels (both high and low) as being extreme. This threshold selects the pixels on the ends of the projected vector. The threshold should be approximately 2-3 times the noise level in the data.
7. Enter the **Output Filename** and click **OK**
8. A dialog appears that indicates the amount of memory needed and prompts you to continue if that amount of memory is acceptable.

A processing status dialog appears with the PPI plot as shown in Figure 67. This plot shows the total number of extreme pixels satisfying the threshold criterion found by the PPI processing as a function of the number of iterations. It should asymptotically approach a flat line (zero slope) when all of the extreme pixels are found.

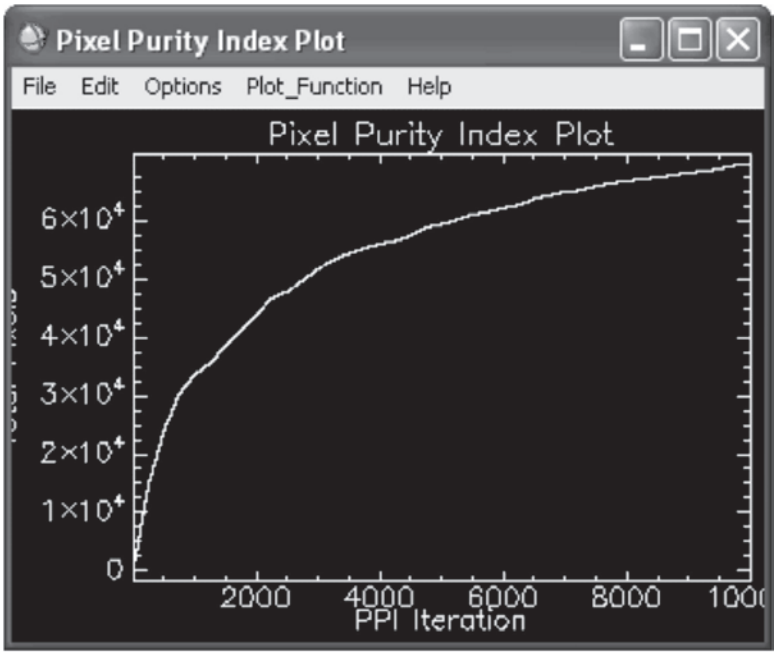


Figure 67. Pixel Purity Index Plot

4.2.1. PPI Images for Endmember Selection

1. Display the PPI image. Brighter pixels represent more spectrally pure and extreme hits. Darker pixels are less spectrally pure.
2. Select **Window** → **Cursor Location/Value** from the ENVI main menu bar, or select **Tools** → **Cursor Location/Value** from the Display group menu bar to determine the range of values present in the image.
3. From the Display group menu bar, select **Overlay** → **Region of Interest** to open the ROI Tool dialog.
4. From the ROI Tool menu bar, select **Options** → **Band Threshold to ROI** to create an ROI containing only the pixels with high PPI values (i.e. the pure pixels)
5. This ROI contains the pixel locations of the purest pixels in the image regardless of the endmember to which they correspond. The ***n*-Dimensional Visualizer** will be used in the next section to extract the specific pure endmembers.

4.2.2. n-D Visualizer

Spectra can be thought of as points in an n-dimensional scatter plot, where n is the number of bands [11]. The coordinates of the points in n-space consist of "n" values that are simply the spectral radiance or reflectance values in each band for a given pixel. The distribution of these points in n-space can be used to estimate the number of spectral endmembers and their pure spectral signatures. ENVI's n-Dimensional Visualizer provides an interactive tool for selecting the endmembers in n-space.

1. From the ENVI main menu bar, select **Spectral** → **n-Dimensional Visualizer** → **Visualize with New Data**.
2. Select the **file** to extract the n-D scatter plots from (**typically an MNF file**).
3. Spectrally subset the MNF data to exclude noise bands determined by reviewing the eigenimages and eigenvalue plot.

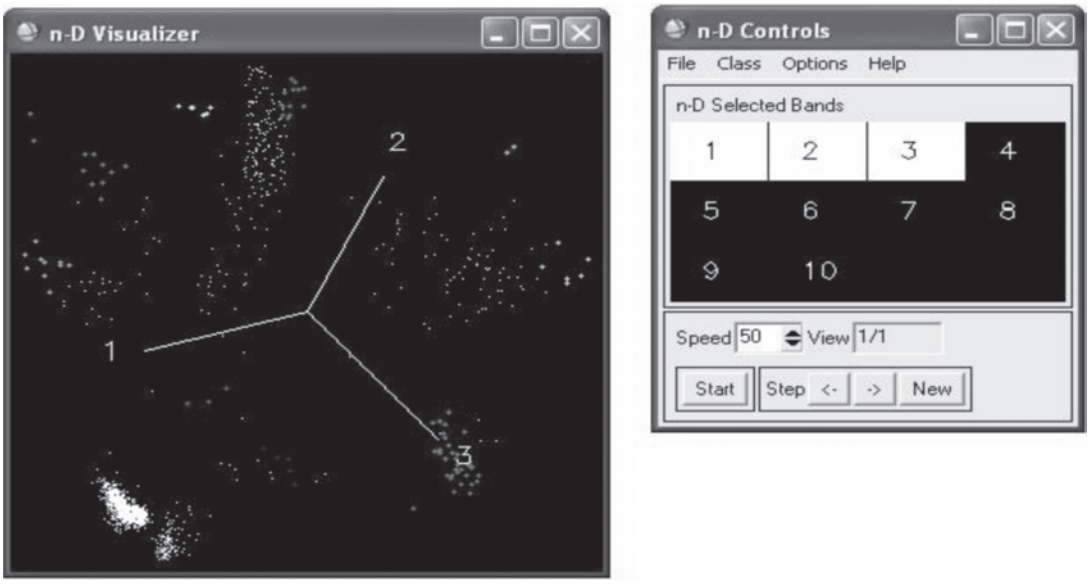


Figure 68. n-D Visualizer (left) and n-D Controls dialog (right)

4. For speed and clarity, an ROI is used to limit the number of pixels that are input into the n-D Visualizer. If only one ROI is present for the input image, it is automatically used as input to the n-D Visualizer. If more than one ROI is present, the n-D Visualizer Input ROI dialog appears. Select the ROI to use.
5. A status box appears while the ROI is loaded. The n-D Visualizer and n-D Controls dialogs appear.
6. In the n-D Controls dialog, click the band numbers to be projected in the n-D Visualizer. Select three or more bands for rotation to be possible.
7. Visually identify and distinguish the purest endmembers in the image by selecting the pixels lying at the tip of a corner in the data cloud and assign a different colour to each corner which corresponds to a different and spectrally unique endmember.

4.2.3. Defining classes using n-D Visualizer

Classes are defined when groups of pixels stay together during rotation and are separated from the rest of the pixels. Multiple classes can be defined at the same time.

1. Click **Stop** in the **n-D Controls** dialog to stop the rotation when a group of pixels is isolated from the main body of pixels plotted in the **n-D Visualizer**. Or, use the arrow buttons to go to a particular projection view.
2. Highlight the desired pixels on **the n-D Visualizer** by left-clicking to set vertices, and right-clicking to close the polygon.
3. From the **n-D Controls** menu bar, select **Class** and choose a color for the class.

   To automatically use the next available class color for the next ROI; select **Class** → **New** from the n-D Controls menu bar (or right-click in the n-D Visualizer and select **New Class**).
4. Click **Start** to rotate the scatter plot until additional groups of pixels are isolated, and repeat the class definition process.
5. Export your best set of classes to ROIs by right clicking in the N**-D visualize window** and select **Export ALL.**
6. From the N-D controls dialog box select **Options** → **Class Control**
7. Extract the average spectra for the different ROIs using either the "**Stats" or "Mean"** tabs in the **n-D class controls** dialog box and compare it with the image spectra.

4.3. Spectral Angle Mapper

The spectral angle mapper (SAM) as explained in [2] computes the spectral similarity between a test (or pixel) spectrum, t, and the reference spectrum (target spectrum or laboratory spectrum or another pixel spectrum), r, and is expressed in terms of vector angle, φ, as:

$$\text{Cos}\ \varphi = \frac{\sum_{i=1}^{n} t_i r_i}{\sqrt{\sum_{i=1}^{n} t_i^2}\ \sqrt{\sum_{i=1}^{n} r_i^2}} \tag{4.1}$$

where, φ - spectral angle, t - test or pixel spectrum

r - reference spectrum, n - number of bands

SAM assumes that the data has been converted to apparent reflectance. While computing the SAM each spectrum is considered a vector in the n-dimensional space, The output of spectral angle mapping for each pixel is an angular difference between the test and the reference spectrum measured in radians, ranging from zero radians to Ð/2. The smaller the spectral angle more is the similarity between the test and the reference spectrum. Figure 69 gives an example of the spectral angle between a pixel and the reference or target spectrum.

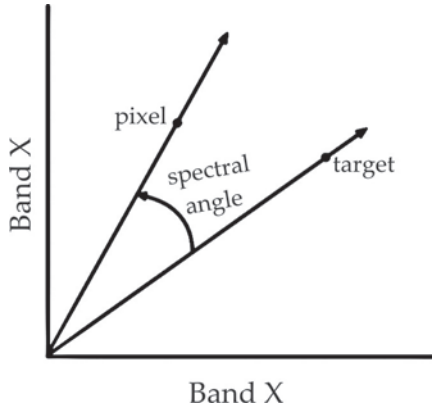


Figure 69. Spectral angle between target and the reference spectra

The spectral angle distance is preferred over other distance metrics as it is insensitive to illumination differences in a pixel. Any illumination change will change the magnitude of the vector but not the direction.

For each reference spectrum chosen in the analysis of a hyperspectral image, the spectral angle, á, is determined for every image spectrum (pixel). This value, in radians, is assigned to the corresponding pixel in the output SAM image, one output image for each reference spectrum. The derived spectral angle maps form a new data cube with the number of bands equal to the number of reference spectra used in the mapping.

The SAM algorithm implemented in ENVI takes as input a number of "training classes" or reference spectra from ASCII files, ROIs, or spectral libraries. It calculates the angular distance between each spectrum in the image and the reference spectra or "endmembers" in *n*-dimensions. The result is a classification image showing the best SAM match at each pixel and a "rule" image for each endmember showing the actual angular distance in radians between each spectrum in the image and the reference spectrum. Darker pixels in the rule images represent smaller spectral angles, and thus spectra that are more similar to the reference spectrum. The rule images can be used for subsequent classifications using different thresholds to decide which pixels are included in the SAM classification image.

1. From ENVI menu bar, select **Classification** → **Supervised** → **Spectral Angle Mapper** or **Spectral** → **Mapping Methods** → **Spectral Angle Mapper.**
2. The **Classification Input File** dialog box appears. Select a file and click **OK.**

3. In **Endmember Collection: SAM** dialog box, select **Import** → ***source of spectra from the drop down menu*** and click **Apply.**
4. The **Spectral Angle Mapper Parameters** dialog appears.
5. Select the **Thresholding options (Maximum angle),** enter the **Output Filename** and **Output Rule Filename** and click **OK.**
6. The results are added to the Available Bands List dialog box.

4.4. Linear Spectral Unmixing

Natural surfaces are rarely composed of a single uniform material. Spectral mixing occurs when two of more materials with spectrally distinct qualities are represented by a single image pixel. If the scale of mixing is large (macroscopic), mixing occurs in a linear fashion. For microscopic or intimate mixtures, the mixing is generally nonlinear. The linear model assumes no interaction between materials. If each photon only "sees" one material, these signals add (a linear process). Multiple scattering involving several materials can be thought of as cascaded multiplications (a non-linear process).

The simplest and the most commonly assumed model for a mixed spectrum is a linear model. A single pixel can be portrayed as a checkerboard mixture, as illustrated in Figure 70 and assuming that there is no multiple scattering between components, then the spectral response of the pixel is a linear combination of the fractional abundances (area covered by each endmember in the pixel) of the individual substances [13], hence the term Linear Mixture Model (LMM).

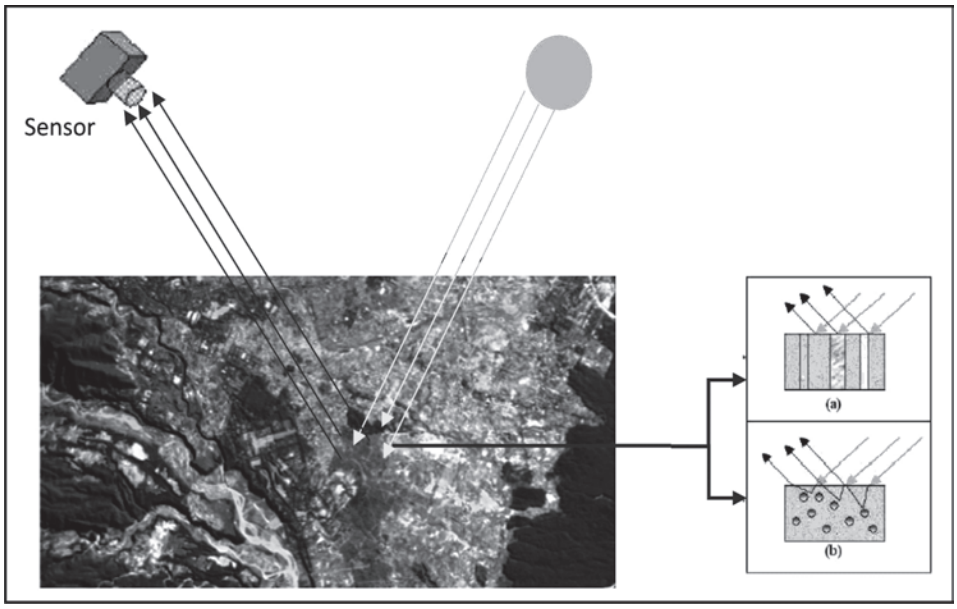


Figure 70. Mixing model illustration, a) Linear mixing (no multiple scattering) and b) Non Linear mixing scenario (multiple bounces due to intimate mixture)

If there are ρ endmembers, then the linear mixture model can be expressed as

$$x = \sum m_i s_{ii} + w_i = M_s + w, \qquad j = 1, 2, \ldots \ldots, N \tag{4.2}$$

where, x - L × 1 received pixel spectra

M - *L* × *p* matrix, whose columns are L×1 endmembers.

s - abundance fraction of each endmember in a pixel

w - *L* × 1 additive noise

N - number of pixels in the image

To be physically meaningful the linear mixture model is subjected to following two constraints; the first is the non negativity constraint,

$s_{ii} \geq 0$

and the second is the full additivity constraint,

$\sum s_{ii} = 1$

Spectral unmixing can defined as the process of determination of the number of image endmembers and their pure signatures and the amount in which they appear in the given mixed pixel. The whole process of end to end spectral unmixing can be presented as a sequence of three consecutive procedures [13]:

- **Dimensionality Reduction:** Reduce the dimension of the data in the scene. This step is optional and is only invoked by some algorithms to reduce the computational load of subsequent steps.
- **Endmember Determination:** Estimate the set of distinct spectra (endmembers) that constitute the mixed pixels in the scene.
- **Spectral Unmixing:** Estimate the fractional abundances of each mixed pixel from its spectrum and the endmember spectra.

The procedure of spectral unmixing in ENVI after the first two steps is given below:

1. From the ENVI main menu bar, select **Spectral** → **Mapping Methods** → **Linear Spectral Unmixing**. The Input File dialog appears.
2. Select the input file in **Unmixing Input File** dialog box and click **OK**.
3. In **Endmember Collection: Unmixing** dialog box, select **Import** → ***source of spectra to match from the drop down menu*** and click **Apply.**
4. To apply a **Unit-Sum Constraint** in the unmixing, use the Toggle Button to select **Yes** and enter a **Weight** value. This weight is added to the system of simultaneous equations in the unmixing inversion process. Larger weights cause the unmixing to honor the unit-sum constraint more closely.
5. Enter the **Output Filename** and click **OK**.

The result of the unmixing step will be the fraction abundance images for each representative class. The pixel values of these images indicate the fraction of the pixel that contains the endmember material corresponding to that image.

4.5. Matched Filtering

Matched Filtering is a signal processing technique in which the response of a known endmember is maximized and the response of the composite unknown background id suppressed, thus matching the known spectra [14]. It is used to find the abundances of user-defined endmembers using a partial unmixing. It provides a rapid means of detecting specific materials based on matches to library or image endmember spectra and does not require knowledge of all the endmembers within an image scene. This technique produces images similar to the unmixing, but with significantly less computation and without the requirement to know all the endmembers.

1. From the ENVI main menu bar, select **Spectral à Mapping Methods** → **Matched Filtering**. The **Input File** dialog box appears.
2. Select the input file in **Matched Filter Input File** dialog box and click **OK**.
3. In **Endmember Collection: Matched Filter** dialog box, select **Import** → ***source of spectra to match from the drop down menu*** and click **Apply.**
4. Use the toggle button to select **Compute New Covariance Stats** and enter an **Output Statistics Filename**.
5. Enter the Output Filename and click **OK**.

The results of MF appear as a series of gray scale images, one for each selected endmember. Floating-point results provide a means of estimating the relative degree of match to the reference spectrum and approximate sub-pixel abundance, where 1.0 is a perfect match.

4.6. Binary Encoding

The binary encoding classification technique encodes the data and endmember spectra into zeros and ones, based on whether a band falls below or above the spectrum mean, respectively. An exclusive OR function compares each encoded reference spectrum with the encoded data spectra and produces a classification image. All pixels are classified to the endmember with the greatest number of bands that match, unless you specify a minimum match threshold, in which case some pixels may be unclassified if they do not meet the criteria.

1. From the ENVI main menu bar, select **Classification** → **Supervised à Binary Encoding** or **Spectral** → **Mapping Methods** → **Binary Encoding**
2. The **Classification Input File** dialog box appears
3. Select the input file in **Classification Input File** dialog box and click **OK**
4. In the **Select Classes from Regions** list, select ROIs and/or vectors as training classes. The ROIs listed are derived from the available ROIs in the ROI Tool dialog.
5. Select one of the following **thresholding options** from the **Set Minimum Encoding Threshold** area:
   - **None:** No threshold.

- **Single Value:** Use a single threshold for all classes. Enter a decimal percentage value (from 0.0 to 1.0) in the Minimum Encoding Threshold field. The percentage value represents the number of bands that must match.
- **Multiple Values:** Enter a different threshold for each class. Use this option as follows:
  - In the list of classes, select the class or classes to which you want to assign different threshold values and click Multiple Values. The **Assign Minimum Encoding Threshold** dialog appears.
  - Select a class, and enter a threshold value in the field at the bottom of the dialog. If you do not enter a minimum value, ENVI classifies all pixels. Repeat for each class. Click **OK** when you are finished.

6. Enter the **Output Class Filename**
7. Toggle button to select whether or not to create rule images. Rule images are created for intermediate classification of image results before final assignment of classes.
8. Enter the **Output Rule Filename**
9. Click **OK**. ENVI adds the resulting output to the Available Bands List. If you selected to output rule images, ENVI creates rule images for each class with the pixel values equal to the percentage (0-100%) of bands that matched that class.

4.7. Spectral Feature Fitting and Analysis

Spectral Feature Fitting (SFF) is an absorption-feature-based method for matching image spectra to reference endmembers. Most methods used for analysis of hyperspectral data still do not directly identify specific materials. They only indicate how similar the material is to another known material or how unique it is with respect to other materials. Techniques for direct identification of materials, however, via extraction of specific spectral features from field and laboratory reflectance spectra have been in use for many years.

These methods require that data be reduced to reflectance and that a continuum be removed from the reflectance data prior to analysis. A continuum is a mathematical function used to isolate a particular absorption feature for analysis. Spectra are normalized to a common reference using a continuum formed by defining high points of the spectrum (local maxima) and fitting straight line segments between these points. The continuum is removed by dividing it into the original spectrum (Figure 71).

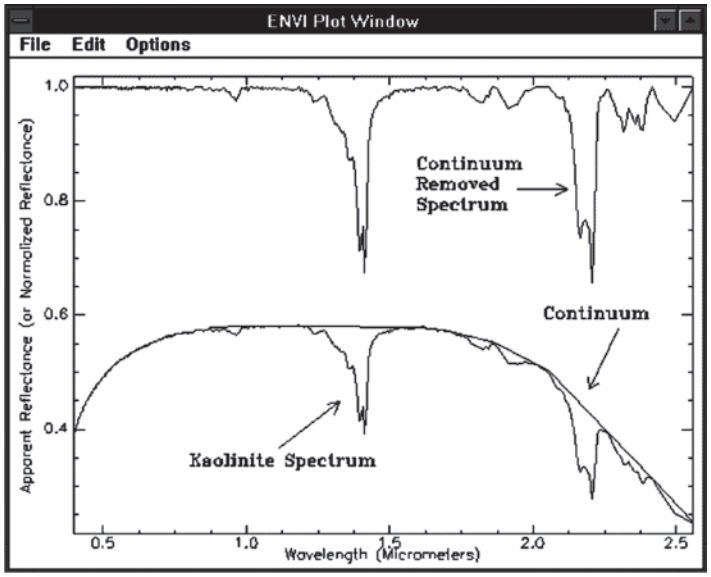


Figure 71. Example of a fitted continuum and a continuum removed spectrum

Continuum removal can be performed on data files or on individual spectra in a plot window:

1. From the ENVI main menu bar, select **Spectral** → **Mapping Methods** → **Continuum Removal**. The Input File dialog appears.
2. Select the Input file and click **OK.**
3. The **Continuum Removal Parameters** dialog appears.
4. Enter the Output File name and click **OK**. ENVI adds the resulting output to the **Available Bands List**.

4.7.1. Recovering the Continuum Curve

The Continuum Removal tool only outputs the continuum-removed spectra; it does not show you the curve of the calculated continuum.

1. Display a hyperspectral image.
2. From the Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. A Spectral Profile window appears.
3. From the Spectral Profile menu bar, select **Options** → **New Window with Plots**. An ENVI Plot Window appears.
4. From the ENVI Plot Window menu bar, select **Plot_Function** → **Continuum Removed**.
5. From the ENVI main menu bar, select **Spectral** → **Spectral Math**. The Spectral Math dialog appears.
6. In the **Enter an expression** field, enter the following:
   - float(S1) / (S2)
7. Click **OK**. The **Variables to Spectra Pairings** dialog appears.
8. Map S1 to the original spectrum (in the Spectral Profile window), and map S2 to the continuum-removed plot (in the ENVI Plot Window).
9. Ensure that the **Output Result to toggle** button is set to Same Window.
10. Click **OK**. The continuum curve plots over the original spectrum as in Figure 72.

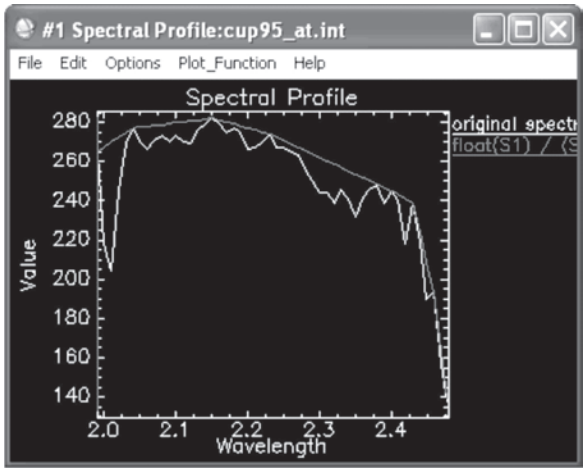


Figure 72. Continuum Curve

4.7.2. Spectral Feature Fitting

Spectral feature fitting requires that reference endmembers be selected from either the image or a spectral library, that both the reference and unknown spectra have the continuum removed, and that each reference endmember spectrum be scaled to match the unknown spectrum. A "Scale" image is produced for each endmember selected for analysis by first subtracting the continuum-removed spectra from one, thus inverting them and making the continuum zero. A single multiplicative scaling factor is then determined that makes the reference spectrum match the unknown spectrum. Assuming that a reasonable spectral range has been selected, a large scaling factor is equivalent to a deep spectral feature, while a small scaling factor indicates a weak spectral feature.

1. From the ENVI main menu bar, select **Spectral** → **Mapping Methods** → **Spectral Feature Fitting.** The Input File dialog appears.
2. Select the input file and click **OK**.
3. In the Input File dialog box, select **Spectral Subset**. The File Spectral Subset dialog appears.
4. Select bands to subset around the region containing the absorption features of interest and click **OK**.
5. Click **OK** in the Input File dialog. The **Endmember Collection:Feature Fitting** dialog box appears.
6. Import the reference spectra and click **Apply**.
7. The **Spectral Feature Fitting Parameters** dialog box appears.
8. Use the **toggle button** to switch between **Output separate Scale and RMS Images or Output Combined (Scale/RMS) Image.**
9. Click **OK**. ENVI adds the resulting output to the **Available Bands List**.

A scale image and RMS image or a combined "fit" (scale/RMS) image is output for each reference spectrum. The image is a measure of absorption feature depth, which is related to material abundance. The brighter pixels in the scale image indicate a better match to the reference material in those pixels (for areas with a low rms error). However, a large scale value (> 1) can result if incorrect reference endmembers are input or if the incorrect wavelength range is used. The image and reference spectra are compared at each wavelength in a least-squares sense, and the RMS error is calculated for each reference spectrum. Dark pixels in the rms error image indicate a low error. You can use the RMS errors and scale image results to locate areas that best match the reference spectrum.

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Appendix – A

Scene center location	Lat:- 75.38439941 Long:- 31.76269913
Sensor altitude	705 Km
Ground elevation	0.100 Km
Pixel size	30 m
Flight date	May 12th, 2008
Flight Time	0.22
Atmospheric Model	Mid Latitude Summer
Water Retrieval	Yes
Water Absorption Feature	820 nm
Aerosol Model	Urban
Aerosol Retrieval	2-Band (K-T)
Initial Visibility	40 Km
Spectral Polishing	Yes
Width (No. of bands	9.00
Wavelength Recalibration	No
Aerosol Scale Height	2 Km
CO2 mixing ratio (ppm)	390 ppm
Use Square Slit Function	No
Use Adjacency Correction	Yes
Reuse MODTRAN Calculation	No
Modtran Resolution	15 cm-1
MODTRAN Multiscatter Model	Scaled Distort
No of Distort Streams	8.00
Zenith Angle	7.50
Azimuth Angle	115:31:43:68
Use Tiled Processing	Full Scene
Automatically Save Template File	Yes
Output Reflectance Scale Factor	1000.00
Output Diagnostic Files	No