

Airborne Visible/Infrared Imaging Spectrometer Next Generation (AVIRIS-NG) Data User's Guide - India Campaign 2015



Contacts:

Robert O. Green Robert.o.green@jpl.nasa.gov

Sarah Lundeen sarah.r.lundeen@jpl.nasa.gov

Ian McCubbin ian.b.mccubbin@jpl.nasa.gov

David R. Thompson david.r.thompson@jpl.nasa.gov

Brian D. Bue brian.d.bue@jpl.nasa.gov

Revision: Version 1.0

July 28, 2015



Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109-8099

Copyright 2015 California Institute of Technology.
All Rights Reserved. US Government support acknowledged.

ACRONYMS

ASCII	American Standard Code for Information Interchange
ATREM	Atmosphere Removal Program
AVIRIS-NG	Airborne Visible/Infrared Imaging Spectrometer Next Generation
BIL	Band Interleaved By Line Format
BIP	Band Interleaved By Pixel Format
BSQ	Band Sequential Format
CM	Centimeter
DN	Digital Numbers
ENVI	Environment for Visualizing Images
FWHM	Full-width-at-half-maximum
GLT	Geographic Lookup Table
GPS	Global Positioning System
HDR	Detached Header File
IEEE	Institute of Electrical and Electronics Engineers
IGM	Input Geometry File
IMU	Inertial Measurement Unit
JPL	Jet Propulsion Laboratory
L0	Level 0 Data Product (raw)
L1B	Level 1B Data Product (radiance)
L2	Level 2 Data Product (reflectance)
μ W	Microwatt
NASA	National Aeronautics and Space Administration
NM	Nanometer
PPS	Pulse Per Second
SDS	Science Data System (JPL)
SR	Steradian or square radian
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator

1 Introduction

This document describes use and interpretation of data from the Next Generation Airborne Visible Infrared Imaging Spectrometer (AVIRIS-NG). The data has been prepared especially for the specific needs of the 2015 India campaign.

The AVIRIS-NG data is distributed in an ENVI-compatible format: each image is a binary image “cube” with a detached ASCII header file. A detached header provides compatibility with ENVI software. The header file is a separate ASCII text file that contains information ENVI uses to read an image data file.

The header file provides:

- The dimensions and interleave convention
- The embedded header, if present
- The data format
- Other pertinent information such as spectral calibration data

The ENVI-compatible format is open and generic with interfaces available for many possible software packages. A full description can be found on the Exelis ENVI web site (<http://www.exelisvis.com/docs/ENVIImageFiles.html>). We find that the ENVI software provided by Exelis is the most convenient way to view and manipulate these data, and this document assumes that the user has installed a recent version of the software. Other libraries such as the Matlab ENVI Toolbox or spectral python (<http://www.spectralpython.net>) can also parse this format.

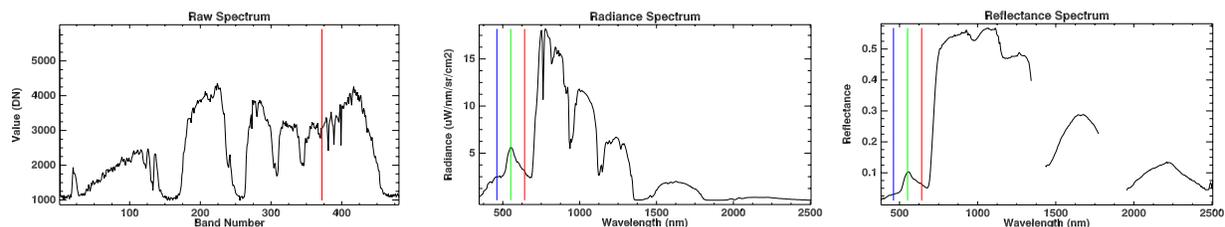


Figure 1: Spectrum for a single AVIRIS-NG measurement, at different levels of analysis. The left panel shows the raw data, known as Level 0. The center panel shows calibrated radiances, known as Level 1. The right panel shows Level 2, surface reflectance.

The three main levels of processing are Level 0 (raw data), level 1 (calibrated radiances) and Level 2 (atmospherically-corrected surface reflectances). Figure 1 shows examples of a single vegetation spectrum at each stage. The first two levels of processing are available on site, while Level 2 is produced at the JPL Science Data System (SDS). Separately from this processing, *orthorectification* maps the data onto a grid of regular X,Y positions with embedded map projection information. The data required to perform this operation is stored in files called Input Geometry Files (IGMs) and Geographic Lookup Tables (GLTs), and can be applied directly to the Level 1 data. IGM and GLT files are also available on-site; they can be applied easily using the ENVI software package. For example, a flightline that was collected at 18:42:01 UTC on April 23, 2015 might produce the following files:

Level	Filename	Contents	Available
Level 0 (raw)	ang20150423t184201_raw	Raw spectrometer data	On site
	ang20150423t184201_raw.hdr	Header	“
	ang20150423t184201_gps	GPS / IMU position data	“
	ang20150423t184201_pps	Timing synchronization data	“
	ang20150423t184201_raw_igm	Input Geometry (IGM) for orthorectification	“
	ang20150423t184201_raw_igm.hdr	Header	“
	ang20150423t184201_raw_glt	Geographic Lookup Table (GLT)	“
	ang20150423t184201_raw_glt.hdr	Header	“
Level 1 (radiance)	ang20150423t184201_rdn	Radiance data	“
	ang20150423t184201_rdn.hdr	Header	“
	ang20150423t184201_rdn_igm	Input Geometry (IGM) for orthorectification	“
	ang20150423t184201_rdn_igm.hdr	Header	“
	ang20150423t184201_rdn_glt	Geographic Lookup Table (GLT)	“
Level 2 (reflectance)	ang20150423t184201_rfl	Reflectance data	JPL SDS
	ang20150423t184201_rfl.hdr	Header	“

This document describes each of the file formats in greater detail. To facilitate review, we have also provided a “redaction tool” that will erase specific data segments from Level 1 and Level 0 data. The final chapter describes how to use this tool.

2 Level 0 (raw)

The Level 0 files record data captured directly from the instrument and position sensors. They are in the form of 16-bit unsigned integer “digital numbers” (DN) with 680 cross-track samples and 481 channels, recorded using the Band Interleaved by Line (BIL) convention. This is illustrated in Figure 2-1. These files are typically very large because they are oversampled in the along-track dimension. They also contain calibration segments at the beginning and end of the flightline, and embed Global Positioning System (GPS)/Inertial Measurement Unit(IMU) data as well as timestamps in each line of data. All of this embedded data is important for subsequent processing. In addition, GPS/IMU and synchronous timing information are stored separately in files suffixed *_gps and *_pps respectively. The average user will not need these data, but they serve as the input to the JPL processing pipeline so they are important to recover higher-level products.

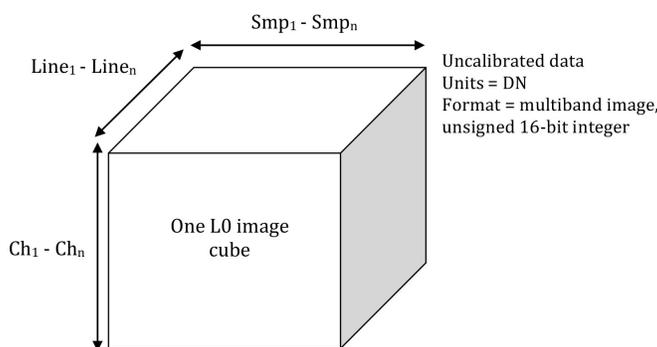


Figure 2-1. Illustration of an AVIRIS-NG Level 0 Spectral Radiance Image Cube

Onboard processing generates ancillary files that can be used to orthorectify the radiance image cube. These files follow the convention of ENVI and prior AVIRIS-NG and AVIRIS data products. The GLT file (*_glt) is an orthorectified product with a fixed pixel size projected into

a rotated Universal Transverse Mercator (UTM) system that contains the information about which original pixel occupies which output pixel in the final product. Additionally, each pixel is sign-coded to indicate if it is real (indicated by a positive value) or a nearest-neighbor infill (indicated by negative values). The GLT file contains two parameters:

- 1) sample number
- 2) original line number.

They are stored in 16-bit integer format, IEEE little endian, BIL format.

The Input Geometry File (IGM) contains the location for each pixel in the unorthorectified radiance image cube. It has three parameters:

- 1) WGS-84 longitude (reported in decimal degrees)
- 2) WGS-84 latitude (reported in decimal degrees)
- 3) Estimated ground elevation at each pixel center (reported in meters).

No map correction or resampling is applied to the raw image cube; the IGM file only reports the surface location of the unadjusted pixel centers. Values are stored in IEEE floating point, 64-bit double precision format with BIL interleave.

For detailed instructions on how to orthorectify an image using IGM and GLT files, see Appendix A for a tutorial.

3 Level 1 (radiance)

Radiance files (*_rdn) provide units of radiance at-sensor in $\mu\text{W}/\text{sr}/\text{nm}/\text{cm}^2$. Values are stored in an IEEE little-endian floating point format (32-bit single precision) with 598 cross-track samples and 432 channels per line, with BIL interleave. This is illustrated in Figure 3-1 and Figure 2-2. The associated header files provide image dimension information, as well as the wavelength calibration and Full Width at Half Maximum (FWHM) of the spectral response function.

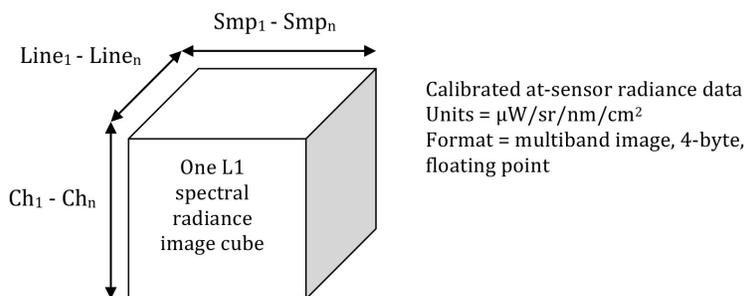


Figure 3-1. Illustration of an AVIRIS-NG Level 1 Spectral Radiance Image Cube

Note that the radiance data is smaller than the raw data because the data has been averaged in the downtrack (flight) direction to account for oversampling. It has also been clipped spatially and spectrally to the active areas of the detector. The radiance cube is associated with its own set of GLT and IGM files for orthorectification, similar to those of the raw data. The procedure for using them is the same.

4 Level 2 (reflectance)

Level 2 processing performs atmospheric correction to recover the Lambertian surface reflectance. This stage of processing involves modeling the atmosphere, dynamically retrieving quantities such as water vapor content. The AVIRIS-NG pipeline is based on the ATREM algorithm originally by Bo-Cai Gao and later modified. A full description can be found in:

David R. Thompson, Bo-Cai Gao, Robert O. Green, Dar A. Roberts, Philip E. Dennison, Sarah R. Lundeen, Atmospheric correction for global mapping spectroscopy: ATREM advances for the HypsIRI preparatory campaign, Remote Sensing of Environment, 2015, ISSN 0034-4257, <http://dx.doi.org/10.1016/j.rse.2015.02.010>.

5 Redaction tool

The redaction tool is designed to allow a person browsing unorthorectified Level 1 data to zero-out certain segments of spectral data from Level 1 and Level 0 products, while preserving the other segments. In order to run this tool, a recent version of Python is required and is available from <http://www.python.org>.

Before attempting to zero-out lines, we recommend saving a copy of the raw data in case of errors. After downloading and installing Python, run the tool from the command line using the (UNIX) syntax:

➤ `python redact.py`

The redaction wipes a specified segment of lines from the Level 1 radiance file. It will also translate these lines into corresponding locations in the Level 0 (raw) file, and wipe out that data as well. However, it will preserve the integrity of the file format so that the rest of the data can still be used in later processing. The result is just as if someone had covered the instrument during the zeroed segment. When you run the program, there are several steps to perform:

1. The program will present a dialogue window asking for a Level 0 file. Select the *raw file associated with the flightline you wish to redact.
2. The program will present a dialogue window asking for a Level 1 file. Select the *rdn file associated with the flightline you wish to redact.
3. The program will ask for beginning and ending lines. Select the rows that you wish to zero out. **Here, row numbers refer to the unorthorectified version of the Level 1 radiance data.**
4. The program will ask you whether you wish to continue. If the user continues, it will zero out the appropriate segments in both raw and radiance files, writing the result to new files in the same directories, but appending the string “_redacted” to the filename.

We advise checking the redacted image data in ENVI to ensure that the appropriate segment was deleted.

APPENDIX A ENVI-compatible Image File Description

The ENVI image format is a flat-binary raster file with an accompanying ASCII [header file](#). The data are stored as a binary stream of bytes in one of the following formats, often referred to as the *interleave type*:

- **Band Sequential:** BSQ format is the simplest format, where each line of the data is followed immediately by the next line in the same spectral band. This format is optimal for spatial (x,y) access of any part of a single spectral band.
- **Band-interleaved-by-pixel:** BIP format stores 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, and so forth, interleaved up to the number of pixels. This format provides optimum performance for spectral (z) access of the image data.
- **Band-interleaved-by-line:** BIL format stores 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. This format provides a compromise in performance between spatial and spectral processing and is the recommended file format for most ENVI processing tasks.

The ENVI raster format does not support 64-bit integer (signed or unsigned) data types.

APPENDIX B How to orthorectify/georeference an image using IGM and GLT files using ENVI

Reference: <http://www.exelisvis.com/docs/GeoreferenceFromInputGeometry.html>

Use Georeference from Input Geometry to georeference data that have an associated file containing map locations for every pixel. Georeferenced images have null values around their edges that must be masked in processing; these are often inflated by replicated pixels. Therefore, it is suggested that you process the data first, then apply the georeferencing to derive final products.

Build GLT Files

Use **Build GLT** to build a geographic lookup table (GLT) file from an input geometry file. A GLT file contains map locations for every pixel of the image it is associated with. A GLT consists of two bands: sample numbers and line numbers of the georeferenced image. Pixel values indicate the sample or line number of the pixel in the original input image that belongs at the given map location in the output image.

If the GLT values are positive, then an exact match from the input image was found; in other words, the input image actually contained a pixel for this map location. If the GLT values are negative, then a nearest-neighbor pixel is being used because the input image does not actually contain a pixel for the corresponding map location. If the GLT value is 0, then there was no nearest neighbor within seven pixels of this map location in the input image. This is a very accurate method of georeferencing data because it places every pixel at its exact map location, avoiding the use of GCPs and polynomial warping.

A GLT places all of the pixels in the input image (since there is a map x,y location for each pixel) exactly where they belong in the output image, rounding to the nearest integer location in output pixel space. The output image may still have remaining "holes" where no input pixel landed. These holes are filled with the nearest valid pixel from the first step, which is essentially a nearest-neighbor resampling.

The GLT file has a fixed pixel size projected into a rotated UTM system. It uses one-based coordinates (the upper-left pixel is located at 1,1).

Note: ENVI currently does not allow a geographic lookup table (GLT)-based image to be displayed along with an image georeferenced to a standard map projection.

Perform the following steps to build a GLT file:

1. From the Toolbox, select **Geometric Correction > Build GLT**. The Input X Geometry Band dialog appears.
2. Select the band that contains the x geometry coordinates.
3. Click **OK**. The Input Y Geometry Band dialog appears.
4. Select the band that contains the y geometry coordinates. Click **OK**. The Geometry Projection Information dialog appears.
5. In the **Input Projection of Geometry Bands** list, select the projection type.
6. In the **Output Projection for Georeferencing** list, select the projection for the georeferencing.
7. Click **OK**.

A default output pixel size and rotation angle is calculated, and it appears in the Build Geometry Lookup File Parameters dialog.

The default output pixel size is calculated based on the map coordinates in output space. The default output rotation angle is used to minimize the output file size. If the rotation angle is set to 0 then north will be up in the output image. If it is set to another angle, then north will be at an angle and will not be “up” in the output image. The rotation angle is stored in the ENVI header and is used when overlaying grids, so the grid lines appear at an angle.

- To change the output pixel size, replace the value in the **Output Pixel Size** field.
- To change the output rotation angle, replace the value in the **Output Rotation** field.

Note: If you change a non-zero rotation angle to 0 so north is up, your resulting image may contain a lot of background fill and may become very large.

The process runs in two parts. ENVI adds the resulting output to the Layer Manager.

Georeference from GLT

Use **Georeference from GLT** to georeference image data or results using a Geographic Lookup Table GLT file.

Note: ENVI currently does not allow a geographic lookup table (GLT)-based image to be displayed along with an image georeferenced to a standard map projection.

1. From the Toolbox, select **Geometric Correction > Georeference from GLT**. The Input Geometry Lookup File dialog appears.
2. Select a GLT file and click **OK**. The Input Data File dialog appears.
3. Select an input file and perform optional spectral [subsetting](#), then click **OK**. The Georeference from GLT Parameters dialog appears.
4. If you used a subset of the original data as the input file, click the **Subset to Output Image Boundary** toggle button to select whether to output only the warped subset region or whether to output that subset warped within the entire output boundary.
5. In the **Background Value field**, enter the DN value to use as the background value around the edges of the warped data.
6. Enter an output filename.
7. Click **OK**.

Georeference from IGM

Use **Georeference from IGM** to georeference data using an Input Geometry (IGM) file. An IGM file contains the map information of the image, stored in two bands: one for x coordinates (longitude or easting) and one for y coordinates (latitude or northing). Some datasets come with specific latitude and longitude bands, which make up the IGM file. Additionally, ENVI generates IGM files for various sensors such as SeaWiFS and AVHRR. The IGM file itself is not georeferenced, but it does contain the georeferencing information for each original raw pixel. The IGM file is used to create (on-the-fly) a

geographic lookup table (GLT) file that contains the information about which original pixel occupies which output pixel in the final product.

Perform the following steps to georeference an image using an IGM:

1. From the Toolbox, select **Geometric Correction > Georeference from IGM**. The Input Data File dialog appears.
2. Select an input file and perform optional spectral [subsetting](#), then click **OK**. The Input X Geometry Band dialog appears.
3. Select the band that contains the x geometry coordinates and click **OK**. The Input Y Geometry Band dialog appears.
4. Select the band that contains the y geometry coordinates and click **OK**. The Geometry Projection Information dialog appears.
5. In the **Input Projection of Geometry Bands** list, select the projection type.
6. In the **Output Projection for Georeferencing** list, select the projection for the georeferencing.
7. Click **OK**.

A default output pixel size and rotation angle are calculated, and they appear in the Build Geometry Lookup File Parameters dialog.

The default output pixel size is calculated based on the map coordinates in output space. The default output rotation angle is used to minimize the output file size. If the rotation angle is set to 0, then north will be up in the output image. If it is set to another angle, then north will be at an angle and will not be “up” in the output image. The rotation angle is stored in the ENVI header and is used when overlaying grids, so the grid lines appear at an angle.

- To change the output pixel size, replace the value in the **Output Pixel Size** field.
- To change the output rotation angle, replace the value in the **Output Rotation** field.

Note: If you change a non-zero rotation angle to 0 so north is up, your resulting image may contain a lot of background fill and may become very large.

8. In the **Georeference Background Value field**, enter the DN value to use as the background value around the edges of the georeferenced data.
9. Enter an output filename.
10. Click **OK**.

Build Super GLT Files

Use **Build Super GLT** to build super GLT files from IGM files. The super GLT file is not an image file; it contains information about how many and which input pixels contribute to the output pixel.

The Super GLT process involves optimal radial resampling, where every input pixel within a given radius that contributes to the value of an output pixel is considered in a weighted fashion. In comparison, bilinear resampling arbitrarily averages a group of 2 x 2 neighbors, and cubic convolution resampling averages a group of 4 x 4 or 16 x 16 neighbors. Super GLT averages every relevant pixel in the file within

a given radius to determine the best possible output pixel value. Super GLT, therefore, is much slower than a normal GLT process.

The Super GLT method is particularly useful for aircraft data where the sensor may scan a given point on the ground multiple times, due to the roll, pitch, or yaw of the aircraft. This means an output pixel might be best represented by an average of three different input pixels that are located in three different locations in the input file. This example illustrates why the Super GLT process can take a longer time to process.

Follow the steps below to build a Super GLT.

Note: You can use **Super Georeferencing from IGM** to combine building the super GLT and georeferencing from it into one step.

1. From the Toolbox, select **Geometric Correction > Build Super GLT**. The Input X Geometry Band dialog appears.
2. Select the band that contains the x geometry coordinates and click **OK**. The Input Y Geometry Band dialog appears.
3. Select the band that contains the y geometry coordinates and click **OK**. The Geometry Projection Information dialog appears.
4. In the **Input Projection of Geometry Bands** list, select the projection type.
5. In the **Output Projection for Georeferencing** list, select the projection for the georeferencing.
6. Click **OK**.

A default output pixel size and rotation angle are calculated, and they appear in the Build Geometry Lookup File Parameters dialog.

The default output pixel size is calculated based on the map coordinates in output space. The default output rotation angle is used to minimize the output file size. If the rotation angle is set to 0, then north will be up in the output image. If it is set to another angle, then north will be at an angle and will not be “up” in the output image. The rotation angle is stored in the ENVI header and is used when overlaying grids, so the grid lines appear at an angle.

7. To change the output pixel size, replace the value in the **Output Pixel Size** field.
8. To change the output rotation angle, replace the value in the **Output Rotation** field.

Note: If you change a non-zero rotation angle to 0 so north is up, your resulting image may contain a lot of background fill and may become very large.

9. Enter an output filename.
10. Click **OK**.
11. The process runs in two parts. ENVI adds the resulting GLT file to the Layer Manager. It does not add the Super GLT file to the Layer Manager.

Georeference from Super GLT

Use **Super GLT Georeference** to georeference data using a super GLT file. This function performs radial resampling to derive the output image using a specified kernel size. Each output pixel is calculated by weighting all the pixels in the kernel by the inverse of their radial distance to the center of the output pixel. You specify the kernel size and minimum number of pixels used in the resampling.

Note: Because super GLT functions are slow, allow a significant amount of time for processing.

1. From the Toolbox, select **Geometric Correction > Super GLT Georeference**. The Input File dialog appears.
2. Select an input file and perform optional spectral [subsetting](#), then click **OK**. The Select SGL Filename dialog appears.
3. Select the super GLT file and click **OK**. The Georeference from SGL Parameters dialog appears.
4. In the **Background Pixel Value** field, enter the DN value to use as the background value around the edges of the warped data.
5. In the **Kernel Size Min** and **Max** fields, enter minimum and maximum kernel sizes, respectively.

The minimum kernel size is used in the resampling unless fewer than the minimum number of pixels to resample, or valid pixels, are contained in the kernel. If fewer than the minimum number of valid pixels are contained in the kernel, the kernel size is increased until either the minimum number of valid pixels is met or the maximum kernel size is met. If there are fewer than the minimum number of valid pixels in the maximum kernel size then the output pixel value will be set to the background value.

6. Enter a value for **Minimum Pixels to Resample**.

If fewer than the minimum number of pixels are contained in the maximum kernel size, then the output pixel value will be set to the background value.

7. Select output to **File** or **Memory**.
8. Click **OK**. ENVI adds the resulting output to the Layer Manager.

Super Georeference from IGM

The **Super Georeference from IGM** tool combines building a super GLT file and georeferencing from it into a single process. The process georeferences an image using an IGM file and uses radial resampling to derive the output image. Additionally, you have the option to output the super GLT that is built during this process.

The initial steps for super georeferencing from IGM files are the same as those for regular georeferencing from IGM files. However, there are additional steps required for building the super GLT file and creating output.

1. From the Toolbox, select **Geometric Correction > Super IGM Georeference**. The Input File dialog appears.
2. Select an input file and perform optional spectral [subsetting](#), then click **OK**. The Input X Geometry Band dialog appears.

3. Select the IGM band that contains the x geometry coordinates and click **OK**. The Input Y Geometry Band dialog appears.
4. Select the band that contains the y geometry coordinates and click **OK**. The Geometry Projection Information dialog appears.
5. In the **Input Projection of Geometry Bands** list, select the projection type.
6. In the **Output Projection for Georeferencing** list, select the projection for the georeferencing.
7. Click **OK**. A default output pixel size and rotation angle are calculated, and they appear in the Build Geometry Lookup File Parameters dialog.
8. In the **Kernel Size Min** and **Max** fields, enter minimum and maximum kernel sizes to use, respectively.

The minimum kernel size is used in the resampling unless fewer than the minimum number of pixels to resample, or valid pixels, are contained in the kernel. If fewer than the minimum number of valid pixels are contained in the kernel, the kernel size is increased until either the minimum number of valid pixels is met or the maximum kernel size is met. If there are fewer than the minimum number of valid pixels in the maximum kernel size then the output pixel value will be set to the background value.

9. Enter a value for **Minimum Pixels to Resample**.

If fewer than the minimum number of pixels are contained in the maximum kernel size, then the output pixel value will be set to the background value.

10. Enter an output SGL filename.
11. In the **Georeference Background Value** field, enter the DN value to use as the background value around the edges of the warped data.
12. Select output to **File** or **Memory**.

Click **OK**. ENVI adds the resulting output to the Layer Manager.