USING DARK CURRENT DATA TO ESTIMATE AVIRIS NOISE COVARIANCE AND IMPROVE SPECTRAL ANALYSES

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1.   INTRODUCTION AND RATIONALE

Starting in 1994, all AVIRIS data distributions include a new product useful for quantification and modeling of the noise in the reported radiance data. The "postcal" file contains approximately 100 lines of dark current data collected at the end of each data acquisition run. In essence this is a regular spectral-image cube, with 614 samples, 100 lines and 224 channels, collected with a closed shutter. Since there is no incident radiance signal, the recorded DN measure only the DC signal level and the noise in the system. Similar dark current measurements, made at the end of each line are used, with a 100 line moving average, to remove the DC signal offset. Therefore, the pixel-by-pixel fluctuations about the mean of this dark current image provide an excellent model for the additive noise that is present in AVIRIS reported radiance data. The 61,400 dark current spectra can be used to calculate the noise levels in each channel and the noise covariance matrix. Both of these noise parameters should be used to improve spectral processing techniques. Some processing techniques, such as spectral curve fitting, will benefit from a robust estimate of the channel-dependent noise levels. Other techniques, such as automated unmixing and classification, will be improved by the stable and scene-independent noise covariance estimate. Future imaging spectrometry systems should have a similar ability to record dark current data, permitting this noise characterization and modeling.

2.   DARK CURRENT DATA PROCESSING

2.1   Estimation of Noise Level and Covariance in Units of Raw DN

The postcal file reports 100 lines of dark current data, each with a full 614 samples and 224 spectral channels in units of raw DN. A measure of the background constant, or DC, signal offset is given by the mean of these spectra. Figure 1 shows one such mean for a 1994 scene. This mean is the average of the full 100 lines, similar to the offset spectrum subtracted in the standard AVIRIS data processing. An estimate of the noise level in the data is given by the standard deviation of the dark current data, with respect to the mean spectrum shown in Figure 1. The standard deviation spectrum for the same scene is shown in Figure 2.

The acquisition of over 60,000 dark current spectra permits a robust estimation of the full, 224-by-224 noise covariance matrix. The data are processed as 224-channel multivariate signals and covariance about the mean is calculated in the standard fashion. Figures 3 and 4 show the intriguing patterns evident in the dark current covariance images. These images are linearly stretched so that -0.02 and 0.15 correspond to black and white. Since these data are recorded with no incident signal, this covariance matrix

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provides our best model for the noise statistics in the radiance data. Several interesting features are worthy of discussion.

First, note the overall similarity between the two images. These are from two different AVIRIS data acquisition runs, more than two months apart in the summer of 1994. The high degree of similarity is a testament to the stability of AVIRIS, even on the sub-DN level, throughout a flight season.

The patterns in the covariance matrix can be used to reveal and to understand the sources and the properties of the noise in AVIRIS data. The blocks defined by the four spectrometers are evident, as is a complex inter-relationship among their various sources of noise. The diagonal stripes and "plaid" effects reflect noise sources with varying frequencies and amplitudes, affecting the four spectrometers differently.

2.2   Conversion to Apparent Reflectance

Analysts typically process apparent reflectance data, not raw DN. So the noise model must be converted from units of raw DN to those of apparent reflectance. This is done in two steps: 1) DN to spectral radiance; 2) spectral radiance to apparent reflectance. The dark current data are reported as raw DN and must be multiplied by appropriate scale factors to convert them to units of spectral radiance. The scale factors, included in the AVIRIS radiometric calibration file, are the product of a constant factor of 500 and a spectrally-variable radiometric calibration function.

Conversion from spectral radiance to apparent reflectance is done by deriving the appropriate scale factors that match the reduction of the actual image data to apparent reflectance. Several methods (Gao et al., 1993; Green et al., 1993) are now available to reduce observed spectral radiance to apparent surface reflectance, accounting for atmospheric effects on a pixel-by-pixel basis. These data were reduced with ATREM (Gao et al., 1993) resulting in an almost a linear conversion. Suitable scale factors for the noise model are determined through a linear regression of the apparent reflectance and radiance data sets. The best-fit scale factors are then used to convert the radiance noise model to apparent reflectance units. The linear regressions for bands 22 and 60 are shown in Figures 5 and 6. Although the pixel-by-pixel water vapor removal has introduced some non-linearity in certain channels, the scale factors are still well-determined from the slopes of the scatter plots. Once reduced to apparent reflectance, the noise standard deviations can be used to estimate signal to noise ratios. Figure 7 shows the estimated signal to noise spectrum, for the particular scene, at a reference reflectance of 0.5.

3.   APPLICATION TO SPECTRAL ANALYSES AND CONCLUSIONS

The noise modeling outlined above can be used to improve quantitative numerical analysis of AVIRIS spectra. The dark current standard deviation spectrum is a noise level estimate that should be used as an inverse weighting function. It will improve curve fitting procedures such as unmixing and spectral feature matching. In addition, the dark current covariance matrix is an estimate of the noise covariance in the observed data. This matrix can be used to precondition the data, through a series of affine transformations, to whiten the noise (Green et al., 1988; Lee et al., 1990). The noise-whitened data has unit-variance noise in all spectral channels and no correlation of noise between

channels. This noise modeling permits direct quantification of spectral discrimination and unmixing precision.

4. ACKNOWLEDGMENTS

5. REFERENCES

Gao, B-C, K. B. Heidebrecht and A. F. H. Goetz, 1993, Derivation of Scaled Surface Reflectances from AVIRIS Data, *Remote Sensing of Environment*, vol. 44, no. 2, pp. 165-178.

Green, A. A., M. Berman, P. Switzer and M. D. Craig, 1988, A Transformation for Ordering Multispectral Data in Terms of Image Quality with Implications for Noise Removal", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 26, no. 1, pp. 65-74.

Green, R.O., J. E. Conel and D. A. Roberts, 1993, Estimation of Aerosol Optical Depth and Additional Parameters for the Calculation of Apparent Surface Reflectance form Radiance Measured by the Airborne Visible/Infrared Imaging Spectrometer, *4th Annual JPL Airborne Geoscience Workshop*, JPL Pub. 93-26, v. 1, pp. 73-76.

Lee, J.B., A.S. Woodyatt and M. Berman, Enhancement of High Spectral Resolution Remote Sensing Data by a Noise-Adjusted Principal Components Transform, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 28, no. 3, pp. 295-304.
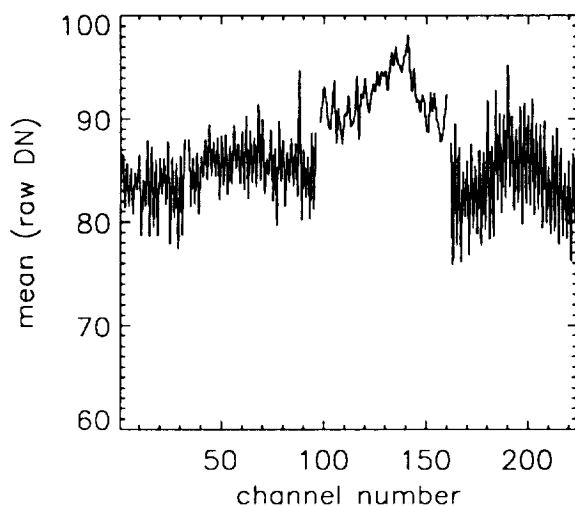

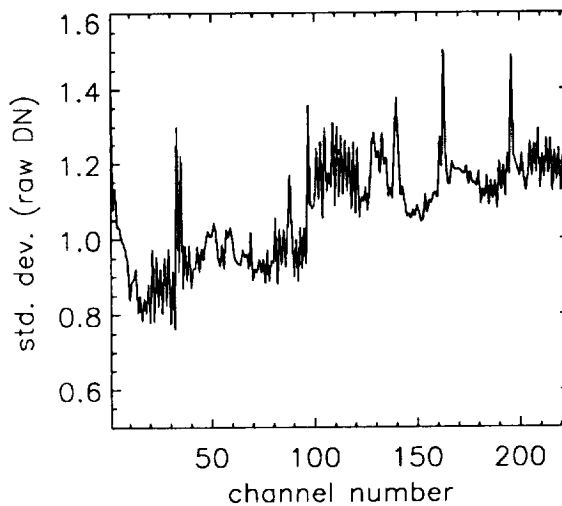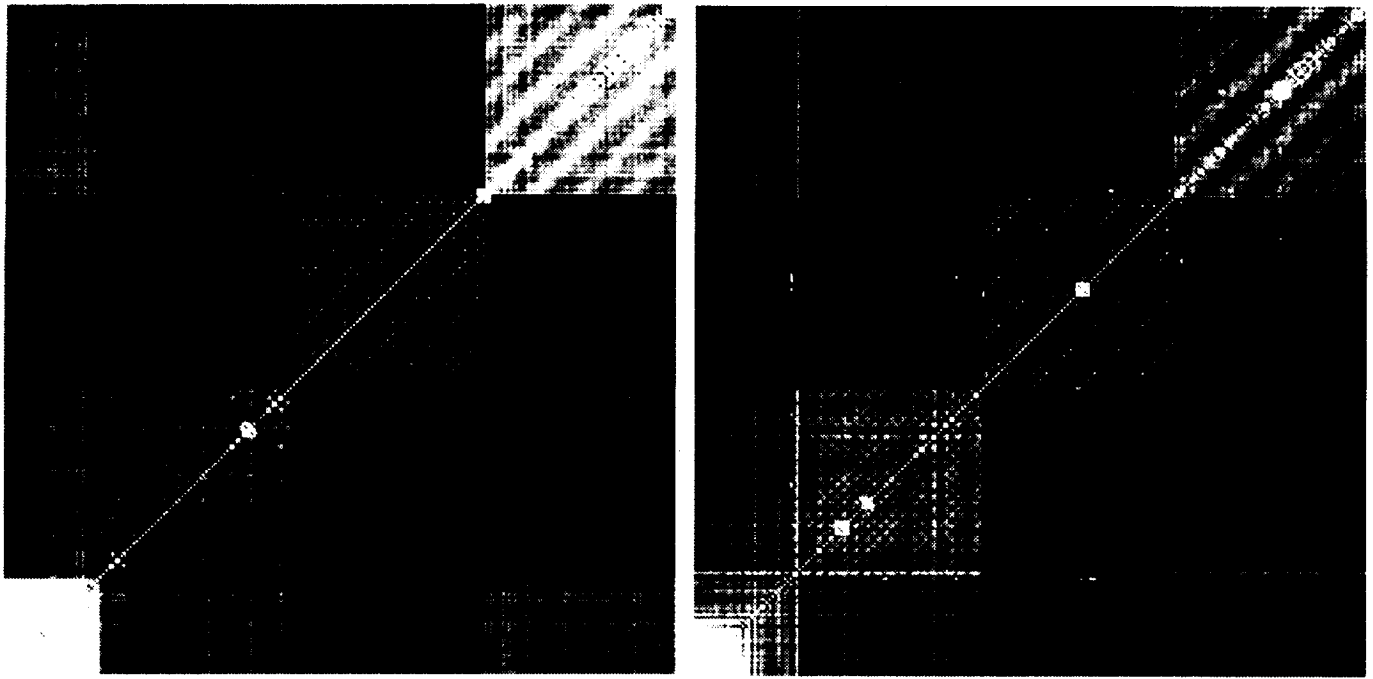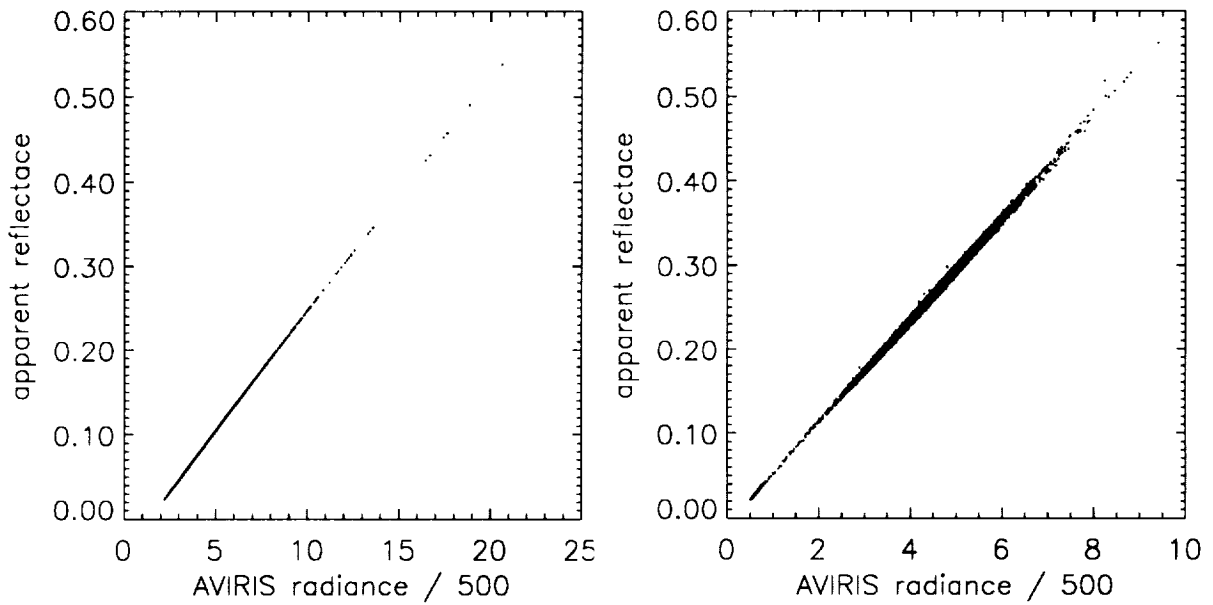Figure 1. Mean of the dark current spectra.

Figure 2. Standard deviation of the dark current.

Figures 3 and 4. Dark current covariance images for two different AVIRIS runs.

Figures 5 and 6. Scatterplots of apparent reflectance versus observed radiance, bands 22 and 60.
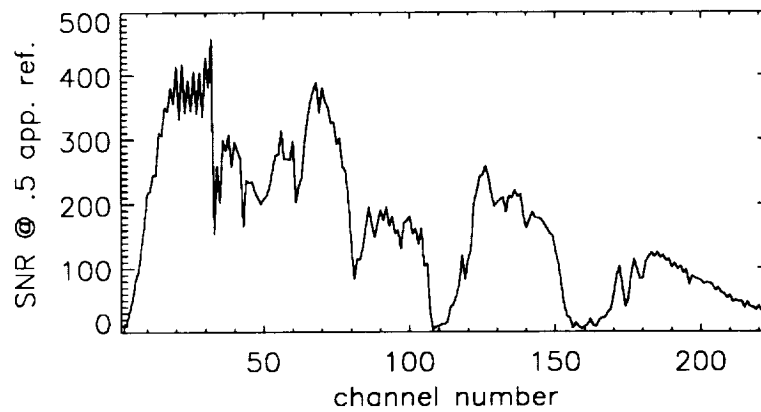

Figure 7. Predicted signal-to-noise ratio for the particular AVIRIS scene, based on a nominal 0.5 reflectance target.