Increasing the signal-to-noise ratio of AVIRIS imagery through repeated sampling

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Abstract. AVIRIS is currently one of the few imaging spectrometers available for investigations of the remote sensing of foliar chemistry. Unfortunately, the signal-to-noise ratio (SNR) of AVIRIS imagery is inadequate for discrimination of many of the spectral details associated with foliar chemicals. To increase the SNR of AVIRIS imagery the data can be averaged spatially but with a loss in spatial detail and an increase in the sample area needed in controlled field experiments. Here we investigated the potential of averaging temporally as a means of increasing the SNR of AVIRIS imagery. Three AVIRIS images were collected within a half hour period for a single study area in both March and September 1990. The SNR was estimated using 17-18, 2 x 2 matrices of spatially homogeneous pixels on both (i) the first image on each date and (ii) the temporal average of all three images on each date. Temporally averaging three AVIRIS images increased the SNR of the radiance spectra by an average of 66% and the derivative radiance spectra by an average of 50%. This technique offers the AVIRIS user increased SNR without the penalty of a decrease in spatial resolution. The adequacy of the resultant SNR for detecting signals caused by changes in foliar chemistry is still under investigation.

Introduction

The early flights of AVIRIS revealed a signal-to-noise ratio (SNR) that was less than that specified for the instrument (Vane *et al.*, 1988). Since then the SNR of AVIRIS imagery has increased but users, particularly those interested in vegetation, are looking for larger SNRs to enable the resolution of spectral details in radiance and derivative radiance spectra that have been associated with key foliar chemicals (Curran, 1990). Increasing the SNR by spatially averaging pixels is impractical for many of these users because it would decrease the spatial detail and increase the sample area needed for controlled field experiments. At the first and second NASA workshops on the Remote Sensing of Plant Biochemical Content (Peterson and Dungan, 1990), it was suggested that the AVIRIS platform, NASA's ER-2 aircraft, could be used to permit temporal averaging of images as a means of increasing the SNR of AVIRIS data. This paper reports an experiment to determine if such temporal averaging improves this ratio.

Methods

AVIRIS data were acquired by NASA's ER-2 during 3 overpasses of a slash pine plantation near Gainesville, Florida on both 4 March 1990 and 6 September 1990. Between the first and last overpasses on each date there was an interval of approximately half an hour; from 19:02 GMT to 19:26 GMT in March and from 15:34 GMT to 16:00 GMT in September. Twenty plots were chosen for further analysis: on both fertilized and unfertilized forest and one each on pasture, bare ground, water and a road intersection. Radiance and derivative radiance spectra of these plots from the first overpass in September are illustrated in figure 1.

The study area was located on the images using a base map of the study site (Curran *et al.*, 1991) and an affine transform to relate map locations to image locations. The coefficients of the transform were generated using up to 12 ground control points distributed around the study area. The accuracy of the transform was estimated at $\pm$0.52 of a pixel. Some of the forested plots had been cropped off of the subscene during pre-processing, leaving a total of between 17 and 18 plots on which to estimate SNR.

Four methods have been used by investigators to estimate the SNR of AVIRIS data (Curran and Dungan, 1989). They differ primarily in the way that noise is measured. In the laboratory the noise is the standard deviation (s) of a mean ($\bar{x}$) signal, in the image data the noise can either be the s of the dark current, the s of a matrix of homogeneous pixels or the 'nugget' of a variogram calculated over a reasonably homogeneous transect or area. All of these measures are biased and so either inflate or deflate the SNR estimate in relation to that in the user's image. Here we used the ratio of the $\bar{x}$ to the s of a 2 x 2 matrix of pixels as our estimate of SNR. This gives an accurate estimate of the signal but an overestimate of the noise as it includes spatial variation among the 4 pixels.

A matrix of 2 x 2 pixels from an apparently homogeneous area was extracted from each plot for each image. The SNR of the radiance and derivative radiance spectra were calculated on data from one image from each date. To estimate the SNR of temporally averaged data, the SNR of the radiance and derivative radiance spectra were calculated on an average of data from three images for each date.

Results

Average SNR values for the 17-18 plots are summarized and presented in figure 2 and table 1. The SNR was larger in

(i) spectrometer B than in spectrometers A, C, or D.
(ii) September than in March imagery
(iii) radiance than in derivative radiance spectra and
(iv) temporally averaged data than in data from a single overpass.

Discussion

The reason for the larger SNR in spectrometer B than in A was not only because of the greater signal for most of the targets in the near infrared, but because of the periodic noise in spectrometer A, which has been a consistent problem with the instrument. The larger SNRs in September were caused by more signal than in March (figure 3) and because the levels of AVIRIS noise had been reduced during the summer of 1990 at the Jet Propulsion Laboratory. The SNR values were quite small in the derivative radiance spectra (figure 2b), reduced by about a factor of ten below the radiance SNRs.

The use of temporally averaged pixels has been shown in this study to increase the SNR of AVIRIS imagery, though this varied with spectrometer and date for both the radiance and derivative radiance spectra. For certain applications the resultant SNR may still be inadequate and so further research is required to determine the relationship between overpass number and SNR in each spectrometer and the number of overpasses needed to reach the asymptote in SNR for each spectrometer.

Conclusion

Temporally averaging three images of AVIRIS data increased the

SNR of radiance spectra by an average of 65% in March 1990 and 67% in September 1990 and increased the SNR of derivative radiance spectra by an average of 53% in March 1990 and 48% in September 1990.

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Table 1. Percent increase in SNR between a single AVIRIS image and a temporal average of three AVIRIS images.

Date	Spectra	Spectrometer			
		A	B	C	D
March 4	Radiance	87	61	61	52
March 4	Derivative radiance	71	63	38	41
September 6	Radiance	114	52	33	68
September 6	Derivative radiance	38	70	48	35

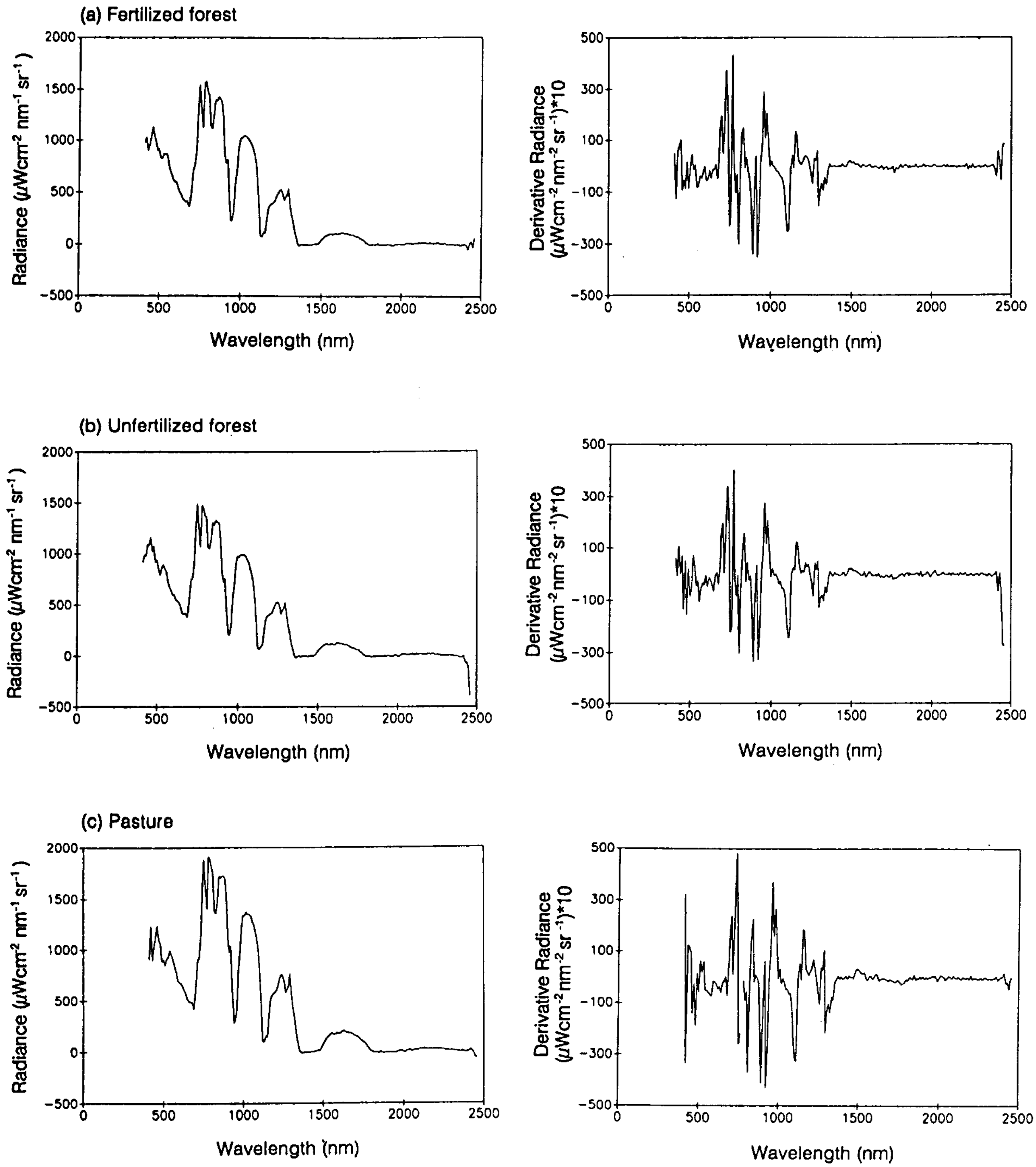

Figure 1. Radiance and derivative radiance spectra for the plots used for the estimation of SNR. These spectra are averages of the 2x2 matrices from the first overpass on September 6, 1990.

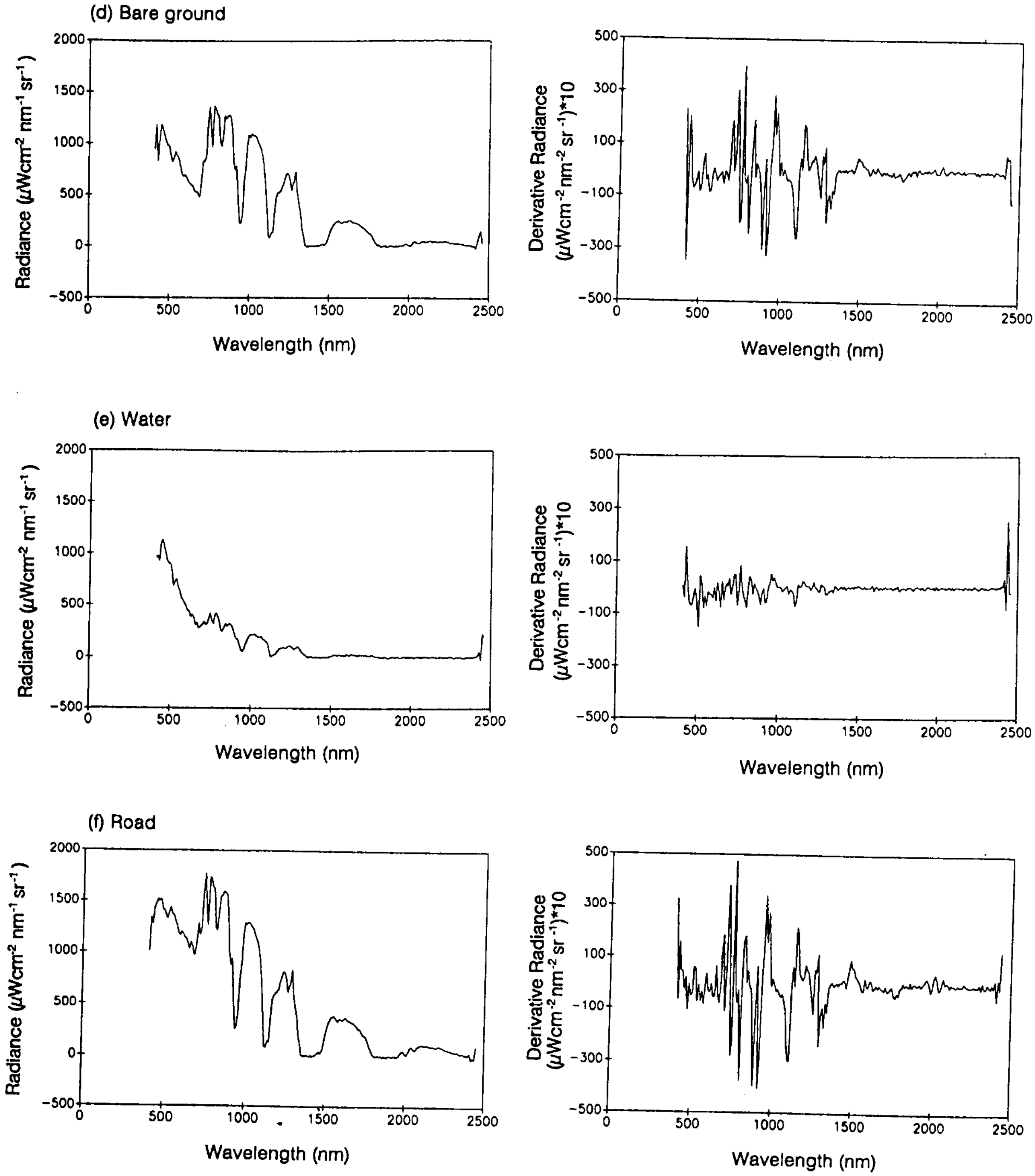

Figure 1. (continued)

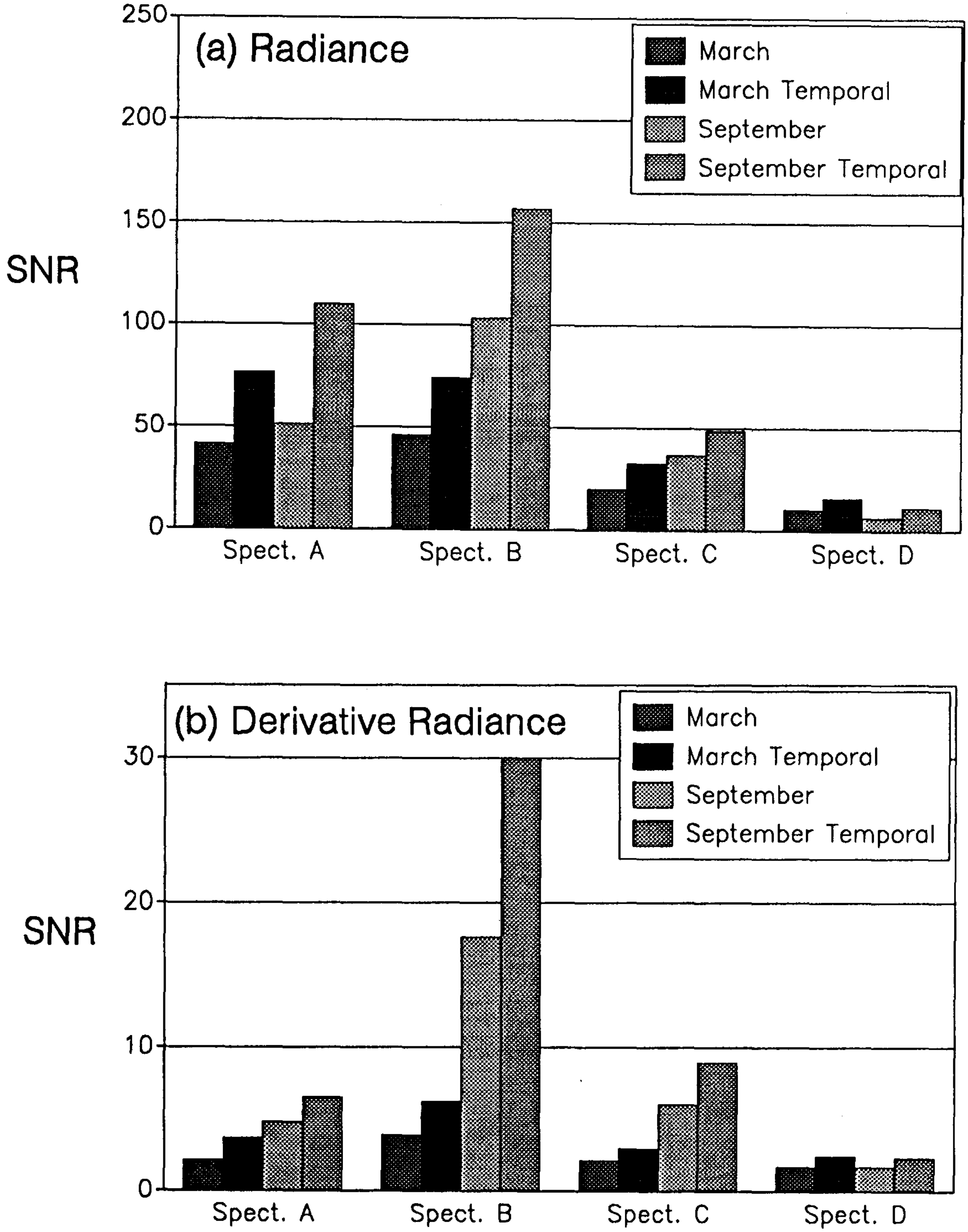

Figure 2. The SNR averaged by spectrometer for radiance spectra and derivative radiance spectra. Note the larger SNR for temporally averaged images and those recorded in September.

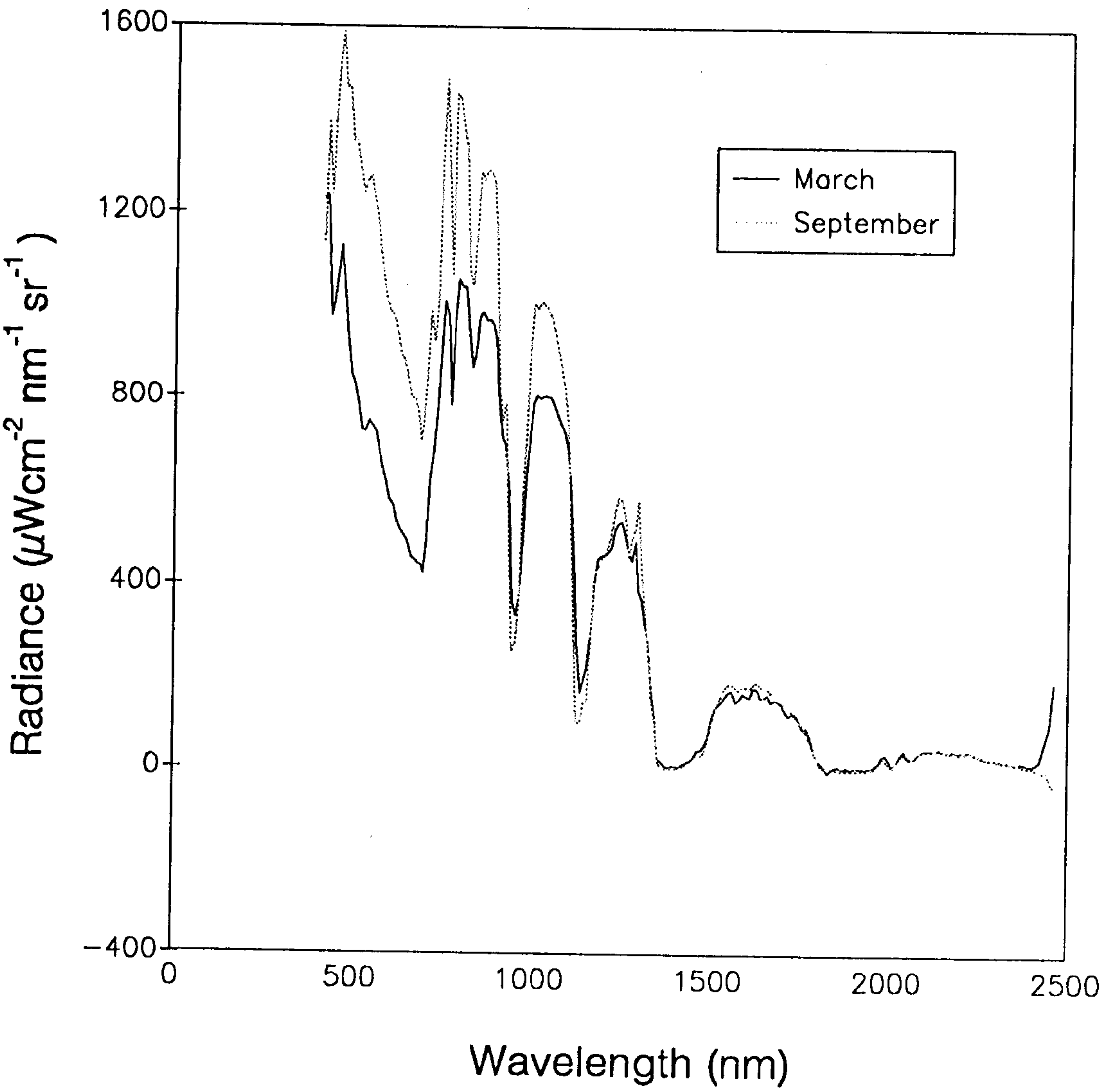

Figure 3. The average radiance for the last overpass on March 4 and September 6; note that the September image is brighter that the March image.