THE EFFECT OF SIGNAL NOISE ON THE REMOTE SENSING OF FOLIAR BIOCHEMICAL CONCENTRATION

Geoffrey M. Smith.
Department of Geography, University College of Swansea,
Singleton Park, Swansea SA2 8PP, United Kingdom.
and
Paul J. Curran.
Department of Geography, University of Southampton,
Highfield, Southampton SO9 5NH, United Kingdom.

1. INTRODUCTION

Spectral measurements made using an imaging spectrometer contain systematic and random noise, whilst the former can be corrected the latter remains a source of error in the remotely sensed signal (Curran, 1989). A number of investigators have tried to determine the signal-to-noise-ratio (SNR) of the instrument (Green *et al.*, 1992), or the resultant imagery (Curran and Dungan, 1989; Gao, 1993). However, the level of noise at which spectra are too noisy to be useful is not usually determined. The first attempt was by Goetz and Calvin (1987), who suggested that the depth of the absorption feature should be at least an order of magnitude greater than the noise and more recently Dekker (1993) suggested a SNR of around 600:1 was required in visible/near infrared wavelengths to measure a 1 gl^{-1} change in chlorophyll *a* concentration in water. The wide range of applications of imaging spectroscopy make it difficult to set SNR specifications as they are dependent on a number of factors, one of the most important being reflectance of a particular target. For example, the SNR of imagery for vegetated targets is relatively low simply because vegetation has a relatively low level of reflectance.

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is being used to estimate the concentration of biochemicals within vegetation canopies. This paper reports a study undertaken to identify first, wavebands that were highly correlated with foliar biochemical concentration and second, to determine how sensitive these correlations were to sensor noise.

2. DATA SET

The foliar samples were collected from a slash pine (*Pinus elliottii* var. *elliottii*) plantation in north central Florida (Gholz *et al.*, 1991). Ten samples of needles were collected in July 1991 from two fertilised and two control plots, these were subdivided into new and old needles giving a total of eighty samples. In the laboratory the spectral reflectance of a single layer of fresh whole needles was measured in the 400 - 2400nm wavelength range using a GER Infrared Intelligent Spectroradiometer (IRIS) and a controlled light source. The needles were then assayed using wet chemical techniques to determine the concentrations of nitrogen, lignin and cellulose.

The IRIS spectra were spectrally degraded to match AVIRIS spectra. The 400 - 1100nm spectral region was removed from further analysis as it contained wavebands that were highly correlated with the three biochemical concentrations but not at explicable wavebands. The spectra were converted to 1st and 2nd derivatives

using a Lagrangian three-point interpolation (Hildebrand, 1974).

3. THE SELECTION OF WAVEBANDS BY CORRELATION ANALYSIS

The wavebands that had the largest correlation with biochemical concentration were selected by comparing the two derivative reflectances of each waveband with the concentration of each biochemical (Ebdon, 1985). For each biochemical and derivative combination a correlogram of correlation coefficient (r) against waveband was produced. From these correlograms the wavebands with the largest r's were selected (table 1).

Table 1. The wavebands with the largest explicable correlation between derivative reflectance and foliar biochemical concentration.

Reflectance derivative	Biochemical	Selected waveband(nm)	Explaining feature(nm)	r
1st	Nitrogen	1491	1485 Protein	0.53
	Lignin	1689	1690 Lignin	0.44
	Cellulose	1281	1275 Cellulose	-0.39
2nd	Nitrogen	1195	1187 Protein	0.41
	Lignin	1709	1696 Lignin	-0.40
	Cellulose	1719	1706 Cellulose	-0.34

The biochemical explanation of the wavebands selected in table 1 were suggested by Williams and Norris (1987), Curran (1989) and Peterson (1991). The selected wavebands did not always have the largest r. The wavebands with the largest r's were sometimes unexplained or within the major water absorption bands. For both derivatives nitrogen gives the largest r and cellulose the smallest.

4. SENSITIVITY OF THE SELECTED WAVEBANDS TO NOISE

To determine the noise sensitivity of the wavebands selected in table 1, noise of increasing amplitude was added to the spectra. The noise was random, normally distributed and scaled by the average reflectance of all the spectra. At each step the noise was added to the original spectra and the derivatives recalculated. The correlation analysis, described above, was then repeated to reselect the wavebands and rank them by their absolute r's. As the amplitude of the added noise increased a point was reached when the rank of the selected waveband in table 1 began to change. At this point the selected waveband was deemed to be sensitive to the added noise. The SNR ratio for this noise amplitude was calculated by dividing the mean of the reflectances in the selected waveband, the signal, by the amplitude of the added noise, the noise. The process of determining this SNR was repeated five times with different randomisation seeds for the noise and then averaged to give a representative SNR (table 2).

Initially the noise present in the IRIS spectra was assumed to be zero. To estimate the SNR of the IRIS a sample of dry slash pine needles were scanned fifty times. These spectra were degraded to AVIRIS spectral resolution and the SNR calculated by dividing the mean reflectance of each waveband, the signal, by its

standard deviation, the noise. The SNR estimates for the IRIS were much lower than expected. Therefore the SNR's from the analysis were corrected for the noise in the IRIS spectra (table 2).

The SNR predictions in table 2 have similar trends to the r's in table 1 except for the 2nd derivative nitrogen waveband at 1195nm. The SNR's from the analysis were very variable and supported the decision to correct for the inherent noise in the IRIS spectra. The corrected SNR's from the analysis were all of a similar magnitude. In the 1st derivative spectra nitrogen is the least sensitive to noise and cellulose the most. Except for nitrogen, the 2nd derivative seem to be less noise sensitive than the 1st derivative, possibly due to the smoothing effect of a second derivative calculation.

Table 2. The SNR at which wavebands selected as having a large correlation between biochemical concentration and derivative reflectance (table 1) become sensitive to the addition of noise.

Reflectance derivative	Biochemical	Selected waveband (nm)	SNR from analysis	Corrected SNR from analysis
1st	Nitrogen	1491	48:1	37:1
	Lignin	1689	114:1	50:1
	Cellulose	1281	525:1	65:1
2nd	Nitrogen	1195	1765:1	61:1
	Lignin	1709	108:1	46:1
	Cellulose	1719	198:1	48:1

5. COMPARISON WITH JPL SNR ESTIMATES

The Jet Propulsion Laboratory (JPL) estimate SNR for the AVIRIS on the assumption of a 50% reflectance (Green et al., 1992), however this level of reflectance is not reached by vegetation in the spectral regions that correlate strongly with biochemical concentration. The JPL SNR values for the start of the 1993 flight season (Green, *pers comm.*) were converted, albeit approximately, to values that would be obtained when recording vegetation (table 3) and compared to the results of this study. The AVIRIS data appeared to have large enough SNR's for the estimation of foliar biochemical concentrations except for the 1st derivative nitrogen waveband which is close to the threshold (table 3).

6. CONCLUSIONS

Laboratory studies using instruments with SNR's in the thousands have indicated that near infrared spectroscopy of foliar biochemical concentrations is possible (Marten et al., 1989). The results of this study suggest that the AVIRIS is now near or just beyond the SNR threshold that is required in order to estimate foliar biochemical concentrations. However, the spectral data for this study had a much simpler origin than those recorded by the AVIRIS; atmospheric effects were reduced by the close proximity of the source, sample and detector and the sample arrangement was not as complex as that of vegetation and background in an actual canopy. This suggests that the AVIRIS data of a vegetation canopy will have a SNR that is barely adequate for the remote sensing of foliar biochemical concentration.

Table 3: A comparison of the SNR achieved by AVIRIS and the SNR required for the spectral estimation of foliar biochemical concentration.

Reflectance derivative	Biochemical	Selected waveband (nm)	JPL SNR @ vegetation reflectance	Corrected SNR from analysis
1st	Nitrogen	1491	25:1	37:1
	Lignin	1689	100:1	50:1
	Cellulose	1281	240:1	65:1
2nd	Nitrogen	1195	210:1	61:1
	Lignin	1709	95:1	46:1
	Cellulose	1719	90:1	48:1

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