DISCUSSION OF BAND SELECTION AND METHODOLOGIES FOR THE ESTIMATION OF PRECIPITABLE WATER VAPOUR FROM AVIRIS DATA

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1. INTRODUCTION

An AVIRIS data set acquired over Canal Flats, B.C., on August 14, 1990, was used for the purpose of developing methodologies for surface reflectance retrieval using the 5S atmospheric code (Tanré et al., 1990). A scene of Rogers Dry Lake, California (July 23, 1990), acquired within three weeks of the Canal Flats scene, was used as a potential reference for radiometric calibration purposes and for comparison with other studies using primarily LOWTRAN7 (Green et al., 1991). Previous attempts at surface reflectance retrieval indicated that reflectance values in the gaseous absorption bands had the poorest accuracy (Teillet et al., 1991). Modifications to 5S to use a 1 nm step size, in order to make fuller use of the 20 cm^{-1} resolution of the gaseous absorption data, resulted in some improvement in the accuracy of the retrieved surface reflectance. Estimates of precipitable water vapour using non-linear least squares regression (Gao and Goetz, 1990) and simple ratioing techniques such as the CIBR (Continuum Interpolated Band Ratio) technique (Green et al., 1989) or the narrow/wide technique (Frouin et al., 1990), which relate ratios of combinations of bands to precipitable water vapour through calibration curves, were found to vary widely. The estimates depended on the bands used for the estimation; none provided entirely satisfactory surface reflectance curves.

2. METHODOLOGY

The original intent was to use the Rogers Dry Lake scene and a corresponding PIDAS (Portable Instant Display and Analysis Spectrometer) reflectance curve to provide calibration coefficients for the Canal Flats scene. Radiometric calibration factors were derived by assuming that all of the discrepancy between the 5S predicted radiance and the AVIRIS radiance data could be attributed to calibration uncertainties, as a multiplicative gain factor. Application of these derived calibration coefficients to the AVIRIS data resulted in very smooth reflectance curve retrievals throughout the Rogers Dry Lake scene. However, the effects of even small variations in water vapour within that scene were detectable. Though the reflectance curves retrieved from the Canal Flats scene were smoother using the Rogers Dry Lake calibration coefficients, irregularities were introduced. While some of the irregularities were again in the water vapour absorption regions, others were attributable to image to image differences in calibration.

The nature of these calibration irregularities would indicate that, as a first approximation, calibration uncertainties could be assumed to be constant over the wavelength interval used to estimate water vapour amount. Should such an assumption be reasonable, it would facilitate reliable estimation of water vapour despite these uncertainties. This assumption, along with the assumption that the surface reflectance curve varies linearly over the interval, and with the intrinsic atmospheric reflectance varying linearly as well, results in a combined linear curve. The slope and intercept are unknown and require estimation, together with the estimation of water vapour. Since the individual effects are not distinguishable, the parameters can not necessarily be interpreted as true surface reflectance unless optical depth and calibration are known. Since the 5S code treats scattering and absorption separately, uncertainties in optical depth have not significantly altered the estimate of water vapour amount. Combining the intrinsic atmospheric reflectance curve with the linear surface reflectance curve, for estimation purposes only, produces a slightly better fit for dark targets, such as water, and is in better agreement with the corresponding CIBR type calculation. This can be explained by the treatment of calibration uncertainties.

Least squares regression achieves optimal parameter estimates when the underlying error distribution is Gaussian. However, the method becomes unreliable with even one outlier present. Since outliers and non-Gaussian noise are common occurrences, robust regression methods with a maximum breakdown point as low as 50% have been developed (Rousseeuw and Leroy, 1987), and applied to image analysis (Meer et al., 1991). These methods are suitable if the researcher has confidence that at least 50% of the data points are "good". "Good" data points are those for which the above assumptions hold, and for which the explanatory model (*i.e.*, the 5S atmospheric code and the gaseous model in particular) is valid. Since gaseous transmittance is poorly modelled in the wings of the water vapour absorption region (Frouin et al., 1990), only a limited number of "good" bands are likely; *i.e.*, the 940 nm, 1130 nm, and bands on the shoulder where gaseous absorption is negligible. Assuming that this small set of bands is "good", robust methods were used to identify other potential bands. This resulting set of consistent bands is dependent on the 5S gaseous model, as well as the AVIRIS calibration at the time of the overflight, and on any deviations from a linear reflectance curve assumption for the targets under investigation.

3. RESULTS

First, a strong shift in calibration was found between the 1131 and 1141 nm bands in both scenes, making it impossible to bridge the 1130 continuum. Next, other bands within the 940 continuum were excluded due to poor fit (outliers), leaving the following candidates (used for subsequent comparisons): 872, 882, 939, 1035, 1045, and 1055 nm. When considering signatures where liquid water absorption is minimal, one finds that the set of consistent bands is larger, and for the opposite extreme of irrigated fields, the 1035 and possibly the 1045 nm bands should be removed. Since the 939 nm band is the only band from the above set influenced by water vapour absorption, it is not possible to test it as an outlier. Hence, the water vapour estimates based on the consistent set were compared to the estimate with the 1131 nm band included, and found to be within 3% of the original estimate for all sample signatures tested (minimum of 10x10 spatial pixels in each case). That the estimates were consistently lower when the 1131 nm band was included indicates that calibration or the gaseous absorption model is a more serious shortcoming than that of atmospheric scattering and absorption being calculated separately by 5S. For the Canal Flats scene, the 930 nm band could be added to the consistent set, though not for the Rogers Dry Lake scene. This variation in consistent bands is attributed to calibration differences, rather than to the gaseous model.

With both the 920 and 949 nm bands identified as extremely significant outliers, whose effects do not cancel, the narrow/wide technique (911 - 959 nm) would not be expected to perform well. Comparing the estimates based on the narrow/wide bands to the above estimates, we found that they were within the 20% accuracy between the narrow/wide estimate and radiosonde data reported by Frouin et al. (1990). The CIBR uses the 997 nm band, which was found to be unsuitable for the forested targets studied, due to liquid water absorption. Water vapour estimates based on the CIBR bands differed by only 1% for the Rogers Dry Lake scene, but larger differences of up to 4% in forested sections of Canal Flats and 8% for an irrigated field were observed. Once the bands are selected, estimated values for water vapour were comparable for the different methodologies: simple ratioing (1 equation and 1 unknown); linear reflectance assumption (3 equations and 3 unknowns, but ignores calibration uncertainties); combined linear assumption (3 equations and 3 unknowns); non-linear estimation using more bands than unknowns.

4. CONCLUSIONS

Due to irregularities in calibration, the appropriate bands for water vapour estimation may differ from scene to scene. The linearity of the surface reflectance curves for targets within the scene, and the choice of atmospheric code, may also influence the selection. The quality of the water vapour estimate is limited by the accuracy of the gaseous transmittance model used. While the identification of a set of "good" bands and robust estimation techniques provide the tools for band selection, a three-band calculation would be satisfactory for the purpose of studying spatial variation in water vapour. For surface reflectance retrieval, improvements in the gaseous transmittance model and methods to address the calibration problem in the AVIRIS data are required.

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