A VICARIOUS CALIBRATION OF THE PROBE-1 HYPERSPECTRAL SENSOR*

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ABSTRACT

Analysis of Probe-1 hyperspectral data obtained during July 1998 revealed that neither the spectroscopic nor the radiometric laboratory calibrations supplied with the data were applicable, presumably because the sensor had suffered an undocumented opto-mechanical realignment between the calibration and the flight. In this paper the calculation of a new set of calibration coefficients is described, based upon the simultaneous acquisition of high-resolution GER3700 field spectra for a calibration site within the Probe-1 image. For the calibration calculations, an average ground-based reflectance spectrum for the target area was convolved and resampled to match the spectral characteristics of the Probe-1 sensor. The MODTRAN3 radiative-transfer code was used to correct the Probe-1 radiance spectra to surface reflectance, and an iterative numerical technique was applied to adjust the Probe-1 radiometric coefficients, to reduce the absolute reflectance difference between the GER3700 and Probe-1 spectra for the calibration site to 0.02 percent. This technique for the vicarious calibration of hyperspectral data has been implemented into the Imaging Spectrometer and Data Analysis System developed at the Canada Centre for Remote Sensing (CCRS).

1.0 INTRODUCTION

Hyperspectral data was obtained with the (Earth Search Sciences, Inc.; ESSI) Probe-1 sensor over the Cape Smith Belt in northern Quebec on 28 July 1998. The Probe-1 sensor has 128 spectral bands spanning the wavelength range from 440 nm to 2500 nm, with 32 bands in each of the four spectrometers. The spectral bandwidths in the visible near-infrared (VNIR) and short-wave infrared (SWIR) regions are between 11 and 18 nm at full width half maximum (FWHM). Field research done in support of the hyperspectral project included the acquisition of ground-based reflectance spectra using the GER3700 portable spectrometer. The GER3700 has 704 channels spanning the wavelength interval between 350 and 2490 nm, and for this field period it was configured with a 10-degree FOV lens, giving a 0.26-m diameter ground field of view (GFOV) from a height of 1.5 m. The objective of this research is to use the hyperspectral and ground-based data together with spectral unmixing techniques to create mineral maps of exposed rock outcrops in this barren region of northern Canada.

The Probe-1 calibration data acquired in the laboratory on 19 November 1998, when applied to the July 28 flight data, yielded spectra that were incorrect. Visual inspection of a few strong atmospheric absorption features in the radiance domain clearly showed shifts in the band centres. Also apparent were errors in the radiometric calibration, which resulted in SWIR radiance values that were too low. These

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errors in the radiometric coefficients were especially obvious when the Probe-1 spectra were transformed to surface reflectance and compared with the GER3700 ground-based spectra for common targets.

However, it was possible to derive a new set of calibration coefficients because of the simultaneous acquisition of GER3700 field spectra for a calibration site within the Probe-1 overflight area. In this paper, the method used to recalibrate the Probe-1 sensor is described. As well, the primary sources of error in these results are discussed. The hyperspectral data analysis and calibration was performed using the Imaging Spectrometer and Data Analysis System (ISDAS; Staenz et al., 1998) software developed at the Canada Centre for Remote Sensing (CCRS).

2.0 SPECTROSCOPIC CALIBRATION

The laboratory calibration coefficients were applied to the raw Probe-1 spectra to convert them radiances, and these were converted to surface reflectances via an atmospheric correction using the MODTRAN3 radiative transfer code (Berk et al., 1989) as implemented in ISDAS (Staenz and Williams, 1997). Inputs to MODTRAN3 included mission-specific and sensor-specific parameters, model-specific choices for atmospheric properties, and the quantity of atmospheric water vapour (g/cm^2), as estimated from the strength of the 940 nm water vapour absorption line in the Probe-1 reflectance spectra. For these calculations, *Subarctic Summer* was chosen for the gaseous component of the model atmosphere, and *Continental (rural)* was selected for the haze component. The visibility was set to 50 km, and the water vapour was estimated to be 1.0 g/cm^2.

The behaviour of the Probe-1 reflectance spectra was analyzed in the vicinity of five atmospheric absorption features in a typical vegetation spectrum. These features are the 760-nm O_2 line, the 820-, 940- and 1130-nm H_20 lines, and the SWIR CO_2 lines near 2005 and 2055 nm. Then, the wavelength shift was calculated which best corrected the reflectance spectrum in the vicinity of each line (i.e., to obtain a smooth spectrum in the vicinity of these absorption features). The Probe-1 sensor has four separate spectrometers, and the wavelength shifts that were applied to the band centres in each spectrometer were derived from the measurements at the five features mentioned above. No shifts were encountered for either of the two SWIR spectrometers, a constant shift of –2.5 nm was applied to each band in the visible spectrometer, and the near-infrared spectrometer was best corrected by applying a linearly-varying shift to the band centres. The latter was constrained by shifts of –2.5 nm at 940 nm and –1.0 nm at 1130 nm for the corresponding absorption regions.

3.0 RADIOMETRIC CALIBRATION

The GER3700 was used between 13:27 and 13:44 local time on 28 July 1998 to collect seven reflectance spectra over the graveled surface at the eastern end of an airstrip located within the Probe-1 flight line. These measurements were taken at 3 to 5-m intervals along a transect covering about half of the width of the airstrip. Skies were clear and no cirrus clouds were visible during the measurement period. The solar zenith angle was calculated to be 46 degrees at the time of the data collection.

Inspection of the individual spectra revealed that the airstrip is a relatively homogeneous target: the spectra have very similar shapes and a maximum absolute difference of six percent in reflectance between the darkest and brightest spectra. These seven spectra were averaged together to yield the spectrum shown in Figure 1. This averaged GER3700 spectrum was convolved with Gaussian response profiles to match

the Probe-1 band widths and resampled to the band centres for the Probe-1 sensor. (A number of the bands are known to deviate significantly from the model Gaussian profile, but the exact shape of these response curves for the state of the sensor in late July 1998 is not known.) This convolved and resampled GER3700 reflectance spectrum was then used to calibrate the Probe-1 data.

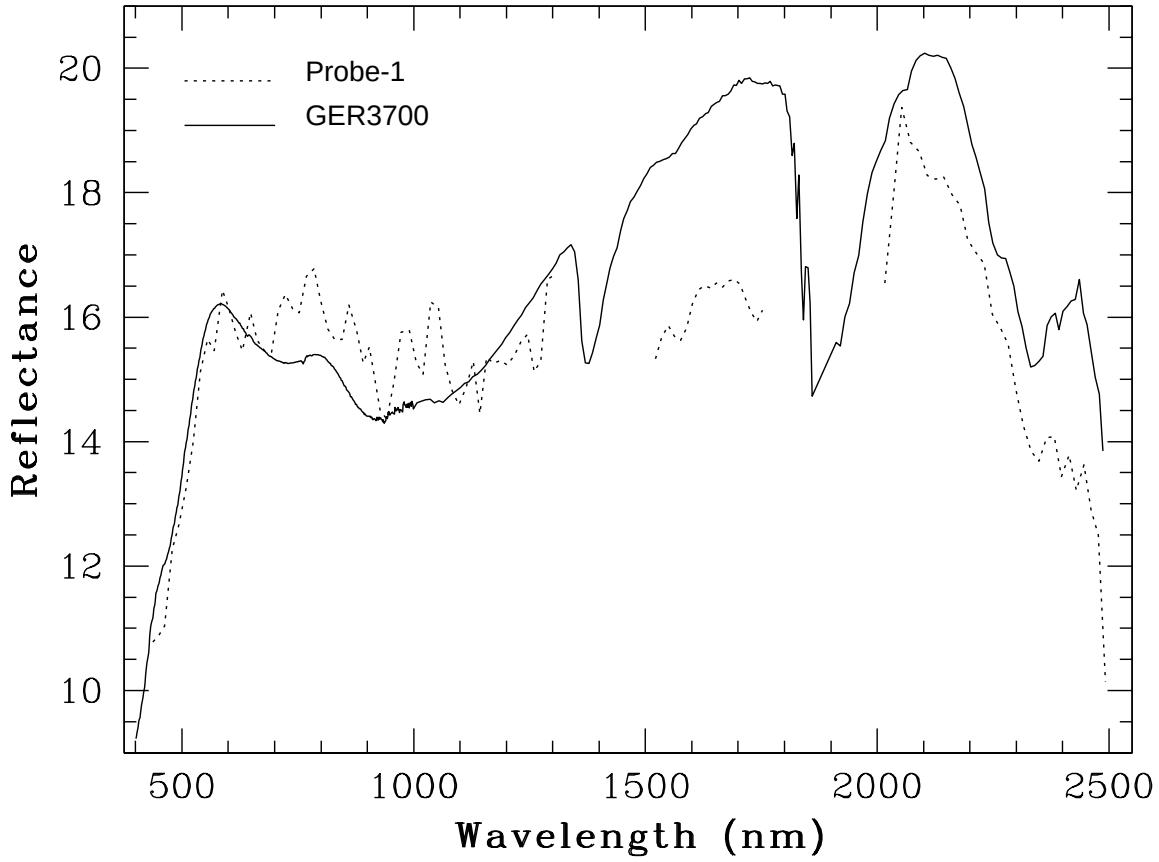

Figure 1: The average GER3700 reflectance spectrum for the target area is compared with the Probe-1 reflectance spectrum (converted to radiance using the laboratory calibration coefficients and atmospherically corrected) for the target area. The differences between these two spectra arise from the incorrect radiometric calibration coefficients. Note that the GER3700 spectrum shown here has not yet been convolved and resampled to match the characteristics of the Probe-1 sensor.

The Probe-1 data was acquired at 13:00 local time on 28 July 1998, the same day as the ground measurements. The GER3700 target site was located within the Probe-1 flight line through visual inspection. The average spectrum of nine pixels (approximately 500 m^2) was extracted from the dark-subtracted raw data, spectrally registered using the coefficients derived in Section 2, and converted to radiance using the laboratory coefficients. To compare the Probe-1 data with the GER3700 data requires a full atmospheric correction. For this purpose the MODTRAN3 radiative transfer code in ISDAS was used, with input parameters as described in the previous section. In Figure 1, the Probe-1 reflectance spectrum (using the laboratory coefficients) for the airstrip calibration target site is compared with the average GER3700 spectrum. There is significant disagreement between the GER3700 and Probe-1 data, apparent throughout the full wavelength range and especially obvious as decreased signal values in the SWIR region, from 1500 nm to 1800 nm.

The Probe-1 sensor was recalibrated using a technique that has been incorporated into ISDAS as the *Match Reflectance Spectra* module. It uses an iterative numerical technique that adjusts the Probe-1 radiometric coefficients to minimize the absolute reflectance difference between the GER3700 and Probe-1 spectra for the target area (Figure 2). To begin this iteration, the Probe-1 raw data is calibrated using the spectral coefficients derived above, converted to radiance using the laboratory radiometric coefficients, atmospherically corrected and compared with the convolved and resampled GER spectrum. Then, at the wavelengths corresponding to the sensor band centres, the reflectance difference between the GER3700 and the Probe-1 spectra determines whether the Probe-1 coefficients are adjusted incrementally (up or down) towards the GER3700 spectrum. In the second iteration, the original coefficients are replaced by the adjusted ones. The new set of coefficients are applied to the raw data (the upward arrow in Figure 2), and the adjusted radiance spectrum was atmospherically corrected to yield a new Probe-1 reflectance spectrum. This Probe-1 reflectance spectrum is again compared with the GER3700 spectrum, and the radiometric coefficients are adjusted incrementally.

This cycle of comparing the spectra and adjusting the radiometric coefficients in an incremental manner is controlled by the MATCH REFLECTANCE SPECTRA module illustrated in Figure 2. It was repeated until the average Probe-1 spectrum matched the GER3700 spectrum to within a tolerance of 0.02 percent (absolute difference) in each band. Once the two spectra match, the MATCH REFLECTANCE SPECTRA module terminates the iterative adjustment process, and this new set of radiometric calibration coefficients are output and used for data calibration.

Note that the radiometric coefficients for several of the Probe-1 bands could not be corrected by this recalibration against the GER3700 field spectra. These include bands in the centres of the water vapour features near 1400 nm and 1900 nm, and bands in the SWIR2 region which lie outside of the range of the GER spectrometer.

4.0 VALIDATION

The wavelength and radiometric recalibrations described in the previous section were validated in a qualitative manner using Probe-1 data from three separate flight lines, all of which were obtained at the end of July, 1998. For each of these flight lines, the raw data was dark subtracted, converted to radiance using the new spectroscopic and radiometric calibration coefficients derived as described in Sections 2 and 3, and atmospherically corrected to reflectance using MODTRAN3. For targets of interest, the shapes of the reflectance spectra are judged to be excellent. Example reflectance spectra extracted from these Probe-1 flight lines are illustrated in Figure 3 and described below:

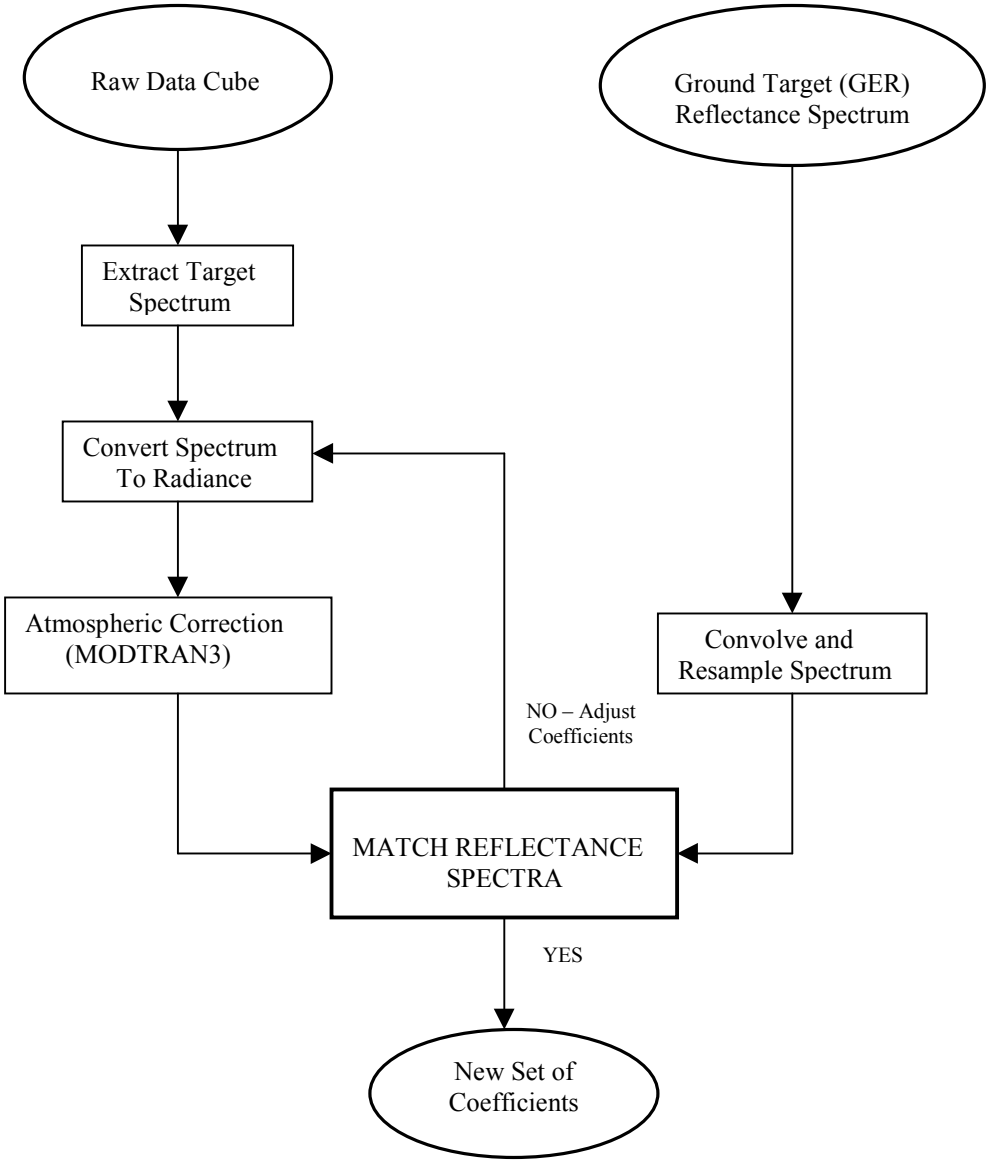

Figure 2: Data processing flow diagram for the vicarious calibration of the Probe-1 sensor. The Match Reflectance Spectra module controls the comparison of the Probe-1 and GER3700 reflectance spectra, and it terminates the iteration when the two spectra match (at every band-centre wavelength) to within a specified tolerance. Note that the MODTRAN3 calculations were performed in advance, and that the wavelength shifts derived in Section 2 have been applied.

1. An east-west flight line with 7.5-m pixels obtained at 13:00 local time on 28 July 1998 within the Cape Smith belt area (the same flight line discussed and used in Section 3). The three spectra correspond to an area on the airstrip (the calibration target), along a gravel road north-east of the airstrip, and within a vegetated region.

2. An approximately north-south flight line with 5-m pixels obtained at 13:20 local time on July 28 1998 within the Cape Smith belt region. The extracted spectrum corresponds to a region chosen along a gabbro intrusion at the north-end of the flight line.

3. A north-south flight line with 5-m pixels obtained on 31 July 1998 over a forested area near Timmins, Ontario. The extracted spectrum represents the average for a forested region, and it has the typical features of a vegetation canopy (e.g., absorptions due to chlorophyll and leaf liquid water).

5.0 SOURCES OF ERROR

Analysis of the calibrated and atmospherically-corrected Probe-1 data reveals that the errors in the reflectance spectra arising from the vicarious calibration are less than 0.5 percent (absolute). These errors are especially apparent in spectra of objects, such as the water bodies with peak reflectances under three percent, for which the reflectance is significantly different from that of the calibrating target (with a peak reflectance of approximately 16 percent in the visible region). The most significant sources contributing to these errors are:

1. Ground calibration site: An exact location of the ground-based GER3700 measurements in the Probe-1 flight line was difficult due to the lack of appropriate GPS information. Therefore, visual identification was used. Based on the uncertainty of locating the measurement sites in the imagery, spectra from a nine-pixel region covering the target site were extracted from the Probe-1 data, averaged, and used for the calibration process. However, the reflectance characteristics of the airstrip's gravelled surface change on a scale of tens of meters, and this spatial variation can manifest itself as a calibration uncertainty.

2. Radiative transfer code: The calibration of the Probe-1 data relied upon the MODTRAN3 radiative transfer code to correct radiance spectra to reflectance for comparison with the GER3700 spectra. However, the gaseous and haze components of the model atmosphere were not measured, and so they were approximated using one of the standard models included in MODTRAN3. These were described in Section 2.

3. Estimation of water vapour: The amount of atmospheric water vapour is an important input to MODTRAN3, and it must be estimated prior to beginning the vicarious radiometric calibration described above. Because of this, the water vapour was estimated from the Probe-1 data converted to radiance using the coefficients derived from the laboratory calibration.

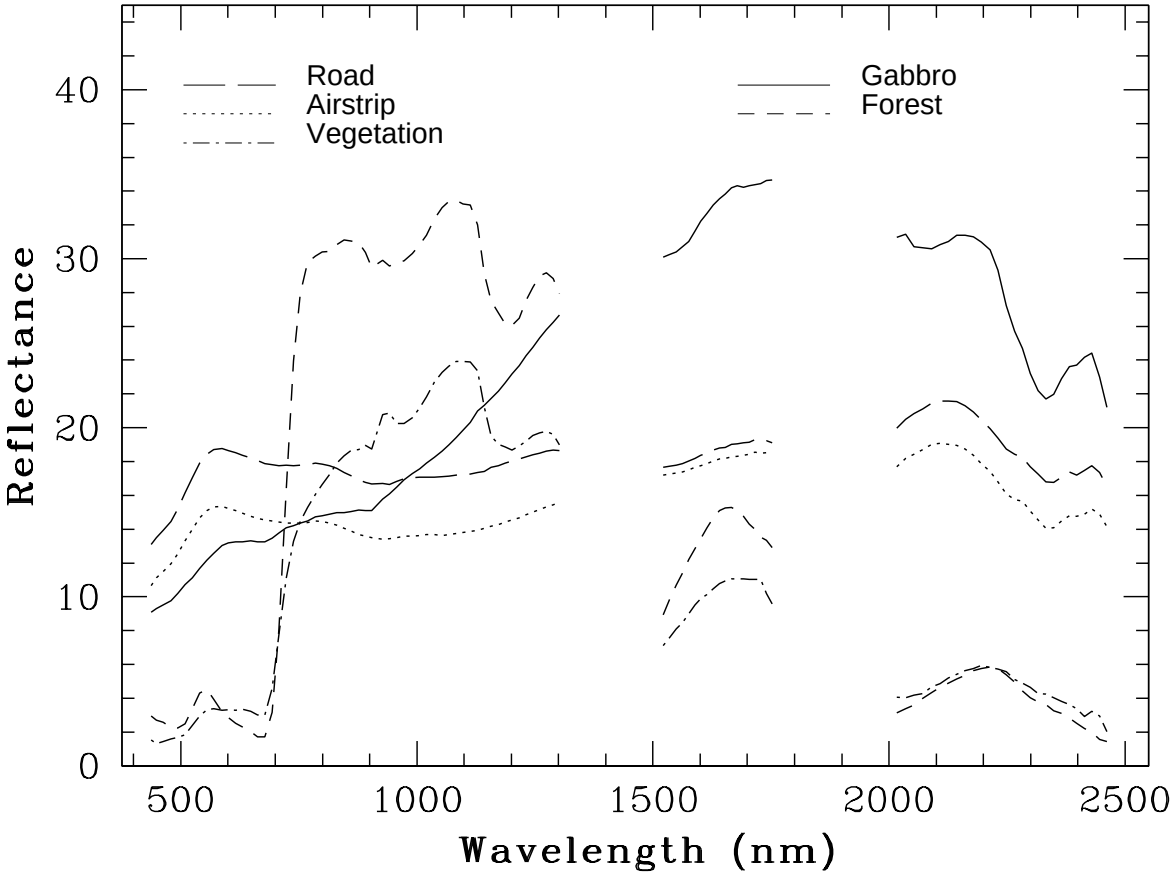

Figure 3: Reflectance spectra for vegetation, gravelled surfaces and a rock outcrop. The calibration coefficients derived in Sections 2 and 3 were applied to data from three different Probe-1 overflights near the end of July 1998, and the radiance spectra were atmospherically corrected to yield these reflectance spectra.

6.0 CONCLUSION

The new calibration coefficients for the Probe-1 sensor include both the wavelengths of the band centres and the multiplicative coefficients to convert dark-subtracted raw data to radiance. We have

applied these new calibration coefficients to Probe-1 data acquired near the end of July 1998, and the results are encouraging. The reflectance spectra extracted from the atmospherically-corrected Probe-1 data have recognizable features at the proper wavelengths, and the relative amplitudes of the VNIR and SWIR regions are appropriate for vegetation and non-vegetation regions.

However, based upon our analysis, it is evident that the Probe-1 calibration changed significantly between late July and mid-November. Therefore, caution must be exercised when applying the new calibration coefficients derived using this vicarious calibration method to data obtained at times other than when the ground-based reflectance measurements were made.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

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