Automated Methods for Atmospheric Correction and Fusion of Multispectral Satellite Data for National Monitoring

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Abstract- **The Earth Observation for Sustainable Development of Canada's forests (EOSD) project monitors Canada's forests from space. Canada contains ten-percent of the world's forests. Initial EOSD products are land cover, forest change, forest biomass, and automated methods. There are more than 500 LANDSAT TM or ETM+ scenes required for a single coverage of Canada's forests. Multi-temporal analysis using satellite data requires automation for conversion of these data to common units of exoatmospheric radiance or ground reflectance. During the next ten years the EOSD project will use a variety of Landsat optical and Radarsat sensors. A diverse set of ancillary and satellite data formats exist which require the development of adaptable data ingest and processing streams. Legacy LANDSAT TM and ETM+ data are available in a number of different formats from several national and US suppliers. In this paper, we present an automated system for managing processing streams for calibration and atmospheric correction of LANDSAT TM and ETM+ data to create data sets ready to analyze for EOSD products. Using known forest attributes from GIS data and field measurements, we validated our results of studies undertaken to assess spectral signal variability using both at-sensor radiance and ground reflectance for LANDSAT TM and ETM+ for a test site on Vancouver Island, BC. We present a strategy for correcting and fusing multi-source and multi-temporal satellite data for meeting EOSD requirements.**

I. Introduction

Canada is a signatory to the Kyoto Protocol and has agreed to reduce its greenhouse gas emissions to 6% below 1990 levels by the year 2012 [1], [2]. Canada contains 10% of the world's forests. Forests are an important repository of carbon, an attribute that can be determined from knowledge of forest cover, forest biomass, and models. Depending upon the successional stage and available nutrients, forests may be viewed as a sink or a source for greenhouse gases. The Canadian National Forest Inventory (CanFI) contains more than 20 parameters characterizing the forest, including distribution of forest types, forest age, and forest volume. A summary of Canadian forest attribute requirements may also be found in [2].

The objective of atmospheric correction to remotely sensed data is to compute the surface reflectance of targets. If atmospheric effects can be removed properly, then the spectral signatures of targets in the imagery can be used to determine their identities using a known spectral signatures library [3]. Removal of atmospheric effects becomes very important when multi-temporal and multi-sensor remotely sensed data are used. Inter-seasonal variability in the atmospheric conditions can pose serious limitations on quantitative relationships between satellite imagery and surface characteristics. Thus, atmospherically corrected imagery should help to improve the accuracy of image classification.

Canada has 9.97 million km^2 of land area. It is estimated that about 740 LANDSAT TM/ETM+ scenes are required to cover the entire Canadian landmass once. LANDSAT multispectral data are available in a variety of formats. There is a need for the EOSD project to have a system that simplifies the complexities arising from knowledge of sensor type, calibration state, ground processing system, and format structures.

In this work, we describe an automated system for calibrating and atmospherically correcting LANDSAT 5 TM and LANDSAT 7 ETM+ data. This system is the Atmospheric Correction and Enhancement System (ACE). We also assess overall classification accuracies using uncalibrated, calibrated and atmospherically corrected TM data acquired at multiple times over a test site in Hinton, Alberta, Canada. A discussion of automated methods for remote sensing applications is available in [4].

II. LANDSAT 5 AND LANDSAT 7 DATA FORMATS

Legacy LANDSAT ETM+, TM and MSS data exists for Canada from 1972. These data are available in a number of formats, including United States Geological Survey (USGS) National Landsat Archive Production System (NLAPS), USGS Hierarchical Data Format (HDF), Radarsat International (RSI) HDF format, Landsat Operations Ground Segment Working Group (LOGSWG), and RSI Geocoded Image Correction System (GICS) formats. Automated systems are the key to voluminous processing of remotely sensed data originating from many suppliers. Other data formats include GEOTIFF from RSI and the Center for Topographic Information (CTI) format. All of the Landsat data formats have processor- and supplier-specific metadata files associated with them. Extracting the metadata can be a challenging and a time-consuming process. A system such as ACE is capable of handling the metadata automatically

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for processing of Landsat 5 and Landsat 7 remotely sensed imagery.

The NLAPS Data Format is the distribution format used by the USGS (Eros Data Center) for Landsat 5 TM data. Products are corrected to one of five levels. These levels are: raw, with no geometric corrections; systematically geocorrected; precision geocorrected; precision registered; and terrain corrected. The HDF Data Formats from the USGS and RSI are similar except for the fact that the digital number range is 1-255 for USGS, and 0-255 for RSI. HDF is a physical file format for storing scientific data developed by USGS and the National Center for Supercomputing Applications (NCSA). It features a collection of tools for writing, manipulating, viewing, and analyzing data across diverse computing platforms. For image processing applications, most commercial software recognizes the HDF format with minimal user intervention.

The LOGSWG data format is important because much of the legacy Landsat MSS and TM data are contained in this format. The GeoTIFF image file format is a TIFF based interchange format for georeferenced raster imagery. In this format a small set of reserved TIFF tags is used to store georeferencing information appropriate to geographic as well as projected coordinate systems needs.

The Centre for Topographic Information (CTI) is Canada's national topographic mapping agency. LANDSAT 7 ETM+ data from CTI are orthorectified using the highest resolution scale maps available and DEMS. A large portion of 2000 data for the EOSD Project will be supplied by CTI. The flexibility of the ACE system is required to address the variety of data formats to be used by EOSD.

III. Methodology for Calibration and Atmospheric Correction

A logical data flow diagram for the ACE system is presented in Figure 1. The system is designed to run in a UNIX environment (SUN Solaris 2.X) on a SUN Ultra 10 440 MHz computer. The ACE system automatically extracts information from metadata files appropriate to TM and ETM+ data sets. The user is required to verify the location of the data and accompanying metadata files. The system offers both automatic and user-specified data ingest capabilities. The metadata used by ACE, user inputs, and a record of the entire run are recorded in a log file.

The radiative transfer model used within ACE is known as Second Simulation of Satellite Signal in the Solar Spectrum (6S) [5]. For the case of the ETM+, ACE can be run in two modes for correction of data to ground reflectance. The first mode enables the user to model the atmospheric conditions by specifying aerosol quantities and the aerosol optical depth explicitly. The second mode, used more commonly, uses a standard atmosphere appropriate to the site and time of the year. ACE is usually run in the standard atmosphere mode. The output from the ACE system consists of calibrated radiance and reflectance files as well as a ground reflectance image. Further information on the ACE system may be found in [6].

IV. Calibration and Classification – A Case Study

In 2000, we conducted a study using three dates of summer Landsat 5, and one date of Landsat ETM+ imagery to estimate above-ground carbon for a forested test site near Hinton, Alberta [7]. Although the objective of this study of [7] was to compute above-ground carbon estimates, an intermediate step involved segmentation, classification and assessment of classification accuracies. For the present case study, we expanded on the classification work of [7]. We constrained our analysis to 1985, 1990 and 1996 imagery, and our additional data now includes Landsat TM data calibrated to top-of-the-atmosphere (TOA) reflectance, and ground reflectance using the ACE system. We use only leaf-on imagery for this study.

Table 1 presents the results of overall classification accuracies (using segment classification with means and covariances) on Landsat uncalibrated, calibrated (to top-of-atmosphere reflectance) and atmospherically corrected data (ground reflectance). The use of spatial information in the form of segments reduced the noise in the data.

TABLE 1
Overall classification accuracies for Hinton, Alberta test site data from 1985, 1990 and 1996 based on Segmentation.

Year	Uncalibrated Images	TOA Reflectance Images	Ground Reflectance Images
1985	91.88 %	92.88 %	92.73 %
1990	92.08 %	92.23 %	92.34 %
1996	91.79 %	92.93 %	92.5 %

The classifications were carried out for each of the years 1985, 1990 and 1996 [7]. From Table 1, it is clear that the overall classification accuracies for uncalibrated, calibrated, and atmospherically corrected data are high enough for operational use. In relation to the results of Table 1, we make the following observations:

(1) For the data set from the Hinton, Alberta test site, the segmentation classification accuracies are very high at the outset. Classification accuracies increase by about one percent for data calibrated to top-of-the-atmosphere, and ground reflectance.

(2) We believe that the atmospheric conditions for the TM data from 1985, 1990, and 1996 were normal. We have assumed standard atmospheric models for our test site for each date. The classification results indicate that these assumptions did not reduce classification accuracies. For greatest precision, it would be desirable to have accurate knowledge of the aerosol optical depth for each pixel [8]. These data are obtainable from hyperspectral sensors. For Landsat analysis, the common practice is to assume a laminar, uniform atmosphere across the entire image.

(3) The results of Table 1 show that generating ground reflectance images does not reduce classification accuracies. Such images are in physical units and can be integrated with measurements of other sensors. Further tests with less well-classified scenes may demonstrate that images with atmospheric correction have classes with smaller variances.

(4) We have assessed classification accuracies for data calibrated using calibration coefficients supplied by the data providers, and calibration coefficients found in literature [9]. We have observed some anomalies when using the calibration coefficients supplied by the data providers for Landsat-5. We have thus chosen to use the calibration coefficients of [9] for this work.

(5) We have studied the statistics of the same channels from year to year for areas of no change for a subscene known as "Tile D" [7]. We have observed an increase in the trend line slope after calibration to ground reflectance, indicating a better agreement from year to year. This is especially true of the blue (1) channel (See Tables 2a and 2b). For example, the correlation between channel 1 for 1985 and 1990 for the uncalibrated data was 0.34. For the data calibrated to ground reflectance, the channel 1 1985 and 1990 correlation coefficient was 0.38. For TM 7 (channel 6), the correlation coefficients did not change between uncalibrated comparisons (Table 2a) and calibrated comparisons (Table 2b).

TABLE 2A: REGRESSION SLOPE, Y-INTERCEPT AND CORRELATION COEFFICIENT FOR MULTI-YEAR CHANNEL-TO-CHANNEL COMPARISONS FOR UNCALIBRATED DATA: TILE D.

Channel and year	Channel and year	Reg. Slope	Reg. y-intercept	Corr. Coeff.
ch1 1985	ch1 1990	0.43	29.02	0.34
ch1 1985	ch1 1996	0.36	30.99	0.34
ch1 1990	ch1 1996	0.22	42.49	0.26
ch2 1985	ch2 1990	0.56	8.06	0.55
ch2 1985	ch2 1996	0.53	7.46	0.54
ch2 1990	ch2 1996	0.42	11.3	0.43
ch3 1985	ch3 1990	0.58	5.68	0.53
ch3 1985	ch3 1996	0.6	5.51	0.51
ch3 1990	ch3 1996	0.44	10.24	0.41
ch4 1985	ch4 1990	0.99	-2.07	0.92
ch4 1985	ch4 1996	0.89	3.2	0.91
ch4 1990	ch4 1996	0.83	8.75	0.91
ch5 1985	ch5 1990	0.75	6.1	0.84
ch5 1985	ch5 1996	0.71	10.15	0.76
ch5 1990	ch5 1996	0.82	8.8	0.78
ch6 1985	ch6 1990	0.54	4.04	0.67
ch6 1985	ch6 1996	0.52	5.06	0.55
ch6 1990	ch6 1996	0.64	4.7	0.54

TABLE 2B: REGRESSION SLOPE AND CORRELATION COEFFICIENT FOR MULTI-YEAR CHANNEL-TO-CHANNEL COMPARISONS FOR DATA CALIBRATED TO GROUND REFLECTANCE FOR TILE D. THE Y-INTERCEPT IS ZERO.

Channel and year	Channel and year	Regression Slope	Correlation Coefficient
ch1 1985	ch1 1990	0.51	0.38
ch1 1985	ch1 1996	0.45	0.39
ch1 1990	ch1 1996	0.23	0.26
ch2 1985	ch2 1990	0.62	0.55
ch2 1985	ch2 1996	0.56	0.54
ch2 1990	ch2 1996	0.41	0.44
ch3 1985	ch3 1990	0.61	0.53
ch3 1985	ch3 1996	0.61	0.51
ch3 1990	ch3 1996	0.42	0.41
ch4 1985	ch4 1990	1.03	0.92
ch4 1985	ch4 1996	0.9	0.91
ch4 1990	ch4 1996	0.8	0.91
ch5 1985	ch5 1990	0.76	0.84
ch5 1985	ch5 1996	0.76	0.76
ch5 1990	ch5 1996	0.87	0.78
ch6 1985	ch6 1990	0.57	0.67
ch6 1985	ch6 1996	0.62	0.55
ch6 1990	ch6 1996	0.72	0.54

V. Conclusions

Our Hinton, Alberta test site imagery from 1985, 1990 and 1996 yields very high classification accuracies with segmentation for both uncalibrated and calibrated data. We have observed a one-percent increase in these classification accuracies when data are calibrated to reflectance at the top-of-the-atmosphere, and the ground by our automated system. We have observed improved multi-date band-to-band correlation after calibration to ground reflectance of the Landsat 5 TM imagery. As future work, we will test other radiative transfer models such as CAM5S and MODTRAN4 to determine if classification accuracies change for atmospherically corrected data of less well-classified scenes. We intend to study the effect of calibration and atmospheric correction on classification accuracies and inter-class variances in LANDSAT TM/ETM+ data acquired over other EOSD [2] test sites.

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REFERENCES

[1] D. G. Goodenough, R. Hall, J. Iisaka, D. Leckie, K. Staenz, A. S. Bhogal, and A. Dyk, A. Hollinger, J. Miller; K. O. Niemann, and H. Zwick, "Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD). EO-1 project under NASA's New Millennium Earth Observer 1 Program 1999.," Pacific Forestry Centre 1999.

[2] J. E. Wood, M. D. Gillis, D. G. Goodenough, R. J. Hall, D. G. Leckie, J. L. Luther, and M. A. Wulder, "Earth Observation for Sustainable Development of Forests (EOSD): Project Overview," presented at IEEE GRS International Geoscience and Remote Sensing Symposium, Toronto, Ontario, Canada, 2002.

[3] T. Takashima, Masuda, K., "Satellite Correction for the Satellite Visible Data Over Homogeneous Surfaces," *Applied Mathematics and Computation*, vol. 116, pp. 181-196, 2000.

[4] D. G. Goodenough, D. Charlebois, A. S. Bhogal, and S. Matwin, "Automated Forest Inventory Update with SEIDAM," presented at IEEE GRS IGARSS'97, Singapore, 1997.

[5] E. Vermote, Tanre, D., Deuze, J.L., Herman, M., Morcrette, J.J., "Second Simulation of Satellite Signal in the Solar Spectrum, 6S User Guide Version 2," July 1997.

[6] B. Rancourt, Bhogal, A.S., Hobart, G., Love, J., "Atmospheric Correction and Enhancement (ACE) System - A Users Guide," Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, B.C. Canada In Progress 2002.

[7] D. G. Goodenough, A. S. P. Bhogal, A. Dyk, M. Apps, R. Hall, P. Tickle, H. Chen, K. Butler, and M. Gim, "Determination of Above-Ground Carbon in Canada's Forests - A Multi-Source Approach," presented at IGARSS 2000, Honolulu, Hawaii, 2000.

[8] Y. Kawata, Mouri, K., Izumiya, T., "New Estimation Algorithm of Aerosol Optical Thickness from Space Remote Sensing Data and its Validation," *Advances in Space Research*, vol. 25, pp. 1007-1013, 2000.

[9] K. J. Thome, Crowther, B.G., Biggar, S.F., "Reflectance and Irradiance-based Calibration of Landsat-5 Thematic Mapper," *Canadian Journal of Remote Sensing*, vol. 23, pp. 309-317, 1997.

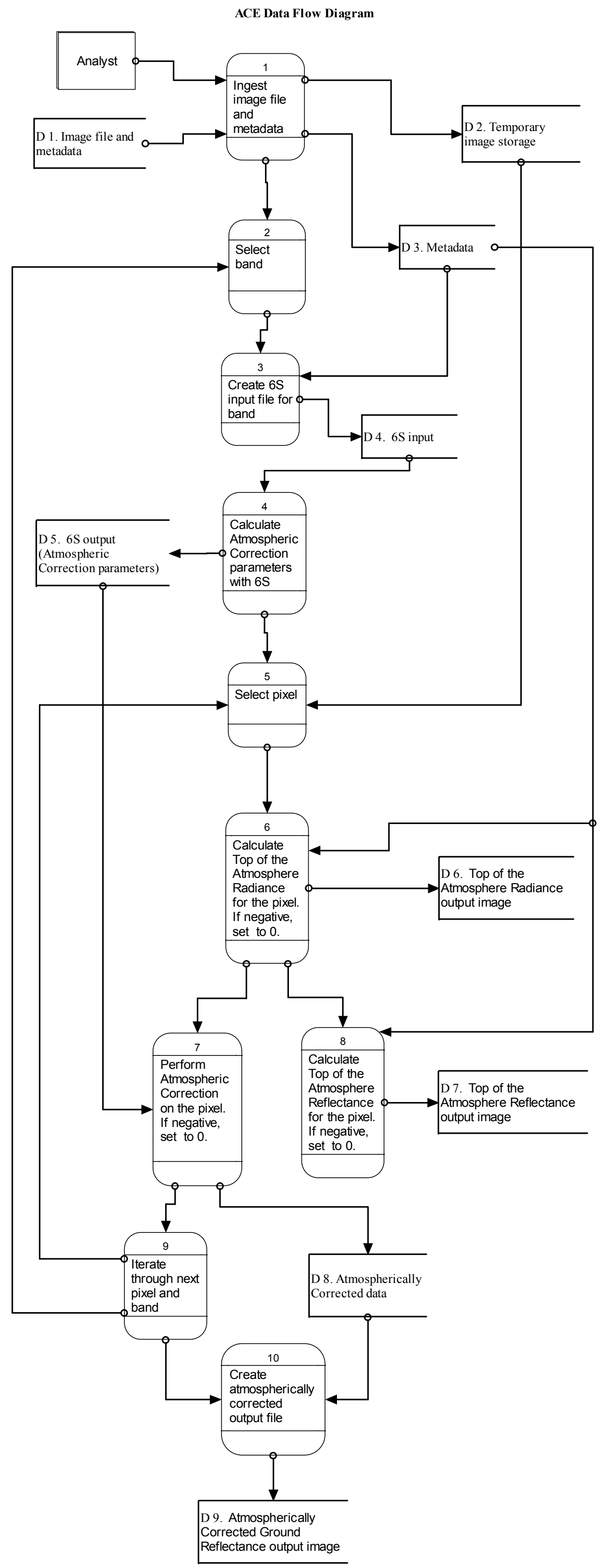

Fig. 1. ACE data flow diagram.