

Mapping the land cover of the forested area of Canada with Landsat data

Mike Wulder

Canadian Forest Service, 506 West Burnside Road, Victoria, B.C., Canada V8Z 1M5
email: mwulder@nrcan.gc.ca, phone: 250 363-6090, fax: 250 363-0775

Abstract: A priority of the Canadian Forest Service and Canadian Space Agency joint project Earth Observation for Sustainable Development of Forests (EOSD) is the production of a land cover map of the forested area of Canada. The land cover map of the forested area of Canada will be based upon Landsat data. The land cover will be produced through a partnership of federal and provincial governments, universities, and industry. The short term goal of EOSD is to produce a land cover map of the forested area of Canada representing circa 2000 conditions. The satellite land cover of the forested area of Canada is to be completed in early 2006. Over the longer term, EOSD will aim to produce land cover products to capture the conditions present for 1990, and important reporting years occurring after 2000. Many provincial and territorial mapping agencies have on-going land cover mapping programs. EOSD will work in partnership with the provincial agencies to produce a complete satellite mapped coverage of the forested area of Canada. The forested area of Canada represents approximately half of Canada's land mass, requiring over 450 scenes for complete coverage (with overlap minimised). The combined output of EOSD and provincial / territorial land cover mapping programs will produce maps of the forested area of Canada which can be combined with maps developed by other sectors and agencies (such as agriculture) to produce a full coverage of Canada.

Large area land cover mapping using remote sensing is a relatively new phenomenon. Advances in data storage capabilities, computing power, and increasingly economical data availability have allowed for large area projects to be tackled in ways never before possible. How a large area mapping project is approached is related to a number of factors including the spatial extent of the area of interest, the spatial resolution of the selected sensor, and the products which are to be generated. In this communication we will illustrate some of the issues to be addressed, including examples, followed by suggestions and examples of how we plan to map the forest cover of Canada.

I. INTRODUCTION

Land cover mapping has become a matter of great political and scientific interest. Countries which have signed on to such agreements as the Kyoto Protocol, the International Convention on Biological Diversity, and the Framework

Convention on Climate Change, have responsibilities both to their own citizens and the world's to perform timely and accurate reporting of key environmental criteria. Land cover mapping is often the primary source for determining current land cover status and is used as a baseline for future changes. These reporting obligations are not a particularly onerous task for many jurisdictions, but some countries, provinces, and states are of such a large size that monitoring is difficult. Increasingly, remote sensing is being turned to as a timely and sufficiently accurate data source for land cover mapping.

Earth Observation for Sustainable Development of Forests (EOSD) is a joint program of the Canadian Forest Service (CFS) and the Canadian Space Agency to develop a forest monitoring system for Canada. An overview of the EOSD program is provided in these proceedings [1]. As mentioned in the overview paper, forests are critical to Canada for both economic and environmental reasons. As a result, monitoring of Canada's forests is required for internal monitoring and reporting and for participation in international programs. EOSD is designed to provide, over the long term, using space-based earth observation data, products for forest inventory, forest carbon accounting, monitoring of sustainable development, and landscape management.

Utilising Landsat data as a data source for mapping the land cover of the forested area of Canada will provide for data with a known vintage and broad areal coverage to generate information on the state and distribution of Canada's forests. This information is valuable to a broad range of stakeholders. Many provincial and territorial mapping agencies, having recognised the importance and utility of Landsat land cover mapping, have initiated mapping programs of their own.

In Canada, provinces and territories are tasked with the stewardship of the natural resources within their respective borders. Provincial forest mapping agencies often follow standards and definitions specific to their

jurisdictions, resulting in a need for harmonisation when national summaries are desired. The CFS has worked with provincial and territorial mapping agencies to develop a National Forest Inventory (NFI) that allows for standardisation of forest mapping results. The NFI is based upon a systematic sampling of 1% of Canada's territory utilising a 20 x 20 km grid with 2 x 2 km photo plots at the grid vertices (additional details and description available at [2]). EOSD will work closely with the NFI to ensure harmonisation of standards and definitions to allow for a multi-source approach to characterising Canada's forests. EOSD land cover is viewed as a primary source of NFI data for Canada's north. At the national level, comprehensive information on the land cover of Canada's forests is also required for carbon accounting purposes.

The planned mapping approach is based upon using proven, or new and tested, methods. This approach is intended to ensure delivery over the short production timelines identified. Initial methods have been identified and will be built upon and improved in an incremental fashion for future mapping iterations. The approach will allow for provide timely and useful information for use within, and external, to Canada. To date some key milestones are the development of a classification legend and an international image radiometry workshop including non-government, government, and university representatives. We have also reviewed international initiatives and methods [3], which we used to aid in our methods development, including an Implementation Manual (version 1) [4]. We have also been testing our methods on pilot regions. Based upon experience gained testing methods on the pilot regions, we are developing a version 2 methods manual.

The initial goal of EOSD is to produce, through partnership with Canada's provinces, territories, universities and industry, a national map of the forested land cover of Canada. In this communication, we will describe the nature of the land cover product, some of the issues related to production of a large area land cover map, and a summary of the envisioned implementation strategy. Currently, EOSD is working closely with provincial and territorial mapping agencies on a phased process to complete the mapping the land cover of the forested area of Canada to be completed in early 2006. To enable the completion within this time horizon, the CFS and provincial / territorial mapping agencies will determine areas already being mapped, areas to be mapped, and areas not being mapped to enable development of a plan to ensure complete coverage of the forested

area of Canada. The phased implementation of EOSD will also prioritise Canada's north for initial mapping efforts. Canada's north is not characterised as completely with traditional forest inventory methods as the south and, as a result, has been identified as a priority. The methods and products produced by EOSD are designed to combine easily with provincial and territorial Landsat land cover map products.

II. LARGE AREA LAND COVER MAPPING

Utilising single scenes of Landsat data to produce land cover information is not uncommon. Combining several, or hundreds of Landsat scenes for the development of a large area land cover map is still relatively uncommon [5]. While many jurisdictions have undertaken large area mapping projects with Landsat data, an increase in the level of activity can be linked to changes to United States government copyright regulations with regard to satellite data. United States Government data sharing and copyright policy have been altered to allow the unfettered sharing of Landsat-7 data once it is purchased. This change allowed for affordable access to Landsat-7 data enabling jurisdictions responsible for the stewardship of large areas to consider satellite data as a viable data source.

In our review of large area mapping programs, we note that atmospheric correction is rarely undertaken and some form of geometric correction is always applied [3]. Unsupervised classification or clustering (i.e. K-means) followed by cluster merging and labeling in a manual fashion is the most common classification methodology [5]. Some programs have mosaiced numbers of images, while others classify single scenes and have to match the edges post-classification. In many cases, the amount of documentation of methods applied is limited. Other non-image based issues also have an impact upon final classification results, such as topography, cloud cover, image year and month, and the availability and quality of training data (i.e. plot, photos, or GIS data). In most cases, to address any issue impacting image characteristics results in increased costs, either through increased processing needs, staff time, or supplemental data purchases. The goals of the classification must guide the processing needs. For instance, mosaics composed of images collected during both leaf-on and leaf-off conditions are often desired for classification. The ability to collect imagery representing a single season is very difficult due to the presence of cloud cover. As a result, in an

operational mapping program there is a need to range out in time over seasons and years. Large area coverages are often composed of the best image available as close as possible to the project base year. Large area mosaics, by necessity, are an assemblage of images representing multiple years and seasons. The use of images from differing seasons can often cause greater problems for land cover mapping than using a scene from a different year, yet the same season [6]. When dealing with large area coverages, mosaicking may be undertaken prior to classification on the satellite data or post-classification single scene stitching may be undertaken. While some problems may be radiometric, phenologic problems (from leaf-off conditions to snow on the ground) likely pose a greater problem for classification programs. The classification structure also has an impact on the ability to map regions or single scenes. A highly detailed classification structure can result in individual pixels in the image overlap area being placed in to differing classes that are equally likely.

EOSD land cover will have available Landsat-7 data from a national Canadian consortium led by the Centre for Topographic Information-Sherbrooke (CTI-S). Over the next 3 years the CTI-S project Ortho7 will produce with federal, provincial, and terrestrial partnerships a complete set of orthorectified imagery for Canada. The orthorectified imagery will be freely available to the public via the WWW. For additional information on the CTI-S Ortho7 project see [7].

A goal of EOSD is also to classify a 1990 Landsat-5 coverage of Canada. The analysis needs for classifying the historic data are the same as when mapping current conditions, such as training, ancillary, and validation data. Yet when attempting to backcast and classify the historic data problems exist such as, data unavailability, data not collected for the purpose it is desired for, data of poor quality, the data may be insufficient or non-spatial, or the data may be non-representative (i.e. only merchantable timber polygons inventoried).

III. IMAGE CLASSIFICATION METHODS

The image classification approach that has been developed for EOSD is based upon unsupervised clustering and labelling. Hyperclustering and labelling is the selected approach as it is established and well understood and appropriate for application by a wide range of users. The hyperclustering and labelling is to be applied within a hierarchical masking framework. Masks are generated by thresholding an 8 bit NDVI channel into 4 broad classes (to represent

water, non-vegetated, coniferous, and deciduous). The masks are not intended to be exhaustive, but to provide a narrowing of the variability of digital numbers processed by the K-means classifier. Prior to clustering, we generate 2 texture channels. From the Landsat-7 ETM+ data we use the Texture module in PCI EASI/PACE to produce a homogeneity measure from a grey level co-occurrence matrix (9x9 pixel window, zero degree angle, step size of one, on ETM+ IR channel 4). The second texture channel we generate is a variance of the panchromatic channel. The "Intra-pixel texture" is generated by computing the variance on the panchromatic data within a 3 x 3 moving window. The panchromatic variance is resampled using a bilinear algorithm to 30 m to correspond to the spatial resolution of the other channels input to the classifier. As a result of the resampling, we have an indication of the within pixel variability of the Landsat optical channels. We then submit the 6 optical ETM+ channels and the 2 texture channels to the K-means classifier (requesting 241 classes, a movement threshold of 0.1, 12 iterations, and a 50% sample of the pixels under the mask). Following the clustering a process of merging similar clusters together is applied. Once the merging stage is complete the labelling of the clusters to meaningful classes takes place. Some steps in the classification process are sped through batch processing and/or specialised automation of tasks.

IV. CLASSIFICATION LEGEND

Land cover and *land use* are terms that are often used interchangeably; however, they have different meanings. Land cover results from a complex mixture of natural and anthropogenic influences and is the composition and characteristics of land surface elements [8]. In contrast, land use is characterised by economic uses of land and people's relationships with the environment. For EOSD we developed a classification legend based upon the NFI. The NFI is a hierarchical land cover classification. The level of detail captured by the NFI is greater than that available from Landsat imagery. To remain compatible, we have developed a legend that is compatible with the cover type level of the NFI class structure [9]. The NFI legend was developed in co-operation with provincial and territorial forest inventory agencies, through the Canadian Forest Inventory Committee. By utilising the NFI class structure as a base, EOSD is able to standardise classified image products,

and work in close association with provincial and territorial mapping agencies. For instance, we have worked with Alberta Environment and the University of Alberta to ensure compatibility of classification legends and the methods used to produce the classification maps [10].

V. IMPLEMENTATION STRATEGY

EOSD land cover is planned to be completed in early 2006. The CTI-S Ortho7 data will be viewed as a primary source of image data for the project. The CTI-S Ortho7 project is to be completed in 2005, which leaves a lag for completion of the land cover maps from the final images to be orthorectified. Working in partnership with provincial and territorial mapping agencies, we will determine areas covered by existing or proposed programs and work together to ensure complete coverage. Over the next four years we envision having to classify, or compile, over 110 Landsat scenes per year to remain on schedule [11]. Nationally distributed production centres are envisioned to ensure local knowledge is incorporated into the mapping where possible. Project organisation and co-ordination will be undertaken by the CFS at the Pacific Forestry Centre. Provincial / territorial partnerships are critical to the success of EOSD and the acceptance of the map products generated.

VI. CONCLUSIONS

The goal of EOSD land cover is to produce a land cover map of the forested area of Canada with Landsat-7 ETM+ data, using proven methods, to provide timely and useful information for use within, and external, to Canada. The current status of the project has background development complete, partnerships initiated, national production nodes scoped, a design for a phased implementation aiming for early 2006 completion, with a flexible product dissemination strategy. With production and partnerships started we are on course to meet the 2006 completion goal. We also intend to implement with an ability for on-going improvements to the approaches utilised. Future research opportunities for the integration of new technologies are being sought, such as the use of Radar data. Opportunities for the use of other technologies are also being researched, such as the potential for high spatial resolution imagery as a surrogate for photos.

ACKNOWLEDGEMENTS

This research is enabled through funding of the Canadian Space Plan of the Canadian Space Agency, Natural Resources Canada, and the Canadian Forest Service.

REFERENCES

- [1] J. E. Wood, M.D. Gillis, D.G. Goodenough, R.J. Hall, D.G. Leckie, J. L. Luther³, M. Wulder. "Earth Observation for Sustainable Development of Forests (EOSD): Project Overview" Proc. International Geoscience and Remote Sensing Symposium 2002. Toronto, Ontario.
- [2] "Canada's National Forest Inventory," <http://www.pfc.forestry.ca/monitoring/inventory/> 2001.
- [3] M. Wulder, "Large area land cover mapping projects incorporating remotely sensed data," http://www.pfc.forestry.ca/profiles/wulder/large_area_rs/large_area_rs.html/ 2000.
- [4] M. Wulder, M. Gillis, J. Luther, A. Dyk. "Manual for classification of Landsat data to NFI specifications," <http://www.pfc.forestry.ca/profiles/wulder/NFIUsersGuide.pdf> 2001.
- [5] S. Franklin, and M. Wulder, "Remote sensing methods in high spatial resolution satellite data land cover classification of large areas," Progress in Physical Geography, *In Press*.
- [6] M. Wulder and S. Franklin, "Spatial and spectral variability due to Landsat image acquisition date: The impact on image classification" Proc. International Geoscience and Remote Sensing Symposium 2002. Toronto, Ontario.
- [7] M. Wulder, E. Loubier, and D. Richardson, "A Landsat-7 ETM+ Orthoimage Coverage of Canada", Canadian Journal of Remote Sensing, *In review*.
- [8] J. Cihlar, "Land cover mapping of large areas from satellites: Status and research priorities," International Journal of Remote Sensing, Vol. 21, No. 6&7, pp. 1093-1114. 1999.
- [9] M. Wulder and T. Nelson, "EOSD legend: characteristics, suitability, and compatibility," Canadian Forest Service, Pacific Forestry Centre, 74p. 2001.
- [10] M. Wulder, G.A. Sanchez-Azofeifa, S. Hamilton, and K. Dutchak, "Use of high spatial resolution satellite data as a calibration data source to aid in the cluster labeling when classifying Landsat data," Proc. 23rd Canadian Symposium on Remote Sensing, Remote Sensing in the Third Millennium: From Global to Local, Université Laval, Sainte-Foy Québec, Canada, August 20-24, 2001.
- [11] M. Wulder, and D. Seemann, "Spatially partitioning Canada with the Landsat Worldwide Referencing System," Canadian Journal of Remote Sensing, Vol. 27, No. 3, pp. 225-231, 2001.