Evaluation and Validation of EO-1 for Sustainable Development (EVEOSD) of Forests

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In this investigation, EO-1 data were acquired to evaluate the ability of the EO-1 spaceborne sensors to measure forest attributes. Experiments were conducted with EO-1 data to validate that products obtained from the Advanced Land Imager (ALI) and Hyperion were as good as or better than products produced earlier with Landsat sensors with an eye toward ensuring Landsat continuity. The EVEOSD team, with members from the Canadian and U.S. government, academia, and industry, also validated Hyperion imagery by comparing it with Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) hyperspectral data and detailed field data. Further, since it was determined that precise geometric correction of remotely sensed data was critical to link ground spectral data with satellite data, the investigators also examined the process of calibrating and correcting Hyperion and ALI data.

EO-1 data were collected over seven of eight test sites in Canada and one in Washington State for the Evaluation and Validation of EO-1 for Sustainable Development (EVEOSD) project. Two of the sites, the Greater Victoria Watershed District (GVWD) located on south Vancouver Island, British Columbia, and Hoquiam in southwestern Washington State, were used to examine the atmospheric correction process and the creation of bioindicators and determination of forest chemistry. The EO-1 satellite successfully acquired imagery over Hoquiam on August 9, 2001, and over GVWD on September 10, 2001. Figure 1 shows the EVEOSD sample plots in GVWD.

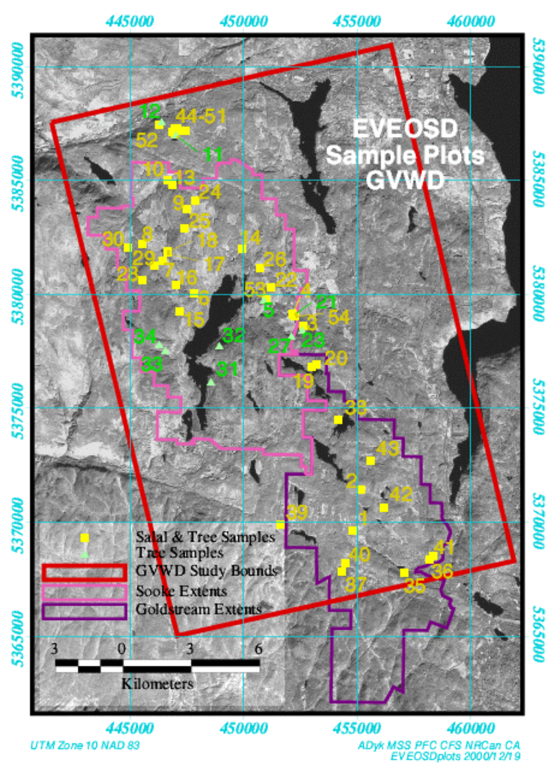
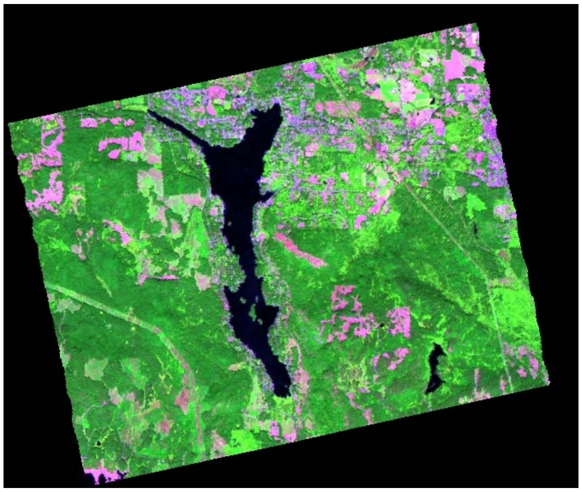


Figure 1. Sampling locations in GVWD.

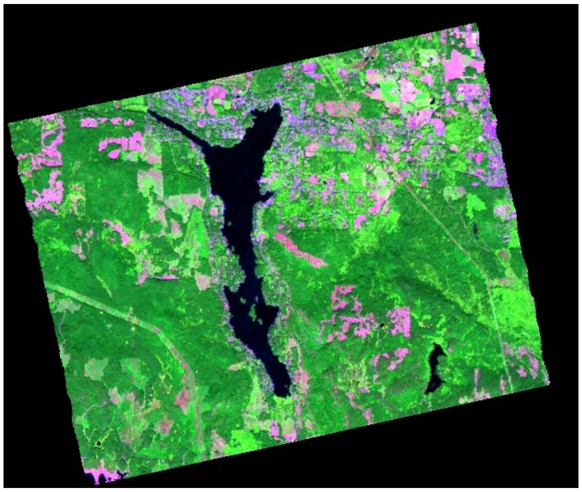
Ground samples of treetop foliage and salal (a shrub) were also collected, and organic and inorganic data analyses were performed on these samples in September 2000 and July 2001. The organic chemical analyses on the treetop samples were separated into current (during the last year) and non-current growth. Analyses contained data on chlorophyll, the percentages of moisture and nitrogen, and the concentration of several chemical elements in each sample. Four plots identified Douglas fir foliage that had elevated arsenic levels. The arsenic level in the elevated Douglas Fir plots reached as high as 348 parts per million (ppm), while normal plots averaged only 29 ppm. Neither salal nor soil samples nearby showed such elevated levels.

The correction process consisted of GCP (ground control point) collection, Hyperion and ALI registration (separately for data from each instrument), and orthorectification. Hyperion data required that “smile errors” be fixed. Hyperion images also commonly contained stripes that needed to be removed, as more than 15% of Hyperion bands exhibited some stripes. Destriping could be accomplished in two ways. One used an algorithm to replace the striping pixels by taking the average of their immediate left and right neighbors. The second used an algorithm (based on work by Alexander F.H. Goetz) to perform minimum noise fraction (MNF) rotation on the original Hyperion image, force the column mean to zero of each MNF band, and apply the inverse MNF to the mean removed data.

GCP collection used a feature-fitting method in which ground features were adjusted to match the same features as they appeared in a hyperspectral image such as acquired from AVIRIS or Hyperion. Images were calibrated to reflectance. Final adjustment factors were determined to force the image reflectance to agree with the ground reflectance for a calibration target. Figure 2 shows pre- and post-force-fit AVIRIS images. For Hyperion, GCPs were collected independently from both the visible and near infrared (VNIR) and shortwave infrared (SWIR) arrays to determine the adjustment factor required to remove the displacement and skew between these arrays. When the adjustment factor had been determined, it could then be applied to GCPs that had been collected from both the VNIR and SWIR arrays and the effects of geometric correction of the spectra analyzed.



Pre force-fit



Post force-fit

Figure 2. Force-fit AVIRIS images.

Geocorrection had good results. It was found that both Hyperion and ALI data could be geocorrected with considerable accuracy. Using the Rational Function Model (RFM) and a digital terrain model, excellent geocoding accuracies were obtained in orthorectifying the data to merge with GIS (Geographic Information System) data, with rms (root mean square) errors of collected GCPs at or under the 10-meter accuracy of the source vectors. Hyperion was geocoded to an rms of 10.01 meters and ALI to an rms of 5.18 meters.

Two EO-1 products were produced from this investigation: classification products and bioindicator products. For forest classification, Hyperion produced an aggregated classification accuracy of 94.2%. This compared with an accuracy of 77.5% for Landsat's Enhanced Thematic Mapper Plus (ETM+), 94.0% for AVIRIS, and 87.5% for ALI using 70% of the training data and accuracies of 90.0%, 75.0%, 92.1%, and 84.8% for Hyperion, ETM+, AVIRIS, and ALI respectively with 30% of the test data (Figure 3).

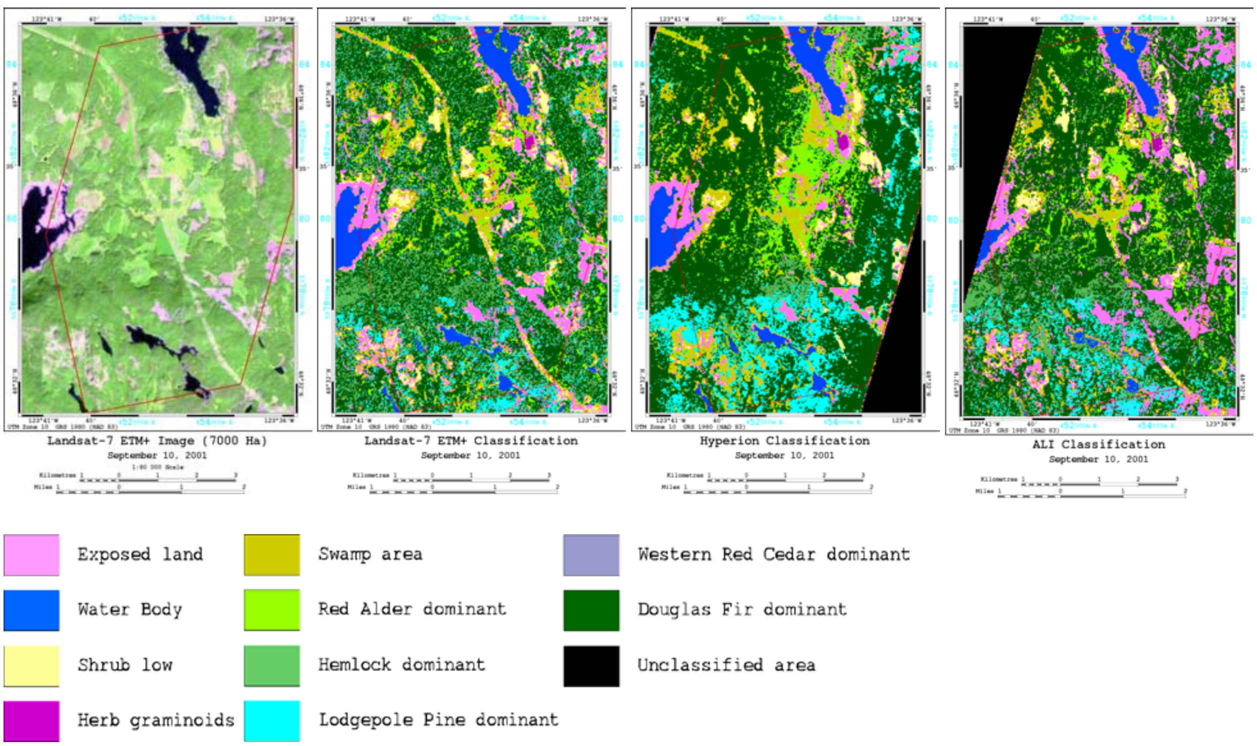


Figure 3. Classification results.

Bioindicators, indicators of forest health, involve assessing ecological processes in forested environments. They provide insight into the health of forest ecosystems by revealing current ecological conditions and have the potential to assess and improve large-scale management of forest environments. Bioindicators are being developed to characterize chlorophyll and nitrogen distribution in forests and to identify moisture and environmental stresses. The concentration of chlorophyll a in the GVWD was measured using Hyperion bands at 750 nm and 700 nm (Figure 4). Figure 5 shows the corresponding chlorophyll a and bioindicator values for mature Douglas Fir plot locations.

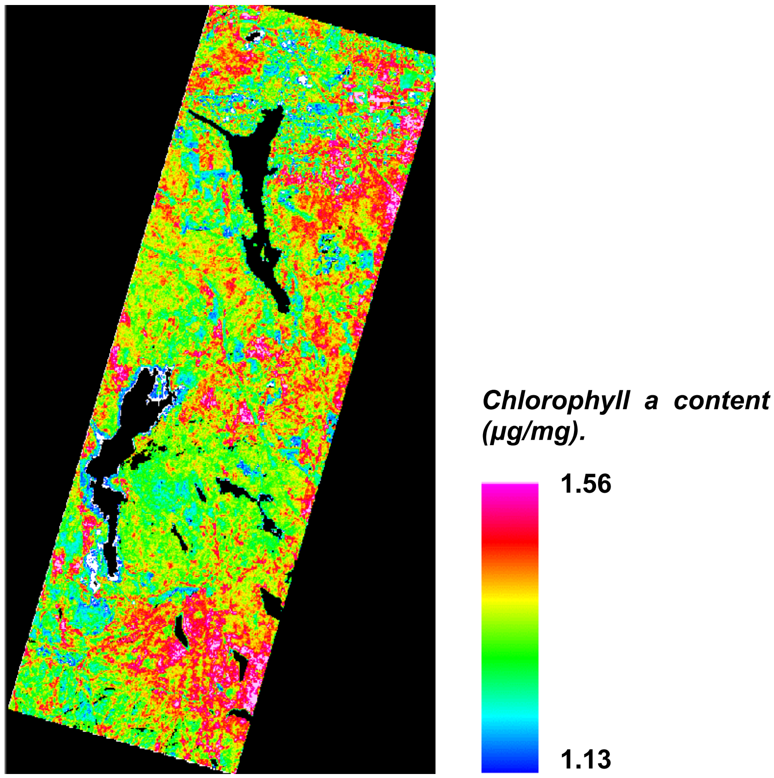


Figure 4. Chlorophyll a concentrations acquired by Hyperion, September 10, 2001.

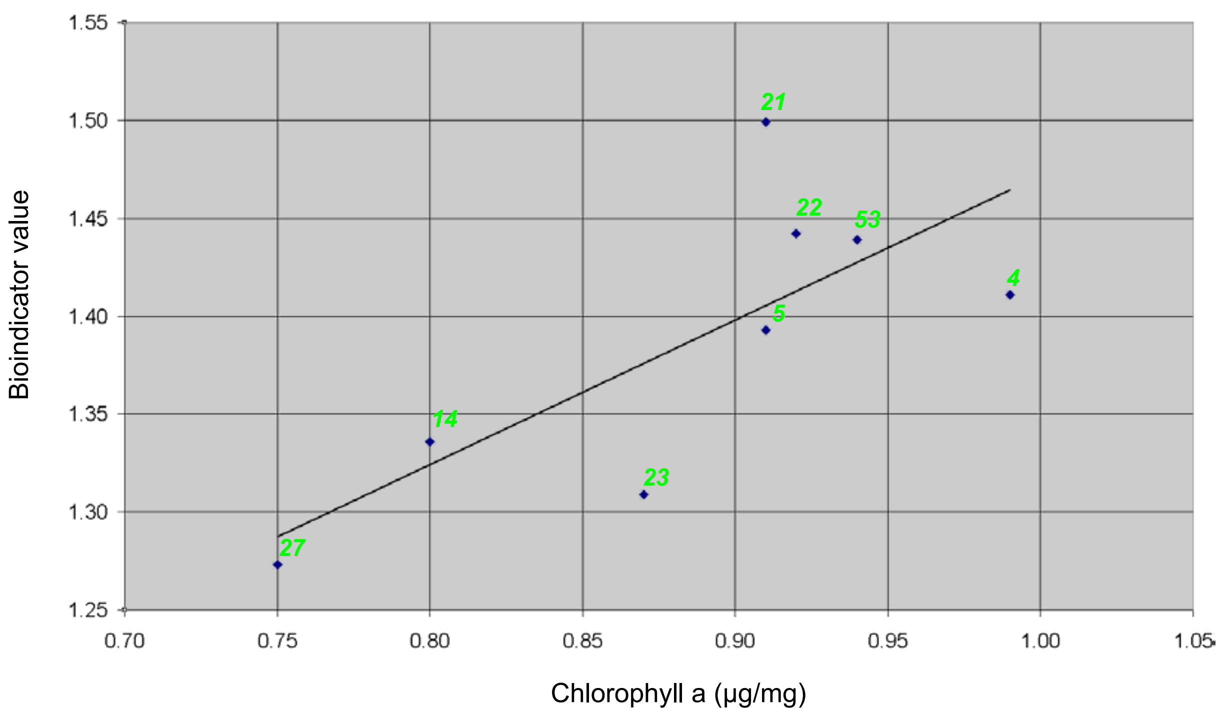


Figure 5. Chlorophyll a and bioindicator values in mature Douglas Fir plots.

Conclusions:
Hyperion data can be corrected automatically for stripes and smile, but atmospheric correction needs further research. Radiometric errors remain. Image resampling needs to be improved for 12-bit inputs; 12-bit data challenge the current capabilities and accuracies of commercial image analysis software. Excellent geocoding accuracies of 10.1 meters for Hyperion and 5.18 meters for ALI were obtained. Hyperion produced operational forest classification accuracies of 90.0% and AVIRIS of 92.1% for several tree species in GVWD. ALI forest classifications were much better than that for ETM+, with ALI producing accuracies of 84.8% compared with 75.0% for ETM+. Calibration databases of foliar and ground organic and inorganic chemical measurements, forest mensuration parameters, and spectral reflectances were constructed.

The investigators also identified future steps to be taken. The need exists to better understand the chemistry of forests based on ground measurements, three-dimensional monitoring, and modeling. The investigators found that the best correlations were obtained with stratification into species of similar forest maturities. They anticipate that chemistry products from hyperspectral remote sensing will revolutionize GIS and forest information systems. Hyperspectral remote sensing also has the potential to provide early detection of insect damage in forests, and accurate hyperspectral nitrogen maps will make forest company fertilization programs much more effective.