

Continental Scale Validation of MODIS-Based and LEDAPS Landsat ETM+ Atmospheric Correction Methods

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Abstract – The potential of Landsat data processing to provide systematic continental scale products has been demonstrated by several projects including the NASA Web-enabled Landsat Data (WELD) project. The recent free availability of Landsat data increases the need for robust and efficient atmospheric correction algorithms. This study compares the accuracy of two Landsat atmospheric correction methods: a MODIS-based method and the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) method. Both methods are based on the 6SV radiative transfer code but have distinctly different atmospheric aerosol characterization approaches. The MODIS-based method uses the MODIS Terra derived dynamic aerosol type and optical thickness to atmospherically correct ETM+ acquisitions in each coincident orbit. The LEDAPS method uses aerosol characterizations derived independently from each Landsat acquisition and assumes a fixed continental aerosol type. Validation results are presented comparing ETM+ atmospherically corrected data generated using these two methods with each other and with AERONET corrected data at 102 10km x 10km sites centered on AERONET sites located across the conterminous United States. The results indicate that the MODIS-based method has better accuracy than the LEDAPS method for all the ETM+ reflective bands.

Key words: Landsat; MODIS; atmospheric correction; Web-enabled Landsat Data (WELD); Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS).

1. INTRODUCTION

The impact of the atmosphere is variable in space and time and is usually considered as requiring correction for quantitative remote sensing applications. Consistent Landsat surface reflectance data are needed in support of high to moderate spatial resolution geophysical and biophysical studies. The NASA funded Web-enabled Landsat Data (WELD) project is systematically generating 30m composited Landsat Enhanced Thematic Mapper Plus (ETM+) mosaics of the conterminous United States (CONUS) and Alaska from every ETM+ acquisition with cloud cover < 80% (Roy, et al. 2010; Roy et al. 2011). The planned Version 2.0 WELD products will be corrected for atmospheric effects to provide 30m land surface reflectance. Two candidate atmospheric correction methods are being considered: a new MODIS-based method and the established Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) method. Both atmospheric correction methods use the 6SV radiative transfer code which has an accuracy better than 1% over a range of atmospheric stressing conditions (Kotchenova et al. 2006).

The MODIS-based method uses the atmospheric characterization data used in the generation of the standard MODIS Terra land surface reflectance product suite (Vermote et al. 2002) to correct the Landsat ETM+ data sensed in the same MODIS Terra orbit. The MODIS Terra aerosol optical thickness and aerosol type (dust, polluted urban, clear urban, high absorption smoke, low absorption smoke), derived using an approach based on the Kaufman et al. (1997) dense dark vegetation (DDV) methodology, and MODIS derived water vapor, in conjunction with daily ozone derived from NASA's EP TOM instrument and surface atmospheric pressure from NCAR/NCEP 6-hourly Reanalysis data are used (Vermote and Kotchenova, 2008).

The LEDAPS method (Masek et al. 2006) derives the aerosol optical thickness independently from each Landsat acquisition using the Kaufman et al. (1997) DDV approach and assuming a fixed continental aerosol type. The LEDAPS method also uses the NCAR/NCEP 6-hourly Reanalysis water vapor data, and like the MODIS-based method, uses the NASA's EP TOM ozone data and surface atmospheric pressure from NCAR/NCEP 6-hourly Reanalysis data.

The MODIS instrument has superior spectral and radiometric characteristics and senses a much larger swath compared to the Landsat ETM+ and so should provide more reliable atmospheric characterization than the LEDAPS approach. However, the MODIS atmospheric characterization describes the atmosphere approximately 27 minutes after the Landsat ETM+ overpass and so dynamic aerosols may be better defined from the ETM+ acquisition itself under the LEDAPS approach provided that DDV targets are available in the ETM+ acquisition.

2. DATA AND METHODS

The accuracies of the MODIS and LEDAPS atmospherically corrected Landsat ETM+ surface reflectance products were quantified by comparison with surface reflectance derived independently using AERONET sun-photometer aerosol and water vapor measurements (Holben et al. 1998, Dubovik, et al. 2002). The AERONET atmospheric measurements enable atmospheric correction to 2% accuracy (Kotchenova et al. 2006) and so the Landsat data corrected using the AERONET data are assumed to be "truth" for validation purposes. In this study the AERONET aerosol and water vapor, EP TOM daily ozone data, and surface atmospheric pressure from NCAR/NCEP 6-hourly Reanalysis, were used to atmospherically correct the Landsat data using the 6SV radiative transfer code.

All the Landsat ETM+ L1T acquisitions over the conterminous United States (CONUS) in a 12 month period (December 1st

2007 to November 30th 2008) with cloud cover <80% (more than 8,300 acquisitions) were compared with the available CONUS AERONET data. Of these acquisitions, only 102 were acquired coincident with good quality AERONET atmospheric measurements made within 30 minutes of a Landsat ETM+ overpass. The 102 acquisitions were distributed at 23 AERONET sites across the CONUS and capture a range of vegetated and desert surfaces. For each of the 102 Landsat acquisitions spatial subsets of 10 km x 10 km, centered on the AERONET sites, were atmospherically corrected by the AERONET, MODIS, and LEDAPS methods.

Surface reflectance residuals were defined for the MODIS and LEDAPS corrected data as the absolute value of the difference between their surface reflectance and the AERONET surface reflectance for each 30m ETM+ pixel. Only cloud-free pixels, as labeled by the WELD cloud masks (Roy et al. 2010), were considered. The mean residual in each reflective wavelength band was computed for all the pixels in all 102 subsets (a total of approximately 5.6 million pixels). In addition, a 25% random sample of these data were used to produce surface reflectance scatter plots comparing the atmospheric correction methods.

3. RESULTS

The mean surface reflectance residuals computed from all the pixels in the 102 10 x 10km subsets pixels are summarized in Table 1. The spectral pattern of the residuals is complex and is driven by the spectral variation in atmospheric contamination (which generally should decrease with wavelength) and by the spectral properties of the surface, whereby for example, healthy vegetation has low red reflectance and high near-infrared reflectance. Despite this complexity, the mean residuals for the MODIS atmospheric correction method are consistently smaller than for the LEDAPS method in all the Landsat ETM+ reflective wavelength bands.

Table 1. Mean surface reflectance residuals (in reflectance units) computed with respect to AERONET surface reflectance “truth” for the Landsat ETM+ reflective wavelength bands: band 1 (blue: 0.45–0.52 μm), band 2 (green: 0.53–0.61 μm), band 3 (red: 0.63–0.69 μm), band 4 (near-infrared: 0.78–0.90 μm), band 5 (mid-infrared: 1.55–1.75 μm) and band 7 (mid-infrared: 2.09–2.35 μm).

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
LEDAPS method	0.0075	0.0054	0.0055	0.0104	0.0075	0.0067
MODIS method	0.0065	0.0042	0.0035	0.0049	0.0028	0.0025

Figures 1 and 2 show Landsat ETM+ reflectance scatter plots for the red (band 3) and near-infrared (band 4) Landsat ETM+ bands respectively. In these plots the points show the 30m pixel values colored with a rainbow scale to illustrate the frequency of the reflectance values (purple least frequent), the solid lines show regression fits, and the dotted straight lines show the 1:1 line for reference. About 1.4 million 30m pixel values are plotted. The four sub-plots are discussed below.

The upper-left corners shows the top of atmosphere (TOA) reflectance plotted against the corresponding AERONET surface reflectance values, and the straight line shows the ordinary least squares regression fit of these data. Evidently in the red band (Figure 1) the TOA reflectance is about 0.87 of the surface reflectance, whereas in the near-infrared band (Figure 2) the TOA reflectance is about 0.91 of the surface reflectance, reflecting the greater impact of atmospheric contamination at shorter wavelengths.

The upper-right corners show the LEDAPS surface reflectance plotted against the MODIS-based surface reflectance values, and the straight line shows a median based regression fit of these data (used as both methods cannot be assumed to be error free) with the regression line constrained to pass through the origin. For both the red and near-infrared bands the LEDAPS and MODIS corrected data are quite similar - with LEDAPS surface reflectance generally slightly greater than MODIS-based surface reflectance.

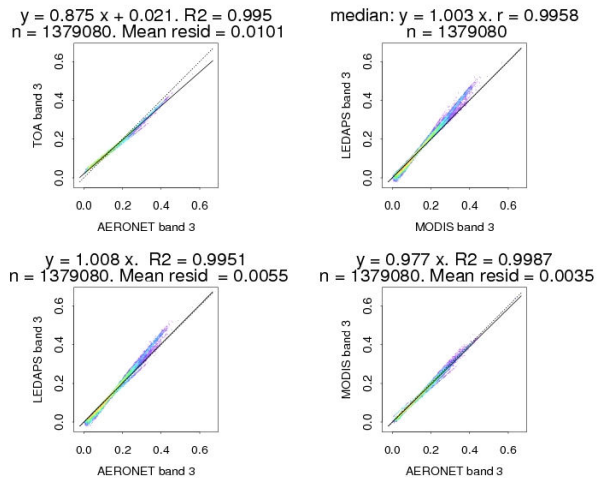


Figure 1. Red wavelength Landsat ETM+ (band 3) reflectance scatter plots (1,379,080 30m pixels). See text for details.

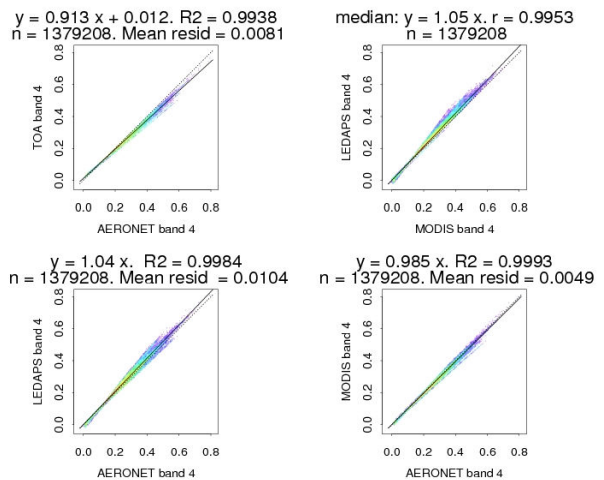


Figure 2. Near-infrared wavelength Landsat ETM+ (band 4) reflectance scatter plots (1,379,208 30m pixels). See text for details.

The lower-left and lower-right corners show the LEDAPS and the MODIS surface reflectance values (y axes) respectively plotted against the corresponding AERONET surface reflectance values (x axes), and the straight lines shows the ordinary least squares regression fit of these data with the regression line constrained to pass through the origin. For both the red and near-infrared bands the LEDAPS surface reflectance is generally greater, and the MODIS surface reflectance smaller, than the corresponding AERONET surface reflectance values. In both bands the MODIS corrected reflectance shows slightly better linear relationships with the AERONET corrected reflectance (higher R² values and slopes closer to unity) than the LEDAPS corrected reflectance. This pattern of results is found in the other reflective wavelength bands.

4. CONCLUSION

Based on the Landsat ETM+ and AERONET data available in 2008, the MODIS-based atmospheric correction method was found to have slightly better accuracy than the LEDAPS method. This is most likely due to better aerosol characterization from MODIS Terra data using a greater number of bands spectrally more suitable for atmospheric aerosol characterization and because the wider MODIS swath provides more opportunities for dense dark vegetation target identification. Further research is required to investigate these results in more detail, and with respect to individual AERONET sites, particularly those including smoke plumes and desert and snow covers.

We note that while the MODIS-based atmospheric correction provides better performance than the image-based LEDAPS approach, the LEDAPS approach can be applied to the historic Landsat Thematic Mapper archive (available since 1982) and can also be applied to future Landsat sensors in the absence of a morning VIIRS imager.

These preliminary findings only reflect the performance of the two atmospheric correction methods at the current stage of their evolution. Inspired by the MODIS method, the LEDAPS method is currently under refinement to consider the incorporation of dynamic aerosol types in place of the fixed continental aerosol type.

REFERENCES

O. Dubovik, B.N.Holben, T.F. Eck, A. Smirnov, Y.J. Kaufman, M.D. King, D. Tanré, and I. Slutsker, "Variability of absorption and optical properties of key aerosol types observed in worldwide locations," *Journal of Atmospheric Science*, vol 59, p.p. 590-608, 2002.

B.N. Holben, T.F. Eck, I. Slutsker, D. Tanré, J.P. Buis, A. Setzer, E.F.Vermote, J.A.Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenue, I. Jankowiak, and A. Smirnov, "AERONET - A federated instrument network and data archive for aerosol characterization," *Remote Sensing of the Environment*, 66:(1) 1-16. 1998.

Y.J. Kaufman, D. Tanre, L.A. Remer, E.F. Vermote, A. Chu, and B.N. Holben, "Operational remote sensing of tropospheric aerosol over the land from EOS-MODIS" *Journal of Geophysical Research-Atmosphere* , vol 102(14), p.p.17051-17068, 1997.

S. Kotchenova, E.F. Vermote, R. Matarrese, and F. Klemm Jr., "Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance," *Applied Optics*, vol 45, p.p. 6762-6774, 2006.

J. G. Masek, E.F. Vermote, N.E. Saleous, R. Wolfe, F.G. Hall, K.F. Huemmrich, F. Gao, J. Kutler, and T.K. Lim, "A Landsat surface reflectance dataset for North America, 1990-2000," *IEEE Transactions on Geoscience and Remote Sensing Letters*, vol 3(1), p.p. 68-72, 2006.

D.P. Roy, J. Ju, K. Kline, P.L. Scaramuzza, V. Kovalsky, M.C. Hansen, T.R. Loveland, E.F. Vermote, C. Zhang, " Web-enabled Landsat Data (WELD): Landsat ETM+ Composit

Mosaics of the Conterminous United States," *Remote Sensing of Environment*, vol 114, p.p. 35-49, 2010.

D.P. Roy, J. Ju, I. Kommadreddy, 2011, Web-Enabled Landsat Data (Weld): A Consistent, Long-Term, Large-Area, 30m Data Record For The Terrestrial User Community, This conference.

E.F. Vermote, N. El Saleous, and C. Justice, "Atmospheric correction of the MODIS data in the visible to middle infrared: First results," *Remote Sensing of Environment*, vol 83(1-2), p.p. 97-111, 2002.

E.F. Vermote, and S. Kotchenova, " Atmospheric correction for the monitoring of land surfaces," *Journal of Geophysical Research - Atmospheres*, 113(D23), D23S90, 2008.