Comparison of Atmospheric Correction Algorithms for Multispectral Satellite Imagery

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ABSTRACT

Correcting satellite imagery for atmospheric effects is a common procedure today. Indeed there are many techniques and software applications that offer atmospheric correction processes. This study compared several techniques (apparent reflectance, dark-object subtraction, Cos(t), and the full cost model) in both Idrisi and ENVI software to determine the level of similarity between resulting imagery and the interoperability of these data. In nearly all cases comparison of resulting imagery revealed no differences (r = 1.0). However, other results suggest that for a given project, all imagery should be corrected using the same technique within the same software application. Furthermore, use of full cost models should probably be avoided unless optical thickness and spectral diffuse sky irradiance parameters can be accurately computed and consistently applied. As an alternative, both Cos(t) and dark-object subtraction algorithms offer viable correction techniques that are well documented and appear to be robust and reliable.

KEYWORDS: atmospheric correction, full-cost model, Cos(t), Dark object subtraction, apparent reflectance, Lake Superior

INTRODUCTION

The effect (e.g., attenuation and scattering) the atmosphere has on ground response signals has been an active area of research since Chandrasekhar's radiative transfer theory was published in 1960. Since that time, numerous algorithms have been developed to correct satellite imagery for known atmospheric effects (Dave 1980; Forster 1984). Most, if not all approaches have been similar and apply the same parameters. These parameters include 1) the date and time of image acquisition, 2) ambient weather conditions (temperature, humidity, atmospheric pressure), 3) solar zenith angle (Θ_0) and derived μ_0 as the cos(Θ_0), 4) normal optical thickness (derived from ozone optical thickness for affected bands and aerosol optical thickness of each band), 5) satellite viewing angle, 6) atmospheric transmittance, 7) spectral solar irradiance, 8) path radiance, and 9) global irradiance. Many of these parameters represent known values (1 and 3), values considered waveband-dependent constants (4) or values derived from previous steps in the atmospheric correction process (4, 6-9). Other parameters, such as ambient weather conditions (2) and satellite viewing angle (5), are applied generalized values even though variability exists across the extent of the imagery being corrected. Potential errors associated with this approach are well recognized and areas of active research today. For instance the satellite viewing angle and solar zenith angle are used to calculate the solar incidence angle (SIA). However, without the use of an adequately resolved digital elevation model, SIA is at best an estimate. The associated error can be partially corrected for using the bi-directional reflectance distribution factor (BDRF) (Schott 1997) although this is not commonly done as it is computationally expensive. In addition, it should be realized that BDRF corrections represents a generalized estimate as the characteristics of the earth's surface (surface roughness, vegetation, soil moisture and albedo, etc.) play a significant role in determining the amount of light reflected by that surface. In essence, while the application of atmospheric correction processes are critical to geographic information science, it is equally important to recognize that imagery corrected for atmospheric effects will always retain residual errors.

Today, numerous techniques exist within various software applications that perform atmospheric correction. In some cases, analysts are even presented a choice among several techniques within the same software. Frequently, one technique will be chosen and applied repeatedly over the course of a career because the analyst understands that technique or feels comfortable with the procedure. Others working alongside the analyst may apply a different technique. Ultimately, imagery that has been atmospherically corrected using different techniques, may be involved in an analysis (e.g., temporal land cover change) with little consideration given to the affect the atmospheric correction techniques will propagate through the subsequent analysis. For this reason, a study was undertaken to compare various atmospheric correction techniques and determine the potential error mixed techniques might have on image analysis.

METHODS

Landsat 5 TM imagery was acquired for path 39, row 30 representing a region of semiarid rangelands in southeast Idaho (scene acquisition date: July 20, 2008). Bands 3 (red) and 4 (near infrared) were corrected for atmospheric effects using each of the following algorithms, 1) Cost(t) (Chavez 1996) using Idrisi Taiga, 2) Dark object subtraction (DOS) (Chavez 1988; Cracknell and Hayes 1991) using Idrisi Taiga, and DOS using ENVI IDL, Apparent reflectance (AR) in Idrisi Taiga, and the Idrisi Full-Cost Model (FCM) (Forster 1984). Within each of these algorithms input parameters were modified as appropriate. For instance, Lmin Lmax was used and compared with results where gain and bias were used instead. In addition, Dn haze settings were either read from an apparent black body (American Falls Reservoir

[Figure 1]) or set at zero (0) (Lillesand et al. 2008). In total, 13 variations in atmospheric correction were performed for each band.

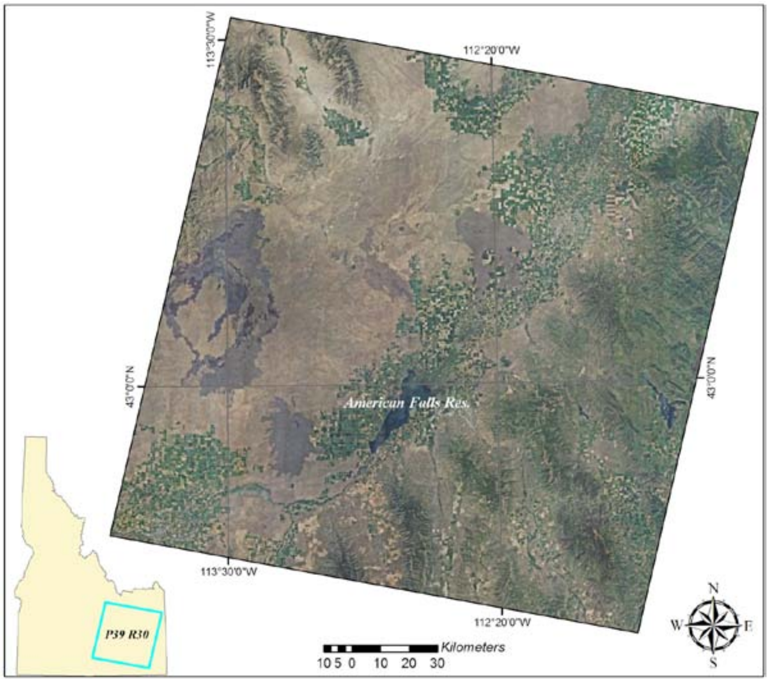


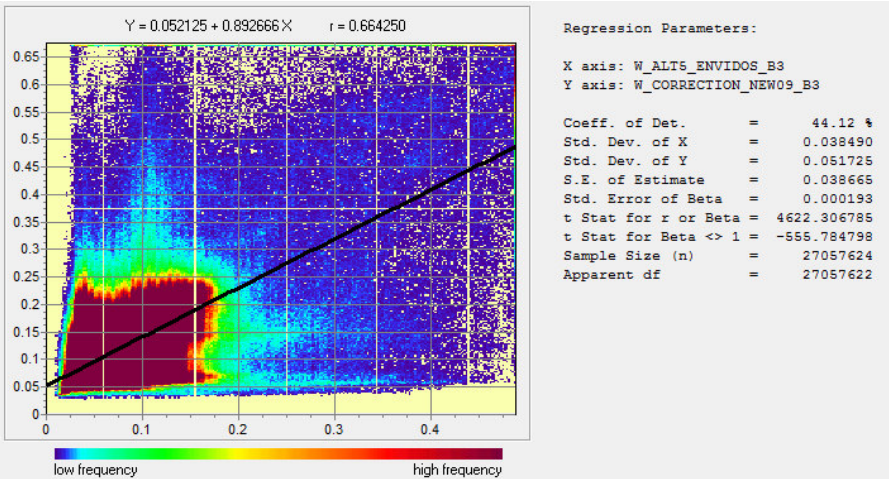
Figure 1. Extent of Landsat imagery (path 39 row 30) used in this study and the American Falls Reservoir (an apparent black body) which was used to derive Dn haze values.

The atmospherically corrected imagery was windowed to exclude all background pixels and thereby facilitate a robust statistical comparison of techniques that would not be skewed by agreement among background pixels (pixel values = 0). The resultant imagery was statistically compared using regression analysis within Idrisi Taiga (REGRESS) and a t-test of r. These tests allowed eight fundamental questions to be answered relative to this set of Landsat 5 TM imagery; specifically, is there a difference in atmospherically corrected imagery 1) using gain/offset versus Lmin/Max, 2) using different Dn haze settings within the Cos(t) algorithm, 3) using different Dn haze settings with the DOS algorithm, 4) between AR and Cos(t) when Dn haze equaled zero, 5) between AR and DOS when Dn haze equaled zero, 6) between Cos(t) and DOS, 7) between Cos(t) and a FCM, and 8) between DOS performed within Idrisi versus an ENVI IDL algorithm.

RESULTS AND DISCUSSION

In nearly all cases, atmospherically corrected imagery was identical, or nearly so, regardless of the type of atmospheric correction technique applied within Idrisi Taiga. More specifically, the Y-intercept equaled zero, the slope of the line equaled 1.0000, r equaled 1.0000, the coefficient of determination equaled 100%, and the t-test of r was not significant ($P < 0.0001$).

The exceptions to these observations were as follows: 1) while not statistically significant ($P < 0.0001$; $r = 1.0$), the comparison between AR and Cos(t) corrected imagery when Dn haze equaled zero revealed a resulting slope of 0.864, 2) similar comparisons between Cos(t) and DOS corrected imagery resulted in a slope of 0.864 ($r = 1.0$). Of greater interest were differences observed between DOS correction methods performed in Idrisi and ENVI (Figure 2). These comparisons were dissimilar enough (r = 0.67) to prudently suggest that imagery corrected with different software applications not be used in the same image analysis project.



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Regression Parameters:

X axis: W_ALT5_ENVIDOS_B3
Y axis: W_CORRECTION_NEW09_B3

Coeff. of Det.        =       44.12 %
Std. Dev. of X        =    0.038490
Std. Dev. of Y        =    0.051725
S.E. of Estimate      =    0.038665
Std. Error of Beta    =    0.000193
t Stat for r or Beta =  4622.306785
t Stat for Beta <> 1 =  -555.784798
Sample Size (n)       =    27057624
Apparent df           =    27057622
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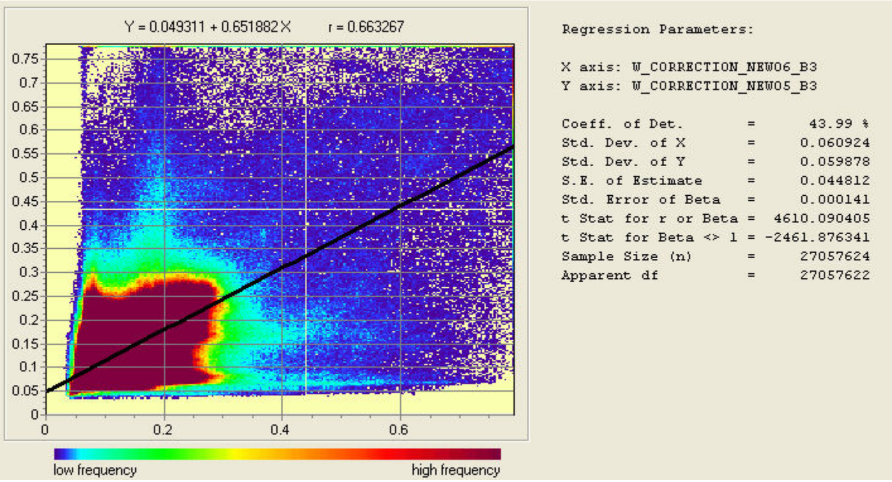
Figure 2. Comparison of DOS-corrected imagery calculated in ENVI (X-axis) and Idrisi (Y-axis) demonstrating an incompatible difference.

Similar results were observed by comparing Cos(t) and FCM corrected imagery (Figure 3; r = 0.66). These results suggest that while all other algorithms exhibited near perfect agreement, the FCM within Idrisi Taiga responded differently. This is of interest as the response appears to be attributable to a change in only two input parameters, optical thickness and spectral diffuse sky irradiance. In this study, optical thickness values for the FCM were set at 0.05 and 0.01 (red and near-infrared bands, respectively) following Forster (1984). Spectral diffuse sky irradiance followed the BRITE code (Bird 1984). Optical thickness is itself an estimate primarily influenced by aerosols in the atmosphere (Turner and Spencer 1972) which varies as a function of standard pressure and declines exponentially with altitude. In mountainous regions, optical thickness is typically generalized to facilitate processing.



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Regression Parameters:

X axis: W_CORRECTION_NEW06_B3
Y axis: W_CORRECTION_NEW05_B3

Coeff. of Det.        =       43.99 %
Std. Dev. of X        =    0.060924
Std. Dev. of Y        =    0.059878
S.E. of Estimate      =    0.044812
Std. Error of Beta    =    0.000141
t Stat for r or Beta =  4610.090405
t Stat for Beta <> 1 = -2461.876341
Sample Size (n)       =    27057624
Apparent df           =    27057622
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Figure 3. Comparison of imagery corrected with the FCM (X-axis) and Cos(t) (Y-axis) demonstrating relatively large but yet non-significant differences.

Spectral diffuse sky irradiance assumes a cloudless atmosphere and is a modeled variable which will vary depending upon solar incidence angle. There are five primary model parameters required to determine spectral diffuse sky irradiance and no less than five alternatives algorithms as well (Bird 1984; Justus and Paris 1984). In light of these complexities and uncertainties it seems use of the FCM is not advisable under most conditions. Rather, to maintain consistency, other well accepted atmospheric correction techniques should be utilized.

It is interesting to note that no difference was observed between atmospherically corrected imagery where Dn haze was equal to zero and where Dn haze values were extracted from an apparent black body (deep water areas within American Falls Reservoir). The extracted values used consistently throughout this study were 15 and 14 for the red and near infrared bands, respectively. Still, even with these differences in Dn haze, no difference in atmospherically corrected imagery was detected (Y-intercept = 0.000, slope = 1.000, r = 1.000, and $P < 0.0001$).

It was considered that perhaps American Falls Reservoir did not adequately approximate a black body and for this reason, no difference was noted among comparisons. To investigate this, three additional Landsat 5 TM scenes were acquired for the Lake Superior and Keweenaw Peninsula region (path 024 row 027). This area was selected as the lake is very deep and oligotrophic (secchi disk depths range from 10-20 meters [cf. Minnesota Sea Grant]). As a result, the characteristics of Lake Superior should better approximate a black body. Analysis of these images proceeded in the same way as described earlier with no difference in atmospherically corrected results observed between Dn haze settings of zero and when Dn haze settings were read from deep water areas within the imagery (Y-intercept = 0.005, slope = 1.01, r = 1.00, and $P < 0.0001$).

CONCLUSIONS

Landsat 5 TM imagery was atmospherically corrected using a variety of algorithms within both Idrisi and ENVI software. In nearly all cases comparison of resulting imagery revealed no differences, including corrected imagery where Dn haze was intentionally set to zero in comparison with imagery where Dn haze was derived from an apparent black body. This suggests that Dn haze values have little overall effect within the correction algorithms and may not be necessary. The only notable exceptions to these general observations were comparisons of 1) imagery corrected in Idrisi with imagery corrected in ENVI (Figure 2) and 2) imagery corrected using the FCM technique (Figure 3). It is suggested that within a given analysis project, all imagery be corrected following the same technique and within the same software application. Furthermore, use of the FCM should probably be avoided unless optical thickness and spectral diffuse sky irradiance parameters can be accurately computed and consistently applied. As an alternative, both Cos(t) and DOS algorithms are viable correction techniques that are well documented and appear robust and reliable.

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