Removing atmospheric effects for Multi spectral images (OLI 8) using ATCOR model

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Abstract. The atmospheric correction of satellite images is an important first step for different remote sensing applications such as estimation of vegetation indices. In atmospheric corrections, most uncertainties arise from temporal and spatial variations in aerosol types and quantities. Thus, considered validation estimate Aerosol is an essential step in the validation atmospheric correction algorithms. In the current study, two models of atmospheric correction algorithms ATCOR (ATCOR 3 and ATCOR 2) were applied to remove atmospheric effects of test sites in Middle part of Iraq. Statistical results of ATCOR 2 was shown to be successful in the urban parts to remove effective type of aerosol which could be chosen to process satellite images in areas under investigation.

Keywords: ATCOR 2, ATCOR3, Atmospheric correction, OLI.

1. Introduction:

Before reaching to the earth's surface, radiation used for remote sensing should travel through some distance of the earth's atmosphere. Atmospheric gases and particles can affect the incoming lights and radiations. Mechanisms of absorption and scattering can cause these effects [1,2]. Theoretically, depending upon the particle size which lead to scattering and the wavelength of scattered radiation, scattering can be classified into three categories [3]: There is a predominance of Rayleigh scattering, as there is interaction between electromagnetic radiation and particles which are smaller than the incoming light's wavelength, where there is an inverse relationship between the wavelength's forth power and the incoming light's wavelength. There is more scattering of the shorter wavelengths than the longer wavelengths. In the aspect of remote sensing, the most important kind of scattering is Rayleigh scattering. It leads to the distortion of the spectral characteristics of reflected lights in comparison with the measurements performed on the ground [4,5].

Atmospheric particles having the same wavelength size show the dispersion of mi. The emergence of multiple scattering occurs when the size is similar to the wavelength of the radiation contained with a particle size in the atmosphere. This type results from the scattering of aerosols, a mixture of dust, gases and water vapour. It is usually limited to lower atmosphere, where there is huge amounts of large particles that dominate at overcast cloudy conditions. It affects the total spectral part which begins from ultra violet to almost near the infrared region [3,5]. Aerosols exhibit non-selective scatterings, and these aerosols are water droplets with particle size much greater than the wavelength energy (visible and almost mid infrared). Scatterings performed by atmospheric particles are dominant mechanisms which result in radiometric distortions of image data, as well as the probable sensor malfunction impacts [5].

When there is an interaction between electromagnetic radiation and the atmosphere, absorption is the other major mechanism at work. This phenomenon causes the atmospheric molecules to absorb energy at different wavelengths. The three major atmospheric components which absorb radiation are ozone, water and carbon dioxide [1,2].In several canopies, most non-photosynthetic vegetation (NPVs) are obscured under a tightly-closed leaf canopy; the shortwave red wavelengths used for measuring (NPVs) usually can not penetrate the upper canopy for interaction with these (NPVs). Thus, only exposed (NPVs) have important influence on the spectral reflectance of the vegetated ecosystem, and during their exposure, (NPVs) scatter photons so effectively to infrared range shortwaves, in contrast with the green vegetation which are highly absorbed in that range[6].
The potentially ideal source to detect changes and analyze trends is provided by time series of remote-sensed image that is acquired at high temporal and spatial resolutions [7]. Methods of correcting sensor sensitivity changes, and topographic with viewing angle impacts involved in the category of radiometric correction which is well-established. Removal of atmospheric effect is the most complicated step in the radiometric correction processes [8]. The intensity of electromagnetic radiation intensity is recorded by digital sensors of each spot and shown on the surface of earth as digital number (DN) to all spectral bands. The exact DN range that is utilized by the sensor relies on its radiometric resolution. The true units are recorded as W m$^{-2}$ ster$^{-1}$ mm$^{-1}$, though DN values recorded by the sensors are proportional to radiances. Most of image processing depend upon raw values of DN where the true spectral radiance is not a concern [9,10].

Modified darkest pixel atmospheric correction is considered as a darkest pixel DP. The dark target of the surface radiance is proposed to possess approximately a zero surface reflectance or radiance [11,12]. If the images stem from the same sensor, then we can use a simple sun elevation correction. The trick is to normalize the images as if they are taken with the sun at the zenith [2]. Haze is composed of atmospheric aerosols and molecules which scatters and absorbs solar radiations, thus rendering the downward and upward solar radiance to be recorded with remote-sensing sensor. The aim of Haze correction is to remove these effects from raw data, which can be beneficial to several space borne RS applications. Therefore, for each band of a RS image, reducing haze should be done independently [2].

1.1 Study Area
Baghdad province is the first land area, which is the capital and the main educational, cultural and economic city in Iraq. Geographically, it is situated in the right center of Iraq as shown in figure (1). Baghdad province is located between a number of Iraqi provinces (latitudes 33.312805° to the north and longitude 44.361488° E).

2. Methodology
2.1 ATCOR atmospheric correction model
The atmospheric and topographic correction ATCOR is a broadly method used to correct the atmospheric satellite data [13]. ATCOR is applied to compute the reflectances image ground of the reflective spectral band, and the thermal band emissivity image. For nearly flat terrain or horizontal surface, ATCOR (2) is considered as the spatially-adaptive fast atmospheric corrections algorithms, while ATCOR (3) is used for rugged topographic surfaces, therefore, the digital elevation model (DEM) is applied in ATCOR (3) algorithms for atmospheric corrections purpose [14,15]. ATCOR algorithm, also depends upon (MODTRAN-4 RTC), which is a surface reflectance, without considering the adjacency impact, and it is derived by the following equation [16]:

$$\rho = \frac{1}{a_1} (d^2 \pi L' - a_0) \quad \text{.............(1)}$$

Where: $E_{TOA}$ is a solar spectral radiance on the surface that is perpendicular to the sun rays outside the atmosphere. $d^2$: is a direct distance to sun. $a_0$ and $a_1$ coefficients derived from the main atmospheric parameter estimation: the column of water vapor, type of aerosol and the optical thicknesses.
In brief, ATCOR is beneficial for processing solar region bands between 400 –2500 nanometers. ATCOR model was split into separated codes optimized for airborne and satellite sensors. ATCOR (ATCOR-2/3) satellite reinforces the small to moderate FOV sensors only, and it is composed of separate codes to rugged and flat terrain [17]. On applying ATCOR 3, the next set of empirical functions G Eqs. 2&3 serve in decreasing higher values of reflectance in extreme geometry areas to obtain reflectance values that are close to those of nearest areas with a moderate incident angle.

$$G = \frac{\cos(i)}{\cos(t)} \quad \ldots \ldots \ldots (2)$$

$$G = \sqrt{\frac{\cos(i) \cdot \cos(e)}{\cos(t)}} \quad \ldots \ldots \ldots (3)$$

Where G is the empirical function, t is the threshold angle, i is the incident angle and g lower boundary. G function is ranging between specified lower boundary (g) and (1), which means that the specified lower boundary is $g \leq G < 1$. Only the area of extreme incidence and / or existence angle is included, initiating with the threshold angle (t). Values of G more than (1) are set to the figure (1), while values lower than g boundary are set to (g), indicating that the process functions in a geometric order from (t) to (90°). The majority of satellite sensor with high spatial resolution possess viewing angle closer to nadir, but the sun is often at the farthest distance from nadir. Thereby, the incident angles mostly penetrate into the 60°–90° critical regions. Equations 4 and 5 are also based on the existence angle (e), and such options are involved for tilting sensor. When the scene is recorded along with greater off-nadir view angles (i.e. 20–30°), where (e) could be nearer to solar zenith. In this condition, angle (i) and angle (e) may get access into critical region (60–90°) together.

$$G = \cos(i) \cdot \cos(e)/\cos(t) \quad \ldots \ldots \ldots (4)$$

$$G = \sqrt{\cos(i) \cdot \cos(e)/\cos(t)} \quad \ldots \ldots \ldots (5)$$

3. Results and discussion

To be sure result of atmospheric correction in this project are accurate, the researchers have made multiple visits to the region of study area (Baghdad). During these trips, the researcher carried with them a GPS device (GPS 72) shown in figure (2-a). The researchers conducted a field visit and samples were taken from the area of the study area (cover, "water, vegetation and soil"), as shown in Figure (2-b) to measure the spectral reflection of each sample using ASD.

Figure (2): (a) GPS – 72 devices, (b) Analytical Spectral Devices (ASD)

Three different areas were identified and processed in software ENVI by region of interest (ROI) and applied FLAASH and QUAC atmospheric correction methods as shown in (Figure 4):
Figure (4): The image of multi-spectral image of first steady area. The region inside the red square has been processed with atmospheric correction models. (a) first region selected has processed includes water, (b) second region selected has processed includes vegetation and (c) third region selected has processed includes soil. Figure (5) represents the spectral fingerprint measured by an ASD device, and this fingerprint is free of atmospheric effects.

ATCOR processing is implemented in OLI 8 products. These top-of-atmosphere (TOA) data are radiometrically and geometrically corrected. The Major ATCOR output is atmospherically corrected Bottom-of-atmosphere (BOA) reflectance for all sensor spectral bands. Figure (6) and (7) show the result of ATCOR 3. First of all, there was a visual comparison between applying various radiometric corrections algorithm and the landsats image No. (8) of the first studying area. The same type of “urban” aerosol was used to parametrize all atmospheric correction algorithms, in a visibility greater than 15 km. Compared to the genuine DN image, brightnesses of other images vary because of the parameterization that is utilized in every algorithm for the correction of the atmosphere and radiometric impacts. Remote sensing in 2015, Nov., Raw 37 and path 169.

\[ G = \cos(i)/\cos(t) \]

Before ATCOR3

\[ G = \sqrt{\cos(i)/\cos(t)} \]

After ATCOR3
Figure (6): Empirical functions applied Eqs. 2 and 3 for multispectral image

\[ G = \cos(i) \times \cos(e) / \cos(t) \]

Figure (7): Empirical functions applied Eqs. 4 and 5 for multispectral image

\[ G = \sqrt{\cos(i) \times \cos(e) / \cos(t)} \]

Figure (8): The spectral profile for applied Eq. (2) for study area for land cover of water. (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.
Figure (9): The spectral profile for applied Equ. (2) for study area for land cover of Vegetation, (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.

Figure (10): The spectral profile for applied Equ. (2) for study area for land cover of Soil, (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.

Figures (8, 9 and 10, a) representing the spectral fingerprint with distortion. In the range of the wavelength (0.473–0.658), micrometer ATCOR(3) to water land cover indication rating of water vapor absorption. For spectral vegetation, diagnostic dips at (0.866) micrometer due to high absorption because of water vapor, which matches the presence of chlorophyll-b in the healthful leaves as shown in figure (9):
Figure (11): The spectral profile for applied Equ. (4) for the study area for land cover of Water, (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.

Figure (12): The spectral profile for applied Equ. (4) for the study area for land cover of Vegetation, (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.

Figure (13): The spectral profile for applied Equ. (4) for the study area for land cover of Soil, (a) ASD spectral without distortion, (b): Before ATCOR3, (c): After ATCOR3, (d) comparison between a, b and c.

In the range of the wavelength (0.89-1.54) micrometer, there is a very strong correction, because weak atmospheric attenuation land area of study, while the range (0.46-0.77) micrometer is highly strong atmospherically attenuation, because of water vapor, as shown in figures (11, 12 and 13).

Table 1. Delta standard deviation (SD) of the image bands before and after ATCOR3.

| No. of bands | (B1) | (B2) | (B3) | (B4) | (B5) | (B6) | (B7) |
|--------------|------|------|------|------|------|------|------|
| ΔSD(Eq.1)    | 3034.46 | -1681.34 | -993.27 | 370.88 | 1017.71 | 2201.40 | 1130.16 |
| ΔSD(Eq.2)    | 2910.47 | -1791.97 | -1079.21 | 292.05 | 960.74 | 2201.40 | 1130.16 |
| ΔSD(Eq.3)    | 3827.42 | -908.72 | -427.21 | 778.67 | 1211.79 | 2201.40 | 1130.16 |
| ΔSD(Eq.4)    | 3548.08 | -1238.40 | -727.35 | 630.58 | 1152.15 | 2201.40 | 1130.16 |
Figure (14) show the result of ATCOR 2. Atmospheric conditions occurring during each image acquisition date are re-evaluated, and each thermal region model is run for all bands of Landsat image to determine the sensitivity of ATCOR2’s different atmospheres.

Before ATCOR2

After ATCOR2

Figure (14): Applied ATCOR 2 algorithm for study area

Table 2. Delta standard deviation (SD) of the image bands before and after ATCOR2 for study area

| No. of bands | (B1) | (B2) | (B3) | (B4) | (B5) | (B6) | (B7) |
|-------------|------|------|------|------|------|------|------|
| ASD         | 2550.54 | -2205.95 | -2304.07 | -2358.71 | -6195.32 | -22531.52 | -24491.19 |

Figure (15) illustrate convergence spectra of the water after correction when compared with ASD, we note that the reflective is reduced in the visible range (425 – 700) nm. We observe the highest wavelength reversal value in the 750 nm. There is a similarity between ASD and the resulting spectral profile ATCOR2 at wavelengths (426 – 1500) nm.

Figure (16) illustrate at the vegetation deduction area we notice a similarity between the ASD spectra with ATCOR2 technique at the range (1430 – 1450) nm indicating the success of the technique in removing the effects of atmospheric gases. Absorption in the visible area is an indication of the absorption of oxygen gases and water, as well as increased absorption at the wavelength 1470 indicates the presence of CO₂ and H₂O.
Figure (16): Spectral profile of the study area of Vegetation. (a) ASD spectral without distortion, (b): Before ATCOR2, (c): After ATCOR2, (d) comparison between a, b and c

Figure (16) illustrate in the Soil spectra we notice a similarity between the ASD spectra with ATCOR2 technique at the range(1430 – 1480) nm indicating the success of the technique in removing the effects of atmospheric gases.

Figure (17): Spectral profile of the study area of Soil. (a) ASD spectral without distortion, (b): Before ATCOR2, (c): After ATCOR2, (d) comparison between a, b and c

4. Conclusions:

This work included 2 ATCOR modules, which are (ATCOR(2) and ATCOR(3) on OLI 8 images with their accuracy were evaluated means of ground truth measurement. In deep blue channel, ATCOR’s empirical approach for reflectance difference STD computing before and after ATCOR was negative. Water spectra were compared to ATCOR2 illustrate convergence spectra of the water after correction when compared, we noted that the reflective is reduced in the visible range (425 – 700) nm. Spectra vegetation of ATCOR2 and ASD A were comparable in both results indicating that the spectra of both images showed similarity in the behaviour we notice a similarity between the ASD spectra with ATCOR2 technique at the range(1430 – 1450) nm indicating the success of the technique in removing the effects of atmospheric gases. Absorption in the visible area is an indication of the absorption of oxygen gases and water, as well as increased absorption at the wavelength 1470 indicates the presence of Carbon dioxide gas and water vapour. The soil spectra of ATCOR2 and ASD were compared with each other and the results indicated that the spectra of both images showed a similarity in the technique at the range(1430 – 1480) nm indicating the success of the technique in removing the effects of atmospheric gases. The value of difference STD for the bands (b1, b4, b5, b6 and b7) before and after ATCOR3 (Flat region) were positive. Water land cover after ATCOR 3 indication rating of water vapour absorption in the range of the wavelength (0.473 – 0.658), micrometer. For spectral vegetation, diagnostic dips at (0.866) micrometer due to high absorption because of water vapour, which matches the presence of chlorophyll-b in the healthful leaves. The algorithm ATCOR 2 yielded results closer to the ASD in the sedimentary plain region.
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