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Atmospheric and spectral corrections for estimating surface albedo from satellite data

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Land surface broadband albedo is one of the most important physical parameters for climate models, because it governs the exchange of radiation between the land surface and the atmosphere. It depends on the atmospheric conditions through downward fluxes. Satellite remote sensing techniques provide a more accurate pixel-level estimation of surface albedo than traditional field measurements. However, atmospheric effects and band pass limits of satellite sensors are two factors that limit accurate estimation of surface albedo from satellite data. This paper develops a method for making atmospheric and spectral corrections for estimating surface albedo from satellite data. We applied an approach that decouples surface reflectance spectra from radiative transfer simulations so that many different surface reflectance spectra and the atmospheric conditions can be effectively incorporated for calculating the total shortwave albedo, total-, direct-, and diffuse-visible, and near-infrared broadband albedos for several satellite data LANDSAT TM and ETM.

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1. Introduction

Surface albedo is defined as the ratio of reflected to incident solar radiation flux intensity (measured in W m^{-2}) on the earth's surface. The total energy reflected by the earth's surface in the short-wave domain is characterized by the short-wave (0.3-4.0 μm) broadband albedo. The shortwave broadband albedo is one of the most important physical parameters for climate models, because it governs the exchange of solar radiation between the land surface and the atmosphere .Solar radiation energy is the fundamental source of power that drives the circulation of water and energy in the atmosphere, continents, and sea. Moreover, solar radiation at the ground level affects global climate and meteorology. Therefore, accuracy in the measurement of short-wave broadband albedo directly affects the results of a climate model. Before satellite observation became possible, typical representative values of albedos obtained from field measurements at specific sites within a study area were used for an entire area. The generalization of these points to apply to a larger study area was problematic due to significant variation in the spatial and temporal patterns of surface albedo. However, using satellite remote sensing techniques, albedo can be determined at the pixel level over an entire area. This allows more accurate estimation of climate models. There have been several reports on surface albedo estimated from satellite data [1,2,9].

In general, to estimate short-wave broadband albedo from satellite data accurately, it is necessary to correct for geometric, atmospheric, spectral, topographic, and anisotropic effects. Because the satellite data used in this study was previously geometrically corrected, no further geometric correction was needed. In addition, we do not discuss topographic effects here, because our test area Bucharest, Romania is a flat land area. Therefore, this study focuses on methods for making atmospheric and especially spectral corrections.

The objectives of this paper are (1) to develop a versatile method to estimate short-wave broadband surface albedo from satellite data based on a physically based model radiative transfer model 6S code code; and (2) to test and validate this method by using filed data

1.1. Atmospheric code 6S

Atmospheric code 6S predicts the satellite signal between 0.25 and 4.0 μm, assuming a cloudless atmosphere [10]. The main atmospheric effects (gaseous absorption by water vapor, carbon dioxide, oxygen, and ozone, and scattering by molecules and aerosols) are taken into account. Analysis using 6S code simply requires input of the following parameters: (1) geometrical conditions, (2) the atmospheric model for gaseous components, (3) the aerosol model (type and concentration), (4) spectral condition, and (5) ground reflectance (type and spectral variation). Based on the above input parameters, irradiance at ground level, radiance at satellite level, and three atmospheric correction coefficients can be obtained from 6S in optional wavelength range.

Atmospheric code 6S was chosen for this study, because it is a physically based model that is not optimized on one specific satellite scene, test site, and object class. This is very important for analyses using remote sensing data, because for any specific case, it is difficult to obtain all parameters for atmospheric correction (e.g., information about type and concentration of aerosols, ozone, or water vapor in a vertical profile). Limited data of this type present a major obstacle in using satellite remote sensing data. Therefore, a standard atmospheric correction model that provides power, accuracy, and flexibility is needed to conduct atmospheric corrections for different latitudes under the same conditions. Such a model requires only a specification of inputs. This type of model is also important for comparative or global analysis. In addition, 6S code was developed for the purpose of making atmospheric corrections in the short wavelength region, and 6S better handles atmospheric scattering during radiative transfer than other models [5]. In particular, reflectance for four types of surface coverage (vegetation, sand, soil, clear water, and lake water) in the optional wavelength range can be simulated by 6S.

Atmospheric correction improves image clarity by compensating for distortions caused by gaseous absorption and molecular and aerosol scattering along the Sun-target-sensor path. This atmospheric correction technique estimates the true surface reflectance, thus enhancing the clarity of the digital imagery. This significantly improves the quality of land classification and change detection analysis.

2. Study area and data used

2.1. Test area

Study area, urban zone Bucharest, Romania, bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E was selected along a climatic and environmental gradient and was characterized in terms of hydrology, geomorphology, soil and vegetation properties, that control or contribute to functioning.

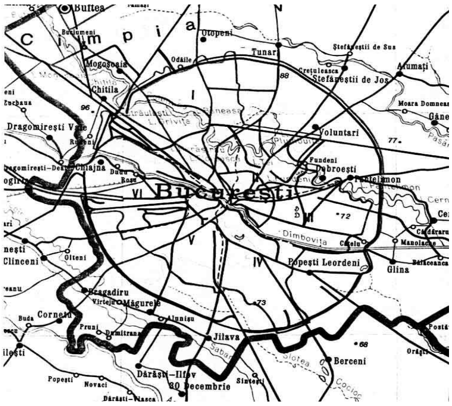

Fig. 1. Test site positioning of Bucharest.

Central part of Bucharest city has the main coordinates: latitude 44^{o}25’ 50’’ and longitude 26^{o} 6’ 50’’. The study area is placed in the Southern part of Romania as is presented by Fig. 1 and Fig. 2. Bucharest has a star-shaped urban structure, as a result of the particular way of the city’s development over more than 5 centuries (documented since 1459). The city has expanded in a concentric manner around a medieval centre (princier house – named Curtea Veche) as well as a radial one along the roads to the capital of Valachia, later all over Romania, in modern city of Bucharest (approximately 2 millions habitants and 230 km^2). The Dambovita river, a tributary of the Danube, crosses the Northern part of the city, and has meanders, partly filled by an artificial lake. Other lakes are visible in the center and in the lower part of the image. The circular zone in the South is a forested area, with a large building in the center.

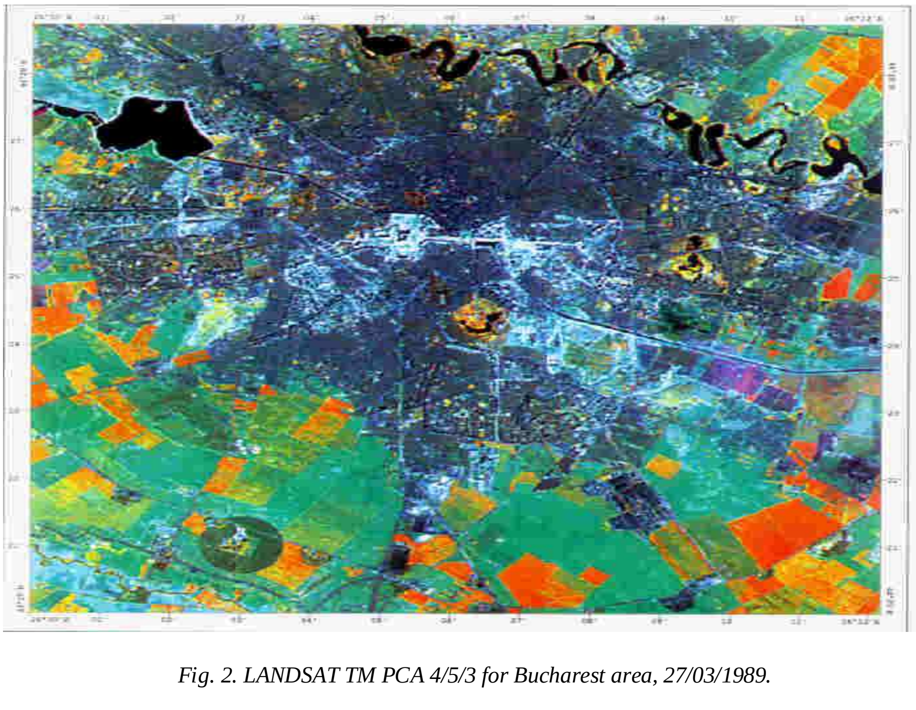

Fig. 2. LANDSAT TM PCA 4/5/3 for Bucharest area, 27/03/1989.

2.2. Data used

The investigations were focused on estimating of urban environmental parameters from satellite multispectral data based on satellite images from Landsat TM, ETM.

Was used Landsat TM data acquired: 27/03/1989, 21/08/1990; Landsat ETM 20/12/2002; The images were geometrically corrected to fit a topographic map with a scale of 1:100 000, on which vectors were digitized for the subsequent geocoding of the satellite images.

3. Methods

3.1. Atmospheric correction using atmospheric code 6S

Atmospheric correction is necessary during the processing of remotely sensed digital imagery because the recorded radiance measured by the sensor differs from the true surface reflectance for each area on the ground. This difference is due to interference by various gases and aerosols which are present in the atmosphere. The path of electromagnetic radiation (ER) from the Sun to the surface and from the surface to the sensor is attenuated and scattered by these gases and aerosols, which are mainly found in the troposphere and stratosphere.

Gases primarily responsible for absorption or attenuation of ER are water vapor and ozone. Absorption by water vapor is of particular concern in certain portions of the near-infrared range because this effect lowers radiance measured at the sensor. Pre-defined atmospheric models describing temperature, pressure and water vapor and ozone concentration as a function of location and season are built into the 6S code.

Rayleigh and aerosol scattering effects are more significant than absorption effects in the visible light spectral range causing an increase in the at-sensor measured radiance values. This scattering is wavelength-dependent with a greater effect at shorter wavelengths, such as the blue band. This results in a hazy-blue appearance in natural color imagery. Aerosol scattering is handled in the 6S code using pre-defined models for urban, continental, maritime and desert environments. User defined models also allow the user to specify percentages of dust-like, soot, oceanic, and water-soluble aerosol components [6,7].

The atmospheric correction code offers three different options for determining the aerosol optical depth, an important variable used in the radiative transfer code. Two iterative approaches, dark target detection and dark dense vegetation, have been implemented. These methods extract the information from the image. Also the option of attaining the aerosol optical depth from the AERONET online database is available.

The reflectance at a given view zenith θ and ϕ, R(θ,ϕ)is the view azimuth angle relative to the solar principal plane; a, b, and c are coefficients derived using a linear least-square fitting procedure and are dependent on solar zenith angle.

$$\mathrm{R}(\theta,\phi) = a\theta^2 - b\theta\cos\phi + c \tag{1}$$

Eq. (1) can be analytically integrated over the 2π sr solid angle containing all view directions to derive an expression for albedo. The result of the integration as:

$$R_H = (2.305a/\pi) + c \tag{2}$$

where R_H is the albedo, a and c empirical coefficients, derived using a linear least-square fitting procedure and are dependent on solar zenith angle.

Was calculated atmospheric coefficients for LANDSAT TM and ETM images:

- To convert digital count (DC) from Landsat-5 TM satellite data for Bucharest area, to satellite radiance, it is necessary to first perform absolute radiometric calibration.
- The input parameters for 6S can be chosen from standard conditions
- To define geometrical conditions when using Landsat-5 TM data, input values for month, day, universal time, center latitude, and center longitude of the image are initially entered. 6S code then automatically estimates the solar zenith angle, view zenith angle, and azimuthal angle difference.

Was used a standard a standard aerosol model was chosen to define aerosol type. To define the concentration of aerosols, a meteorological parameter (the value of the horizontal visibility in km) should be entered directly into 6S radiative model. The aerosol optical thickness at 550 nm should then be computed from a standard aerosol profile for an urban area.

3.2. Spectral correction

Spectral correction, using a weighted mean method must be conducted in order to estimate short-wave broadband surface albedo from satellite data [8,9]. This is because while short-wave broadband surface albedo is determined for the entire short-wave range (0.3-4 μm), satellite sensors provide only filtered albedos for some narrow spectral regions. Short-wave broadband surface albedo A is defined with the following formula:

$$A = \frac{\int_{\lambda_1}^{\lambda_2} E_U(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} E_D(\lambda)d\lambda} \approx \frac{E_{U1} + E_{U2} + ...E_{Un}}{E_{D1} + E_{D2} + ...E_{Dn}} \tag{3}$$

where λ_1 and λ_2 are the minimum and the maximum wavelengths of the defined short-wave broadband surface albedo. E_{U1}.................E_{Un} and E_{D1} …. E_{Dn}, are respectively reflected and incident irradiance in a given wavelength range. So, eq (3) will be:

$$A = \frac{E_{U1}}{\sum E_{Dk}} + \frac{E_{U2}}{\sum E_{Dk}} + ... + \frac{E_{Un}}{\sum E_{Dk}} = \frac{E_{D1}}{\sum E_{Dk}} \cdot \frac{E_{U1}}{E_{D1}} + ... + \frac{E_{Dn}}{\sum E_{Dk}} \cdot \frac{E_{Un}}{E_{Dn}} =$$

$$= w_1 R_1 + w_2 R_2 + ... + w_n R_n \qquad (4)$$

Where R_i is the spectral reflectance in a given wavelength range I and can be written as:

$$R_i = \frac{E_{Di}}{\sum E_{Dk}} \quad i=(1, 2,……,n) \qquad (5)$$

W_i is weighted coefficient in a a given wavelength range i and can be written as:

$$w_i = \frac{E_{Di}}{\sum E_{Dk}} \quad i=(1, 2,……,n) \text{ with } \sum w_i = 1 \qquad (6)$$

3.3. Application of the weighted mean spectral correction method to satellite data

In general, because satellite remote sensors only scan several discrete bands, they do not cover the whole wavelength range (0.3-4 μm) necessary for estimating surface albedo [10]. For the Landsat-5 TM sensor, filtered surface albedo (As) can only be obtained from the following formulas:

$$A_s = \sum w_i . R_{Hi} \quad (i=1, 2, 3, 4, 5, 6, 7) \qquad (7)$$

$$w_i = \frac{E_{Di}}{\sum E_{Dk}} \quad (i=1, 2, 3, 4, 5, 6, 7) \qquad (8)$$

where R_{Hi}, w_i, and E_{Di}, are the atmospherically corrected spectral albedo, weighted coefficient, and irradiance at the ground level in a given band I, respectively.

Landsat TM and ETM data was chosen in this study to test the proposed method, because its high resolution allows comparison of estimated and measured albedo.

In the case of Landsat-5 TM, the spatial resolution is 30 m; one pixel size of Landsat-5 TM is $30^2 m^2$. The measured satellite value represents the average value of that area. Two observation sites were chosen in a large area (the size of several pixels) in which a generally homogeneous vegetative surface exists, chosen for South-Eastern part of Bucharest town, Fig. 3.

Because 6S code can handle a wide range of satellite sensors and optional wavelength ranges, if successful, we can encourage other users to follow the method in this study, modifying some choices according to what they need.

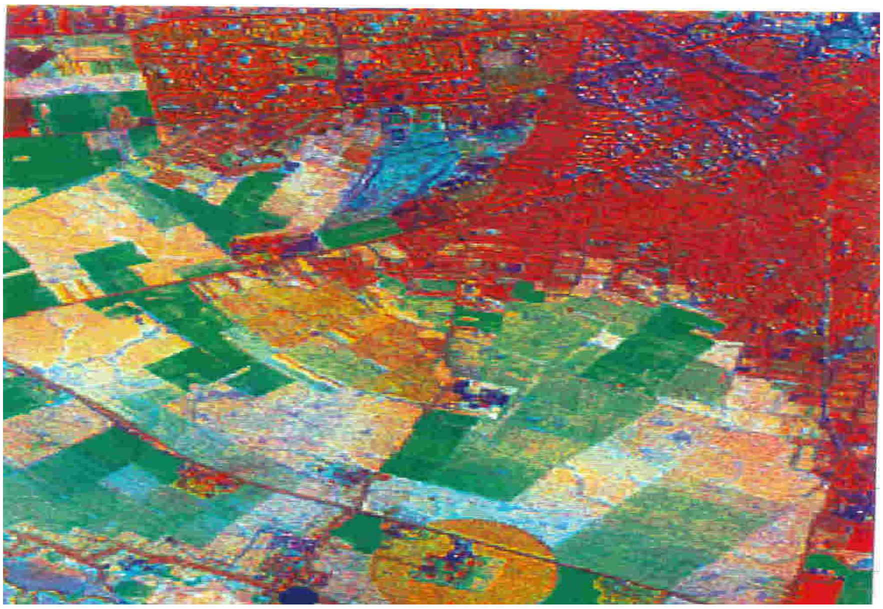

Fig. 3. Landsat TM – PCA 2/3/1 for S-E Bucharest area, 21/08/1990.

4. Results and discussion

Using the above method, the short-wave broadband vegetative surface albedos in Bucharest area were estimated from three available scenes of Landsat TM and ETM data (Fig. 4), described in the data paragraph.

Fig. 4. Landsat ETM, PCA for Bucharest area PCA 3/2/1, 20/12/2002.

The filtered surface albedos (As) were estimated from Landsat-5 TM data by using Eqs. (7) and (8) for pixel-level results. Since per-pixel calculations are too costly, the atmospheric correction algorithm is implemented using either autonomously derived or user-defined grid points. A bilinear interpolation on the output correction parameters is performed between the grid points. Principal Component Analysis (PCA) was done for the available images.

As climate models require a 0.05 level of accuracy for short-wave broadband surface albedo, the error of estimation for short-wave broadband surface albedo from Landsat- 5 TM data ranges from 1% to 13%. However, even with an error of 13%, the estimated short-wave broadband surface albedo has an accuracy of about 0.026, well below the 0.05 requirements.

5. Conclusion

This paper develops a new method of making atmospheric and spectral corrections for estimating vegetative surface albedo from satellite data using 6S code. Though this method was only applied to estimated vegetative surface albedos in Bucharest area from Landsat TM and Landsat ETM data, it can be applied to other study areas and can incorporate other satellite data. For such purposes, single inputs of the parameter values are required. Because 6S code can process almost all types of satellite data and provides several standard atmosphere and aerosol models for atmospheric correction, this method does not require the field observed data to account for excluded visibility data.

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