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Determination of surface temperature over partially vegetated heterogeneous areas using satellite data

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Abstract : In the studies related to land surface processes, satellite data provides, important inputs for estimating regional surface emissivity and surface temperature The paper describes the capability of satellite data in determining the surface emssivity over heterogeneous areas by taking normalized difference vegetation index (NDVI) as modulating parameter at pixel resolution The methodology is based on the calculation of fraction vegetation cover per pixel taking NDVI, of the pure pixels as input The basic concept of fraction of vegetation cover is used for the determination of surface emissivity and temperature The estimated emissivity values over the region had been found to be between 0.93 to 0 95 for soil, podu areas, 0.96 for scrub land, 0 97 to 0.985 for forest area (dry deciduous), 0.99 for shadow areas The calculated surface temperature values are in the range of 10 to 32° C and found to be in conformity with the climatological data over the region The study reveals the potential use of NDVI as a modulating parameter in the land surface temperature estimation from satellite data.

Keywords : Satellite data, Emissivity, Surface temperature

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The physical surface temperature is important because it is one of the key factors determining the exchange of energy and matter between the Earth's surface and the atmosphere. It is therefore an important measurement in energy-balance applications and can be especially useful when determined by thermal infrared (TIR) remote sensing [1,2]. The radiation emitted from a surface at a given wavelength in the thermal infrared (8-14 μm) is a function of its temperature and emissivity. Satellite data acts as an effective tool in evaluation of such measurements at local, regional or global basis. In the direct estimation of surface temperature from satellite data, the main limitation has been on measuring the variable emissivity (which is defined as the ratio of the emitted radiation at a given temperature to the blackbody radiation at the same temperature) of the land surface. For heterogeneous areas where the vegetation cover may vary in proportion, the problem of estimating emissivity from satellite creates problem.

Therefore, the use of an operational and mathematically simple model in such studies is of paramount importance. There is need for some methodology to estimate surface emissivity for partial vegetation cover on a pixel scale through satellite data. In an attempt to solve this, a vegetation sensitive index such as NDVI may be used to estimate emissivity at pixel level. In the present study, NDVI has been taken as a vegetation parameter to find surface emissivity and using it in inverse Planck's law to estimate surface temperature.

Landsat TM data of 19th December 1995 (Figure 1) with path/row 142/48 of parts of East Godavari district in digital form has been used in the present study for estimation of emissivity and the corresponding thermal band (Figure 2) for the generation of surface temperature.

The present method is based on the methodology suggested by Valor & Caselles, 1996. The assumptions considered in the model are [3] :

(i) assuming that the ground surface is a heterogeneous as much in temperature as in emissivity and rough system.

(ii) not considering the shadow influence

(iii) neglecting double scattering process between the different parts of the heterogeneous and rough system, which is equivalent to making an error of about 0.1^{0}C.

(iv) assuming the surface to be flat.

Several vegetation indices can be used to enhance spectral vegetation characteristics from the visible and near-infrared regions of the electromagnetic spectrum [4,5]. NDVI is the most commonly used vegetation index and is given as [5, 6].

$$\mathrm{NDVI} = (\rho_2 - \rho_1)/(\rho_2 + \rho_1) \tag{1}$$

where, ρ_2 and ρ_1 are reflectance measured in NIR and red wavelength band.

Landsat Thematic Mapper (TM) provides 30 m spatial resolution data in six spectral bands in 0.45 – 2.35 µm and 120 m spatial resolution data in 10.4 – 12.5 µm thermal IR band.

A mixed pixel is assumed to be equal to size of the IFOV of TM which is partially occupied by a vegetation cover P_v and rest by a soil proportion $(1-P_v)$. Then for such a pixel the NDVI value as a first approximation is given as

$$i = i_v P_v + i_g (1 - P_v)\,, \tag{2}$$

where i_v and i_g are respectively the NDVI values of pure vegetation and soil pixels. A mixed pixel reflectance is

$$\rho_n = \rho_{nv}\, \rho_v + \rho_{ng}\, (1 - P_v)\,, \tag{3}$$

where $n = 1$ for red and $n = 2$ for near IR.

Substituting eq. (3) in to eq. (1), the NDVI of mixed surface becomes

$$i = \left[P_v(\rho_{2v} - \rho_{1v}) + (1 - P_v)(\rho_{2g} - \rho_{1g})\right] / \left[P_v(\rho_{2v} + \rho_{1v}) + (1 - P_v)(\rho_{2g} + \rho_{1g})\right]. \tag{4}$$

Plate I

Figure 1. Landsat TM FCC of bands 4,3,2

Figure 2. Landsat thermal infrared image of the study area

Figure 3. Classified image of study area showing different land use/land cover categories.

Thus a better way to relate the NDVI to the vegetation cover is

$$i = i_v P_v + i_g (1 - P_v) + di \,, \tag{5}$$

where di is the correcting factor obtained by subtracting eq. (2) from eq. (4).

The NDVI values of pure vegetation and bare soil pixels obtained from the reflectances in red and NIR channels are utilized for calculating proportion of vegetation cover using the relation [7]

$$P_v = (1 - i/i_g) / \left[(1 - i/i_g) - k(1 - i/i_v)\right], \tag{6}$$

$k = (\rho_{2v} - \rho_{1v}) / (\rho_{2g} - \rho_{1g})$, where ρ_{2v}, ρ_{1v} are reflectances in red and NIR region for pure vegetation pixels respectively. ρ_{2g}, ρ_{1g} are respectively the reflectances in NIR and red region for pure soil pixels. The radiance at the sensor level is the average radiance of the component classes in a pixel and in Landsat TM with 30m spatial resolution, the problem of mixed pixels is minimum.

Finally, the relationship between emissivity and NDVI of a given surface is [7]

$$\varepsilon = a\, i + b \tag{7}$$

where $a = (\varepsilon_v - \varepsilon_g) / (i_v - i_g)$ and $b = \left[\varepsilon_g (i_v + di) - \varepsilon_v (i_g + i)\right] / (i_v + i_g) + \Delta\varepsilon$.

For a given area the 'a' coefficient is constant, while coefficient 'b' changes from pixel to pixel with the vegetation cover (which produces the variation of the di term) and with the surface structure (which produces the variation of $d\varepsilon$ term).

The error in emissivity per pixel is given as [7]

$$\Delta\varepsilon = 4 < d\varepsilon > P_v (1 - P_v) \,, \tag{8}$$

where $<d\varepsilon>$ is mean weighted value taking into account the different vegetation in the area, their struct .re and their proportions in it. The maximum value of $d\varepsilon$ is given by $<d\varepsilon>$ and with a separation between boxes varying with P_v.

In order to determine the surface temperature, the digital number of thermal channel (B6) have been converted into radiance values using the relation

$$L_\lambda = \alpha\, DN + \beta \,, \tag{9}$$

where α = gain, β = offset values [8].

Surface temperature values per pixel have been calculated by using inverse Planck's equation.

$$Ts = C_2 / \lambda \ln\left[(\varepsilon C_1 \lambda^{-5} / \pi L_\lambda) + 1\right], \tag{10}$$

where $C_1 = 3.742 \times 10^{-16}$ W m^2, $C_2 = 0.0144$ mK, λ = wavelength in m, ε = emissivity L_λ = spectral radiance.

In the present study, Rampa Revenue division of East Godavari district- Andhra Pradesh has been taken for determining emissivity and surface temperature. The major land use/land cover classes include built-up areas, plantations of teak and pine, crop lands, water bodies and forests which are predominantly of dry deciduous type. The general elevation of the district varies from 300 to 1500 m and has a coastline of 144 kms. The major soil types include alluvial, red soils, sandy loams and sandy clays.

Surface temperature estimation requires information on surface emissivity at pixel level. The determination of emissivity by means of the present methodology requires the use of satellite data together with some emissivity values of vegetation types from literature, which are necessary in order to map the effective surface emissivity. In the absence of emissivity values over the area, the mean value of 0.914 for bare soils and 0.986 for vegetation emissivity in 8-14 μm region has been taken [9]. In the calculation of mean weighted value of the study area taken, three main vegetation structures have been considered in 8-14 μm region. The Maximum likelihood classified image of the study area depicting the land use/land cover is shown in Figure 3. The different features like forest, podu areas, scrub land were identified from the image and the corresponding emissivity values have been taken from literature for calculating $\langle d\varepsilon \rangle$, which has been estimated as 0.015. The error in emissivity values for each pixel has been calculated using eq. (8) by considering the proportion of vegetation cover in that pixel. The estimation of proportion of vegetation cover is done from NDVI which needs reflectances of pure pixels of vegetation and bare soils in NIR and red channels. The maximum and minimum NDVI values obtained from the existing image is 0.60 and 0.11 respectively. The values of proportion vegetation cover has been found maximum over the forest area and minimum over shadow area. Emissivity map generated from TM data is shown in Figure 4. Since the satellite data corresponds to December month, which is typically winter season in the region, most of the areas are having moist conditions leading to slightly higher emissivity values compared with dry conditions. However, for validation of surface emissivity and surface temperature extensive field survey has to be undertaken using infrared thermometer. In the absence, the validation for emissivity is done by comparing the derived values with the already literature suggested values over certain features and for surface temperature the values have been compared with the climatological data of the area. The emissivity values derived from the present method have been compared with the literature values in the 8-14 μm over certain known features [7] and are found to be in reasonable agreement with an error of less than 1%. The average surface temperature estimated from eq. (10) is shown in Figure 5. The surface temperature observed to be in the range of 10 to 32°C with minimum over shady areas. The derived surface temperature values have also been compared with the soil temperature (27.2° C) over the region obtained from Indian Meteorological Department corresponding to satellite date of pass. The surface temperature obtained from the methodology over scrubs areas are found to be in the range of 29-32°C. Thus satellite derived surface temperature values are found to be in reasonable agreement over the region. The difference between the surface temperature and air temperature *i.e.*, $(T_s - T_a)$ during the afternoon satellite overpass is much greater for the semi-arid region ~ 10 to 30°C, than for the vegetated region ~ 0 to 5° C [10]. The methodology adopted in the present study suggests that NDVI would be used as a modulating parameter for estimating surface emissivity and surface temperature.

The results of the study indicates that over heterogeneous areas, estimation of surface emissivity in feasible by taking the percentage vegetation cover of each pixel into account. The surface temperature estimated from the knowledge of emissivity of each pixel has been found to be in good agreement with observed values in the region. The error in the emissivity values

Plate II

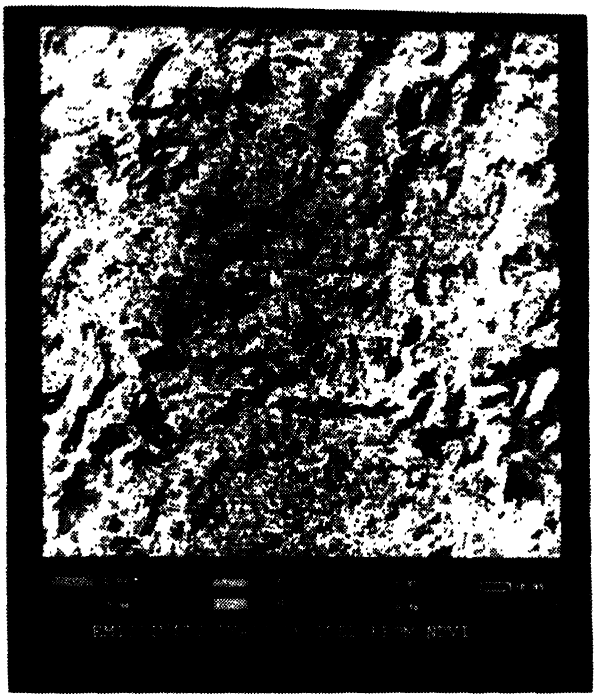

Figure 4. Emissivity image of study area generated from proportion of vegetation cover and NDVI

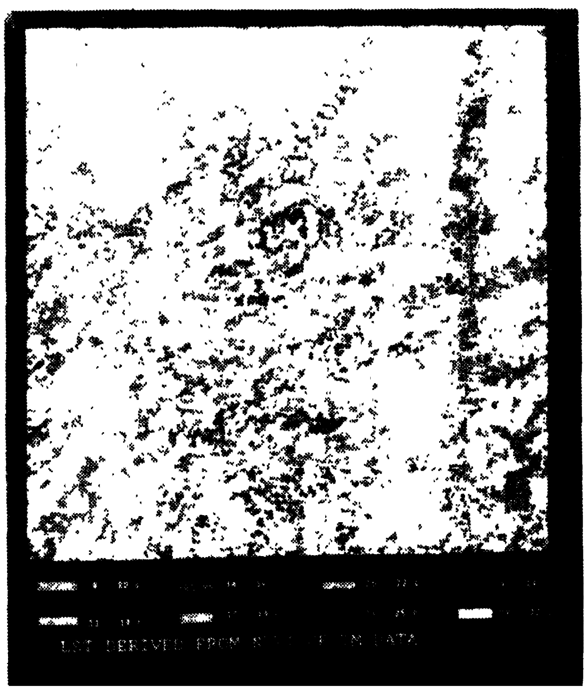

Figure 5. Surface temperature image generated from emissivity and thermal band.

calculated from satellite data per pixel may be due to error in standard emissivity values taken for the vegetation features in the term '$d\varepsilon$' over the study area and the lack of knowledge of atmospheric conditions. The knowledge of correct value of emissivity values could lead to less error. The information obtained from the retrieval of emissivity directly from spectral measurements in visible and infra red bands of satellite data could be used to estimate land surface temperature at regional scale using thermal IR data.

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