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Influence of topography on landscape radiation temperature distribution

I. V. FLORINSKY

Laboratory of Perspective Investigations, Institute of Mathematical Problems of Biology, Pushchino Research Centre of Russian Academy of Science, Pushchino, Moscow Region, 142292, Russia

T. B. KULAGINA

Igumnovo Branch, Russian Institute of Agriculture Mechanisation, Igumnovo, Moscow Region, 140114, Russia

and J. L. MESHALKINA

General Agriculture Chair, Faculty of Soil Science, Moscow State University, Moscow, 119899, Russia

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Abstract. The evaluation of the influence of topography on landscape radiation temperature distribution is carried out by statistical processing of digital models of elevation, gradient, aspect, horizontal, vertical and mean landsurface curvatures and the infrared thermal scene generated by the Thermovision 880 system. Significant linear correlation coefficients between the landscape radiation temperature and elevation, slope, aspect, vertical and mean landsurface curvatures are determined, being −0·57, 0·38, 0·26, 0·15, 0·13, respectively. The equation of the topography influence on the distribution of the landscape radiation temperature is defined.

1. Introduction

Data on the landscape radiation temperature (T) distribution are used in the realisation of agricultural, soil and forest monitoring (Andronnikov and Koroljuk 1985). They may also serve as a generalized characteristic of natural and agricultural land. This is due to the fact that T distribution depends on heat and moisture regimes, which are the main indicators of the state of biogeocenoses and agrosystems (Kaurichev 1982). The thermal radiation of landscape components, i.e. vegetation, soils, water and anthropogenic objects, is registered by remote sensing in the thermal infrared (IR) range (8-14 μm).

One of the main factors of the landscape development is relief. Topography controls migration and accumulation of mineral and organic substances, moistening and illumination of terrain, intensity of slope processes, etc. This is why extensive use has been made of digital elevation models (DEM) and methods of their quantitative analysis with automatic interpretation of remotely sensed data (Hutchinson 1982, Franklin 1990) including those in the IR range (Gillespie and Kahle 1977, Watson 1985, Frank and Thorn 1985, Frank and Isard 1986, Menz 1988, Dymond *et al.* 1992).

Combined automated analysis of remotely sensed data and DEM, which greatly promotes the improvement of interpretation accuracy, is based on three main ideas: (1) spectral data alone are not sufficient for adequate interpretation of components of some landscapes; (2) the influence of topography on generation of remotely sensed images is obvious; (3) known relations between relief and other landscape components should be taken into account in interpretation of remotely sensed data (Franklin 1990).

For better use of high-resolution thermal data, in particular, for proper application of DEM in the thermal scene interpretation, e.g. in correction of such images for topographic effects (Watson 1985), one should have an idea of the topography influence on T distribution. The estimate of this influence is the aim of the present paper.

2. Study site

The study site was on the territory of the experimental station of the Belgorod Central-Chernozem Branch of the Institute of Fertilizers and Agricultural Chemistry (Belgorod Region, Russia). The study site was of size 86 m by 100 m and included a meridian-oriented gully and parts of the adjoining watersheds (figure 1). Soil and vegetation cover were generally uniform. Soils were represented by typical calcaric chernozems on loess-like loam (Classification..., 1977). Vegetation was represented by herbaceous plants with homogeneous floristic composition, detached bushes and trees. Springs and anthropogenic objects were absent.

3. Initial data and methods

A remotely sensed thermal scene of the study site was obtained from helicopter Ka-26 at a height of 300 m at astronomical noon at nadir in fine weather (no clouds) at an atmospheric temperature of about 303 deg K using the Thermovision 880 system (Agema Infrared Systems, Sweden). Thermovision 880 is an IR (8–12 μm) scanner performing thermal surveys in real time. The range of temperatures measured is 253–1773 deg K, and the sensitivity is 0·07 deg K at the object's temperature of 303 deg K.

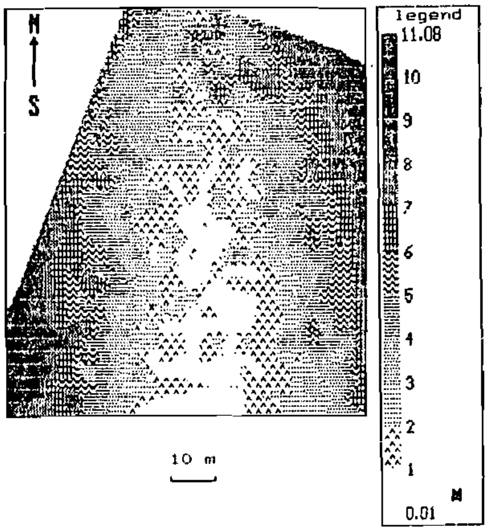


Figure 1. The study site, showing relative elevations (m).

After scanner calibration, a digital thermal scene of the study site and neighbouring areas has been obtained (figure 2). Scene resolution was 3·5 m.

As a result of a tacheometrical survey, performed by theodolite T-35, we have obtained an irregular 270-point DEM constructed in the relative Cartesian coordinate system with reltive elevations, h. Using the software QTA 3.93 (developed by I. V. Florinsky; QTA stands for Quantitative Topographic Analysis) the irregular DEM was converted into a regular DEM with a matrix step of 3·5 m.

The image and DEM were oriented by control points. The scene has been proceeded by a software CATS (developed by Agema Infrared Systems) and a regular matrix **T** of the study site has been constructed. The matrix step is 3·5 m.

Based on the regular DEM and using the software QTA 3·93 we calculated digital models for some local topographic variables by the Evans method: slope (G), aspect (A), horizontal (k_h), vertical (k_v) and mean (H) landsurface curvatures (Evans 1980) (figure 3). The matrix step of the digital models of G, A, k_h, k_v and H is 3·5 m.

Using a 414-point sample, we performed correlative and regressive analysis of the T matrix with matrices h, G, A, k_h, k_v and H with the help of the software STATGRAPHICS 3.0.

Data processing was carried out using an IBM PC AT 80286 microcomputer.

4. Results and discussion

The coefficients of linear correlation between T values and some local topographic variables are given in table 1.

It is seen that in the study site the temperature is mainly determined by the heat radiation produced by vegetation, which screens the radiation given off by soil.

Relief influences the T distribution indirectly: it controls the conditions of terrain insolation and soil properties, which in turn affect the vegetation characteristics.

Conditions of terrain insolation are in many respects controlled by G and A (Frank and Isard 1986). Numerous investigations show that these topographic variables have a considerable effect on the distribution and properties of vegetation cover in regions with contrasting relief (Frank and Isard 1986, Wu 1987, Leprieur

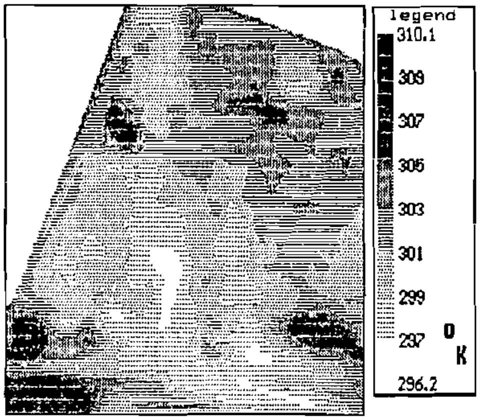
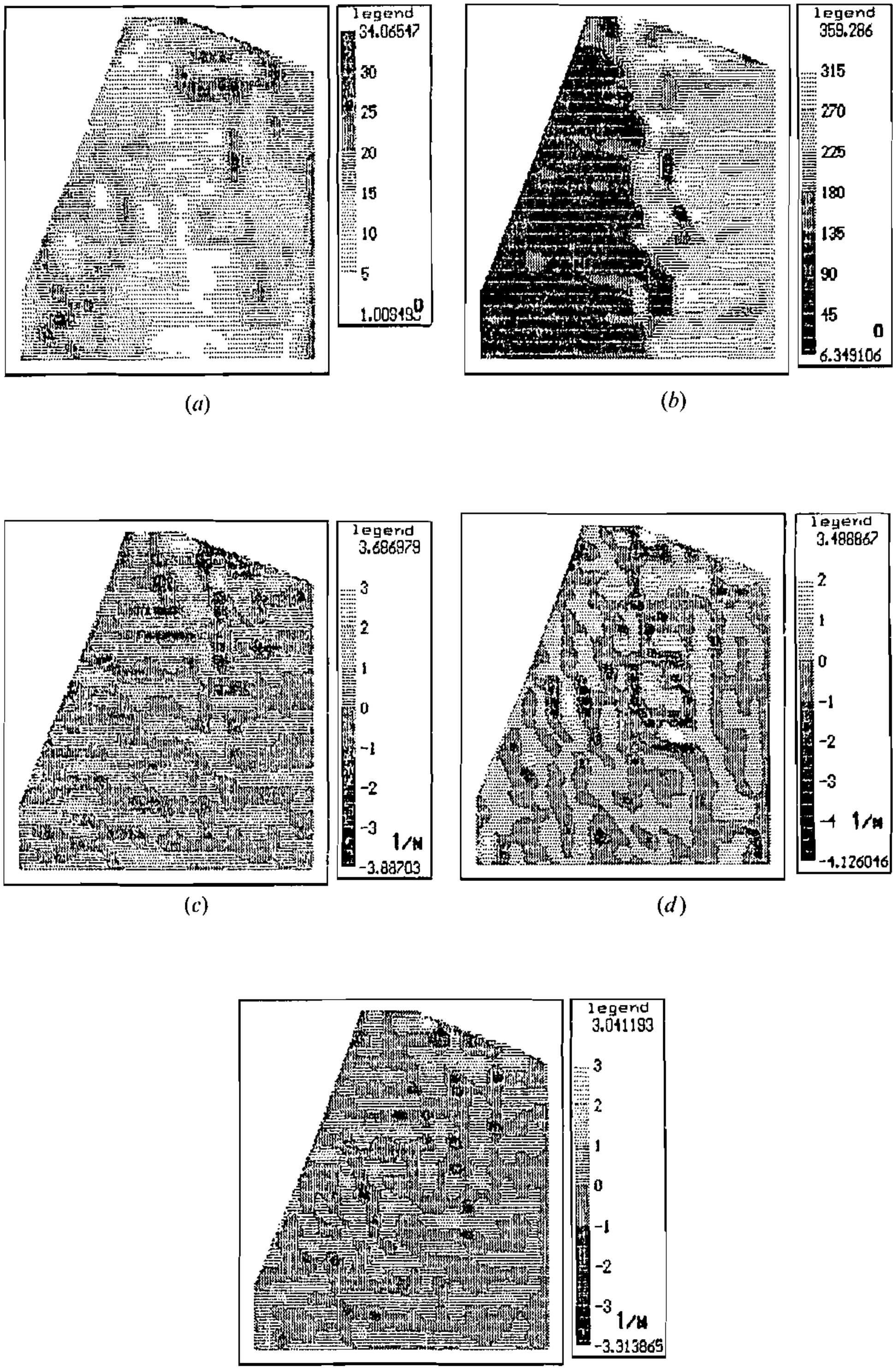


Figure 2. The thermal scene of the study site (K).



(*a*) (*b*)

(*c*) (*d*)

(*e*)

Figure 3. The study site: (*a*) slope (°); (*b*) aspect (°); (*c*) horizontal curvature ($\times 10^{-1}\,\mathrm{m}^{-1}$); (*d*) vertical curvature ($\times 10^{-1}\,\mathrm{m}^{-1}$); (*e*) mean curvature ($\times 10^{-1}\,\mathrm{m}^{-1}$).

Table 1. Point and interval estimates of pairwise coefficients of correlation between the landscape radiation temperature and some topographic variables.

Topographic variable	Correlation coefficient	95% confidence interval of the correlation coefficient	Significance level
h	0·57	0·50–0·63	0·00
A	0·26	0·17–0·35	0·00
G	0·39	0·30–0·47	0·00
H	0·13	0·03–0·22	0·01
k_h	0·04	−0·06–0·13	0·38
k_v	0·15	0·05–0·24	0·00

et al. 1988, Paradella *et al.* 1989). Therefore the correlation of T values with G and A, as shown in table 1, is rather high. Earlier influence of G and A on T distribution was argued, but for terrain with h amplitude of some hundred metres and without any statistical analysis (Gillespie and Kahle 1977).

In addition to local topographic variables, insolation depends on an area's position in the landscape, because neighbouring relief features can cast shadows. Shadow characteristics depend mainly on the Sun's position in the celestial sphere and the relative elevation of the relief elements that cast shadows (Horn 1981). Therefore the greatest correlation coefficient is exhibited by h (table 1). The study site has such topographical characteristics that in the morning (and towards evening) when the watershed areas are lit up by the Sun, the gully floor remains in shadow. As the Sun rises, the area's insolation becomes more uniform, but the temperature contrast generated in the morning is preserved to a certain extent. Relationships between T and h were known earlier, but for high mountain relief with h amplitude about 2000 m (Hummer-Miller 1981).

Soil properties, intensity of slope processes and terrain moistening depend on k_h, k_v and H (for details see Shary *et al.* 1991). For example, H has a practically functional correlation with the moisture content of the soil under various geomorphological and climatic conditions (Sinai *et al.* 1981, Kurjakova *et al.* 1992). Previously we contemplated a strong dependence of T on the topographic variables considered. But in fact, the correlation between T, H and k_v is rather weak and the correlation between T and k_h is of no significance (table 1). It was earlier mentioned (Peddle and Franklin 1991) that k_h and k_v correlate poorly with vegetation properties determined from spectral scenes (SPOT-1) and synthetic aperture radar data. The cited authors suggested that this was due to the local character of k_h and k_v influence on properties of the landscape components. Therefore, in the authors' opinion, in the analysis of sufficiently large regions with a comparatively low density of DEM (the study site was 6 km by 7 km, matrix step = 20 m), the correlation of k_h and k_v with vegetation and landscape properties cannot be registered. But the combined analysis of the thermal scene of an 86 m by 100 m study site with matrix step 3·5 m also failed to reveal any significant correlation between k_h, k_v, H and T (table 1). It seems that weak correlation of k_h, k_v and H with spectral and heat vegetation characteristics can be accounted for by the lower sensitivity of vegetation to changes in k_h, k_v and H as compared to soils (this is not the case for arid regions—see the information on the control of the wheat productivity by H in Israel (Sinai *et al.* 1981).

Table 2. Coefficients of the multiple linear regression equation, describing the dependence of radiation temperature on topographic variables (significance level 0·01).

Topographic variables	Coefficient	Confidence interval for coefficients
h (m)	0·69	0·59–0·78
A (deg)	0·01	0·005–0·015
H (m^{-1})	−3·70	−0·09– −6·60
Constant	14	13–15

The variables for quantitative description of T dependence on topography have been chosen by the step-by-step procedure (Aivazjan *et al.* 1985). The topography influence on T distribution is given by the equation (table 2):

$$T\ (\text{deg K}) = 14 + 0{\cdot}69h\ (\text{m}) + 0{\cdot}01A\ (\text{deg K}) - 3{\cdot}73H\ (\text{m}^{-1}) \qquad (1)$$

The correlation coefficients obtained and the correlation model hold good for large-scale thermal scenes performed during daytime, without clouds, when the atmospheric influence on the thermal scene generation is negligible, and for the studied landscape type with differences in h of the order of 10 m.

For understanding of the landscape development regularities it is important to analyse the topographic influence not only on the brightness temperature, but also on the kinetic temperature of landsurface. However, this problem is beyond the scope of the present work.

5. Conclusion

As a result of the analysis of a remotely sensed thermal scene, obtained with the help of digital models of h, G, A, k_h, k_v and H and using the Thermovision 880 system, the influence of topography on T distribution is estimated. It is shown that for the studied landscape T depends on h, G, A, k_v and H. Weak correlation of k_h, k_v and H with T can be accounted for by the lower sensitivity of vegetation to changes in k_h, k_v and H as compared to soils.

The results obtained allow us to specify the problems of landscape research and to determine the main principles of the solutions to problems.

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