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GEOGRAPHY

Possibility of Mapping Physiographic Zones by Thermal Survey from Space

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Physiographic zones of the Earth are "major units of the geographic (landscape) sphere, which give way to each other in a regular and definite order depending mainly on the ratio of heat and moisture" [1]. The rise in the Earth's annual mean temperature recorded for the instrumental observation period [2] may provoke variations in the global distribution of the heat/moisture ratio and, as a consequence, in displacement of the position and configuration of physiographic zones. The variations may be accompanied by negative socioeconomic impacts. To minimize the negative consequences, it is expedient to carry out a timely forecasting based on data of the space monitoring of physiographic zones. Such monitoring requires analysis of a giant body of data. Therefore, it is necessary to elaborate automatic methods for the mapping of these zones by using satellite-borne survey.

Currently, several quantitative criteria (indices) have been suggested to identify physiographic zones, e.g., Budyko's radiational aridity index [3], which characterizes the ratio between the annual radiation balance and annual precipitation. The space version of this method is limited by the need for obtaining continuous yearlong series of observations over elements of the radiation balance of the day surface and atmospheric precipitation. Cloudiness prevents the recording of such continuous series. Therefore, we have studied the possibility of applying another method for monitoring the position of physiographic zones, namely mapping of the thermal inertia of the Earth's surface based on a satellite-borne thermal survey data [4–11].[1]

The method we applied for the remote mapping of thermal inertia (TI); daily mean evaporation rate (ER) from the Earth's surface, mm/day; and heat flux (HF), W/m^2 involved the mathematical model of the daily variation of the Earth's surface temperature (ESTs) [10], which took into account basic factors affecting the EST formation. The model has the following assumptions: the metrological conditions and concentration of optically active gases in the atmosphere within the whole area under study are identical; emittance, albedo of the Earth, and TI do not vary during the whole period of the satellite-borne thermal survey.

To determine TI and ER, we carried out the thermal multispectral space survey for 3–10 days under stable meteorological conditions in the absence of rainfall in order to characterize the daily EST dynamics more completely. Moreover, mapping of TI and ER was based on the following parameters of routine expedited meteorological observations over parameters involved in the mathematical EST model: total solar radiation; air temperature, moisture, and wind velocity at a height of 2 m above the surface; atmospheric pressure; and cloudiness.

To solve the inverse problem, we performed mathematical EST modeling for all possible combinations of TI, ER, HF, and albedo, i.e., the "library" of ideal ESTs. Then, the measured EST values were compared to ideal values. The TI and ER values sought were deduced from the assigned fitting criterion of measured and ideal EST values. Algorithm errors of solving the inverse problem are given in the table.

Errors of remote measurements of HF, TI, and ER

Cause of errors	Systematic error		Root-mean-square error	
	TI, TIU	ER, mm/day	TI, TIU	ER, mm/day
Algorithm discontinuity and EST modeling error	130	0.3	100	0.1

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[1] Thermal inertia p is the resistance of a surface to heating (or cooling) under the influence of a periodic heat source. $p = (\lambda \cdot c \cdot \rho)^{1/2}$, J/(m$^2 \cdot$ s$^{1/2} \cdot$ K) = 1 TIU, where λ is the thermal conductivity factor, W/(m · K); c is specific heat, J/(kg · K), and ρ is density, kg/m^3.

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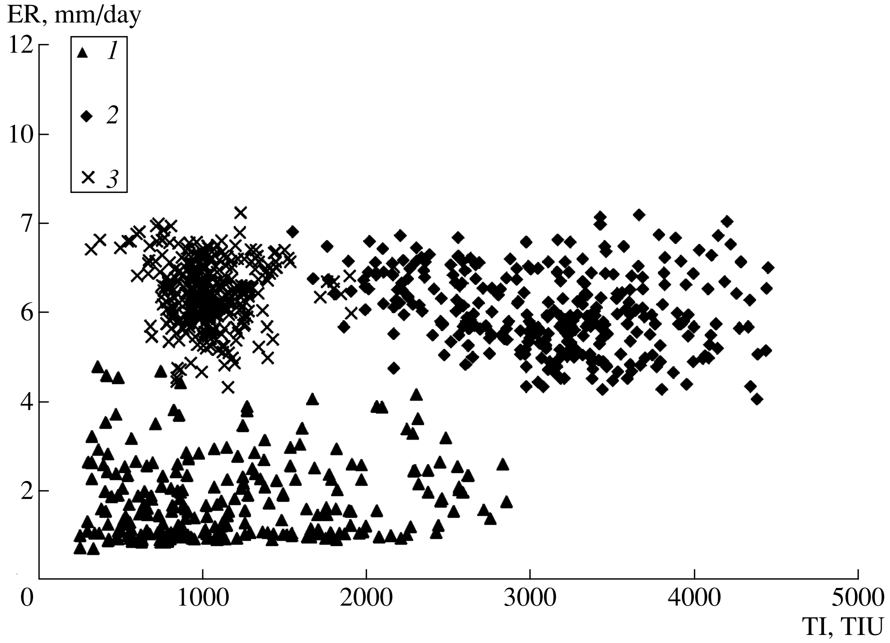

Fig. 1. Distribution of thermal inertia (TI) and daily mean moisture evaporation rate (ER) from the surface for the physiographic steppe–taiga zones and forest-tundra subzone (based on space mapping). (*1*) Forest-tundra, northern part of West Siberia, mid-July, 2002; (*2*) taiga, Leningrad oblast, end of May, 1992; (*3*) steppe, southern part of West Siberia, Kurgan district, mid-July, 2002.

For remote TI and ER mapping, we used digital data on the thermal and multispectral survey obtained by the NOAA (AVHRR) satellite system. The satellites satisfy the demands of the above-mentioned limitations in the survey. The AVHRR scanner has a complete meteorological basement. Software packages are available for consideration of the atmospheric influence and preliminary geometric corrections based on ballistic data.

Using the above-mentioned method, we compiled digital TI and ER maps (geometric resolution ~1 km, total area ~2.5 · 10^6 km^2). The distribution of these characteristics was plotted in TI–ER coordinates for the major physiographic zones of Russia (Figs. 1, 2).

The analysis of the results shows that physiographic zones occupying the largest territories in Russia differ in TI and ER (Fig. 1). For instance, the taiga zone is characterized by high values of TI (1500–4500 TIU) and ER (4–8 mm/day). The forest-tundra zone bounding the taiga zone on the north has low values of TI (250–3000 TIU) and ER (0.5–5 mm/day).[2] TI values for the taiga zone differ from those for the steppe zone (500–2000 TIU).

We should emphasize the difference in TI and ER values between the taiga zone and forest-taiga subzone, because the common criteria (indices) are inefficient in the polar region [1].

TI values for the steppe zone (from ~500 to 2000 TIU) have one mode in the 1000 TIU region (Fig. 2), while ER values show bimodal distribution with maximums at 3 and 5 mm/day. Such a distribution is likely to reflect the difference in ER values for natural territories and irrigated areas, where ER values should be higher.

The analysis of spatial and seasonal variations in TI and ER values for the steppe zone (Fig. 2) showed that they are sufficiently stable in both space and time, suggesting that TI and ER can be used as the information base for mapping physiographic zones.

Thus, the results of our study showed that the steppe and taiga zones, as well as the forest-tundra subzone, have different TI and ER values. Therefore, we can identify such zones based on the satellite-borne mapping of these characteristics. It should also be noted that the TI and ER domains of these physiographic taxons do not intersect (Fig. 1). Therefore, we can elaborate the algorithm for the automated mapping of physiographic zones based on data of space thermal and multispectral surveys. We emphasize that the satellite-borne TI and ER mapping requires a rather short period of cloudless weather (3–10 days). This is a substantial advantage over the conventional method based on annual mean values of the radiation balance and precipitation.

Hence, we can make the following conclusions: (1) TI and ER values of individual territories of a single steppe zone vary slightly both within the whole zone and within the warm period of the year. Therefore, these characteristics can be used for the identification of physiographic zones; (2) physiographic steppe and taiga zones, as well as the forest-tundra subzone, are

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[2] Extremely low TI values in individual forest-tundra areas are likely to correspond to territories covered with reindeer moss, which is an air-dry substance and, therefore, should yield low TI values.

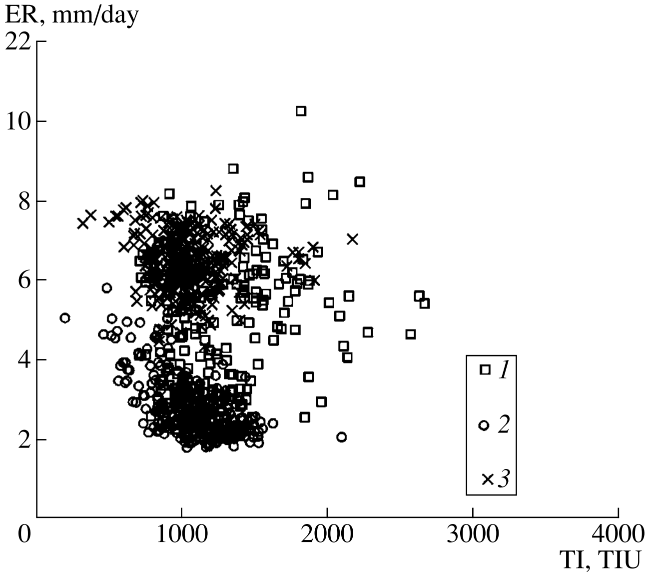

Fig. 2. Distribution of thermal inertia (TI) and daily mean moisture evaporation rate (ER) from the surface for the physiographic steppe zone (based on satellite-borne mapping). (*1*) Steppe between lower courses of the Don and Volga rivers, end of May, 1995; (*2*) steppe between lower courses of the Volga and Ural rivers, end of May, 1995; (*3*) steppe, southern part of West Siberia, Kurgan oblast, mid-July, 2002.

characterized by different TI and ER patterns. Therefore, such zones can be mapped by the method of automated satellite-borne thermal multispectral survey.

REFERENCES

1. A. M. Ryabchikov, *Structure and Dynamics of the Hydrosphere, Its Natural Evolution, and Human-Caused Changes* (Mysl, Moscow, 1972) [in Russian].
2. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Ed. by J. T. Houghton (Camb. Univ. Press, Cambridge, 2001).
3. M. I. Budyko, *Global Ecology* (Mysl, Moscow, 1977) [in Russian].
4. K. Watson, L. C. Rowan, and T. V. Offield, “Application of Thermal Modelling in Geologic Interpretation of IR Images”, in *Proceedings of VII International Symposium on Remote Sensing of Environment* (Ann Arbor, Michigan, 1971), pp. 2017–2041.
5. C. Boulet, A. Chechbouni, I. Brand, et al., Agricult. Forest Meteorol. **105**, 117 (1982).
6. J. C. Price, J. Appl. Meteorol. **21**, 1111 (1982).
7. A. Vidal and A. Perrier, Int. J. Remote Sensing **10**, 1327 (1989).
8. Y. Xue and A. P. Cracknell, Int. J. Remote Sensing, **16**, 431 (1995).
9. A. P. Cracknell and Y. Xue, Int. J. Remote Sensing **17**, 431 (1996).
10. V. I. Gornyi, B. V. Shilin, and G. I. Yasinskii, *Thermal Aerospace Survey* (Nedra, Moscow, 1993) [in Russian].
11. V. I. Gornyi, in *Proceedings of the All-Russia Conference on Current Problems of the Remote Sensing of the Earth from Space: Physical Principles, Methods, and Technologies of Monitoring the Environment, Potentially Hazardous Phenomena, and Objects* (Poligrafservis, Moscow, 2004), pp. 10–16 [in Russian].