Peculiarities of Radiation Balance on Slopes and the Utilisation of These Peculiarities for the Computation of Evaporation from Mountain Basins

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Introduction

A determination of the radiation balance of any given area as a factor bearing on energy resources is one of the objectives of many climatic and hydrologic computations. The methods available make it possible to compute the radiation balance on a flat terrain quite accurately. In the mountains, however, it is necessary to compute the radiation balance on slopes that differ in steepness and exposure. To solve this problem, a theoretical scheme has been developed for a computation of the mean long-term radiation balance of slopes of different exposure and steepness with the use of standard actinometric observations. These computations were made for the periods from six to ten years at six actinometric stations in the trans-Baikal mountains and on adjacent terrain. Mean long-term monthly radiation balances were computed for these stations for slopes of the following steepness: 0°, 5°, 10°, 15°, 20°, and 25° for eight azimuths once every 45°. The azimuth is the angle between the southward direction (Az = 0°) and a horizontal projection of a perpendicular to the slope counted clockwise.

Monthly radiation balances of slopes of different exposures and steepness were computed by the following equation:

$$R_{sl} = (Q_{sl} + q_{sl})(1 - \alpha) - I_{sl} \quad (1)$$

where,

Q_{sl} and q_{sl} are the mean monthly values of direct and dispersed solar radiation on to the slope (taking into account cloudiness), respectively. The symbol α is the mean monthly reflecting capacity of the slope, called albedo, and I_{sl} is the effective radiation of the slope.

The greatest difficulty was caused by the computation of the mean monthly total solar radiation (Q_{sl} + q_{sl}) onto the slope; therefore, a special theoretical formula was elaborated as follows:

$$Q_{sl} + q_{sl} = m \int_{t_1}^{t_2} \{Q[\cos H_S(\cos A_S \cos A_Z + \sin A_S \sin A_Z) \times$$

$$\times \sin\beta + \sin H_s \cos\beta] q \cos^2\frac{\beta}{2}\} dt \quad (2)$$

where,
Q and q are the mean direct and dispersed solar radiation (by standard measurements) onto the surface perpendicular to the sun rays. The variables, t_1 and t_2 are, respectively, time of sunrise and sunset, H_s is the sun's altitude during the time of standard measurements, A_s is the sun's azimuth during the standard measurements, ß is the slope steepness, A_z is the slope azimuth, and m is the number of days in the month.

Computation of the effective radiation of mountain slopes was made according to the following equation:

$$I_{sl} = 0.95\sigma T^4 (11.7 - 0.23e) \times (1 - cn)\cos\beta \quad (3)$$

where,
$\sigma = 5.67 \times 10^{-12} W$ (sq cm K^4) is the Stefan-Boltzmann constant, T is the absolute air temperature, and e is the mean monthly water vapour pressure. The mean monthly values of albedo were taken from the Manuals on Climate of the USSR.

Computations of mean long-term monthly radiation balances of mountain slopes show a necessity to take into account R_{sl} variations, depending on exposure and steepness during the period from May-September only. During the other months, these values are negligibly small.

On the basis of the obtained design data, a table was made displaying the annual values of the radiation balance on mountain slopes as percentages of the radiation balance of a horizontal surface for the study area (Table 1).

Table 1: Annual Radiation Balance of Mountain Slopes as a Per Cent of the Radiation Balance of a Horizontal Surface in the Trans-Baikal Region

	Steepness, in degrees				
Exposure	5	10	15	20	25
southern	103	106	108	109	110
western	99	98	96	94	92
northern	96	91	86	81	75
eastern	100	99	98	96	93

It has been established that changes in the radiation balance on gentle slopes are rather small in summer, depending on their exposure. The radiation balance tends to increase with an increase of slope steepness; at a steepness of 25°, the radiation balance on a northern slope may be 25-30 per cent less than on flat terrain, and the radiation balance on the southern slope is 10-20 per cent more. The course of change in the annual radiation balance on slopes as a function of their exposure and steepness and as based on the computation results are shown in Figure 1.

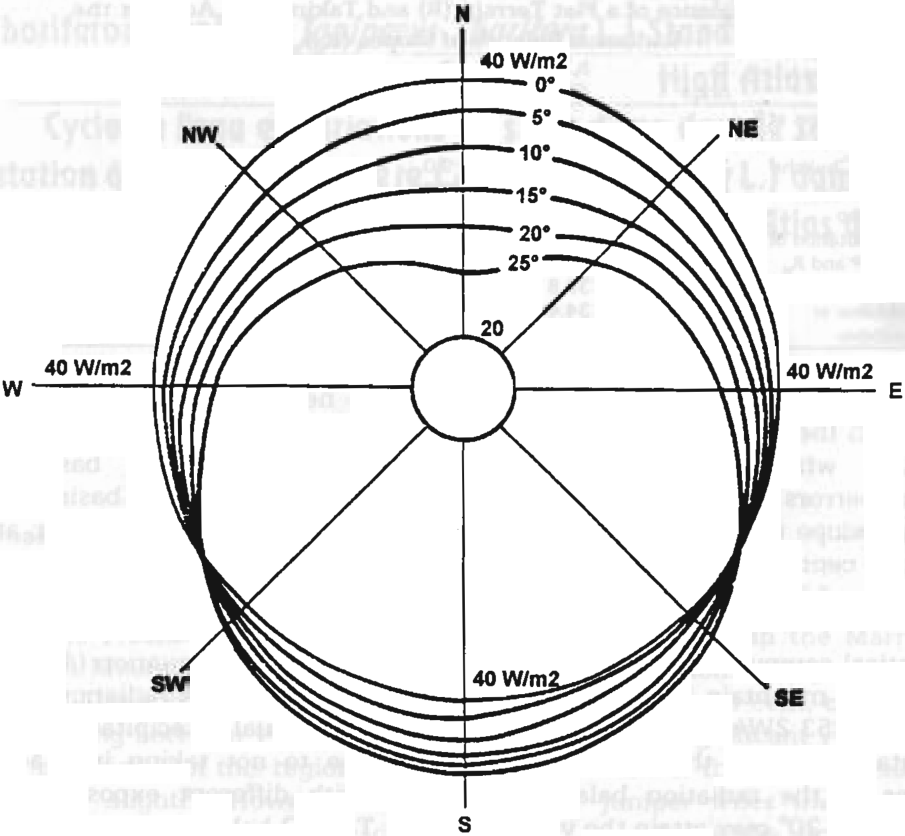

Figure 1: Diagram of Radiation Balance Values Depending on the Exposure and Steepness of Mountain Slopes as against the Radiation Balance of a Flat Terrain, Equal to 40W/sq.m (trans-Baikal region)

The results were obtained by using computed values of the evapotranspiration from the mountain Vitim River basin in the trans-Baikal region. An improved equation of Budyko's was used for estimating evapotranspiration, including the radiation balance as follows:

$$E = \sqrt{\frac{(R-T)P}{L}(1-e^{-\frac{R-T}{PL}})th\frac{PL}{R-T}} \qquad (4)$$

where,
P is precipitation, T is turbulent heat exchange, L is latent heat of evaporation, and th is a symbol for the hyperbolic tangent.

The results of computations made with the help of equation (4) are shown in Table 2.

Table 2: Computation of Normal Annual Evapotranspiration with the Help of the Radiation Balance of a Flat Terrain (R) and Taking into Account the Radiation Balance of Slopes (R_{sl})

River - Station	P (mm)	R,R (W/sq.m)	T (W/sq.m)	E (mm)	Error of computation (%)
1. Computation of E from P and R					
Mama at Chukcha	790	32.0	9.0	259	-
Engazhimo at Engazhimo	683	37.8	7.7	322	-
2. Computation of E from P and R_{sl}					
Mama at Chukcha	790	39.8	9.0	343	+37
Engazhimo at Engazhimo	683	34.4	7.7	287	-11

These results demonstrate quite convincingly the necessity to take into account changes in the radiation balance on slopes (as a function of slope steepness and exposure) when assessing evapotranspiration from mountain basins. For example, errors in the normal annual evaporation from mountain basins on the northern slope (steepness of 20°) without incorporating the above factor attain +37 per cent, as against −11 per cent for the basin at the southern slope (steepness of 25°).

Theoretical computations were also made, with the help of equation (4), for the Vitim River mountain basin using conventional values for the radiation balance (26.6 and 53.2W/sq.m. and various norms of annual precipitation. These computations show that the possible errors due to not taking into account changes in the radiation balance on slopes with different exposure and a steepness of 20° may attain the values given in Table 3 below.

Table 3: Errors in Computation of Normal Annual Evaporation (*E*) from Slopes of 20° Steepness and the Radiation Balance of a Flat Terrain

Slope exposure	Precipitation (mm)	Error of E determination (%)	Slope exposure	Precipitation (mm)	Error of E determination (%)
at R = 53.2 W/sq.m			at R = 26.6 W/sq.m		
Northern	300	+5	northern	300	+11
	500	+10		500	+18
	700	+14		700	+21
Southern	300	-2	southern	300	-5
	500	-4		500	-6
	700	-5		700	-7

References not cited in the text

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