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1961

SovietRxiv

Abstract

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GEOPHYSICS

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WINTER HEAT TRANSFER FROM THE OCEAN AND EFFECTIVE RADIATION WITH A COMPLEX STRUCTURE OF THE CONTINENTAL SURFACE

The unusually warm winter of the current year compels special attention to be focused on heat fluxes in the atmosphere from the Atlantic Ocean to the connected European–Asian continent. In this connection one must regret that over the past 8-9 years our studies of winter heat fluxes from the ocean, published in the form of a preliminary scheme as early as 1952 ([1]), have not been developed further. In the cited article, the winter temperature field over the continent and over the sea was investigated for a flat continental surface and for a variable value of the conditional coefficient of thermal conductivity K.

The active layer of the atmosphere was regarded as a certain film enveloping the Earth, capable of conducting heat along the surface of the planet and at the same time radiating heat. Instead of the temperatures of the film at its various points, the excess τ of the temperature over that which would be observed at the same point under established thermal equilibrium if there were no supply of heat from the ocean to the continent was considered.

With sufficient accuracy it may be assumed that the excess τ leads to an additional effective radiation $\sigma\tau$, where σ is a coefficient readily determined, for example, from experiments with a Michelson-type actinometer.

It was found that the temperature field in the "film" over the continent should be described by an equation which simultaneously takes into account effective radiation with a constant value of σ and conditional thermal conductivity with a variable value of the coefficient K. If the continent has the form of a circle, then the conditional coefficient of thermal conductivity K itself can, with sufficient reliability, be expressed by the formula

$$K = nr^2, \tag{1}$$

where r is the distance from the center of the circle to the point under study. The general differential equation of the temperature field in polar coordinates

Fig. 1

Figure 1: Fig. 1

$$K\,d^2\tau/dr^2 + (K/r + dK/dr)\,d\tau/dr - \sigma\tau = 0 \tag{2}$$

takes, with allowance for (1), the simple form

$$r^2 d^2\tau/dr^2 + 3r\,d\tau/dr - \sigma r = 0. \tag{2'}$$

The integral of $(2')$ gives the distribution of τ along the radius of the continent R:

$$\tau/\theta = 0.841\,r/R, \tag{3}$$

where θ denotes the temperature of the air "film," reckoned from our arbitrary level, at a very large distance from the continent.

In the present article we shall continue the investigation of scheme ([1]) as applied to certain concrete conditions and shall reveal the physical meaning of the connection between heat transfer into the depth of the continent and effective radiation in the form in which it appeared in work ([1]).

Figure 1 presents air-temperature isanomalies for midwinter in Australia. Beside each of the solid curves are indicated the corresponding deviations of the mean monthly temperature from the mean taken along the parallel at the given latitude. It is clearly seen that the outlines of the isanomalies schematically reproduce the outlines of the coastline—because the structure

surface of Australia is very simple, and because heat transfer from the ocean to the continent here proceeds according to the simplest law: at the mean latitude of Australia, both the trade-wind and the zonal circulation of the atmosphere are practically absent, and the determining circulation is the monsoon circulation. As was to be expected ([2]), under such conditions the field of isanomalies proved to be completely analogous to the field of climatological isobars, shown in Fig. 1 by the dashed lines. Both systems of curves have been transferred to Fig. 1 from the corresponding maps of the Marine Atlas ([3]), but in another projection, which provided less distortion of the curves.

Fig. 1

Figure 2 shows a meridional section of the field, with the ordinate axis carrying the values of τ, the absolute temperature anomalies, i.e., the excess of temperature over the value that would be established in the absence of heat fluxes from the ocean. The dashed curve shows the changes in atmospheric pressure with

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

distance from the ocean toward the center of the continent. The course of both curves fully corresponds to the basic equation of the monsoon field ([2])

$$\operatorname{grad} p = -\Pi \operatorname{grad} \tau. \tag{4}$$

Fig. 2

At the same time, both Fig. 2 and Fig. 1 allow us to assume that $\Pi \cong 1.5$. Let us recall that in a number of studies relating to the conditions of Europe and Asia ([2]), almost the same value, $\Pi = 1.6$, was obtained.

Thus, the simplest local conditions obtaining in Australia have led to a linear law of decrease of τ in the direction from the coasts toward the center of the continent. Only in the immediate vicinity of the center is this simple law slightly violated (in all probability, under the influence of unaccounted components of the heat fluxes). The existence of such a linear law of variation of τ points to an extremely interesting connection between the coefficient n in (1) and the coefficient σ, which characterizes the effective radiation of our "atmosphere-film." Namely, here $n = \frac{1}{3}\sigma$, and consequently,

$$K = \frac{1}{3}\sigma r^2. \tag{5}$$

This relation, obtained in (1), may seem unexpected. However, it is entirely natural: conditions (5) state only that *all the heat entering the continent from the ocean is inevitably spent completely on the effective radiation of the active layer of the atmosphere over this continent*, regardless of the route by which the heat is transferred from the ocean coasts toward the center of the continent: by advection of air masses or by turbulent mixing.

Let us now see how the winter temperature field over the conti–

by the influence of the complex structure of the surface. To exclude the influence of the latitude of the place, let us consider a section of the connected Europe-Asia continent along the parallel $\varphi = 67°33'$, passing near the pole of cold. Using the isotherms plotted on the map of the *Great Soviet Atlas of the World* ([4]), we obtain, along the stretch from the coast of the Barents Sea to the coast of the Chukchi Sea, the temperature-variation curve shown in Fig. 3.

Fig. 3

Here the abscissa axis marks longitudes, and the ordinate axis gives air-temperature values. The origin of coordinates is taken at the longitude of Verkhoyansk. In the direction toward it, from both the western and the eastern coast, the temperature falls according to a complicated law, and not according to the linear law observed in the case of Australia. Looking at the inscriptions placed near the convex and concave portions of the curve, it is easy to understand what causes the complications: the Ural Range, the Putorana Mountains, the Verkhoyansk Range, the Chersky Range, and the Yukagir Plateau have produced convexities of the curve in the positive direction of the ordinates; the intervening lowlands and plains have caused concavities in the positive direction of the ordinates.

For the time being it is difficult to analyze the curve in Fig. 3 by the method set forth in ([1]): in its present state this method still does not make it possible to take into account the role of heat fluxes from the Arctic Ocean, which manifest themselves in winter along with fluxes of Atlantic and Pacific origin. However, method ([1]) already makes it possible now to clarify the physical meaning of the convexities and concavities on the curve in Fig. 3 after considering a very simple schematic representation of the phenomena.

Let us assume that, under the influence of heat fluxes from the ocean, the winter temperature field on a circular continent of radius R is characterized by a cur-

···curve 1 in Fig. 4 (r is the distance from the center of the continent to the point under study). The ordinates of curve 1 express the values τ/τ_R, where τ is the temperature anomaly at the point under study[2], and τ_R is the temperature anomaly on the coast. This curve is described by the simple equation

$$\tau = ar - b\sin pr \tag{6}$$

for the particular value $a/bp = 1.5$. Substituting the expression for τ from (6) into (2), we obtain a differential equation expressing the new dependence between the conditional coefficient of thermal conductivity K and the coordinate r:

$$Kbp^2 \sin pr + (K/r + dK/dr)(a - bp\cos pr) - \sigma ar + \sigma b \sin pr = 0. \tag{7}$$

Fig. 4.

To simplify the form of (7), introduce the notation:

$$\frac{a}{bp} = c; \qquad pr = 2\pi\frac{r}{R} = x;$$

$$\frac{K}{\sigma/p^2} = 4\pi^2\frac{K}{\sigma R^2} = \frac{4}{3}\pi^2\frac{K\kappa}{K_R\lambda} = y.$$

Then, instead of (7), we write

$$\frac{dy}{dx} + \left(\frac{1}{x} + \frac{\sin x}{c - \cos x}\right) y + \frac{\sin x - cx}{c - \cos x} = 0. \tag{8}$$

Integration of (8) gives

$$y = \frac{\frac{1}{3}cx^2 + \cos x - \sin x/x}{c - \cos x}. \tag{9}$$

Calculations carried out by (9) for the particular value $c = 1.5$, corresponding to curve 1, gave the distribution of the sought quantities along curve 3 in Fig. 4. The ordinate axis gives the values K/K_R, where K is the conditional coefficient of thermal conductivity at a distance r from the center of the continent, and K_R is that on the ocean shore. For comparison with curve 3, the same figure includes curve 2, which corresponds to a simple, perfectly flat continent. As we see, the convexity on temperature curve 1 in Fig. 4 arose owing to a sharp local decrease in the conditional coefficient of thermal conductivity K in comparison with the value that would characterize a perfectly flat continent. In nature, such a local decrease in the coefficient of conditional thermal conductivity of the active layer of the atmosphere is caused by mountain ranges, which reduce the amount of heat penetrating from the ocean into the interior of the continent. In accordance with the principal connection between heat transfer and effective heat radiation (see the italicized text after formula (5)), we can now assert that the heat not admitted into the interior of the continent is expended on increased effective radiation in the coastal belt of the continent. Such an increase is inevitable: with increasing distance from the ocean shore the temperature (according to curve 1) decreases more slowly than it would decrease in the absence of a mountain range –according to the linear law shown by the segment of the dash-dot straight line in Fig. 4.

The basic scheme investigated describes phenomena well known under the conditions of the Black Sea coast of Crimea, the Caucasus, and other analogous regions. It explains the physical meaning of the convexities and concavities of the curve in Fig. 3.

Received
16 II 1961

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[4] *Great Soviet Atlas of the World*, 1, map 30, 1937.

Note: Figure translations are in progress. See original paper for figures.