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THE HEAT BALANCE ON THE SURFACE OF MARS

BY

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ABSTRACT

The insolations (for $\tau=0$, 0.1, 0.2 and 0.3) and the heat loss on the Martian surface for various seasons have been calculated. Then, the heat balance on the surface and the effect of Martian cloud have been discussed. It is shown that the theoretical results fairly agree with observations.

1. Insolation

Insolation is defined as the solar flux received on a horizontal surface. The insolation on the Martian surface can be expressed as follows:

$$q = S\frac{r_m^2}{r^2}\cos\theta\, e^{-\tau\sec\theta}\,, \qquad (1)$$

where S is the solar constant on Mars, which means the flux of solar radiation at the boundary of the Martian atmosphere, incident on a surface per unit area normal to the Sun's direction at the mean distance between Sun and Mars, and r, the distance between Sun and Mars, r_m, the mean distance between Sun and Mars, τ, the optical depth of the Martian atmosphere, and, θ, the zenith distance of the Sun.

We define also the daily insolation, Q, as:

$$Q = S\frac{r_m^2}{r^2}\int_{t\,(\text{Sunrise})}^{t\,(\text{Sunset})}\cos\theta\, e^{-\tau\sec\theta}\,dt\,, \qquad (2)$$

where t is the hour angle of the Sun, and

$$\cos\theta = \sin\phi\,\sin\delta+\cos\phi\cos\delta\cos t\,, \qquad (2')$$

where δ is the Sun's declination for a particular day of year, and, ϕ, the latitude at the point of measurement.

a) Undepleted insolation

When $\tau=0$, the daily insolation can be written as follows:

$$Q_0 = S\frac{r_m^2}{r^2}\int_{t\,(\text{Sunrise})}^{t\,(\text{Sunset})}\cos\theta\,dt\,, \qquad (3)$$

Using Eq. (2′), Eq. (3) is transformed to:

$$\begin{aligned} Q_0 &= S\frac{r_m^2}{r^2}\frac{24}{\pi}\left\{\sin\phi\sin\delta\cdot t_0+\cos\phi\sin t_0\right\} \\ &= S\frac{r_m^2}{r^2}\frac{24}{\pi}\sin\phi\sin\delta\left\{t_0-\tan t_0\right\}, \end{aligned} \tag{4}$$

where t_0 means the difference of hour angle between sunrise (sunset) and solar noon. Variation of Q_0 is shown graphically in Fig. 1.

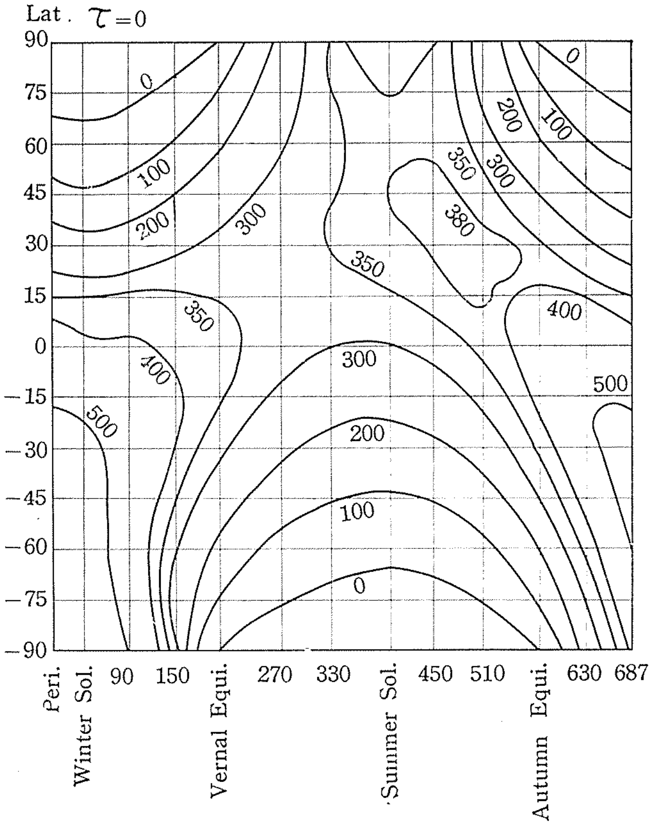

Fig. 1. Undepleted insolation, in cal/cm^2 per day, as a function of latitude and date.

The maximum of daily insolation occurs on south pole at winter solstice (near periherion). The asymmetry of the curve is due to the proximality of periherion of Mars. For each latitude, summer (winter) insolation in southern hemisphere is much greater than that of the corresponding northern hemisphere. There also appears the second maximum of insolation at +35° in the Martian summer (northern hemisphere).

b) Depleted insolation

If any atmospheric absorption exists, we must integrate Eq. (2) numerically. In the Martian atmosphere, there exists some atmospheric absorption mainly due to the violet layer. Taking into account the optical properties of the particle in the violet layer, A. K. Blakadar and others estimated a fairly good agreement between observation and theory by assuming the optical depth $\tau=0.15$ (corresponding to $e^{-\tau}=0.86$). During the period of blue clearing, $\tau=0.05$ ($e^{-\tau}=0.95$) might be the right order of magnitude.

Therefore, we computed daily insolation diagrams with the atmospheric absorption $\tau=0.1$ ($e^{-\tau}=0.90$), $\tau=0.2$ ($e^{-\tau}=0.82$) and $\tau=0.3$ ($e^{-\tau}=0.74$) and the results are shown in Figs. 2, 3 and 4.

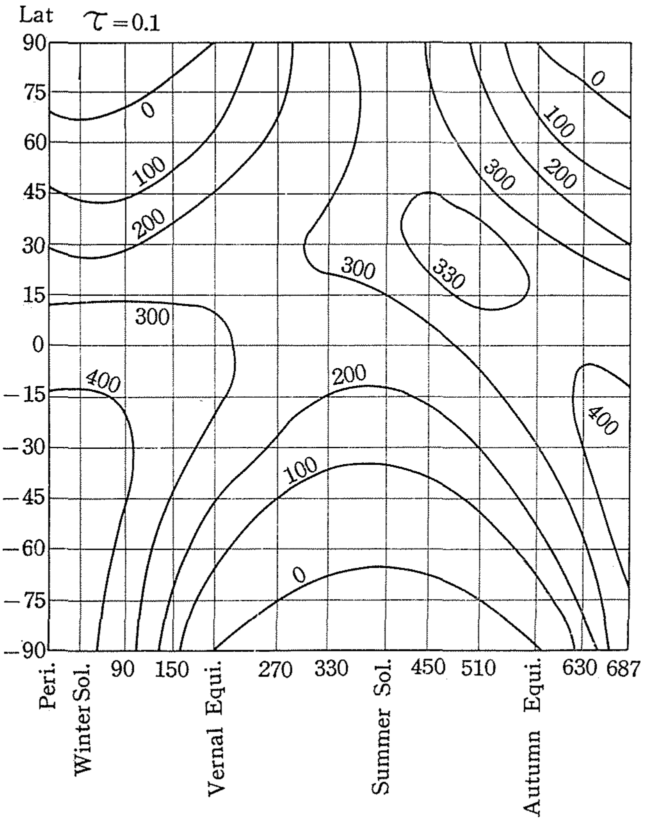

Fig. 2. Daily insolation, cal/cm^2 per day, received at the Martian surface when $\tau=0.1$.

As seen in Figs. 1~4, the daily insolation, Q, is reduced with increase of τ at any latitude. In each diagram the strongest depletion is found at the highest latitude.

For example, the daily insolation on the south pole at the summer is reduced from 589 to 461, 360 and 284 cal. respectively, while at latitude $-30°$, reduction is from 526 to 450, 391 and 344.

As we see in Fig. 1, the maximum point of undepleted insolation value is found on the south pole at winter solstice. It shifts to $-80°$ (464 cal) with $\tau=0.1$, to $-40°$ (389 cal) with $\tau=0.2$ and to $-35°$ (about 350 cal) with $\tau=0.3$ respectively. Then, for $\tau=0.2$ and 0.3 the middle latitude receives the largest solar radiation.

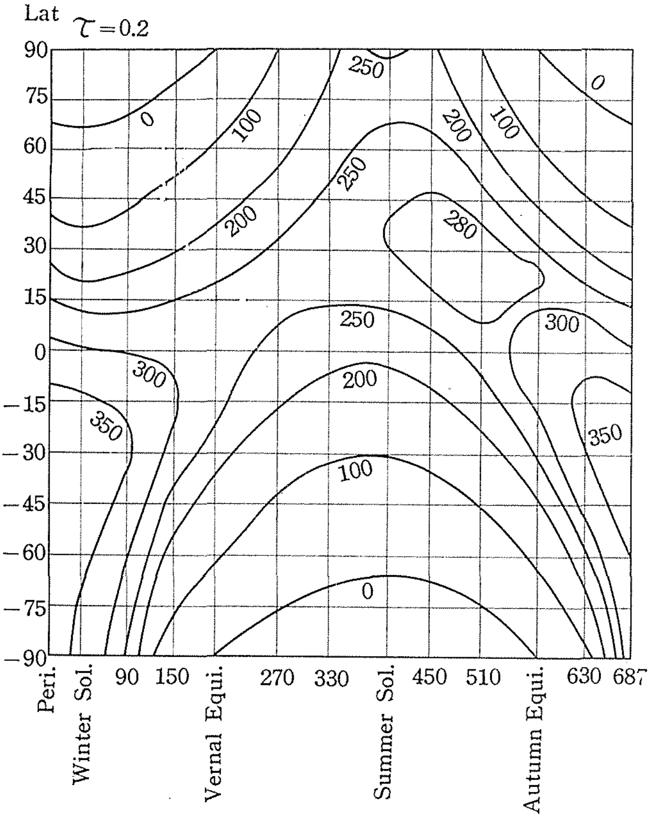

Fig. 3. Daily insolation, cal/cm^2 per day, received at the Martian surface when $\tau=0.2$.

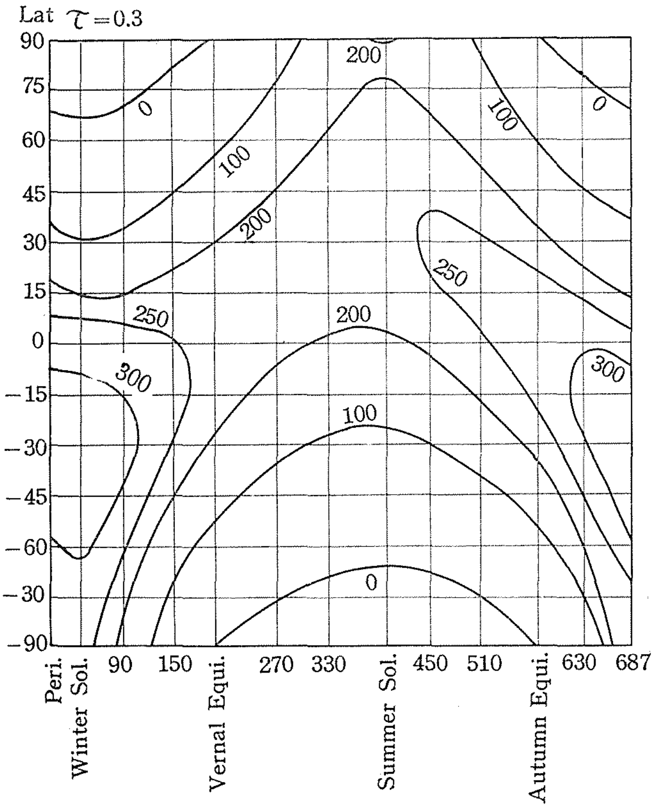

Fig. 4. Daily insolation, cal/cm^2 per day, received at the Martian surface when $\tau=0.3$.

2. Radiation from the surface of Mars

On the surface of Mars, the energy is mainly lost by the long wave radiation. For Mars, we may ignore the blanketing effect of the atmosphere except polar regions. Then we can estimate the lost energy if we know the mean temperature on the surface of Mars.

A few years ago, F. Gifford analysed the Lowell Observatory radiometric measurements of Martian surface temperature between 1926 and 1943, and obtained annual and diurnal temperature variations and seasonal isothermal maps. Fig. 3 in his paper shows average temperature variation along the Martian noon meridian for various seasons. We take these values as the temperature on the surface of Mars. To obtain the mean temperature we must add a correction ΔT to the daytime temperature. Following S. Miyamoto, we tentatively adopt $\Delta T=-30^\circ$ at the equatorial zone and gradually reducing to $\Delta T=0$ to polar regions. But this procedure must be examined more thoroughly.

In Fig. 5 we find the radiation thus calculated. It must be noted that we assumed the Martian soil radiates as a black body, and the obtained values show only the upper limit of long wave radiation.

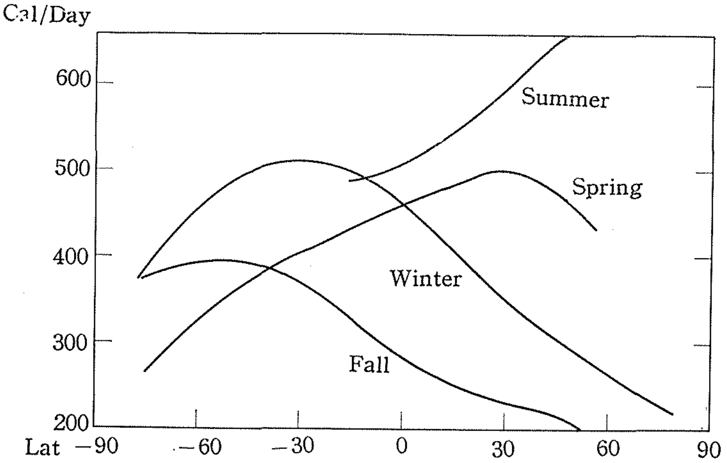

Fig. 5. Radiation from the surface of Mars for various seasons (northern hemisphere). Cal/cm^2 per day *versus* latitude.

3. Heat balance

In §2, we assumed that the Martian soil acts as a black body radiator. If it acts like a gray radiator, the radiation will decrease considerably. Then we must add some correction to the values in Fig. 5. Moreover, various colors of the surface will affect the smoothed temperature values. For example, Gifford obtained very low average values as fall (northern hemisphere) temperatures near the equator. At first he thought those values incorrect, but a check revealed that most of the fall time observations corresponding to the point at −16° had systematically changed to fall near the longitude of Hellas region, one of the brightest area of Martian surface.

But, comparing the inclination of a curve in Fig. 5 with insolations corresponding to that curve, we are able to know the direction of the energy flow on the surface of Mars.

For example, in winter (northern hemisphere) the radiation curve has its maximum in soutern tropical region, so the unbalance between heat gain and loss occurs mainly in southern hemisphere. Energy flows from the southern hemisphere across the equator to the northern hemisphere.

Like this, we find that the energy is flowing from the equator to the southern pole in fall (northern hemisphere). So, in this season we may expect the westerlies over the northern middle latitude. In the northern hemisphere, insolation and radiation decrease towards north in the same manner.

In spring, energy is flowing from the equator to the north pole.

4. Influence of the cloud of Mars

a) Blue cloud

Since 1924 many authors investigated the influence of the high level blue-white cloud on the surface temperature of Mars. They found that the temperatures computed for area observed to be clouded were considerably lower than for the unclouded surface. They attributed a part of the effect to the great reflectivity of the cloud for sunlight.

b) White cloud

In 1960∼61 S. Miyamoto analysed his observations of white cloud and found three major vapor courses connecting southern and northern hemispheres. He concluded that the actual driving mechanism of the air mass change in the Martian atmosphere may be ascribed to the water vapor. He also pointed out that when we consider the Martian atmosphere the vapor content is a factor as important as the seasonal change of the temperature of the soil. These results coincide with our calculation.

c) Yellow cloud

In 1956 the motion of great yellow cloud was observed at Kwasan Observatory. The opposition occurred in the southern summer of Mars. The great cloud drifted to westwards. We may explain this motion if we assume the energy flowing from southern hemisphere to northern hemisphere in this season.

d) Diffuse white patches

The polar cap continues to diminish during summer, and diffuse white patches appear on the polar region. They spread quickly and finally cover the whole polar region and even a part of middle latitude area. This layer will absorb the long wave radiation and the temperature in the polar region may increase.

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