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THERMOPHYSICAL PROCESSES IN PERMAFROST

THE RADIATION HEAT BUDGET OF THE ANTARCTIC AND MARS POLAR REGIONS: COMPARATIVE ANALYSIS

O.N. Abramenko, I.A. Komarov, V.S. Isaev

Lomonosov Moscow State University, Department of Geology, 1, Leninskie Gory, Moscow, 119991, Russia; oleg_abramenko@inbox.ru, ilya_komarov@mail.ru, tpomed@rambler.ru

The time and space radiation heat patterns have been investigated at five polar Antarctic sites (Novolazarevskaya, Molodezhnaya, Bellinshausen, Mirny, and Vostok). Similar variability appears in data from Mars polar ice caps. The reported comparative analysis allows evaluating the contributions from different thermophysical components of the radiation heat budget in the Antarctic and Mars high-latitude regions.

The study has focused on comparing quantitative and qualitative parameters that represent the radiation heat budget in Antarctica and in polar Mars. Mars is a planet with a thin atmosphere, a thick cryosphere, and permanent ice caps at both poles. On the Earth, it is the Antarctic that is similar to the Mars high-latitude regions, especially to the northern cap consisting mostly of water ice; similar are the surface areas and the ice sheet thicknesses (Table 1). The Antarctic climate is the most severe (the coldest natural temperature ever recorded on Earth was –89.2 °C at the Vostok station) and the least affected by anthropogenic loads.

We analyzed records from five Antarctic stations (Novolazarevskaya, Molodezhnaya, Bellinshausen, Mirny, and Vostok) collected by the Arctic and Antarctic Research Institute from the start of observations (1958–1971) through 2008–2009 (till 1992 at Molodezhnaya). The stations are located on or near the shore, or in the continent interior (on ice or within Antarctic oases). The inventory consisted of the following data:

(1) long-term average solar flux during selected observation periods (at clear sky, with cloud amounts less than 2, and at up to 10);

(2) statistically processed data on monthly and yearly totals of the radiation budget components;

(3) statistically processed data on monthly and yearly totals of direct beam solar radiation at normal incidence and atmospheric clearness index.

As part of the 53rd Russian Antarctic Expedition, one of us [*Abramenko, 2009*] set up a test station at the Novolazarevskaya site, in the Schirmacher oasis located 80 km far from the northern Antarctic coast in the central Queen Maud Land. The objective was to test the method for measuring the surface heat budget, to monitor the temperature, the thermal conductivity, and the thaw depth. The annual temperature cycles were monitored with loggers which were courtesy of the Fairbanks University (Alaska, USA). The test station was operated within the limits of the CALM program (Circumpolar Active Layer Monitoring) [*Brown et al., 2000*].

At the stations Bellinshausen, Novolazarevskaya, Molodezhnaya, Mirnyi, and Vostok, the normal beam solar radiation was from 33 to 56 % and dominated over other radiation components that varied in the following ranges: 6 to 26 % reflected, 3 to 23 % absorbed, 6 to 32 % scattered, and 9 to 17 % radiation on a horizontal surface (Table 2). The estimated total annual heat balance of the ice surface was negative, from –20 to –40 W/m^2.

Inside the domain there are zones with a positive balance, such as oases, ice-free ridges, and stationary water clearings. In oases, the annual heat budget is 110 W/m^2. The annual totals of the radiation components range as follows: normal beam radiation from 102 to 830 W/m^2, horizontal radiation from 48 to 199 W/m^2, scattered radiation from 67 to 179 W/m^2, total radiation from 19 to 329 W/m^2, and back radia-

Table 1. **Ice parameters of Antarctic and Martian ice caps, compared**

Area	Surface area, km^2	Maximum ice thickness, km	Ice	
			volume, km^3	composition
Antarctic	$1.4 \cdot 10^7$	4.8	$26.7 \cdot 10^6$	H_2O
Mars South Pole cap	$3.9 \cdot 10^5$	3.7	$1.6 \cdot 10^6$	H_2O and mostly CO_2
Mars North Pole cap	$6.8 \cdot 10^5$	2.0	$1.4 \cdot 10^6$	CO_2 and mostly H_2O

Table 2. **Radiation heat budget components at different Antarctic sites, compared, W/m²**

Site	Radiation budget	Beam radiation		Solar radiation	
		normal	horizontal	total	backscattered
Vostok	–6.7	344.7	105.0	147.8	111.8
Novolazarevskaya	37.2	181.2	67.3	125.0	26.7
Molodezhnaya	38.6	144.5	62.8	134.0	50.5
Mirnyi	–8.5	148.2	62.4	135.3	108.1
Bellinshausen	20.2	42.2	20.7	7.8	45.2

tion from 65 to 263 W/m^2. The monthly means of climate parameters at the selected stations were: albedo 0.2–0.9, air moisture 48–90 %, wind speed 2.9–13.4 m/s.

The time and space patterns of the surface radiation heat budget components in the Mars polar regions were investigated using the Global Mars Climate Database produced jointly by Laboratoire de Météorologie Dynamique du CNRS (LMD, Paris) and Atmospheric, Oceanic and Planetary Physics, Department of Physic (AOPP, Oxford University, Oxford, England UK) [*The global Mars Climate Database*].

The ranges of annual reflected radiation generally for the Mars high latitudes are 414–750 W/m^2 for the northern ice cap and 532–840 W/m^2 for the southern ice cap. The absorbed radiation ranges are, respectively, 658 to 2016 W/m^2 and 702 to 1539 W/m^2. The radiation data for the northern and southern polar regions were processed on a space grid for the coordinates 90°, 86.2°, 82.5°, 78.8°, 75° N and S; 135°, 90°, 45°, 0° W and 45°, 90°, 135°, 180° E to analyze annual cycles of the surface and atmospheric infrared radiation, absorbed and reflected radiation, and mean monthly surface temperatures. Other parameters were mean diurnal and monthly temperatures of the surface and lower atmosphere (5 m above the surface) estimated for midnight and noon times and winter and summer mean diurnal variations of wind speed.

The radiation heat budget components were calculated with an equation used to process the Earth's ground surface data [*Budyko, 1956*]. Turbulent heat transfer was found as the surface-air temperature difference (according to GMCD) multiplied by the heat transfer coefficient. The latter was assumed to be 2–5 W/(m^2·K) proceeding from empirical data obtained in laboratory at pressures and temperatures typical of the Mars high latitudes [*Lebedev and Perelman, 1973*]. The heat spent for sublimation (ablimation) of CO_2 or H_2O ice was evaluated from mean annual values of the process intensity obtained using GMCD. The CO_2 and H_2O ice sublimation heat was estimated with regard to its temperature dependence [*Komarov, 2003*]. The heat flux from the surface to the ice was calculated as a solution to the thermal conductivity differential equation at the respective boundary conditions. The models included a two-layer section for the northern ice cap and a three-layer section for the southern cap [*Komarov and Isaev, 2010*].

The components of the radiation heat budget in the Earth's Antarctic and Mars's high latitudes demonstrate qualitatively similar patterns, but there is some difference in their magnitudes. Namely, backscattered and absorbed radiation is slightly lower on Mars than at the Antractic Novolazarevskaya site (Table 3). Unlike the Earth, the Mars surface temperature is due mostly to beam solar heat rather than atmospheric heat transport. As a result, the temperature may be locally 272 K while the mean of the north ice cap periphery in the early summer is 235 K (Ls = 90°, where Ls is solar latitude). Generally, the mean diurnal air temperature at 5 m above the Mars surface varies through a year from 143.1 to 249.9 K on the southern ice cap and from 147.8 to 230.4 K on the northern cap.

Table 3. **Annual means of heat-radiation budget components at sites of Martian poles and Antarctic Novolazarevskaya site**

Site	Location	Radiation budget components, W/m²					Heat budget components, W/m²		
		Short-wave solar radiation			Albedo	Effective long-wave radiation	Heat loss for evaporation (sublimation)	Heat flux to rocks	Turbulent heat transfer
		total	reflected	adsorbed					
Novolazarevskaya	11° E 70° S	125.0	26.7	98.3	0.2	61.1	$1 \cdot 10^{-3}$	1.1	34.9
Mars South Pole cap	0° E 82.5° S	60.4	14.5	45.9	0.2	26.9	20.5	0.1	0.7
Mars North Pole cap	0° E 82.5° N	57.3	17.2	40.1	0.3	24.1	18.0	0.1	0.5

According to our estimates of the permafrost thickness and the Mars cryosphere as a whole, the permafrost is from 1000 m thick at the equator to 3600–3750 m at the polar caps [*Komarov and Isaev, 2010*]. The mean thickness of frozen ground is 2300 m, which is greater than the terrestrial mean. The total ice volume in a 2300 km thick spherical layer (the Mars outer radius being 3394 km) is (0.4–2.0)·10^8 km^3, as estimated by different authors, which is about two orders of magnitude more than the total volume of the polar ice caps.

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References

Abramenko O.N., 2009. Methods for investigating the surface radiation heat budget components and thaw depths in Schirmacher oasis (Antarctica). Vestnik Moscow Univ., Ser. 4. Geol., No. 4, 67–69.

Brown J., Hinkel K.M., Nelson E.F., 2000. The Circumpolar Active Layer Monitoring (CALM) program: research designs and initial results. Polar Geogr., 24 (3), 165–258.

Budyko M.I., 1956. Heat Budget of the Earth's Surface [in Russian]. Gidrometeoizdat, Leningrad, 256 pp.

Komarov I.A., 2003. Termodynamics and Heat-and-Mass Transfer in Permafrost [in Russian]. Nauchnyi Mir, Moscow, 603 pp.

Komarov I.A., Isaev V.S., 2010. The Cryology of Mars and other Planets of the Solar System [in Russian]. Nauchnyi Mir, Moscow, 232 pp.

Lebedev D.P., Perelman T.L., 1973. Heat and Mass Transfer in Vacuum Sublimation [in Russian]. Energiya, Moscow, 336 pp.

The global Mars Climate Database. (http://www-mars.lmd.jussieu.fr/).

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