ANALYSIS OF THE SEASONAL VARIATIONS OF TES THERMAL INERTIA VALUES IN THE MIDDLE AND HIGH LATITUDES OF MARS. R.O. Kuzmin[1], E.V. Zabalueva[1], P. R. Christensen[2]. [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, 19 Kosygin str., Moscow 119991, Russia, e-mail: rok@geokhi.ru, [2]School of Earth and Space Exploration, Arizona State University, Tempe, Arizona, USA.

Introduction: The thermal inertia (TI) of the Martian surface materials represents the combination of bulk thermal conductivity, specific heat and bulk density of the materials ($I=\sqrt{\kappa\rho c}$), where κ – the coefficient of thermal conductivity (W/m K), ρ - density (kg/m^3) and c – specific heat (J/kg K). For any silicate granular materials over a wide range of particle size, the value of the density and specific heat varies by a factor of 2-4 and by only tens of percent respectively, while the bulk thermal conductivity can vary by up to 3 order of magnitude [1]. It was suggested recently [2] that large seasonal variations of the TI on Mars might to be due to horizontal and vertical heterogeneity of the surface materials. However, on Mars there are two additional factors that might change noticeably the TI of the soils: the atmospheric dust loading and the water ice condensation within a thin surface layer. The goal of our research is to understand what possible contribution each of these two factors has on the seasonal change of the TI values. The mapping of the TI in our work has been done based on algorithm similar with one described in [3,4].

Analysis and results: As the first step in the analysis of the seasonal change of the TI values we selected from the existing TES TI map [4] eight regions (size 5°x 5°) with the same TI value (~200 J/m^2 s$^{1/2}$K) that are located at different latitudes from 0° to 50°N. The seasonal change of the TI values as function of the Ls (with Ls step 20°) was analyzed for each of the selected regions based on the TES data collected during the first Martian year (Fig.1). It was found that all selected regions has similar values of TI during the spring-summer period (Ls=0°-180°), but the TI increased (up to 600) in the autumn-winter period (Ls=200°-360°). As clearly seen from Figure 1, the magnitude of the TI increases from the equator to the higher latitudes and the maximum values of TI are achieved much earlier at low latitudes (at Ls=~220°) and remarkably later at higher latitudes (at Ls=~290°). The maximum values of TI on the high latitudes are 50-80% higher than those at low latitudes. The time range of such intense increasing of the TI value coincides with season of strong atmospheric dust loading, which represents a repeatable process in every Martian year [5]. The dust loading results in an increase in the atmospheric temperature at the 10-40 km altitudes and reduces the diurnal temperature oscillations observed on the surface [5]. This reduction in the amplitude of the temperature oscillation results in a higher apparent TI. In addition, during the autumn-winter seasons the surface temperature on the middle and high latitudes reach the values at or below the water vapor freezing point which may result in ice appearance in the surficial soil. This also may cause an increase in TI. To define the contribution degree of the atmospheric dust loading and water ice condensation on the increase in TI, we mapped the TES TI within the Mars sector (±90°, 0°-70°W) for three seasons: during the dusty autumn season (Ls=230°-240° with dust optical depth 0.37- 0.42), during the summer (Ls=120°-150°) and during winter (Ls=300°-310°) seasons with similar low values of the dust optical depth (0.1- 0.2). Results of the TI mapping are shown on Fig.2 and the TES dust optical depth values as function of the latitude [6] for indicated seasons are shown on Fig.3. Based on these TI maps, the zonally averaged (in the 5°belt) meridian distributions of the TI values for each of the seasons were also computed (fig.4a). As seen from the mapping results (Fig.2 and 4a) the greatest increase of the TI values (with regard to the summer-time TI values) during the autumn and the winter seasons occurs primarily at latitudes higher than 30°. At that, the winter-time maximum values of TI are becoming comparable with the autumn-time maximum TI values at the latitude about 50° in both hemispheres. During selected summer and winter periods the TI values on the low latitudes were mostly constant, while during autumn's dusty season the TI values on the same latitudes were notably higher (on 30-40%) than those in other periods. We suggest that the difference between the autumn and winter TI values (with regard to the summer values) may represent the relative contribution of the atmospheric dust loading factor in the increasing of the TI value. Thus, comparison of degree of the TI values increase and dust optical depth value variations during different seasons provides the mean to separate the dust loading effect from the water condensation effect.

To estimate the probable ice content in the Martian soil (in volume fraction) at which the observed winter-time TI values could be achieved with regard to it's the summer-time value (TI_{dry}

$_{soil}$), we calculated the TI $_{icy\ soil}$ values of the soil at different ice content. Such parameters of two-component mixture (the ice-bearing soil) as the thermal conductivity (k), specific heat (c) and soil bulk density (ρ) have been estimated by the same method as used in [7, 8]. The parameters for the summer-time dry soil have been estimated in accordance with method from [7]. For water ice the parameters k $_{ice}$ and c $_{ice}$ were estimated based on the equations from [9] corresponding to temperature range 108-273K and taking into account the dependence of ρ_{ice} on the temperature in the range 173-233K [10] . Based on the parameters the observing summer-time TI $_{dry\ soil}$ values (for both hemispheres) were recalculated for the cases with different percentages of ice content at a surface temperature 200K (Fig.4b). Additionally, the nomogram for ice content determination based on relationship between the TI $_{dry\ soil}$ and the TI $_{icy\ soil}$ values (computed for different soil's ice content from 0% to 10%) have been compiled (Fig.5). The parameters used for calculations of the TI $_{(icy\ soil)}$ at different temperature are represented in Table 1. The mapped summer-time and winter-time TI values were zonally averaged (in 5° latitude belts) and were plotted on the nomogram (Fig.5). The location of the plotted points relatively of the drawn curves of the nomogram let to define what ice content corresponds to the observed seasonal values of the TI. As seen from Figure 4b and 5, the zonally averaged winter-time TI values are consistent with a soil ice content of 1-5 vol. % for latitude ranges 30°-50°N and 40°-50°S respectively. At the lower latitudes (0°-30°N and 0°-40°S) the winter-time TI values are consistent with much less soil ice content (mostly < 1 vol. % and up to dry soil). It is notable that the TI values within the latitude range 30°-45°N are consistent with more ice-rich soil than ones within the same latitude range of the Southern hemisphere.

Discussion: This analysis of the seasonal change of the TI values on Mars has shown that the greatest increase in the TI values during the autumn-winter period may to be associated not only with the influence of the atmospheric dust loading, but also may to be due to water ice condensation within thin surface layer on the latitudes higher of 30° in the Northern and of 40° in the Southern hemispheres. The observed timing of the TI maximum first the low latitudes and notably later at higher latitudes may be a manifestation of the dominant influence of the dust loading on the TI values mainly in autumn period versus the dominant influence of water ice condensation during the winter. Comparison of the TI values derived in winter-time with model calculation of the TI $_{icy\ soil}$ for different ice content shows that the observed TI values in the latitude range 30°-50° are consistent with the presence of ice within a soil surficial layer at the amount 1-5 vol. % whereas on the low latitudes - with ice content < 1 vol. % (up to dry soil). The first evidence for presence of the surface water ice condensation on the high latitude (in form of the snow layer up to 2 mm thick) was found on the panoramic image of the Viking-2 Lander site [11], imaged in the winter time (Ls=310°). Our calculations show that for this amount of water ice the summer-time TI value of the soil in the region of the Viking-2 landing site (~230) may to be increased by 60-100 %. More recently, due to the MOC monitoring [12] and the Reconnaissance CRISM measurements [13] have found distinct evidence of water ice condensation presence (in form of spotted covers) on the polar-ward sloping surfaces on the latitudes 30°- 40°S during winter. The presence of 3-5 vol. % ice at latitudes 40°-50°N to explain the winter-time TI values is consistent with the HEND data, which shown seasonal appearance of similar water amount within the surface layer up to 20-30 cm thick on the same latitudes during winter [14]. Thus, our results demonstrate that the TES TI data may be effectively used not only for thermal physical properties of the Martian surface geological materials, but also for studies of the seasonal redistribution of the water ice within a thin surficial layer on the middle and high latitudes outside of the edge of seasonal CO_2 snow mantle.

Table 1. The parameters used for calculations of the TI $_{(soil+ice)}$ at different T.

Temperature,K	c(dry), J/kgK	c(ice), J/kg°C	κ(ice), W/mK	ρ(ice), kg/m^3
180	836	1390.9	3.2	927.3
200	836	1553	2.9	925
220	836	1702.9	2.7	923.3

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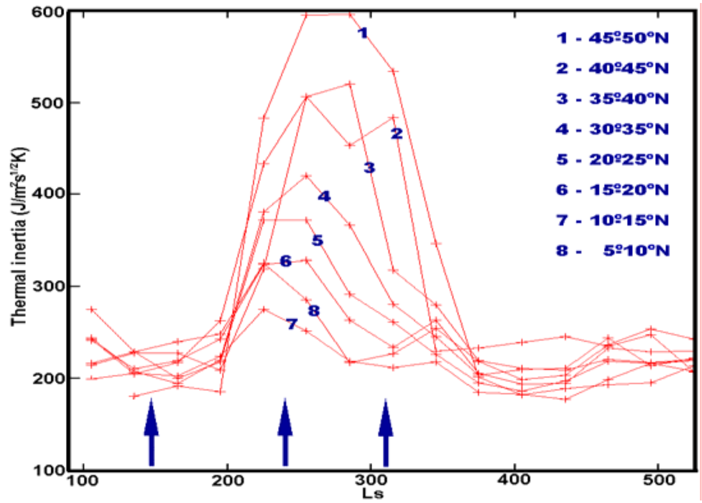
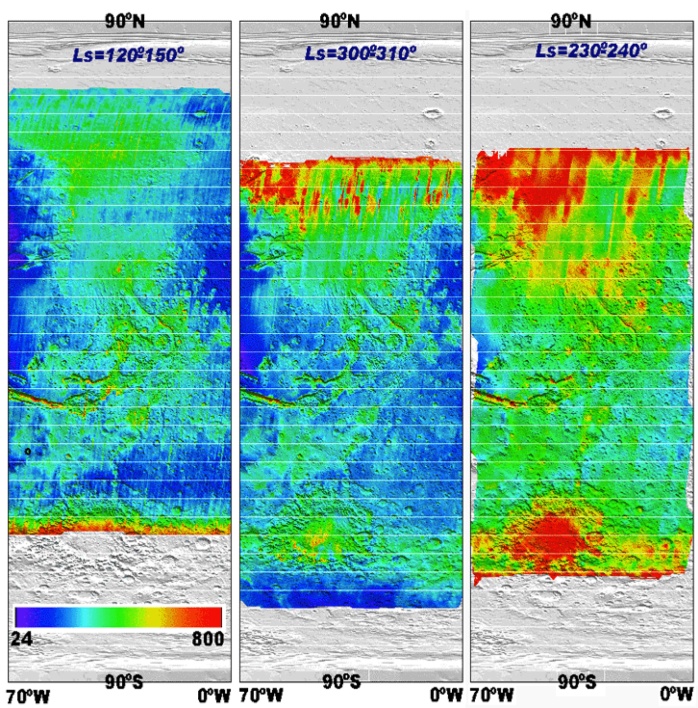


Fig.1. Seasonal change of the TI value in the eight regions with the same TI value (~200 J/m^{2}s$^{1/2}$K) and located on different latitudes of Mars. Arrows show the season's "window" selected for TI mapping.



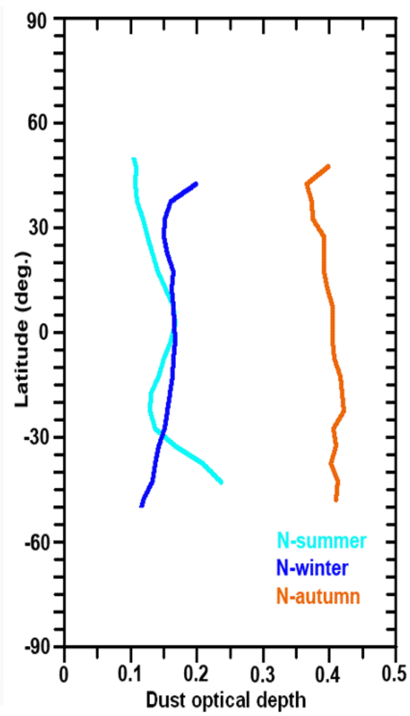


Fig.2.*(Left)* TES TI maps compiled for different seasons (see text): N-summer (left); N-winter (central); N-autumn (right).
Fig.3. (*Right*) The TES dust optical depth (at 1075 cm^{-1}, scaled to a 6.1-mbar surface) as function of the latitudes for different seasons. The data are from [6].

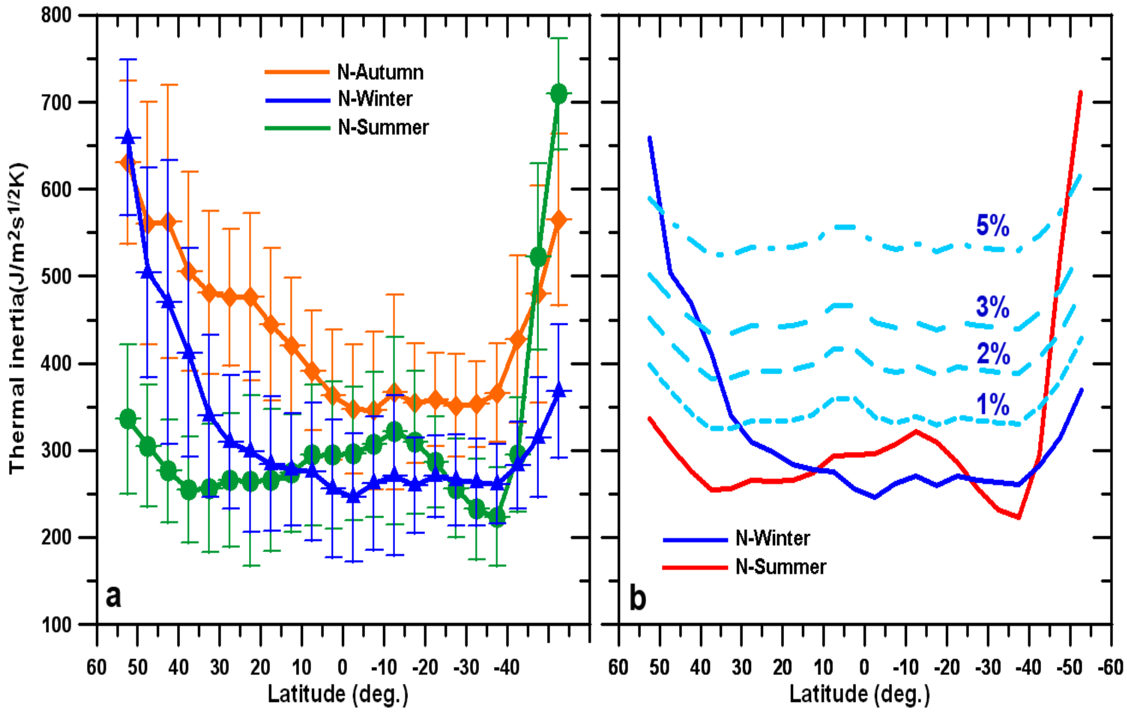


Fig.4. Zonally averaged (in the 5°belt) meridian distribution of the TI values for different seasons (a) and comparison of the summer- and winter-time TI values with computed the TI values of the icy soil (b) with different ice content (dotted lines). Vertical bars represent the standard deviation.

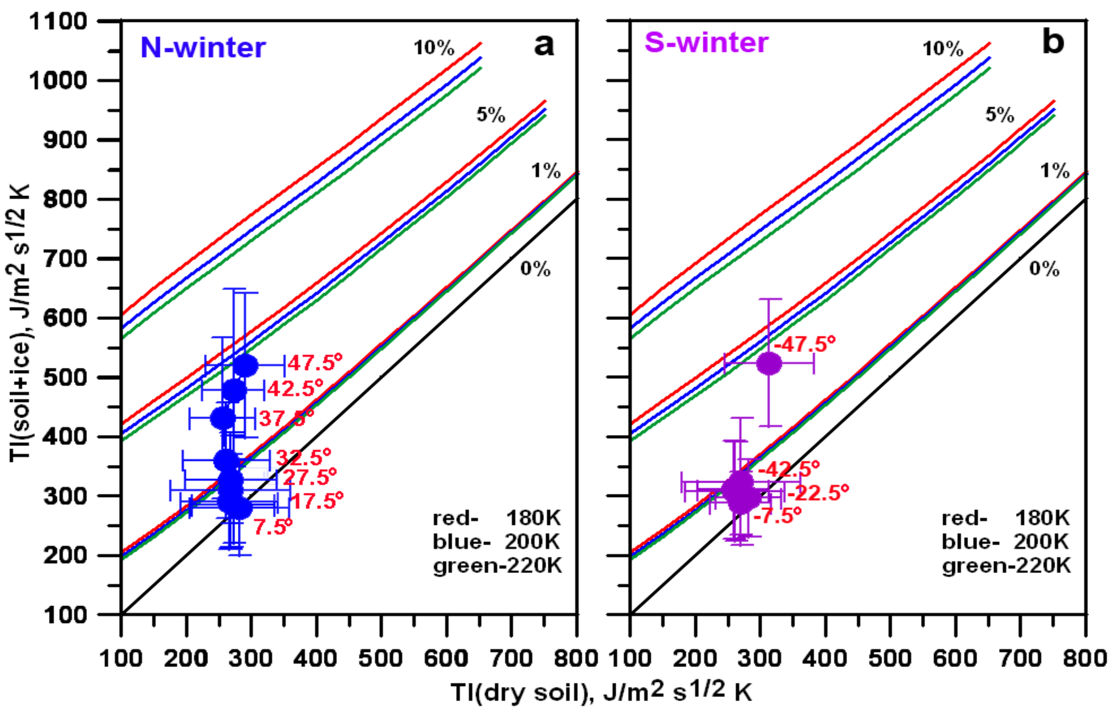


Fig.5. Nomograms for the TI $_{\text{dry soil}}$ and TI $_{\text{icy soil}}$ values at different soil ice content with plotted relationship between zonally averaged summer-time and winter-time the TI values in Northern (a) and Southern (b) hemispheres of Mars. Vertical and horizontal bars represent the standard deviation. Red numbers indicates the latitude.