Near-Surface Ice Likely Cause of Thermal Anomaly in Martian North Polar Erg

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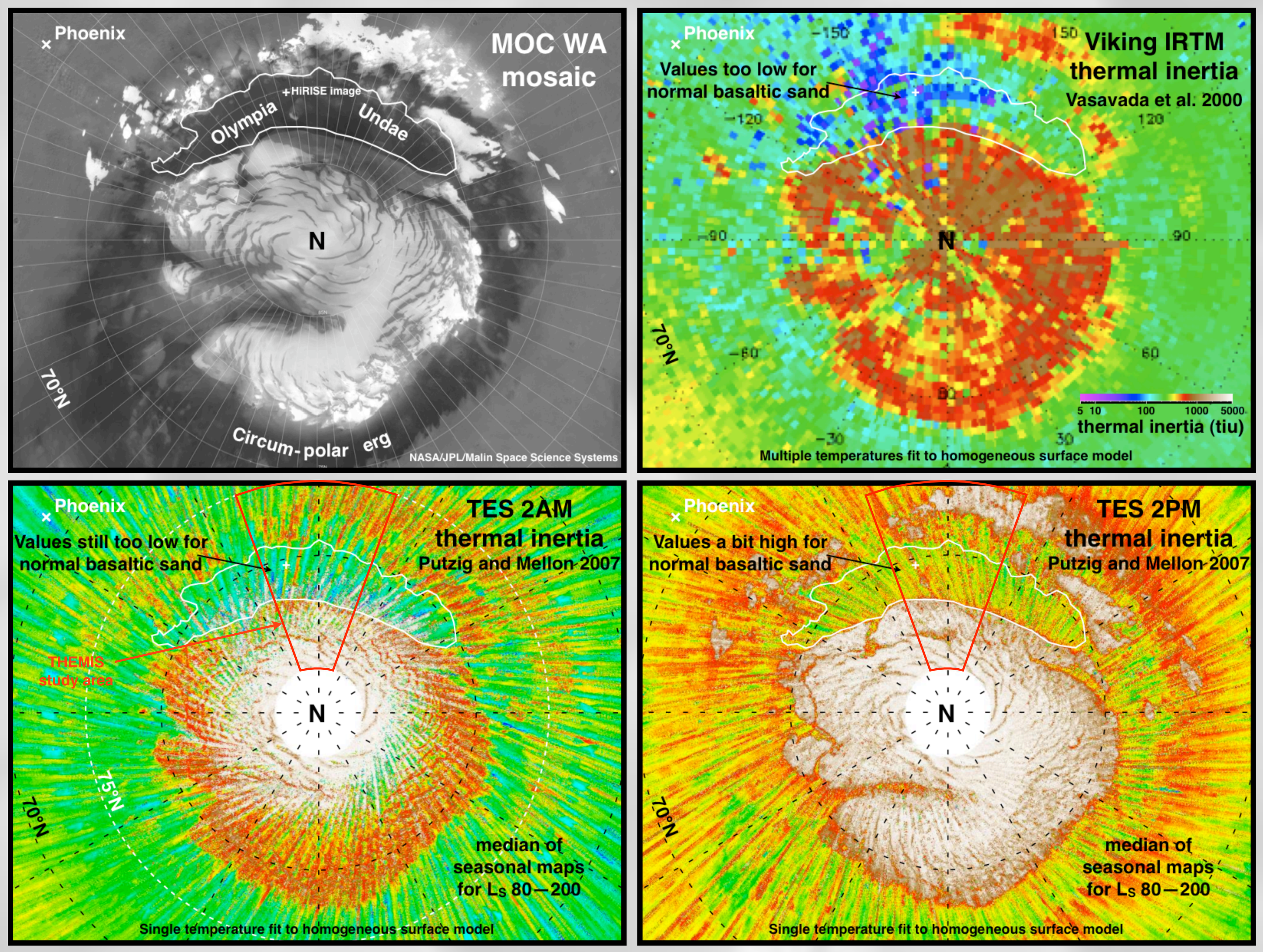
Synopsis:

Previous investigations of Mars' north polar erg report values of thermal inertia much lower than expected for typical dune-forming sand. To account for the thermal anomaly, sand-sized agglomerations of dust were proposed as the primary constituent of the erg. Here, we use a wider range of thermal observations and conduct forward modeling of heterogeneity to find that near-surface layering of normal basaltic sand over shallow ground ice is sufficient to explain the thermal behavior of the erg, obviating the need to invoke more exotic materials.

Background:

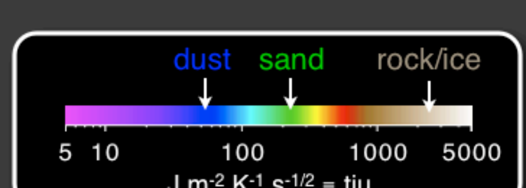
The icy north polar layered deposits, likely the result of cyclical climate variations [1,2], are surrounded by a dark annulus of dunes known as the circum-polar erg. Neutron data indicate that water ice is also present within a meter of the erg's surface [3], providing an additional constraint on climate.

Dunes of similar morphology, color, and albedo at lower latitudes [4] have thermal inertia (~250 tiu [J m^{-2} K^{-1} $s^{-1/2}$]) consistent with sand-sized basaltic grains [5,6,7]. In the erg, much lower values (~75 tiu) that are suggestive of dust-sized grains were reported [8,9]. A widely accepted solution to this thermal discrepancy is bonding of the fines into larger, low-density aggregate particles capable of forming dunes [10,11], perhaps occurring as the dust weathers out of the layered deposits [1,2,11] or from their base [12,13].



Thermal Inertia

$$I \equiv \sqrt{k\rho c}$$



k bulk conductivity - varies by ~ × 1000

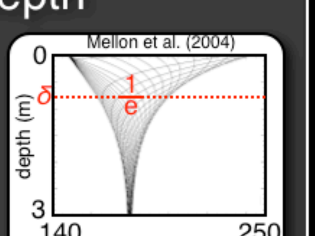
ρc volume heat capacity - varies by ~ × 6

∴ I depends mostly on k

Thermal skin depth

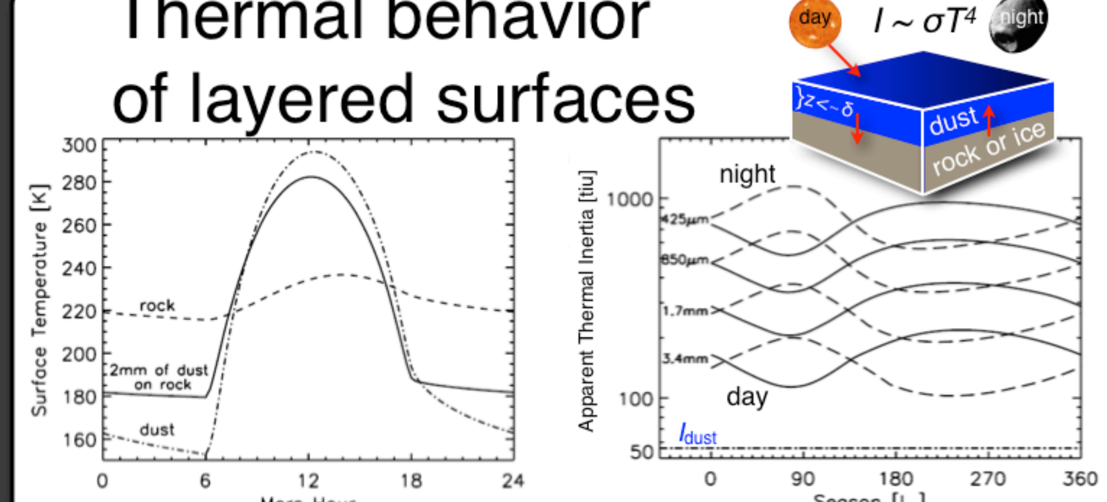
$$\delta \equiv \frac{I}{\rho c}\sqrt{\frac{P}{\pi}}$$

P is period (diurnal or seasonal)



material	δ_{diur} (cm)	δ_{seas} (cm)
dust	0.8	21.2
sand	2.7	70.2
duricrust	9.3	241.3
rock	20.1	520.6

Thermal behavior of layered surfaces

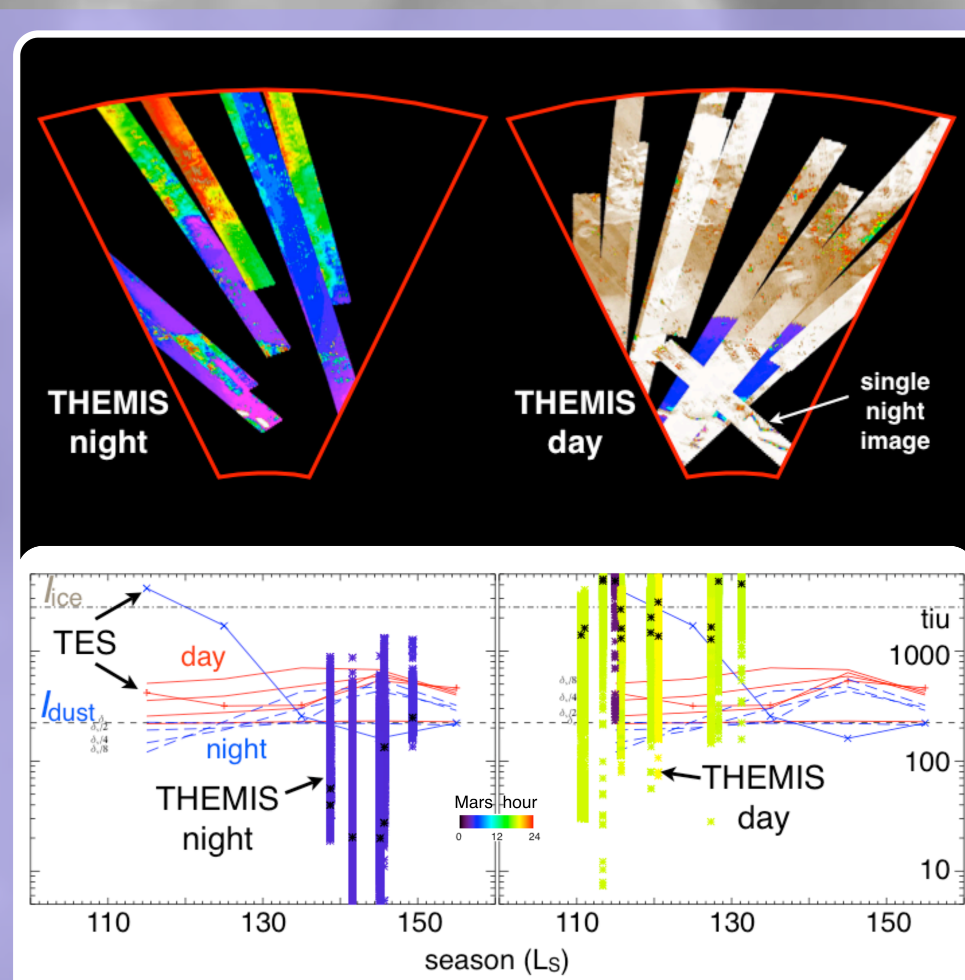


Model diurnal temperature and seasonal thermal inertia (Mellon et al. 2008)

Thermal inertia and heterogeneity:

Modeling studies show that surface heterogeneity may cause anomalous thermal behavior [14,15], allowing an alternative explanation for the thermal properties of the erg. Counterintuitively, certain configurations of near-surface layering may produce apparent thermal inertia (as derived assuming constant properties) substantially lower than the intrinsic thermal inertia of both the surface layer and its substrate [15]. Thus, the polar erg' surface may be ordinary basaltic sand, with its low apparent thermal inertia attributable to an effect of surface heterogeneity due to the presence of an icy substrate.

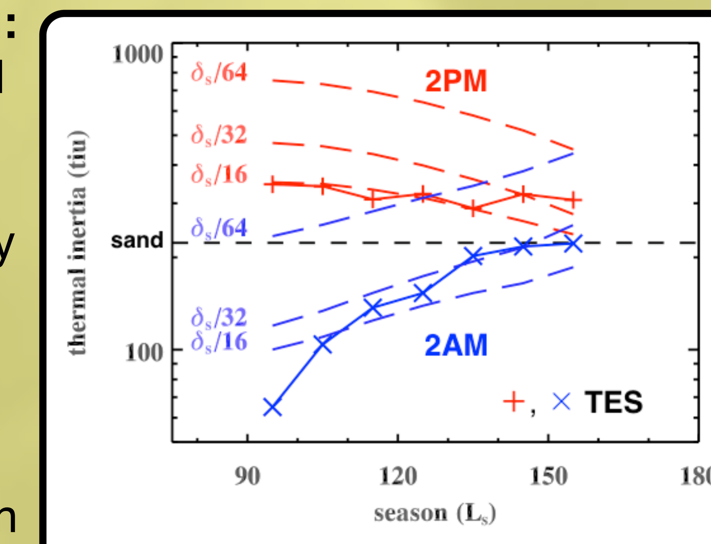
Diurnal and seasonal variations in apparent thermal inertia indicate that heterogeneity is widespread globally, and in the polar region they are broadly consistent with layering [16]. The use of both daytime and nighttime observations is a key element of this analysis, especially near the poles where seasons free of CO_2 ice overlap those when the Sun is predominantly above the horizon.



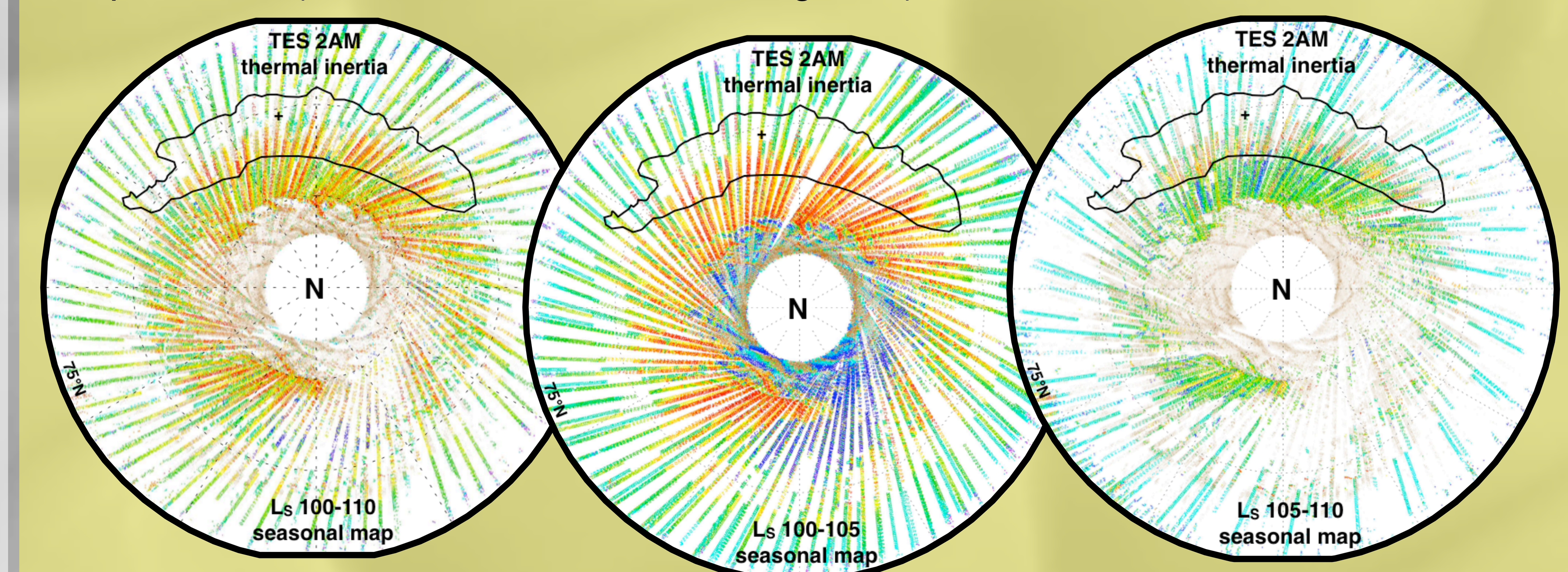
Thermal inertia derived from THEMIS Band 9 for 160°-200°E, 75°-87°N. Thermal-inertia color scale is same as for TES maps. Graphs are for Olympia Undae (center of maps, ~79°-83°N), with values extracted from THEMIS images (✳ symbols, where colors are local time of day and black is median value within each image), median values from TES (×,+ symbols), and results from layered models of sand over ice-cemented soil (solid and dashed colored lines). Large THEMIS image-to-image variations and extreme values relative to TES are not fully explained but may be related to suboptimal observing conditions and larger instrument error, particularly for daytime images.

Heterogeneity at Phoenix and in the polar erg:

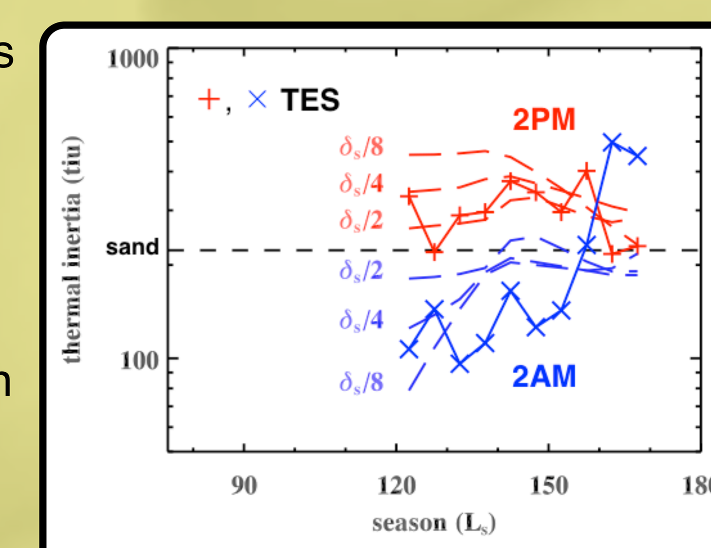
At the Phoenix landing site, seasonal and diurnal variations in apparent thermal inertia as derived from Mars Global Surveyor Thermal Emission Spectrometer (TES) data can be modeled well by ~4-cm of sand overlying ground ice, consistent with the observations made from the lander [17]. When the model sand thickness approaches or exceeds a diurnal skin depth (1/26 of a seasonal skin depth), the 2AM apparent thermal inertia can be substantially less than that of the sand itself. Thus, the thermal inertia (and hence the grain size) of surface materials may be underestimated if one uses annual-mean values fit to diurnal temperatures (i.e., as was done with Viking data).



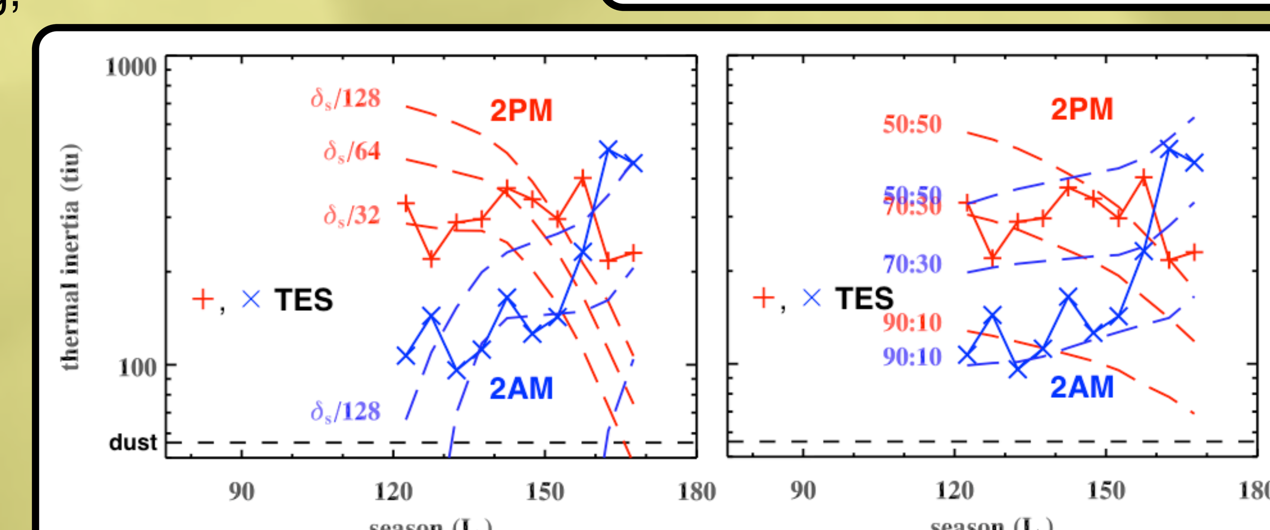
2AM and 2PM seasonal apparent thermal inertia at Phoenix from TES and layered models of sand (223 tiu) overlying ground ice (2506 tiu). Model surface-layer thickness is given in fractional seasonal skin depth, δ_S (70 cm for sand). Best-fit model has ~4 cm of sand. Seasonal range is limited by transient CO_2 frost.



At the higher latitudes of the polar erg, seasons of useful TES data are more restricted than at Phoenix, and season-to-season variations are larger. To resolve the short-term, rapid changes, we remapped the north polar region with a finer seasonal increment of 5° L_S (see maps above). This change allows better discrimination between models for matching to the observed behavior. We found the TES results for the erg to be most consistent with a sand layer of ~15—25 cm, with dust-layer models yielding poorer fits. Between dune crests in the erg, HiRISE images show bright deposits that may be consolidated and thus of higher thermal inertia. However, models of this type (e.g., 70:30 mixture of dust and rock at right) do not adequately capture observed behavior.



Apparent thermal inertia in the polar erg (80°N, 191°E; + in maps) from TES and layered models of sand over ground ice, with best-fit of ~20 cm of sand.



Apparent thermal inertia in the polar erg from TES and layered models of dust (56 tiu) over ground ice (left) and horizontal mixtures of dust and rock (right). Fits are poor relative to the sand-layer models above.

THEMIS thermal inertia in the erg

We investigated the derivation of thermal inertia from THEMIS Band 9 images for the north polar region, using Olympia Undae as our study area. At ~100 m per pixel (cf. TES at ~3 km/px), THEMIS data may allow better discrimination between heterogeneity models. The TES derivation algorithm [18] was previously modified for use in deriving thermal inertia from THEMIS data [19], and we updated it further to include recent TES improvements [16]. We then processed a selection of THEMIS images to produce thermal inertia.

Nighttime and daytime THEMIS coverage in Olympia Undae have little seasonal overlap (see graphs at left). Our nighttime results show a pattern of high and low values in the erg and its surroundings that is grossly similar to that of TES 2AM maps, but the THEMIS median values are typically much lower. In contrast, our daytime results show dramatically higher values of thermal inertia. These images may have been affected by partial CO_2-frost cover on the ground at these earlier seasons.

The sub-optimal seasonal coverage makes it difficult to incorporate daytime results into our analysis at this time. Since THEMIS continues to acquire images (now at times of day more favorable for thermal analysis), we hope to eventually obtain broader seasonal coverage. We are also considering an extension of the THEMIS study to other sites within the north polar erg.

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