Thermal Effects of Physical Heterogeneity in Olympia Undae

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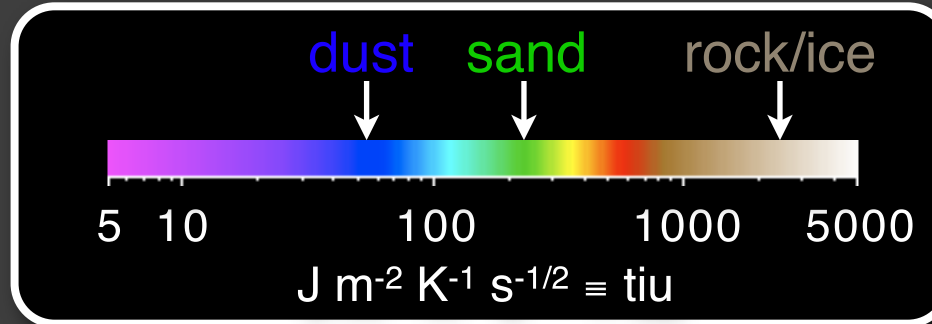
Outline:

- Thermal inertia in a nutshell
- The Viking thermal anomaly
- Layers, mixtures, and slopes
- THEMIS data

Thermal Inertia

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



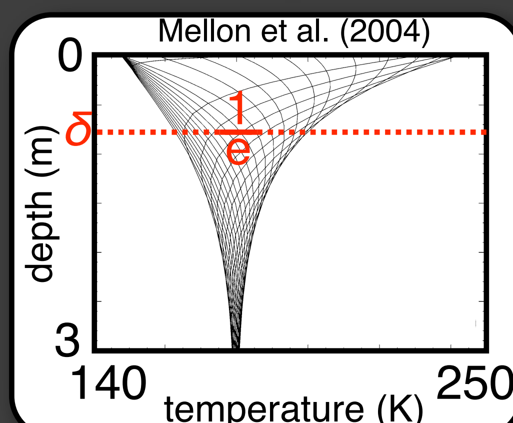
k	bulk conductivity	- varies by ~ × 1000
ρc	volume heat capacity	- varies by ~ × 6

⇒ On Mars, I depends mostly on k

Thermal skin depth

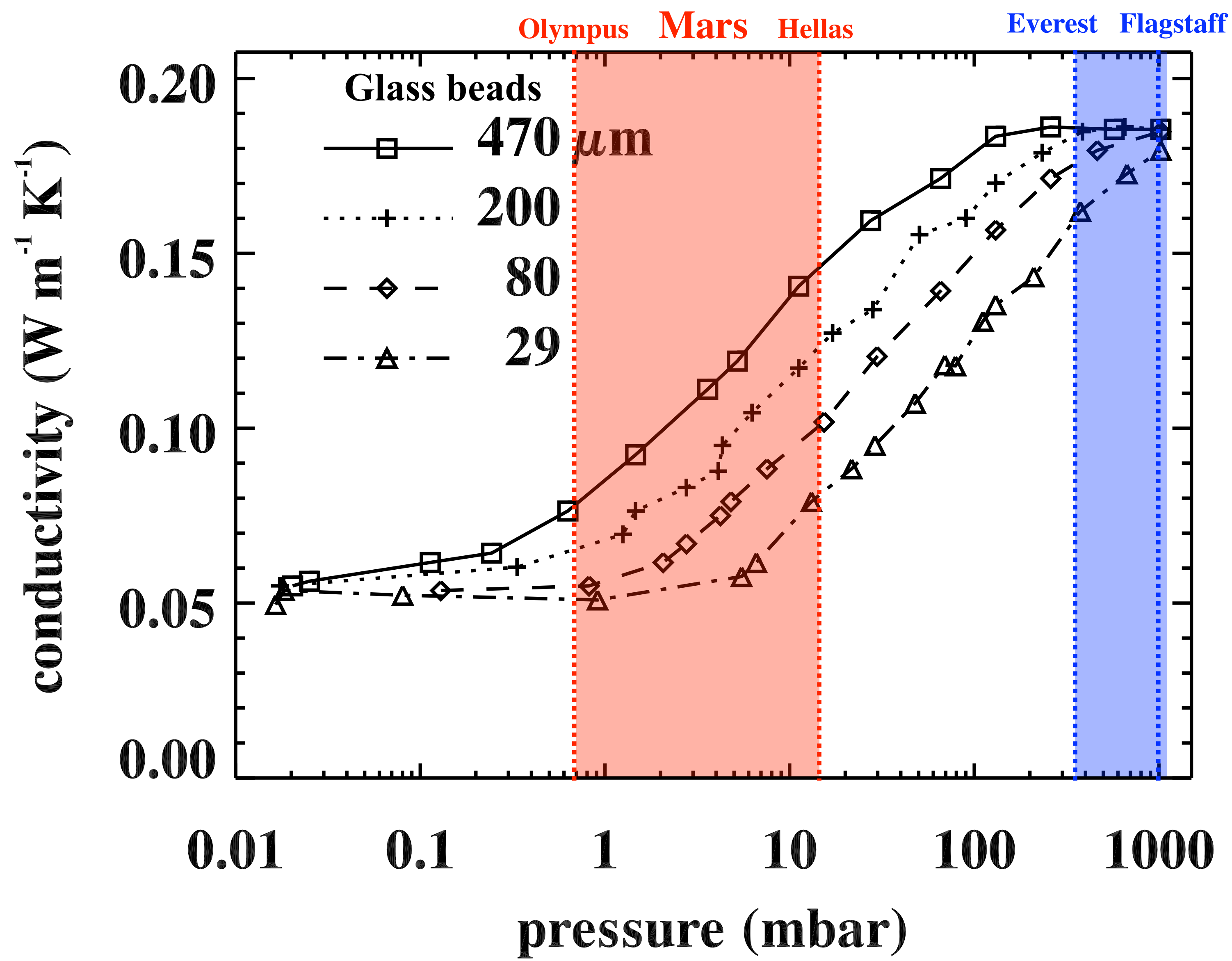
$$\delta \equiv \frac{I}{\rho c}\sqrt{\frac{P}{\pi}}$$

P is period (diurnal or seasonal)



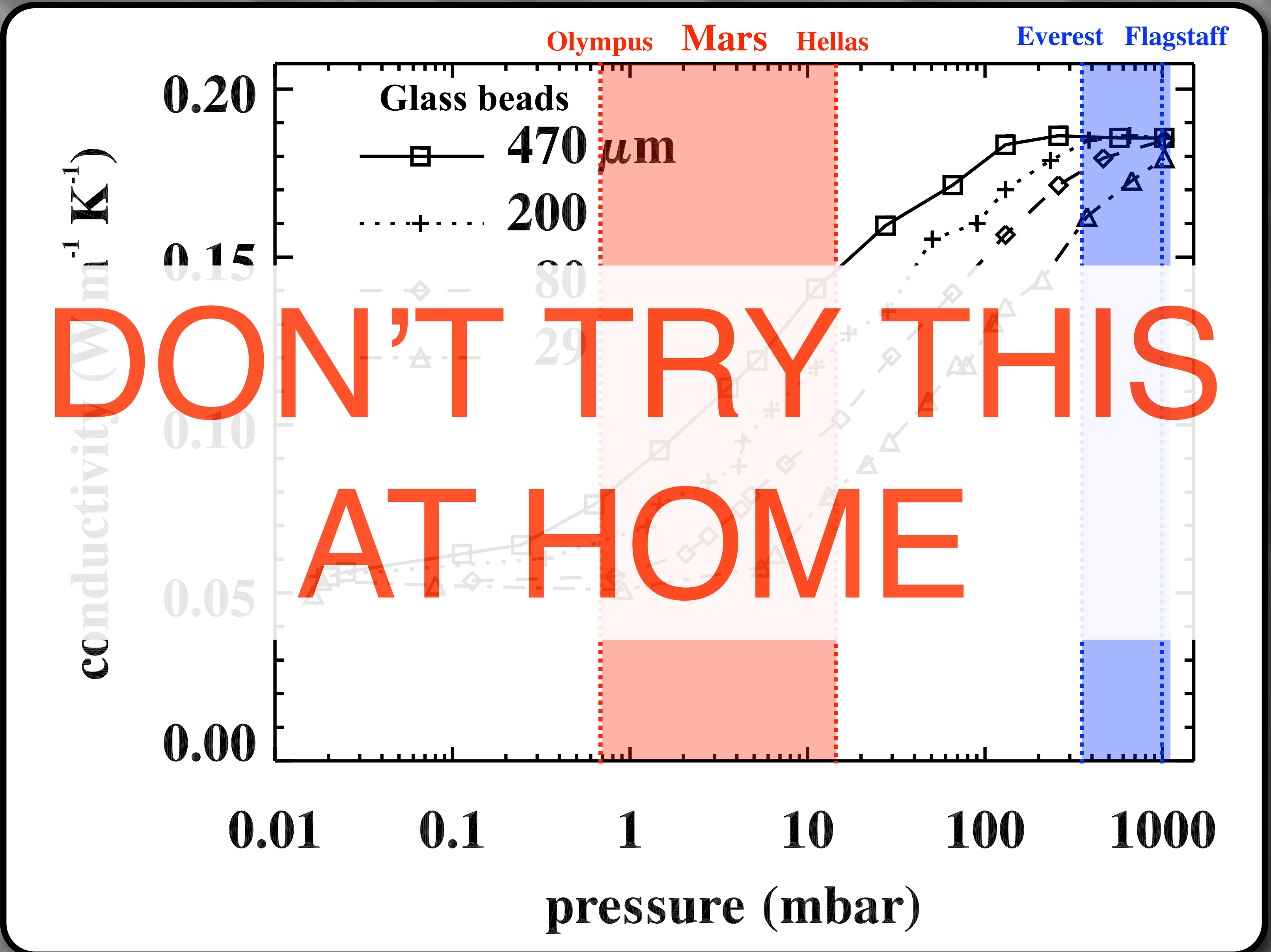
material	δ_{diur} (cm)	δ_{seas} (cm)
dust	0.8	21.2
sand	2.7	70.2
crust	9.3	241.3
rock	20.1	520.6

Conductivity, pressure, & grain size



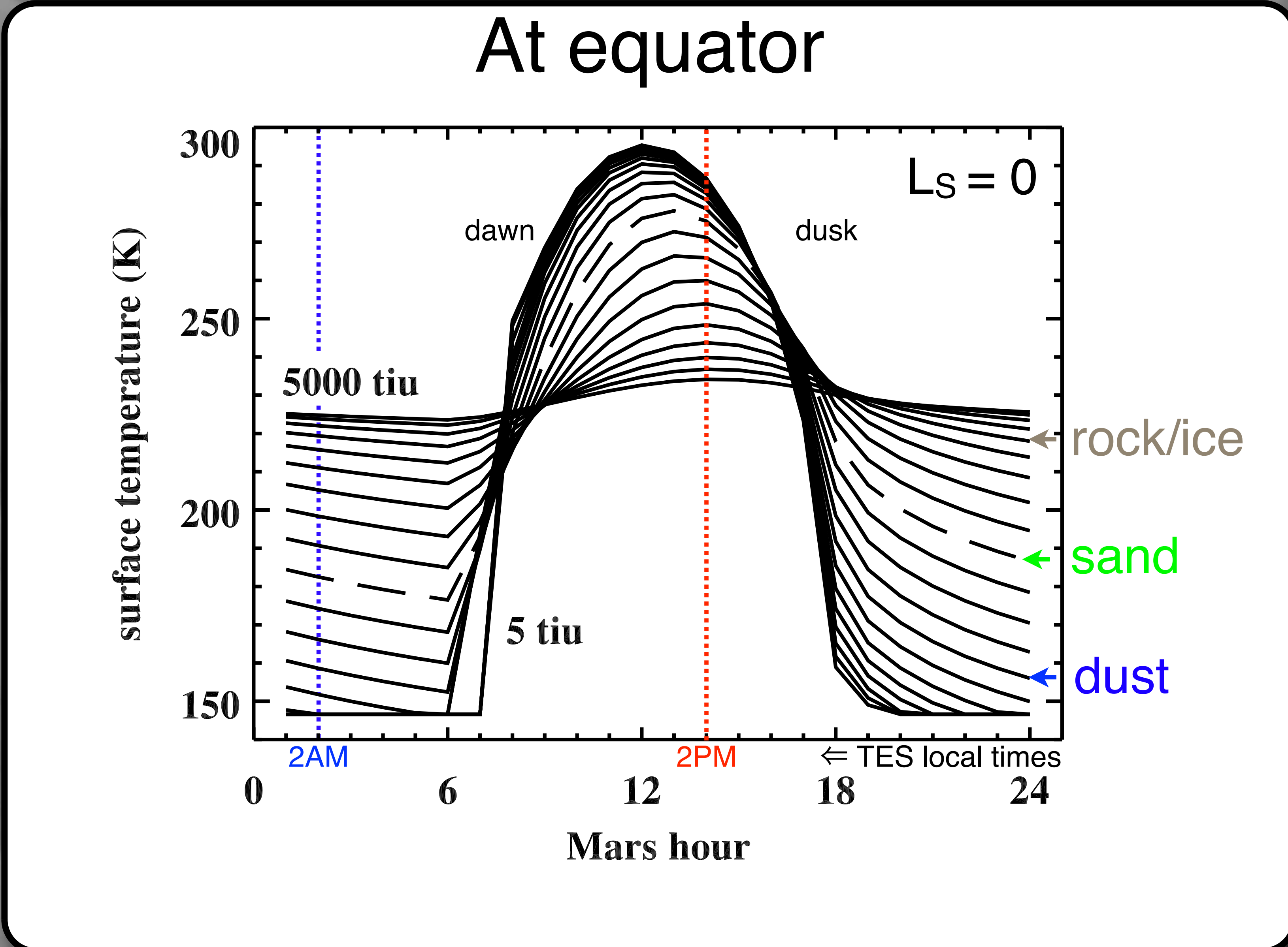
Laboratory data from Masamune and Smith (1963)

Conductivity, pressure, & grain size



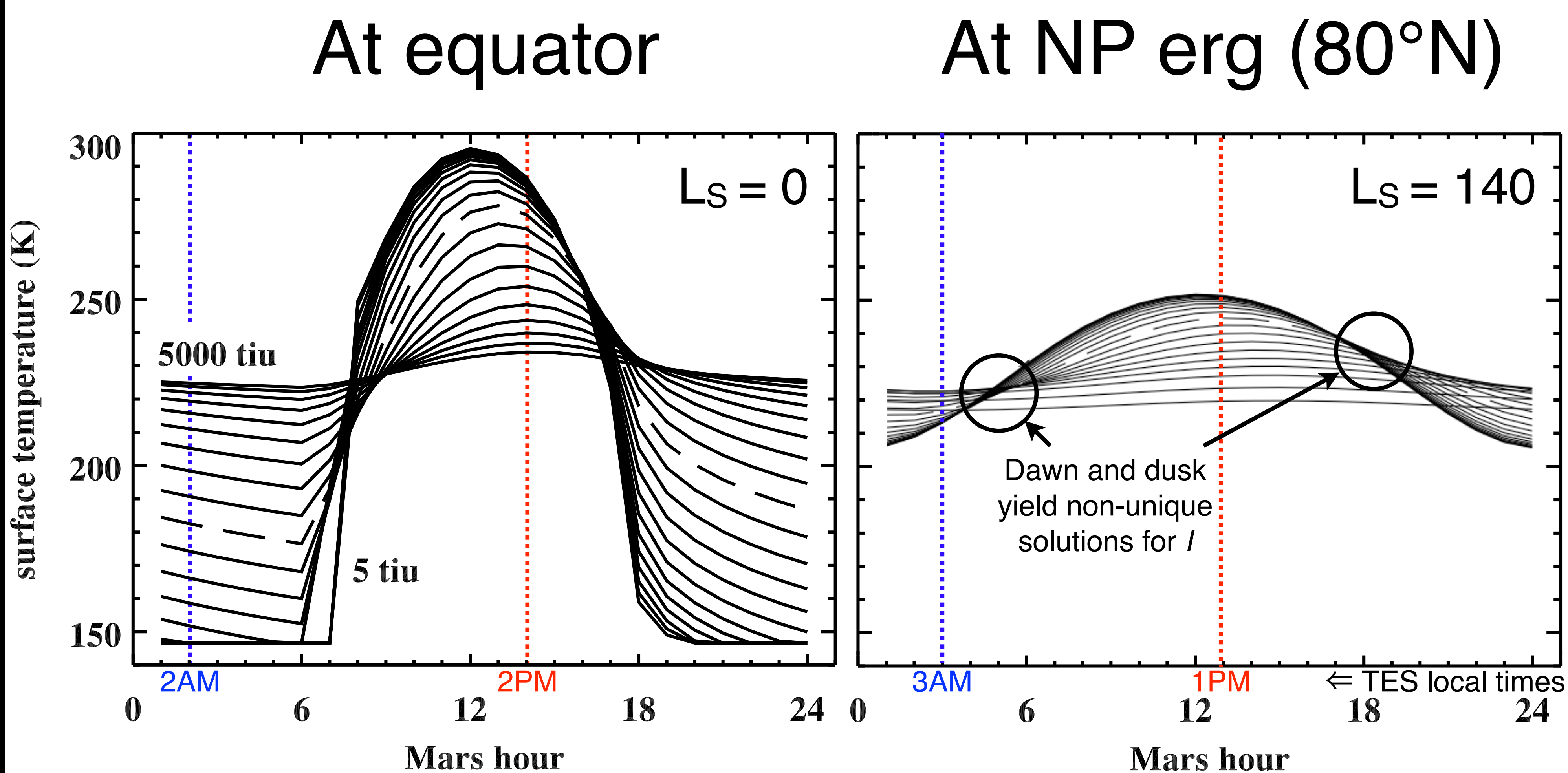
Laboratory data from Masamune and Smith (1963)

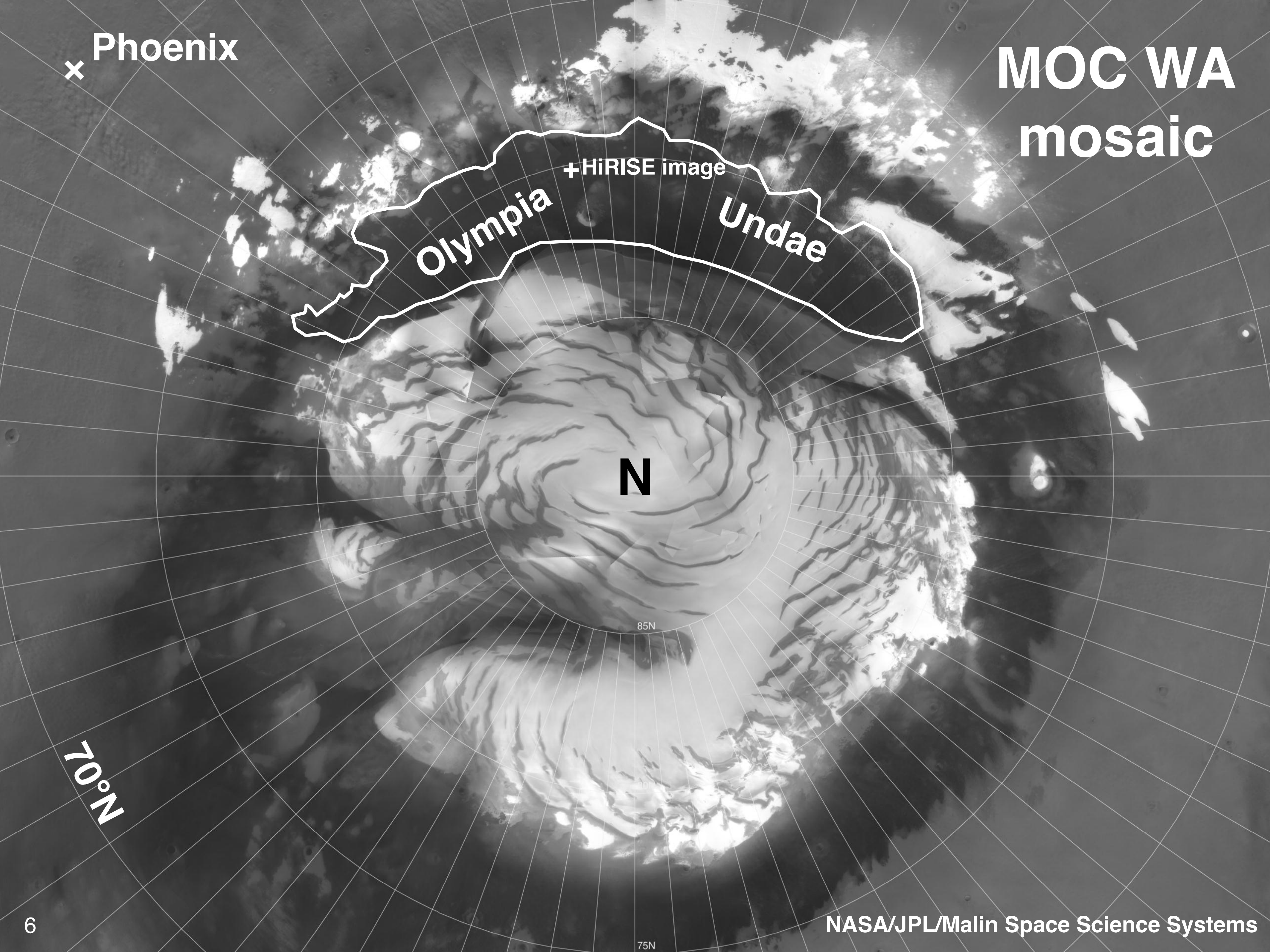
Modeled diurnal temperatures



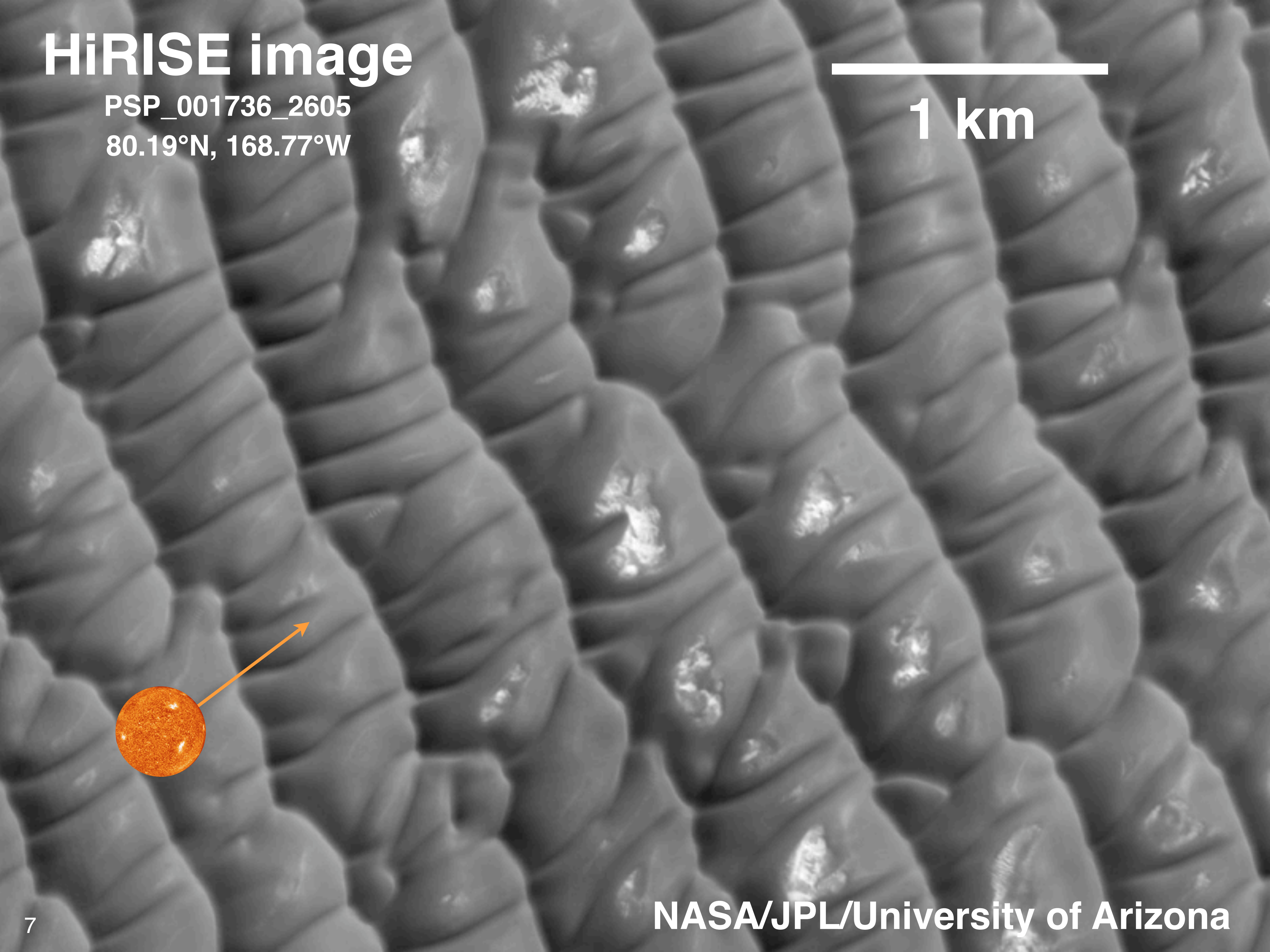
Putzig (2006)

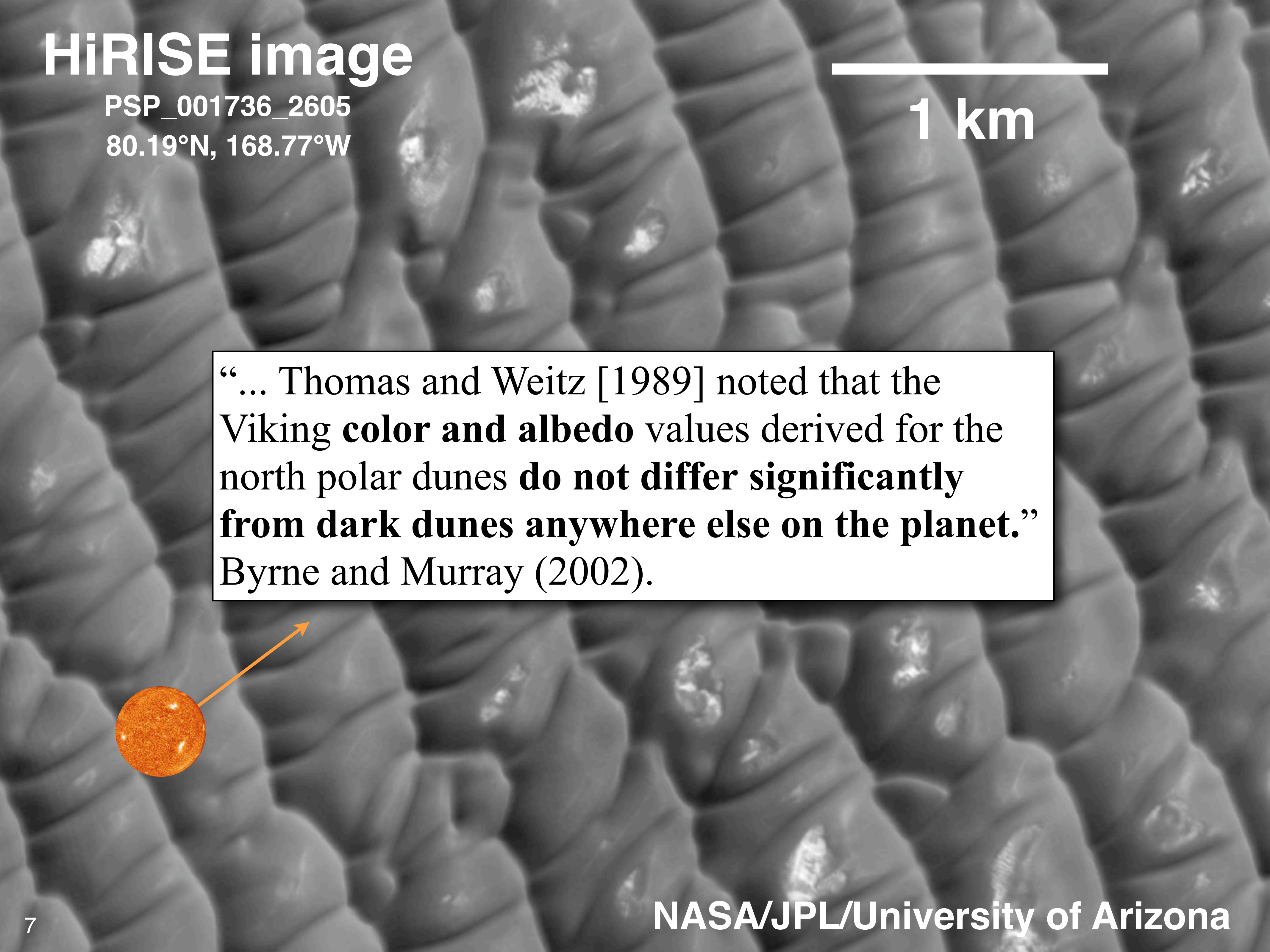
Modeled diurnal temperatures

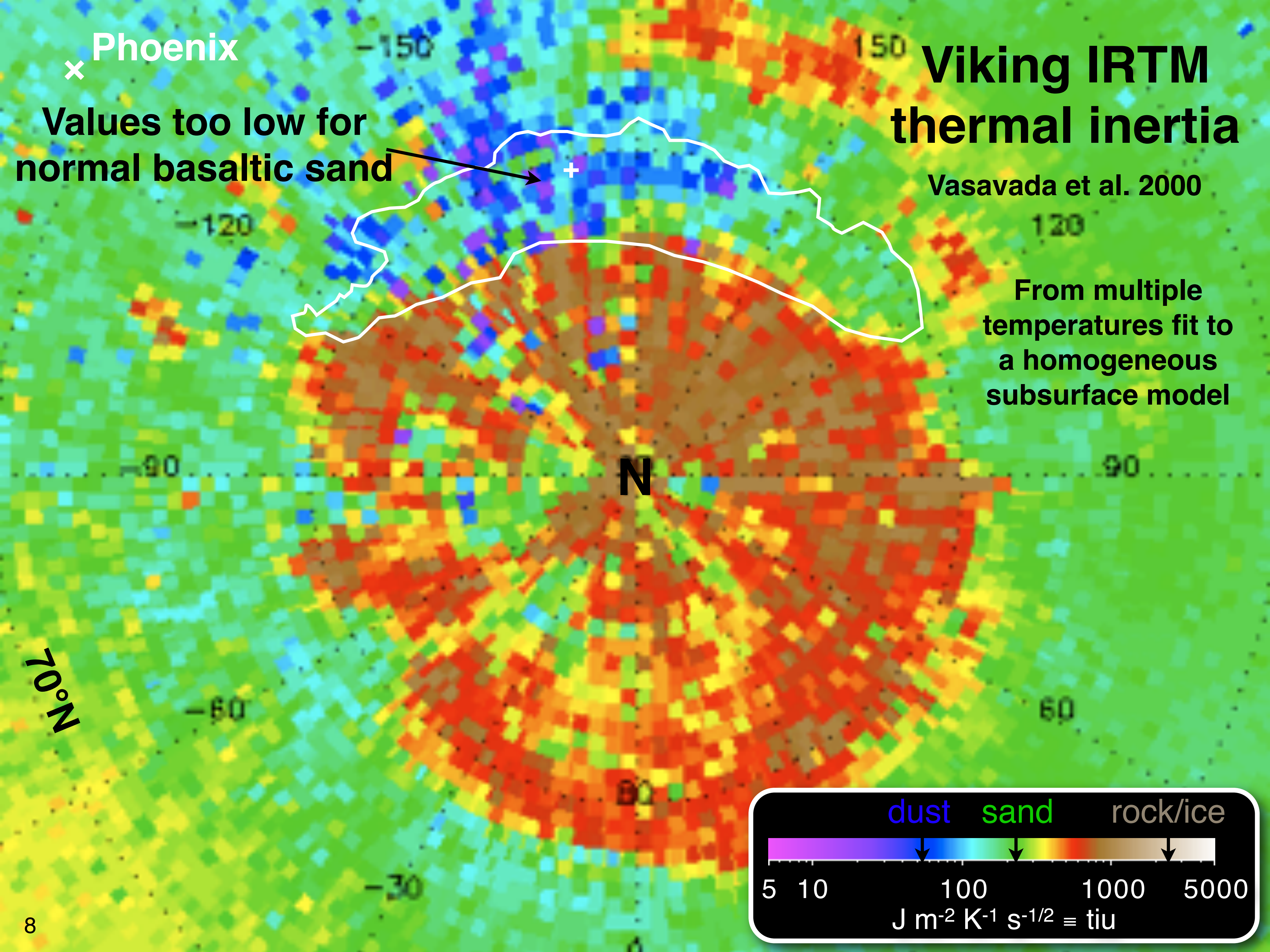




Phoenix
MOC WA mosaic
HiRISE image
Olympia
Undae
N
85N
70°N
75N
NASA/JPL/Malin Space Science Systems

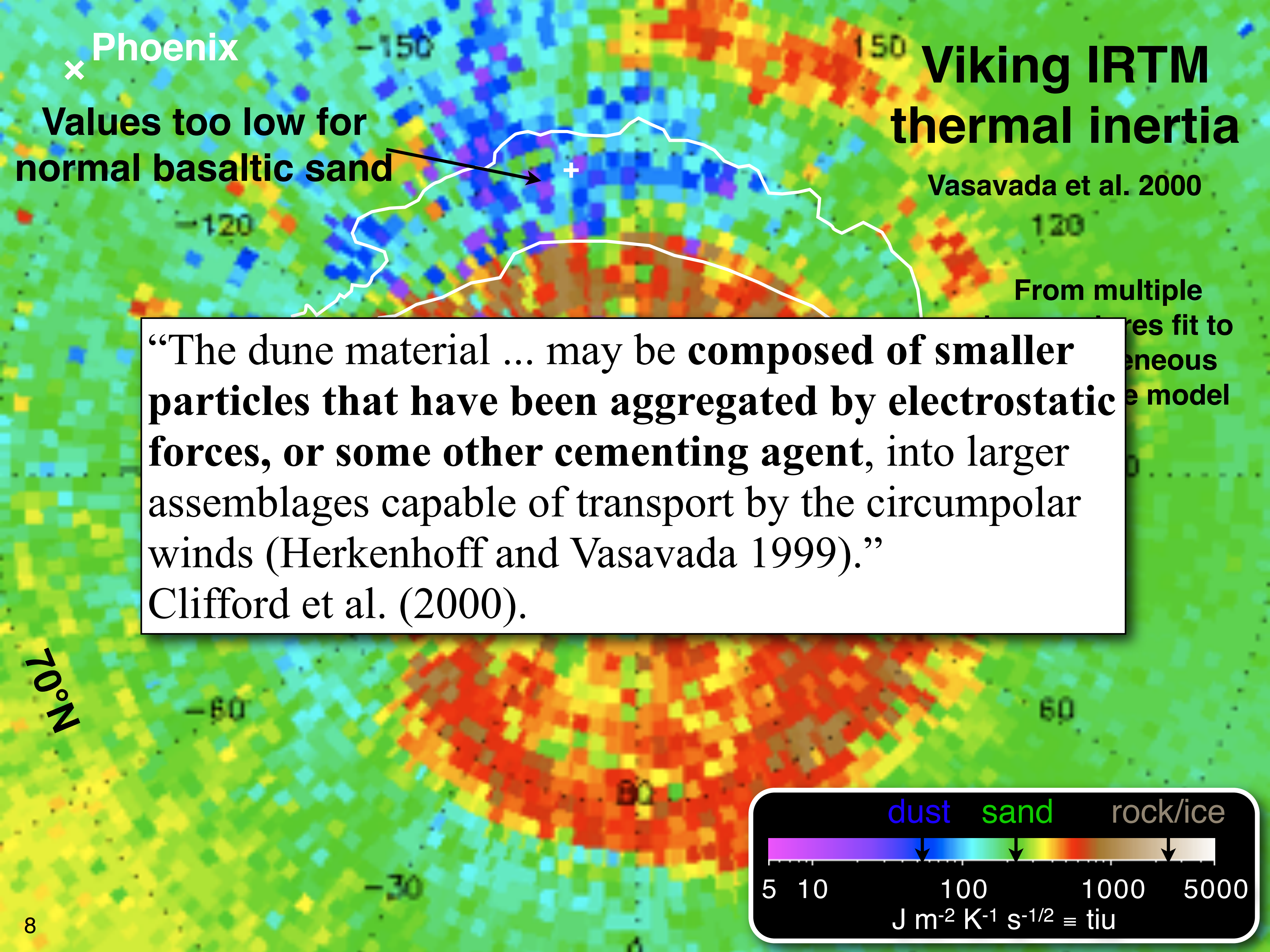

HiRISE image
PSP_001736_2605
80.19°N, 168.77°W
1 km
NASA/JPL/University of Arizona


HiRISE image
PSP_001736_2605
80.19°N, 168.77°W
1 km
“... Thomas and Weitz [1989] noted that the Viking **color and albedo** values derived for the north polar dunes **do not differ significantly from dark dunes anywhere else on the planet.**” Byrne and Murray (2002).
NASA/JPL/University of Arizona

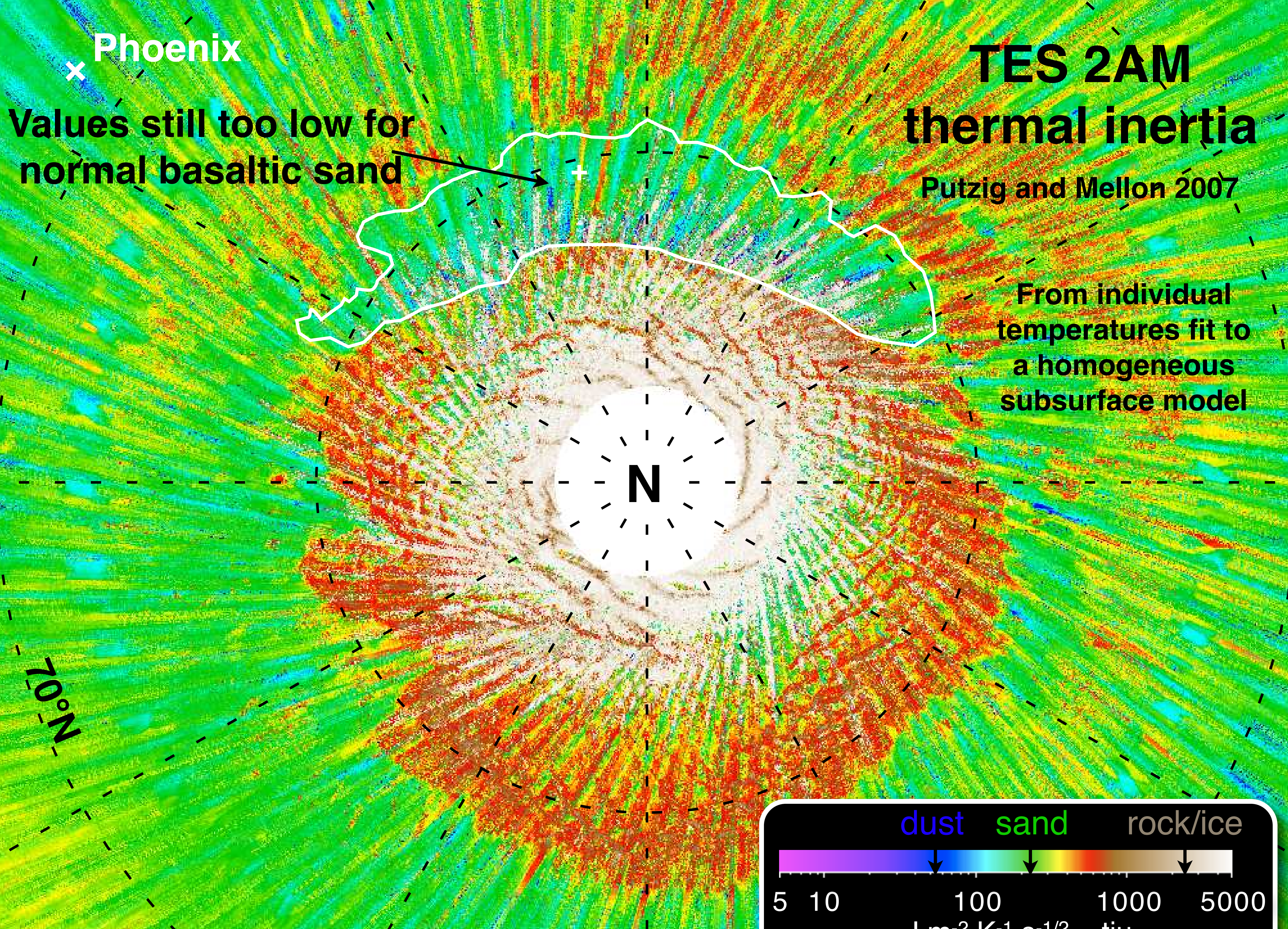

Phoenix
Values too low for normal basaltic sand
Viking IRTM thermal inertia
Vasavada et al. 2000
From multiple temperatures fit to a homogeneous subsurface model
-150
150
-120
120
-90
90
N
-60
60
70°N
-30
dust
sand
rock/ice
5 10
100
1000
5000
J m-2 K-1 s-1/2 ≡ tiu

Viking IRTM thermal inertia

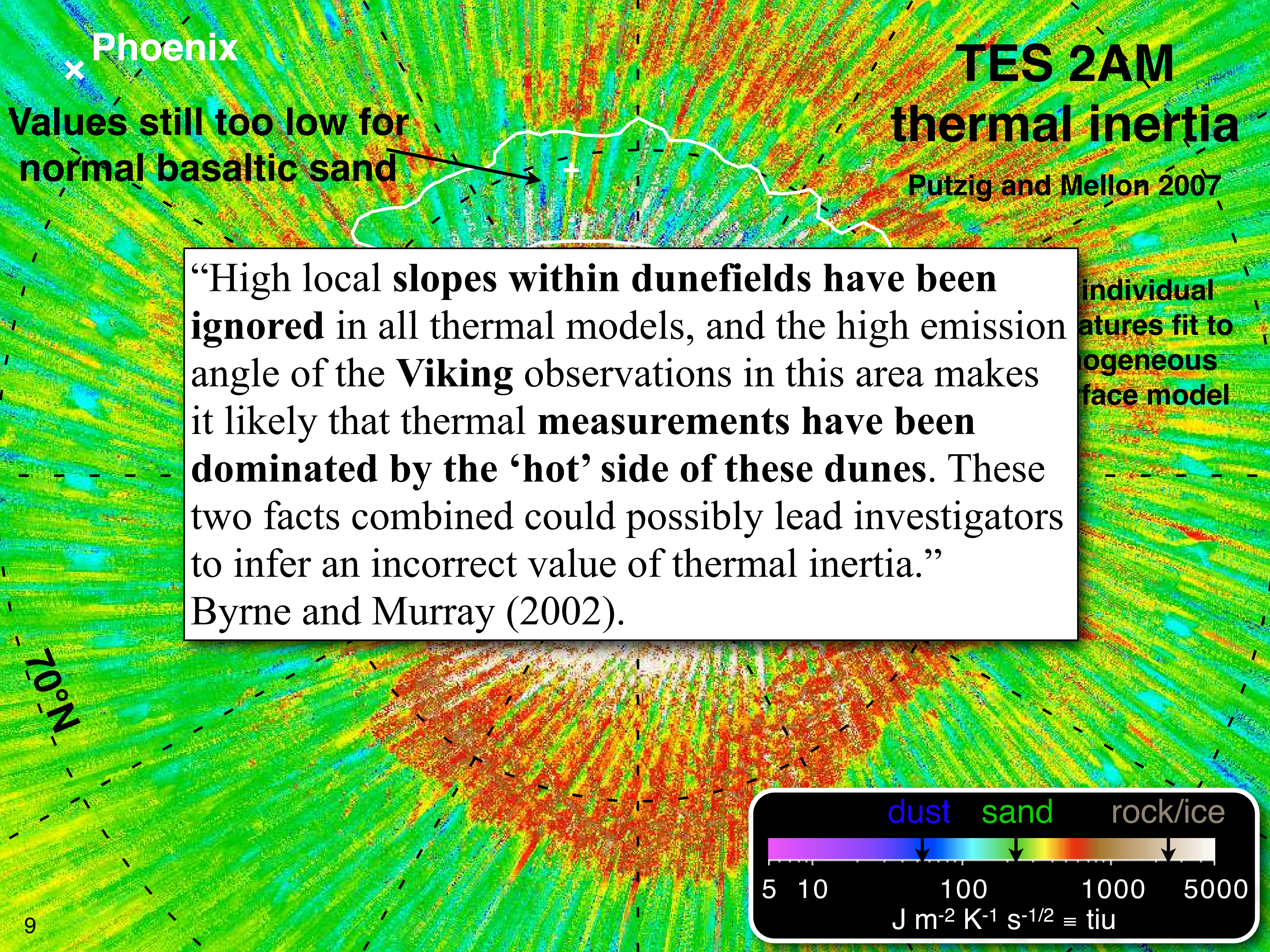
Vasavada et al. 2000



"The dune material ... may be **composed of smaller particles that have been aggregated by electrostatic forces, or some other cementing agent**, into larger assemblages capable of transport by the circumpolar winds (Herkenhoff and Vasavada 1999)."
Clifford et al. (2000).



Phoenix
Values still too low for normal basaltic sand
TES 2AM thermal inertia
Putzig and Mellon 2007
From individual temperatures fit to a homogeneous subsurface model
N
70°N
dust
sand
rock/ice
5 10 100 1000 5000
J m-2 K-1 s-1/2 ≡ tiu



"High local **slopes within dunefields have been ignored** in all thermal models, and the high emission angle of the **Viking** observations in this area makes it likely that thermal **measurements have been dominated by the 'hot' side of these dunes**. These two facts combined could possibly lead investigators to infer an incorrect value of thermal inertia."
Byrne and Murray (2002).

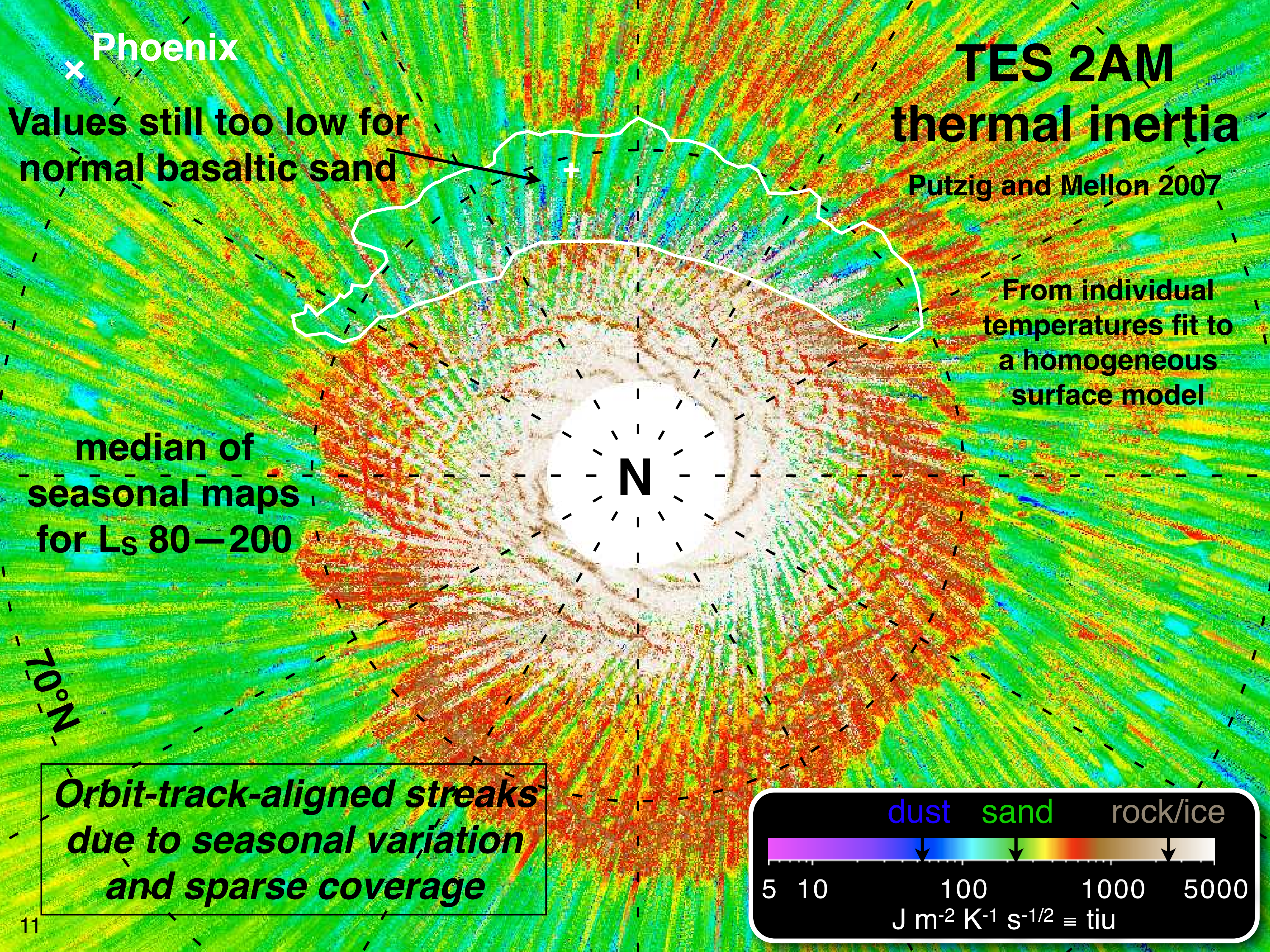
Alternative explanation

Derivation methods are too simplistic, so inferred grain size is incorrect. Material may actually be normal sand.

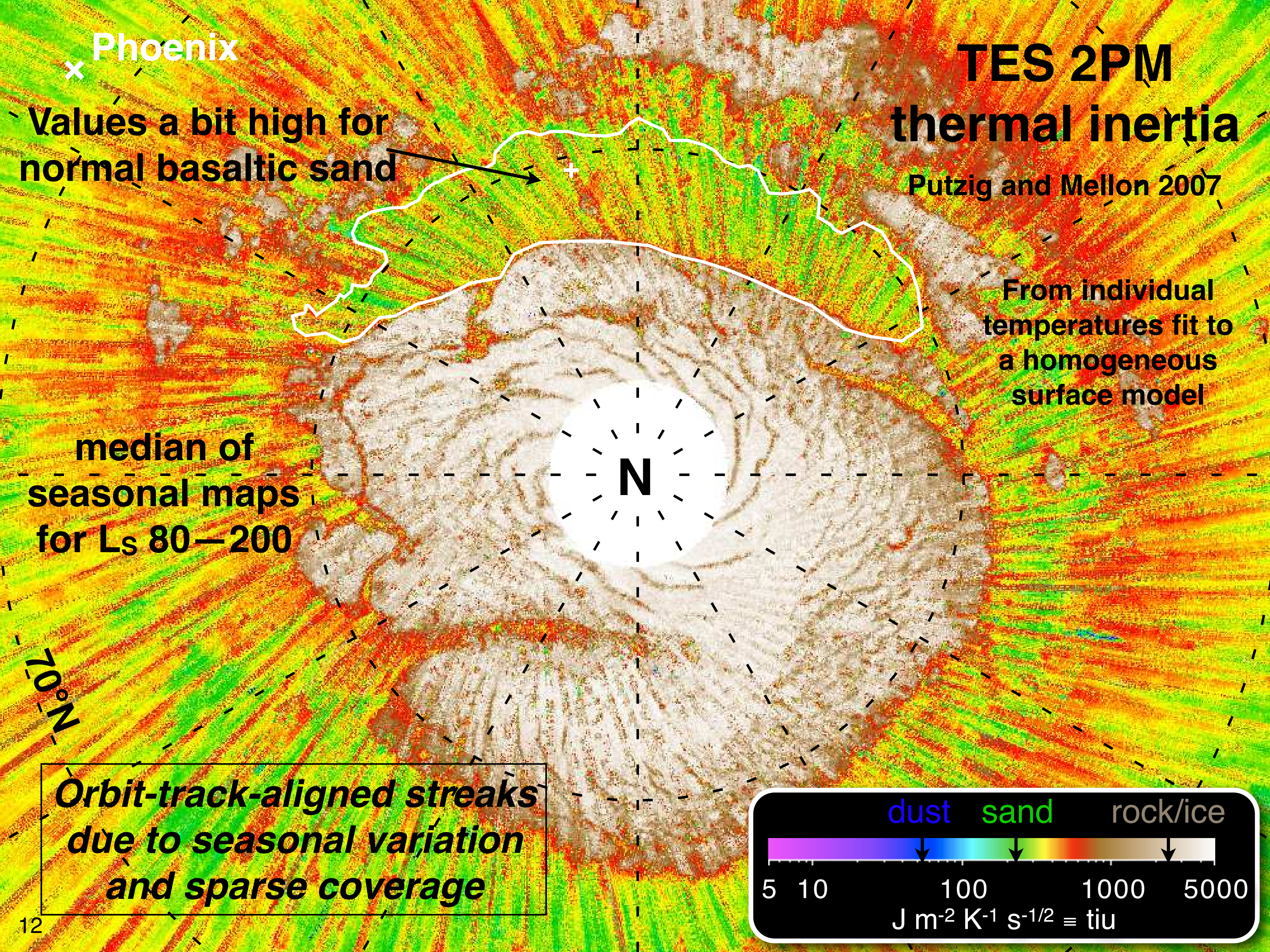
Models typically assume homogeneity within the instrument footprint (3 km for TES), ignoring:

- near-surface layering
- horizontal mixtures of materials
- slope effects

Viking multi-point derivation and TES night-only analysis obfuscates the effects of heterogeneity.



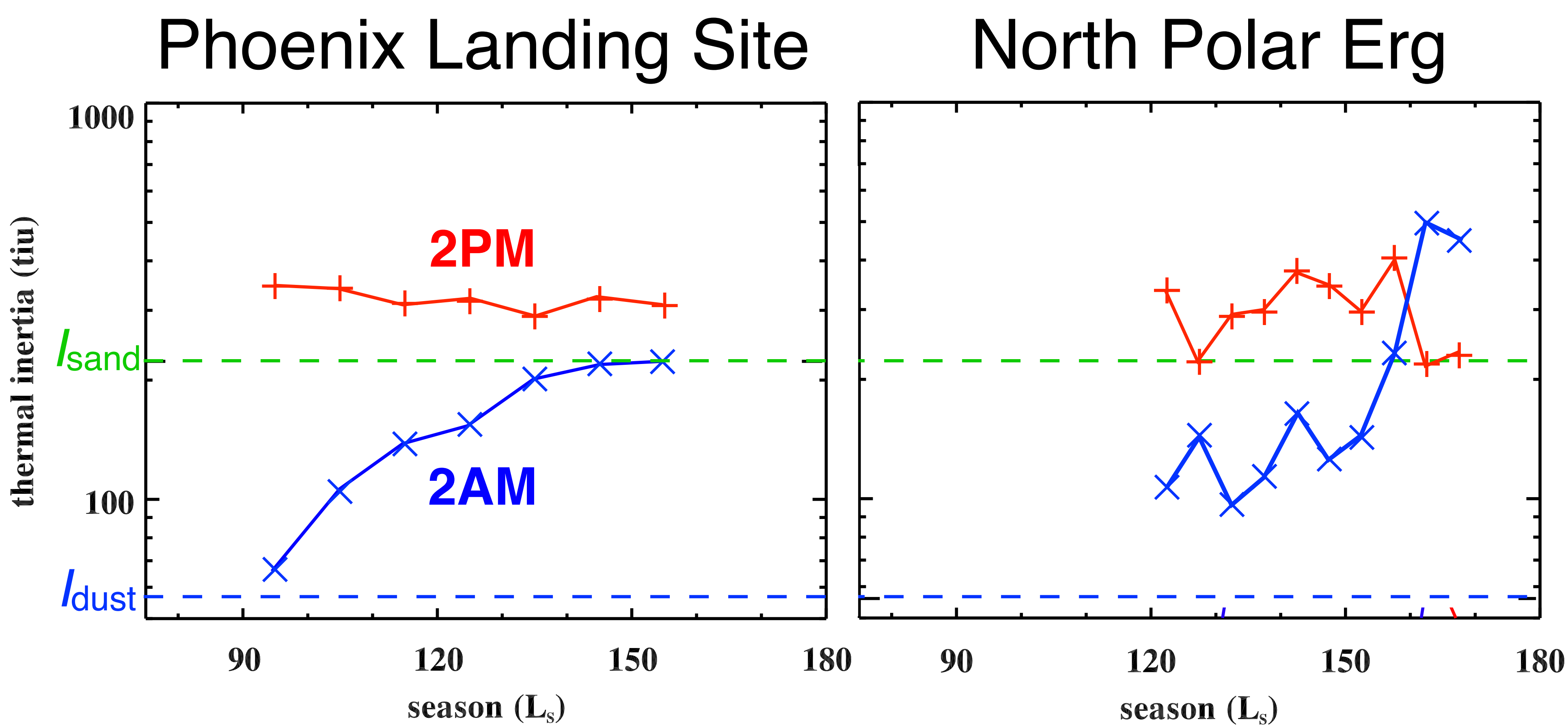
Phoenix
TES 2AM thermal inertia
Putzig and Mellon 2007
Values still too low for normal basaltic sand
From individual temperatures fit to a homogeneous surface model
median of seasonal maps for Ls 80—200
N
70°N
Orbit-track-aligned streaks due to seasonal variation and sparse coverage
dust
sand
rock/ice
5 10 100 1000 5000
J m-2 K-1 s-1/2 ≡ tiu



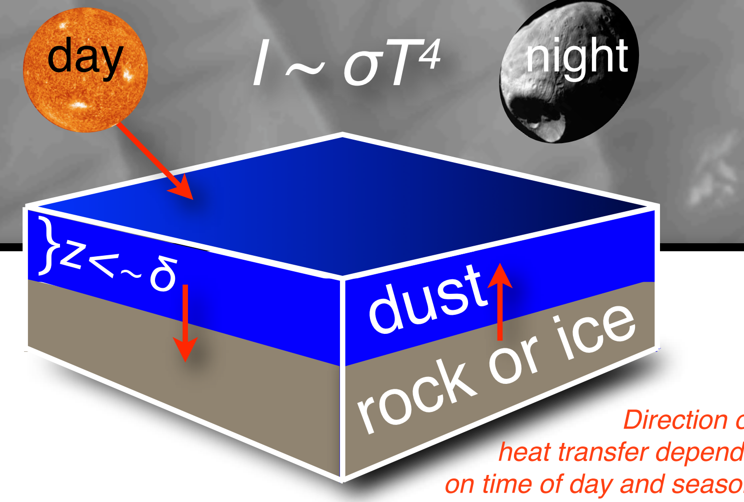
Phoenix
Values a bit high for normal basaltic sand
TES 2PM thermal inertia
Putzig and Mellon 2007
From individual temperatures fit to a homogeneous surface model
median of seasonal maps for Ls 80—200
N
70°N
Orbit-track-aligned streaks due to seasonal variation and sparse coverage
dust
sand
rock/ice
5 10 100 1000 5000
J m-2 K-1 s-1/2 ≡ tiu

Seasonal variation of TES thermal inertia

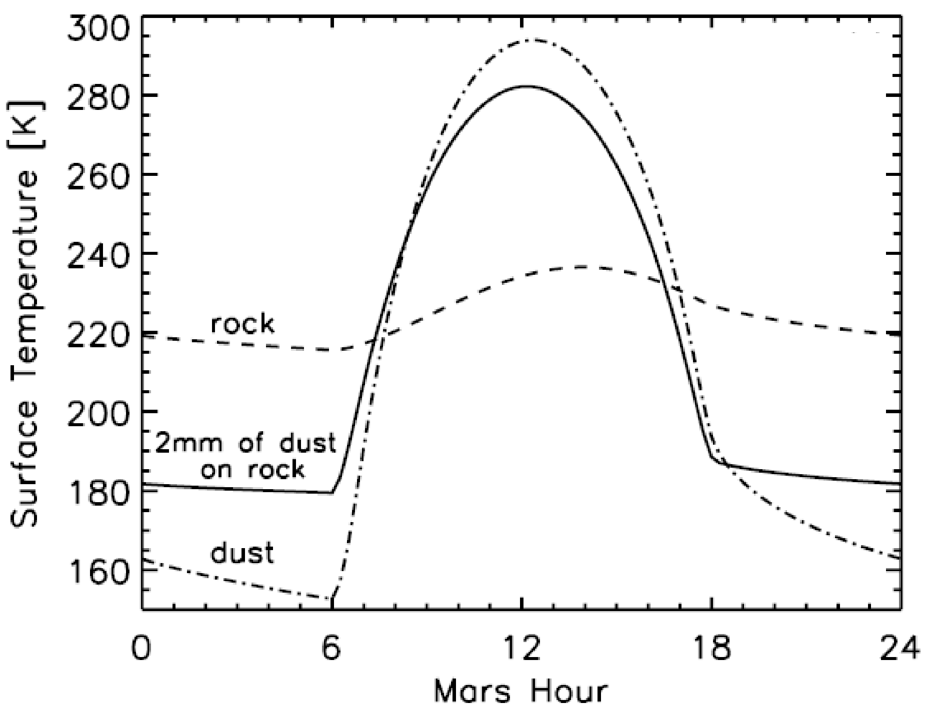
Seasonal ranges are limited by seasonal CO_2 deposits.

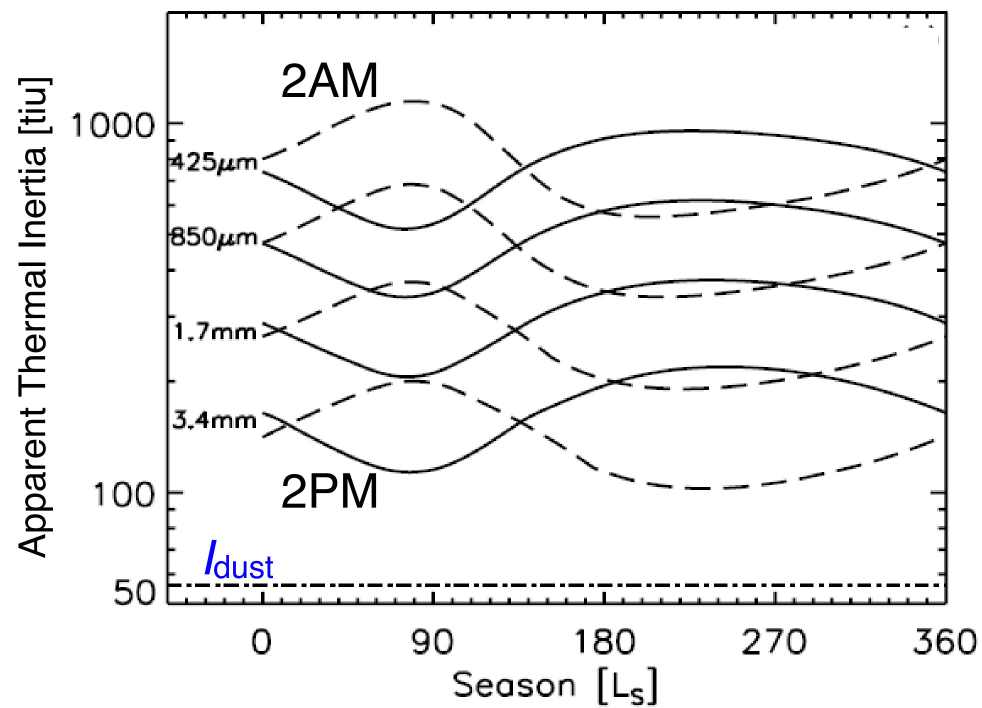


Layered-surface thermal effects



Model diurnal temperature and seasonal thermal inertia

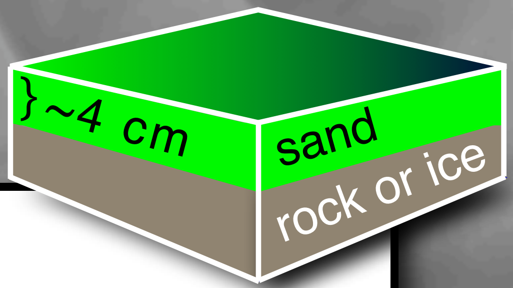


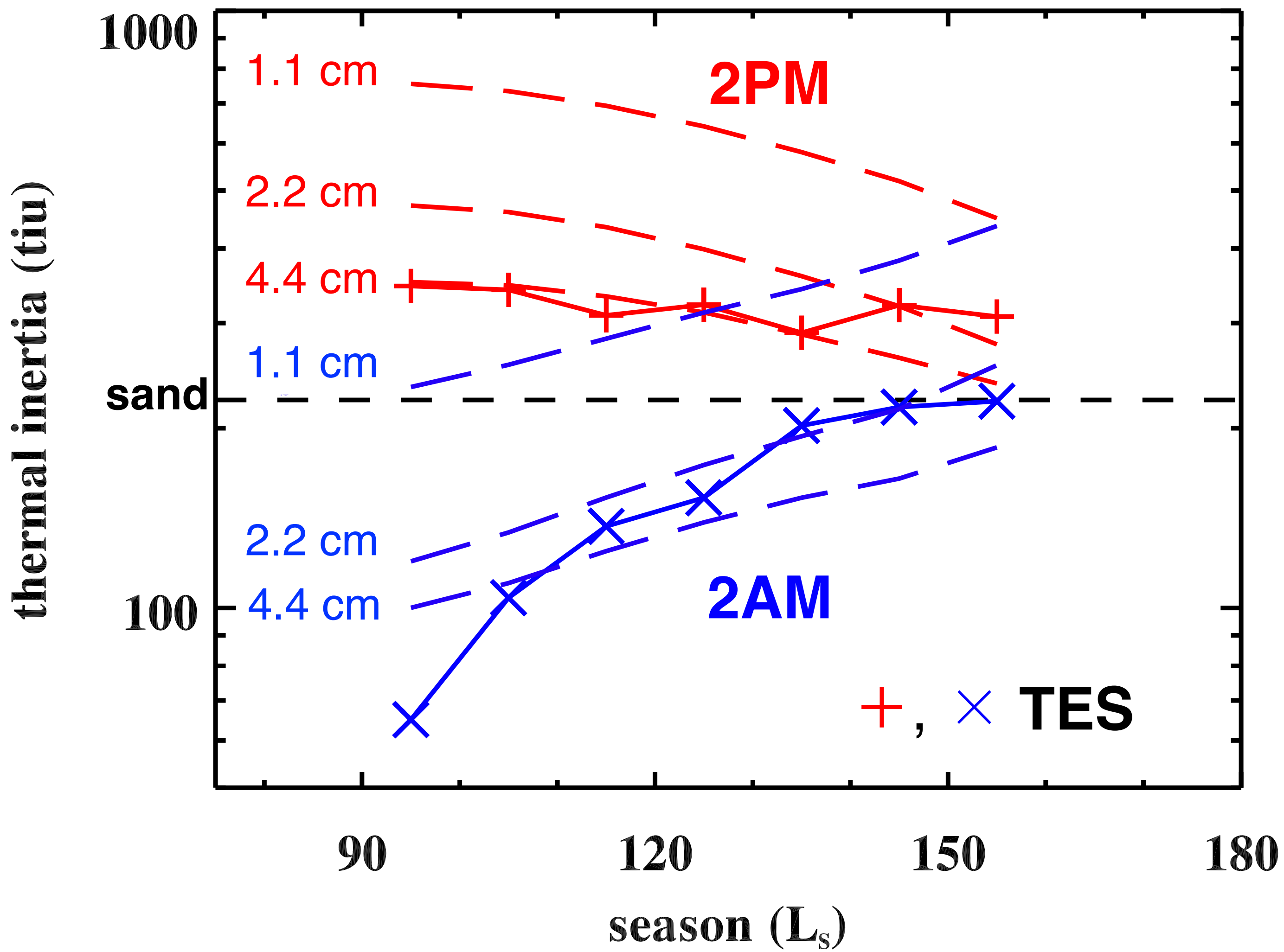


mid-latitudes

Mellon et al. (2008)

At Phoenix: TES thermal inertia fits a layered model of sand over rock/ice

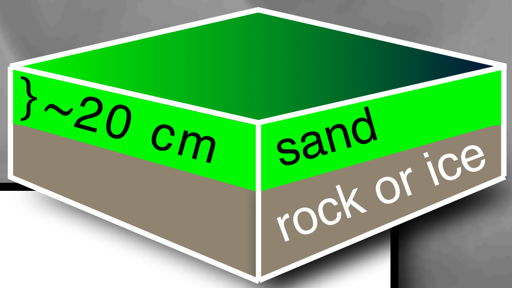


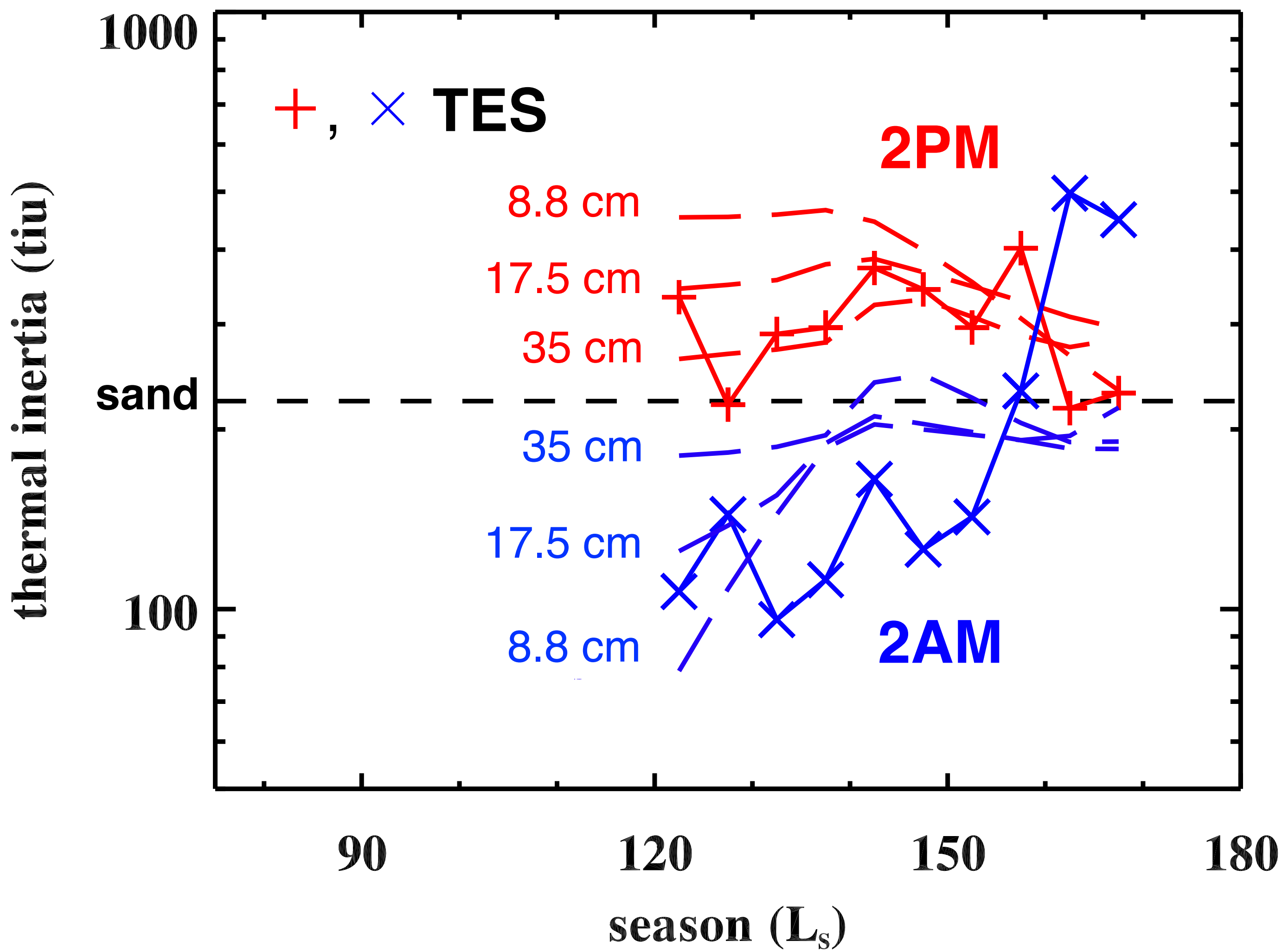


Compare to lander-observed average depth to ground ice: ***4 cm***

Putzig and Mellon (2007)

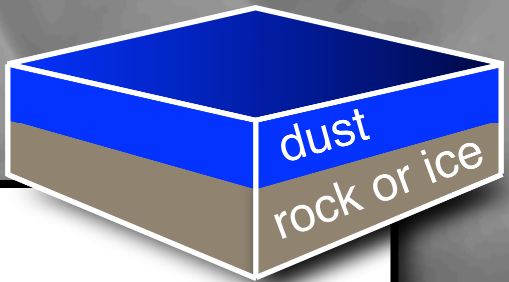
In the erg: TES thermal inertia fits a layered model of sand over rock/ice

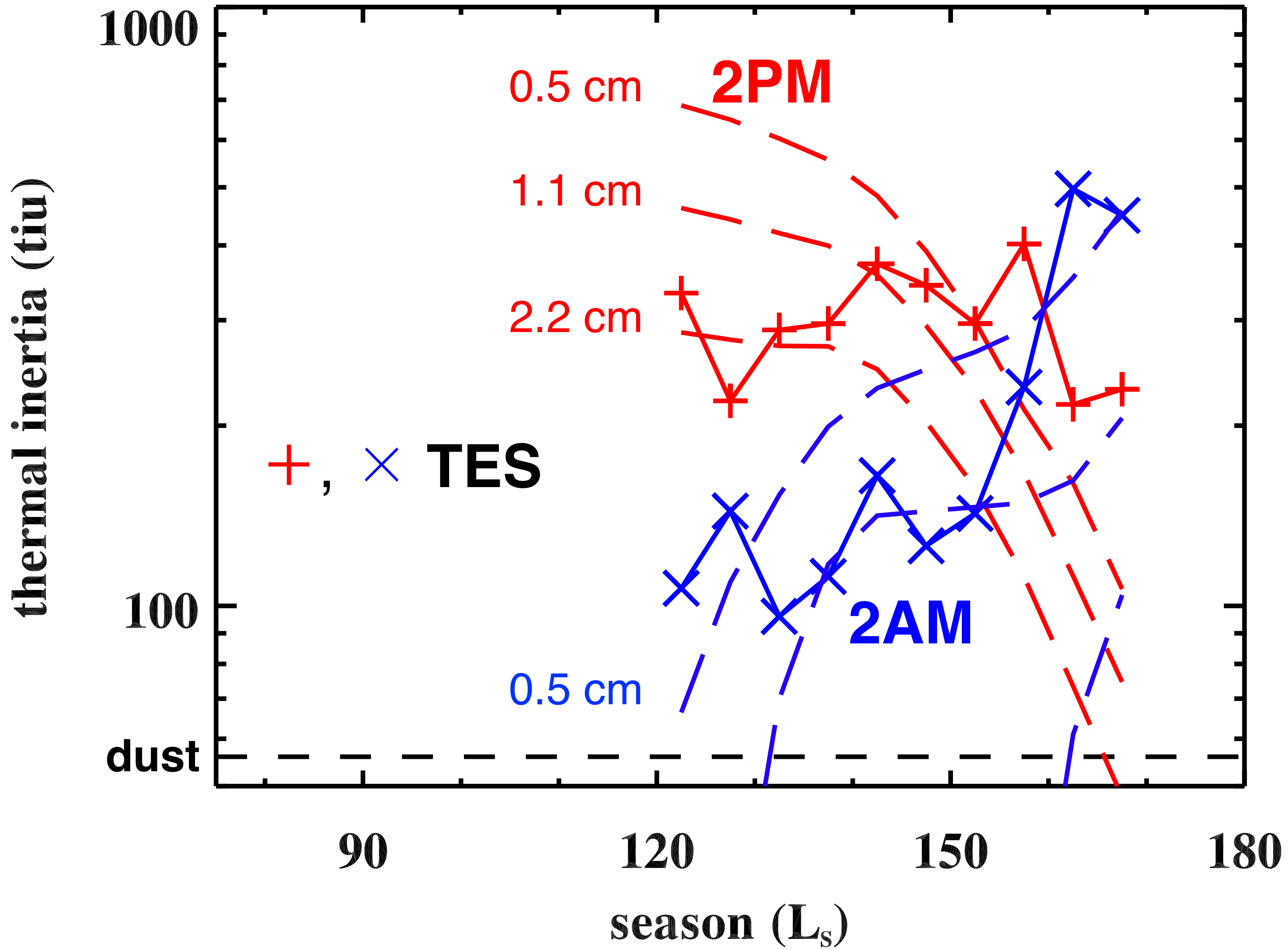




cf. Titus and Cushing (2010) estimates of upper-layer thickness of ~5–20 cm.

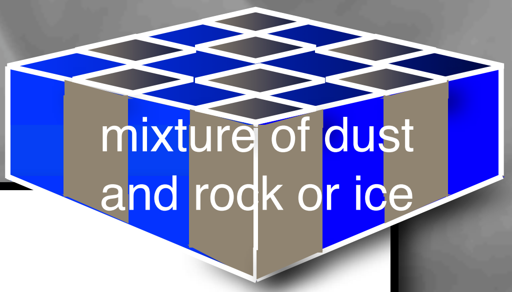
In the erg: TES thermal inertia does not fit models of dust over rock/ice

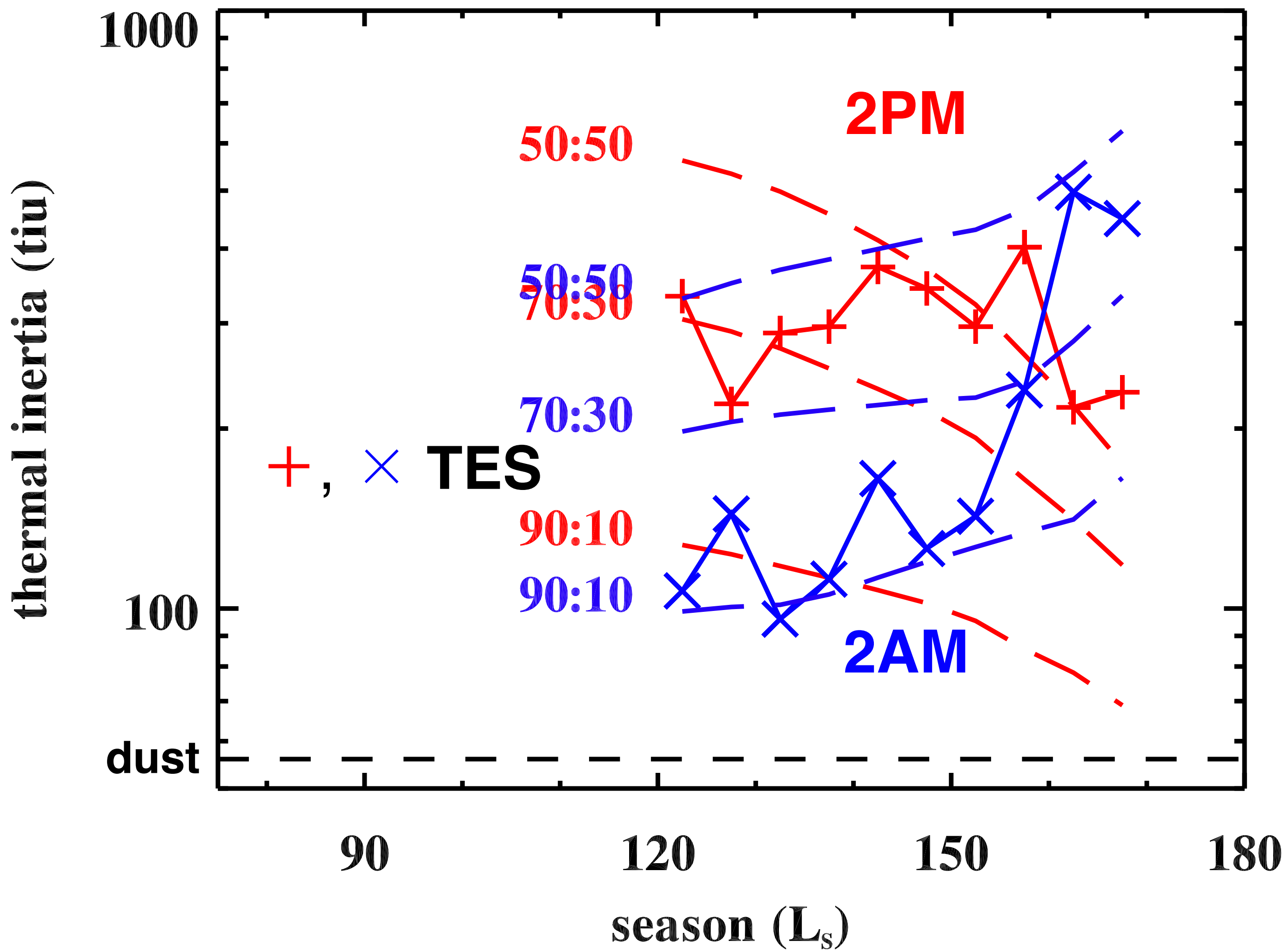




Seasonal changes for the model are much larger than those from TES

In the erg: TES thermal inertia does not fit models of horizontal mixtures





Relative behavior of 2AM and 2PM curves is different

HiRISE image study: Quantify slope orientations and angles

Bowers and Putzig (2011 LPSC)

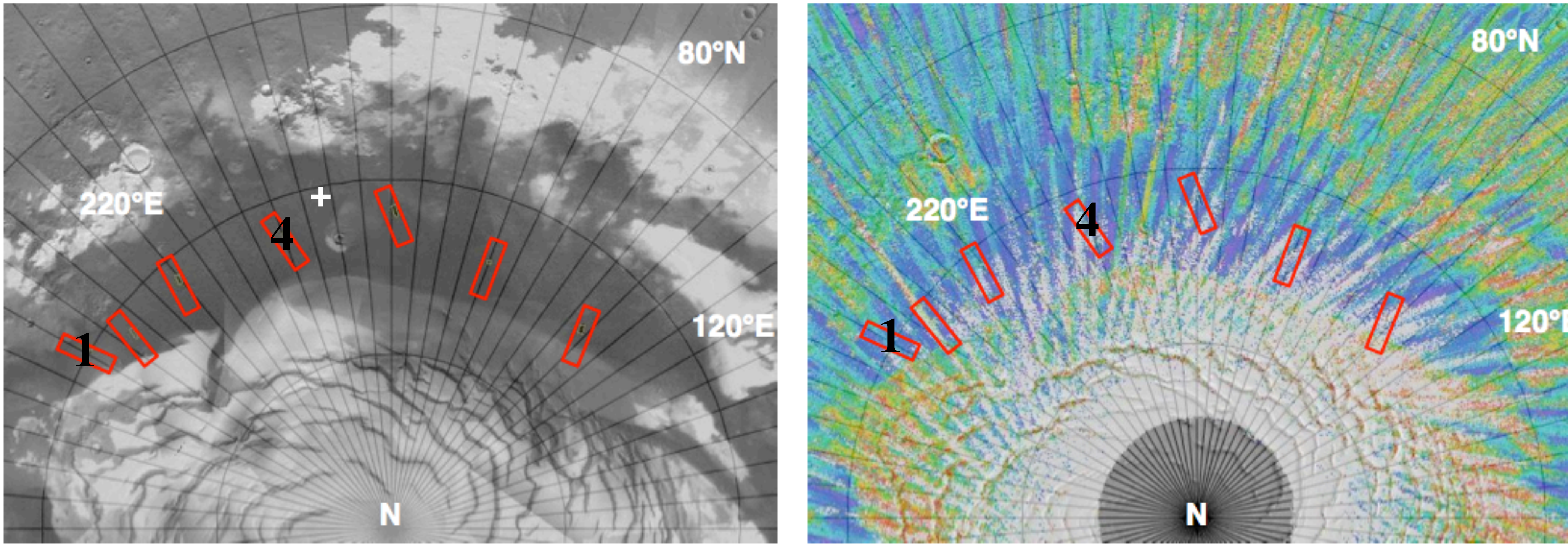
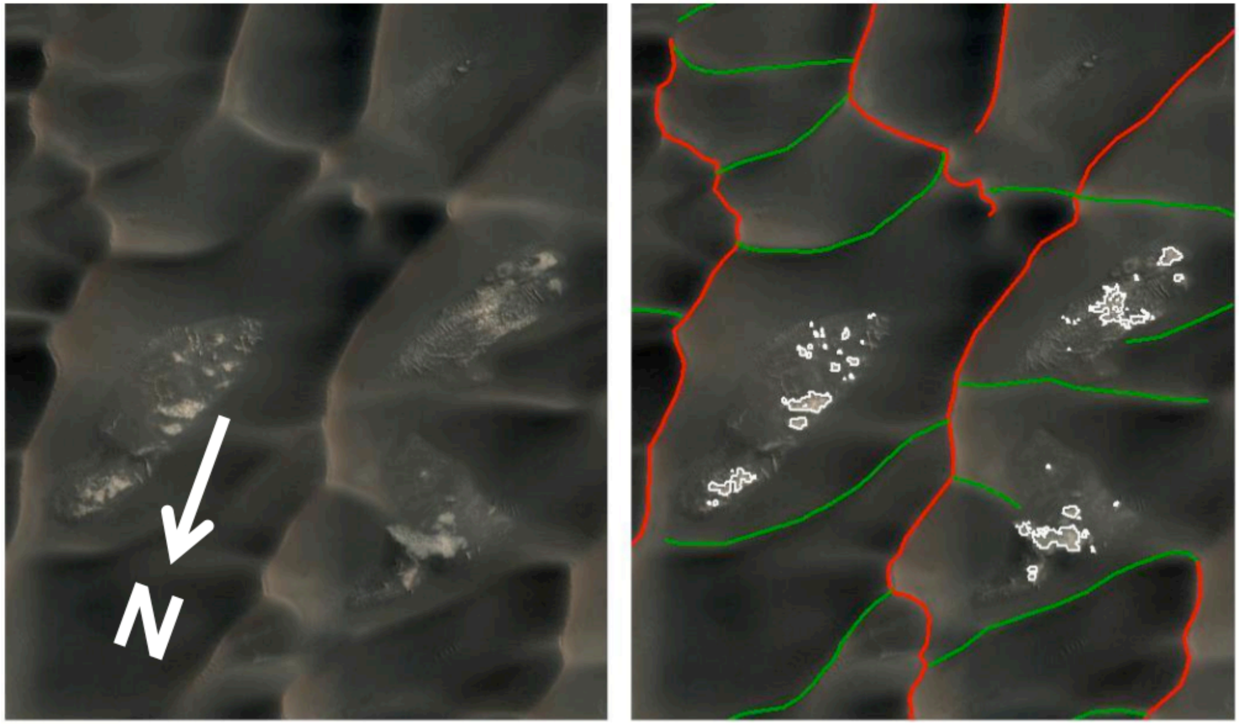


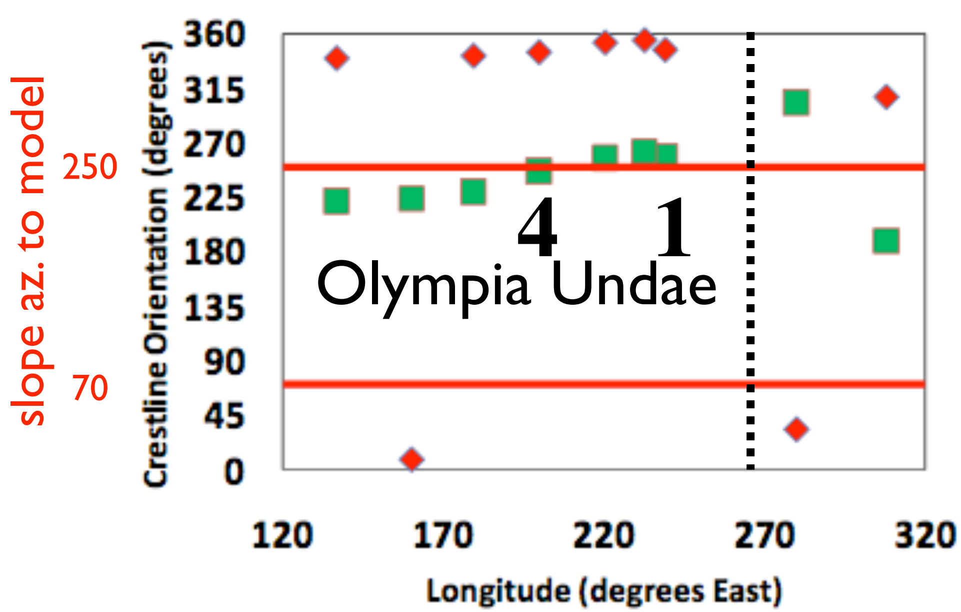
Figure 1. A: Location of HiRISE images within the Olympia Undae Dune Field. Background composed of MOC Wide Angle Atlas map [2] overlaid on MOLA Shaded Relief map [3]. Three dune fields located outside of Olympia Undae not shown. B: Background composed of TES Nightime Thermal Inertia map [4] overlaid on MOLA Shaded Relief map [3].

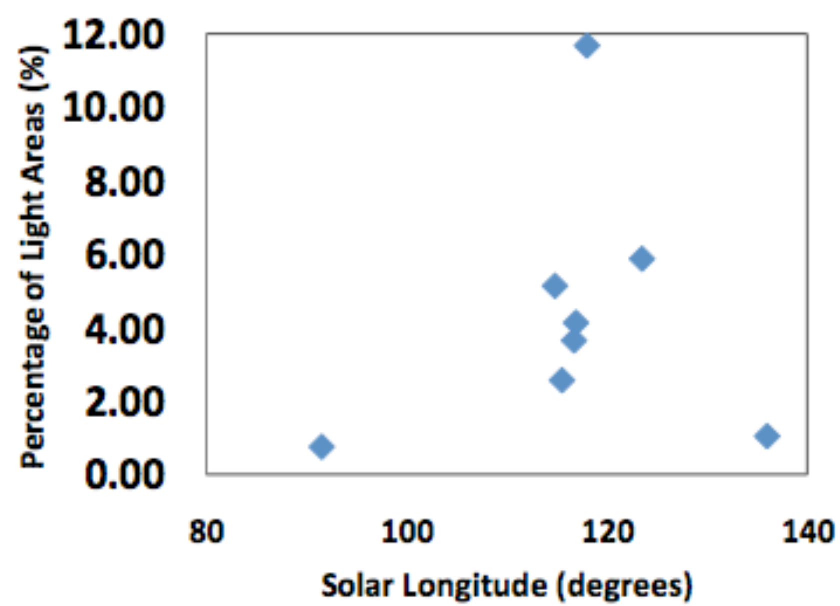
1 Crest tracing example
4 Thermal modeling example

Crestlines are consistently oriented. Light-toned materials typically occupy < 6% area.

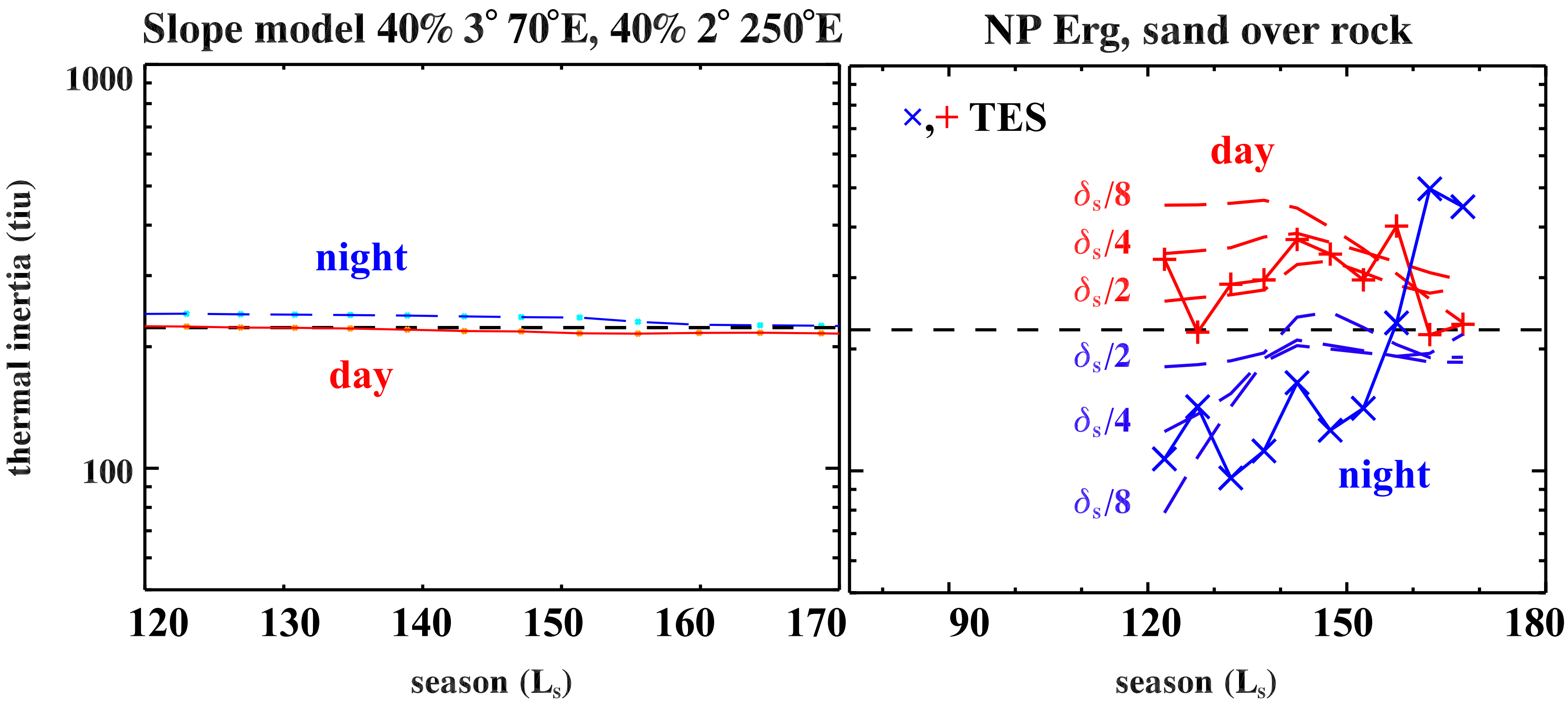


Section of HiRISE image PSP_001432_2610 showing dune crests and inter-dune deposits within Olympia Undae. Bowers & Putzig (2011).



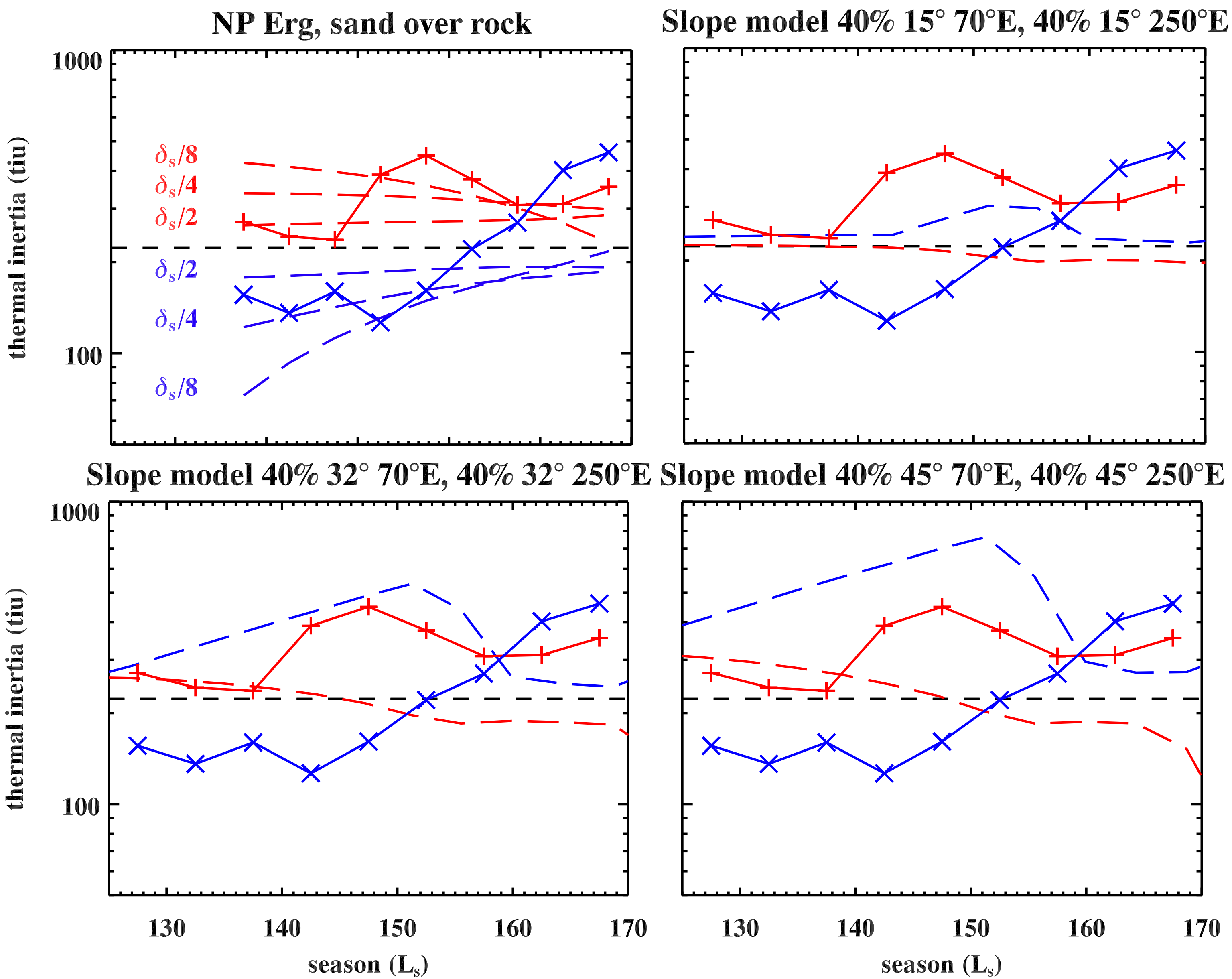


With HiRISE orientations and lower bounds on slope (2°,3°) from MOLA data:



Bowers & Putzig (2011)

Considering typical angles of repose for likely dune-forming materials:



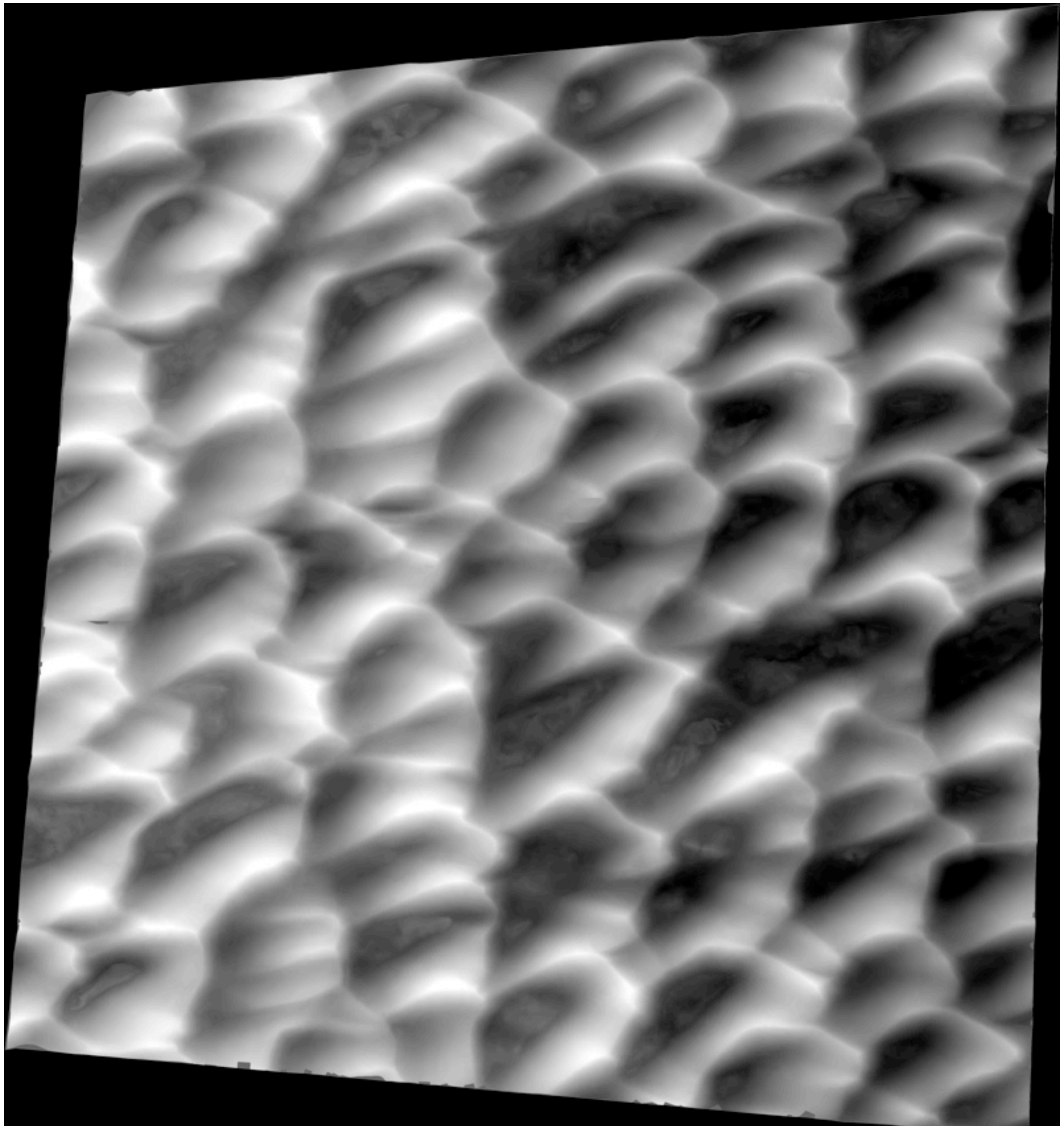
Sense of 2AM and 2PM curves is opposite between TES and models

Slope is not a dominant factor

At location of HiRISE image PSP_009764_2600

This just in...

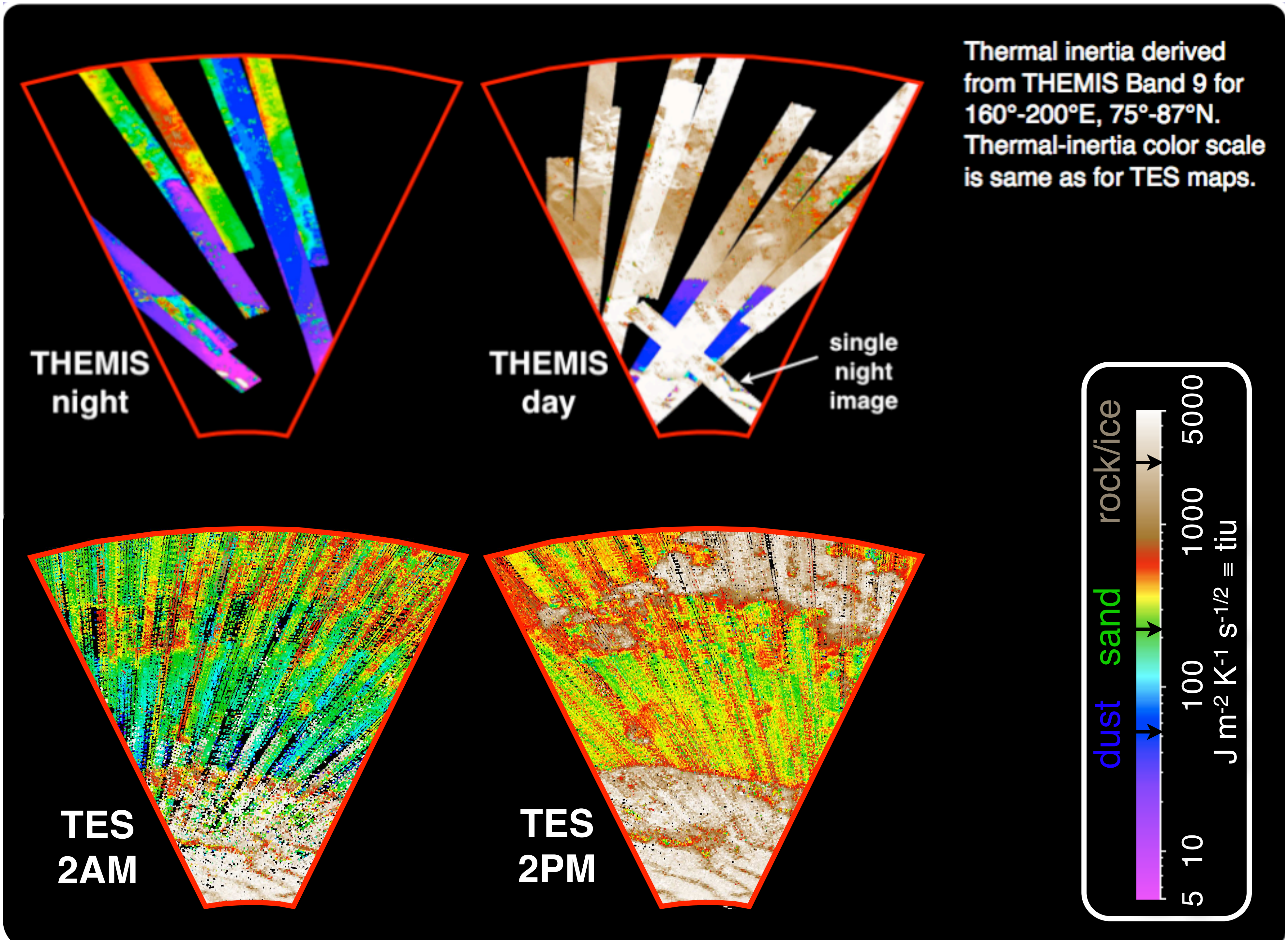
from your friendly local USGS (Redding and Herkenhoff):



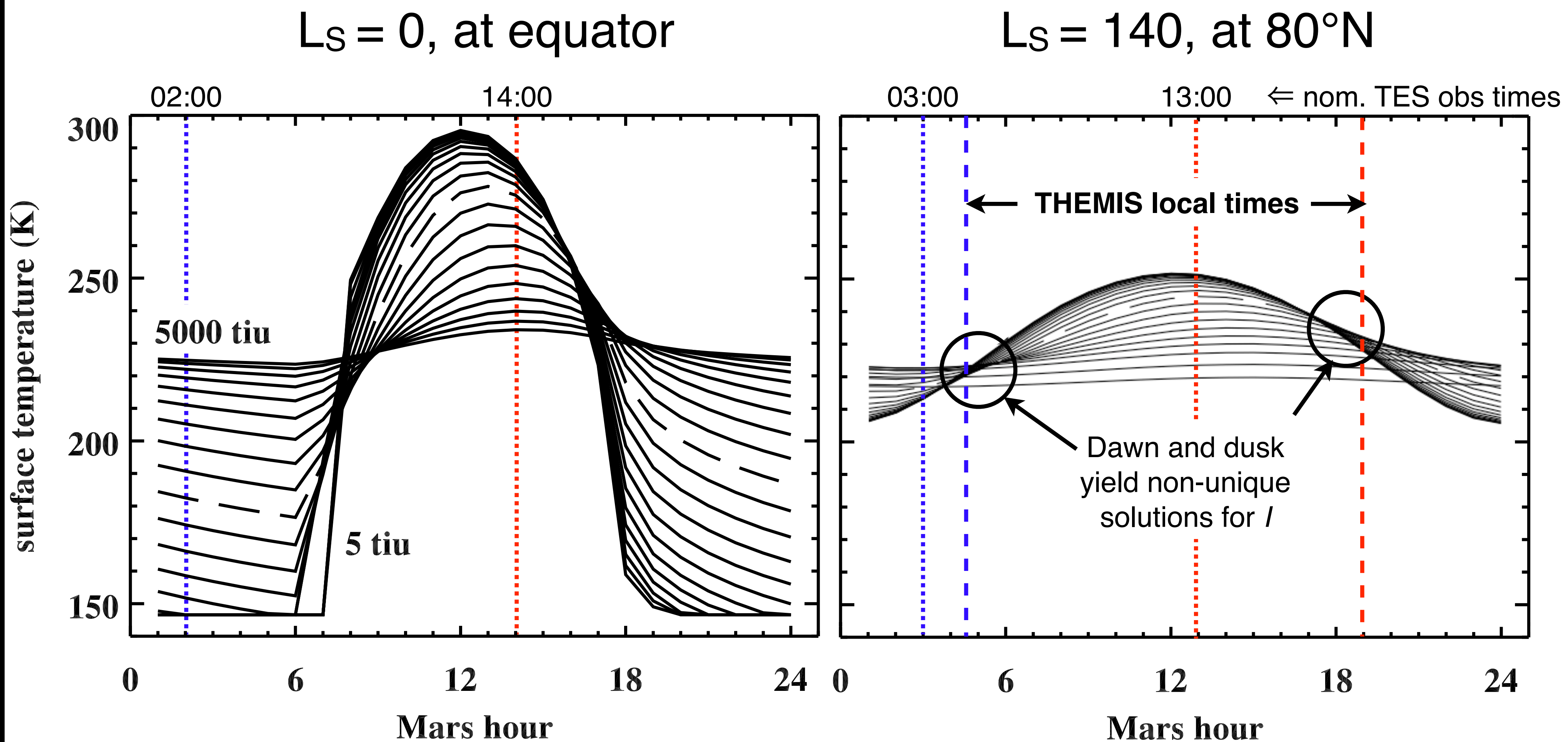
Olympia Undae DEM from a HiRISE image pair

To be incorporated into our slope analysis imminently!

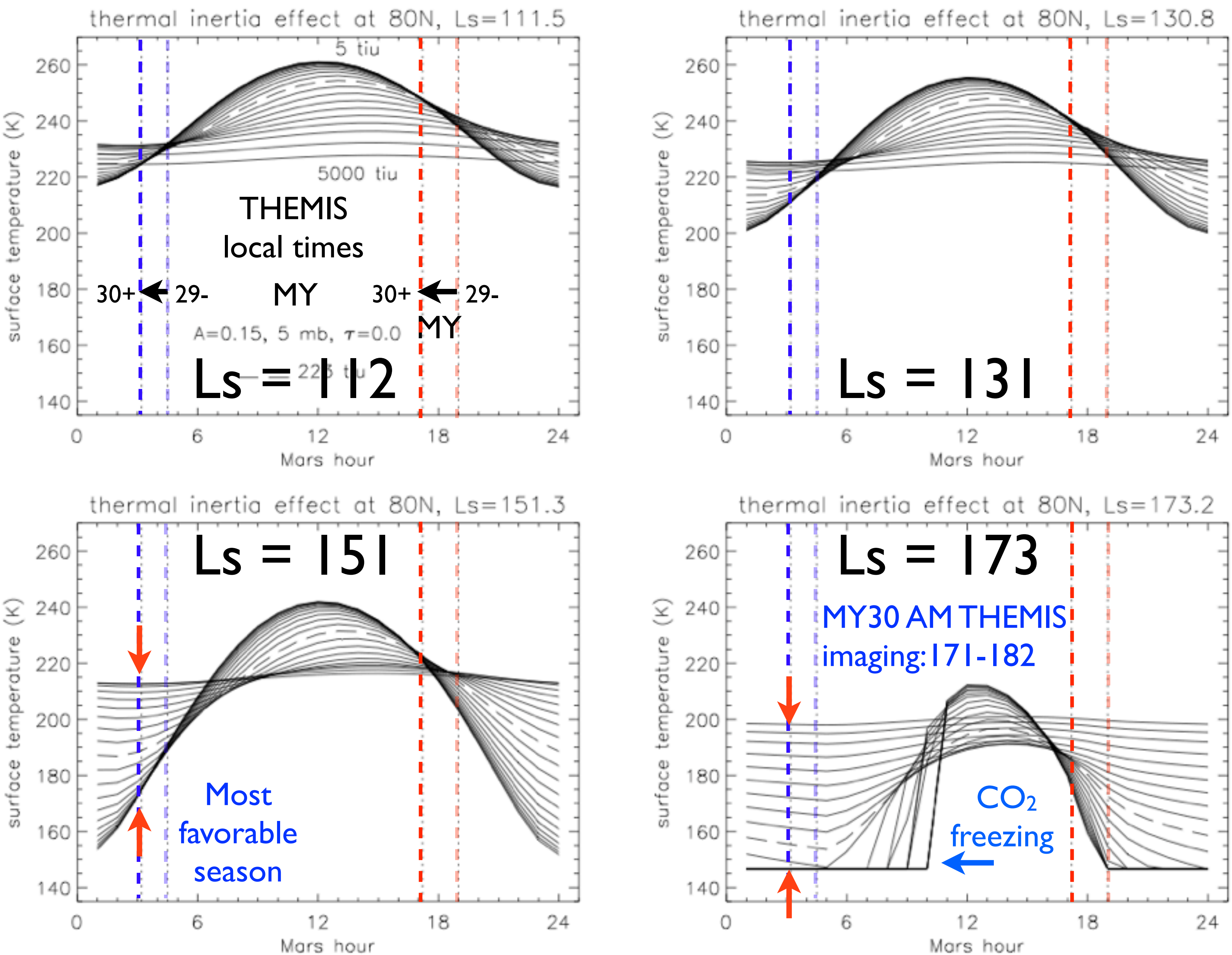
Earlier THEMIS results (Putzig et al. 2010 LPSC)

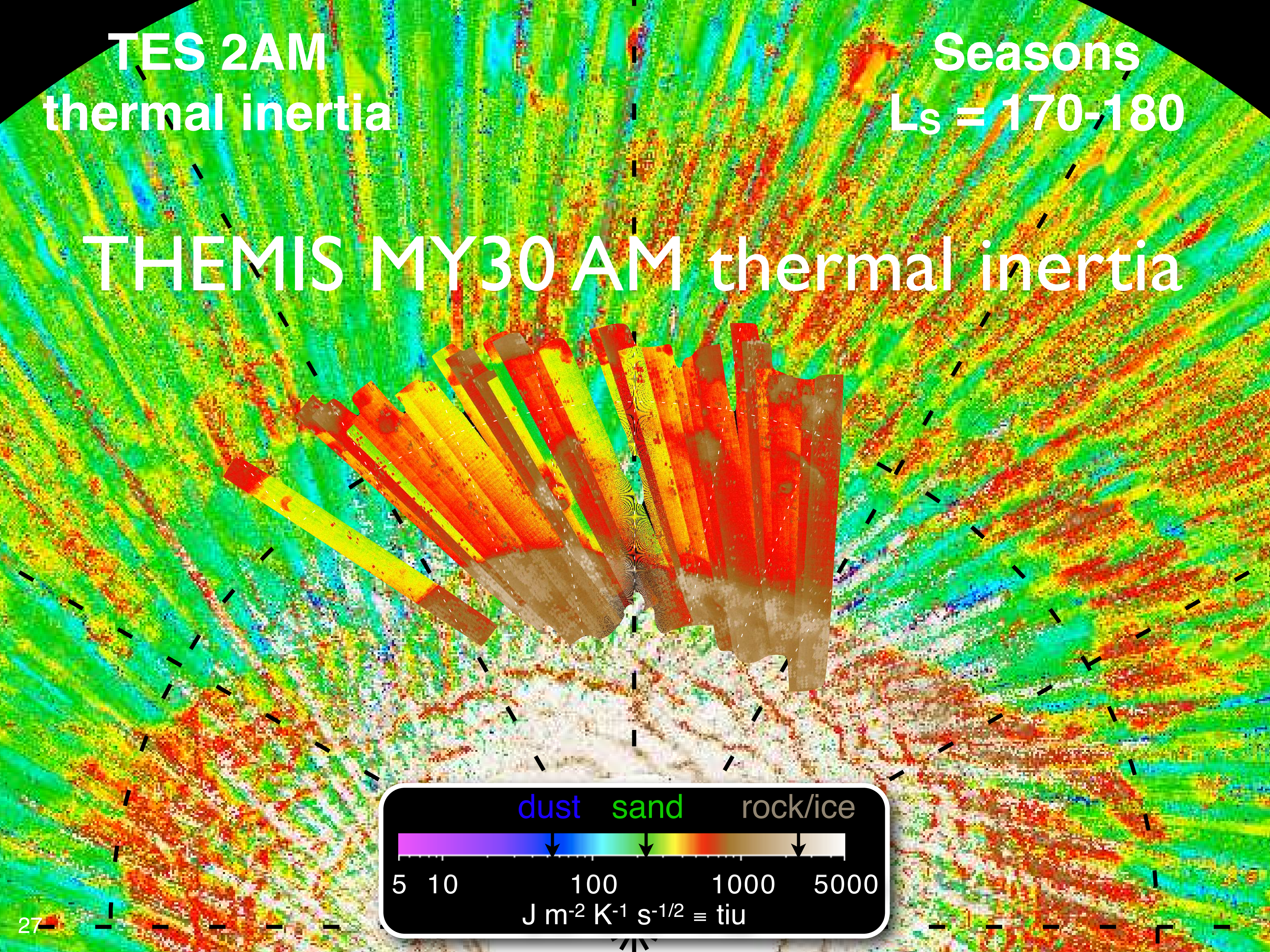


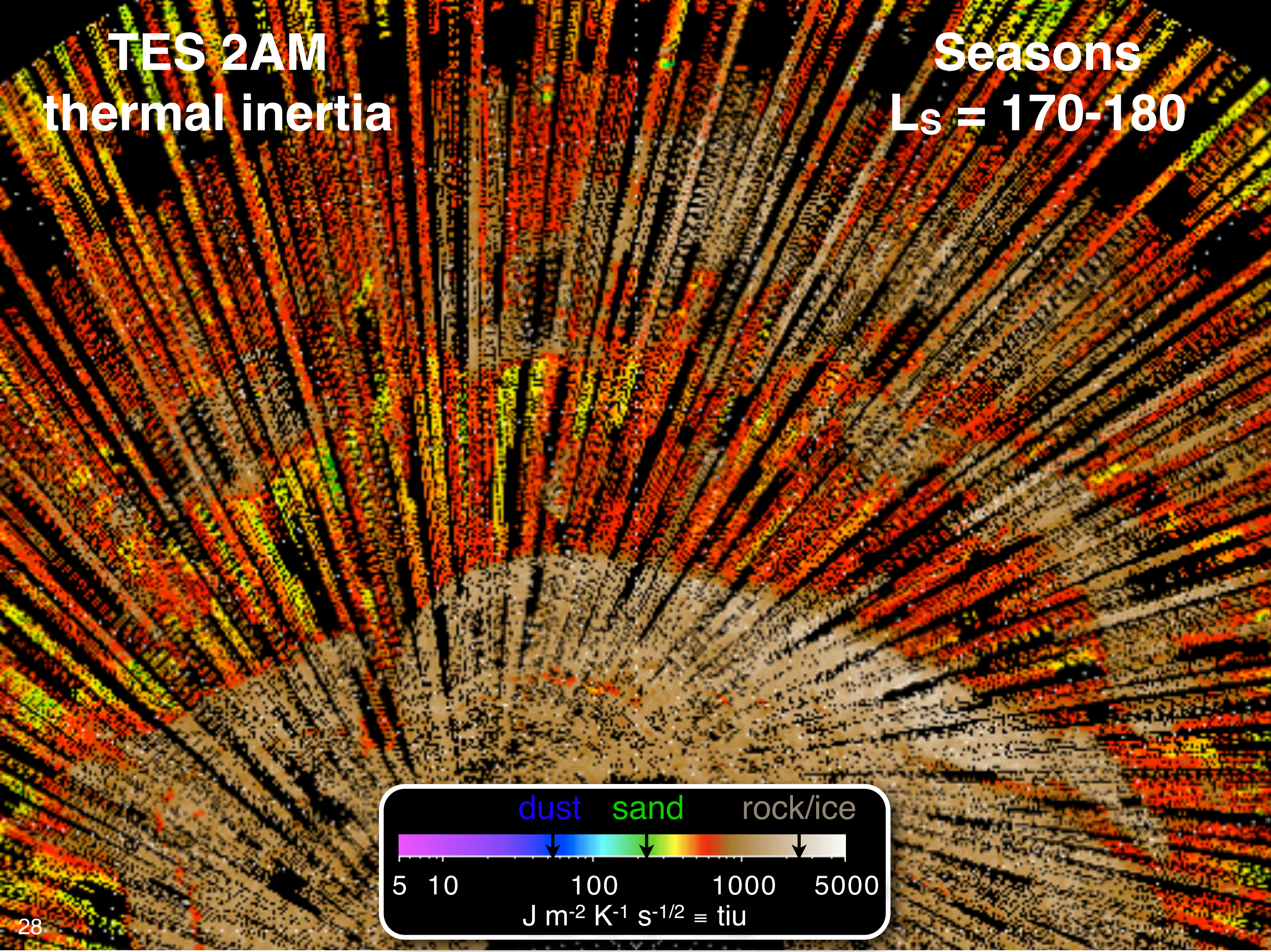
Modeled Martian temperature

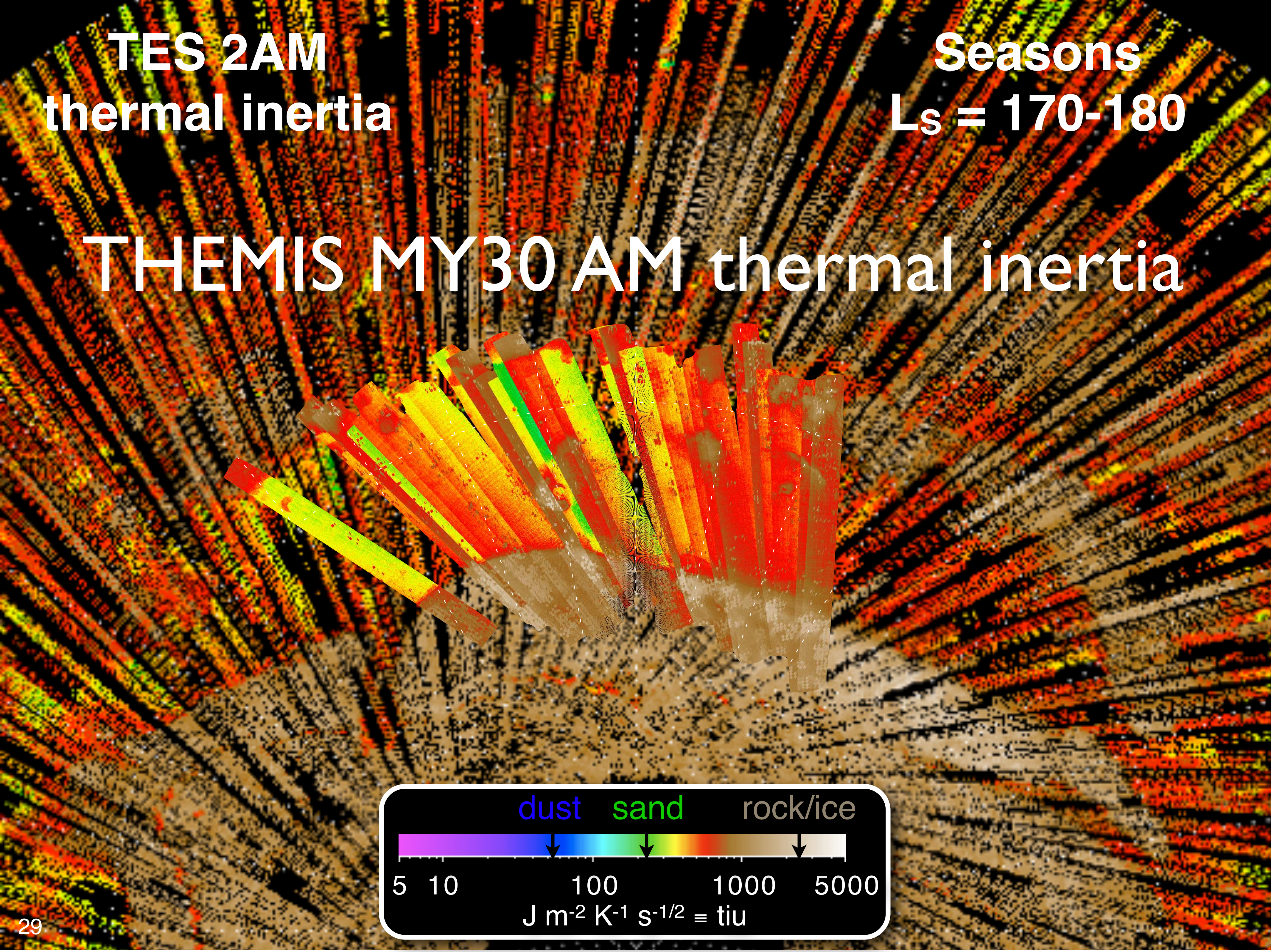


Model T at various seasons




TES 2AM
thermal inertia
Seasons
Ls = 170-180
THEMIS MY30 AM thermal inertia
dust
sand
rock/ice
5
10
100
1000
5000
J m-2 K-1 s-1/2 ≡ tiu


TES 2AM
thermal inertia
Seasons
L_S = 170-180
dust
sand
rock/ice
5 10 100 1000 5000
J m^{-2} K^{-1} s$^{-1/2}$ ≡ tiu


TES 2AM
thermal inertia
Seasons
Ls = 170-180
THEMIS MY30 AM thermal inertia
dust
sand
rock/ice
5 10 100 1000 5000
J m-2 K-1 s-1/2 ≡ tiu
29

Conclusions

- Diurnal and seasonal variations in TES apparent thermal inertia are indicative of a heterogenous surface in Olympia Undae.

- Our analysis of thermal inertia from TES:

  - strongly supports normal sand-sized materials at the surface of erg, likely overlying an ice-cemented substrate.

  - discounts the contribution of slopes and horizontal mixtures of materials to the thermal behavior.

- Better seasonal coverage of AM observations will increase the usefulness of THEMIS in evaluating the thermal behavior of the erg.

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