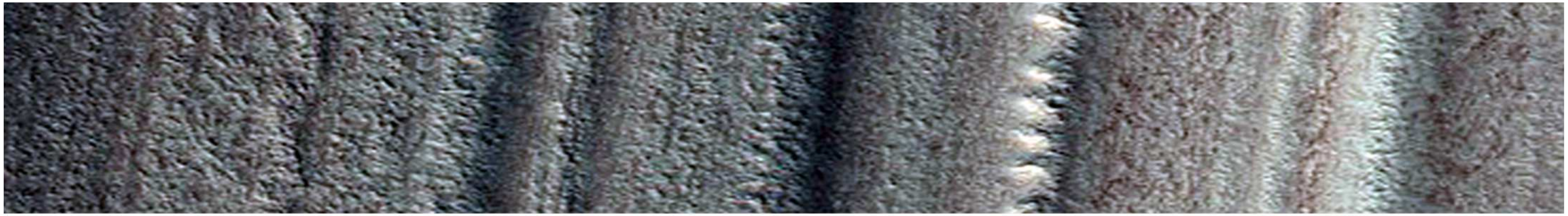

Habitability of the Martian North Polar Residual Cap

Anna Losiak[1], Leszek Czechowski[2], Michael A. Velbel[3]

1) ING PAN Wrocław, Poland (anna.losiak@twarda.pan.pl);
2) Instytut Geofizyki Uniwersytet Warszawski, Poland;
3) Department of Geological Science, Michigan State University, US.

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Outline

- Martian habitability
- North Polar Residual Cap (NPRC)
  - Evaporites around NPRC
  - Contemporary ephemeral liquid water
    - Results of the numerical modeling
- Habitability of the NPRC

Martian habitability

Habitable environment:

one that has the necessary conditions for **at least one known organism** to be **metabolically active**,

– maintenance, growth, or reproduction (Cockell 2014)

Requirements

- Nutrients: CHNOPS
- Energy
- **Liquid water**
- **Time**

Factors

- radiation
- pH
- Presence of brines
- Porosity

Martian habitability

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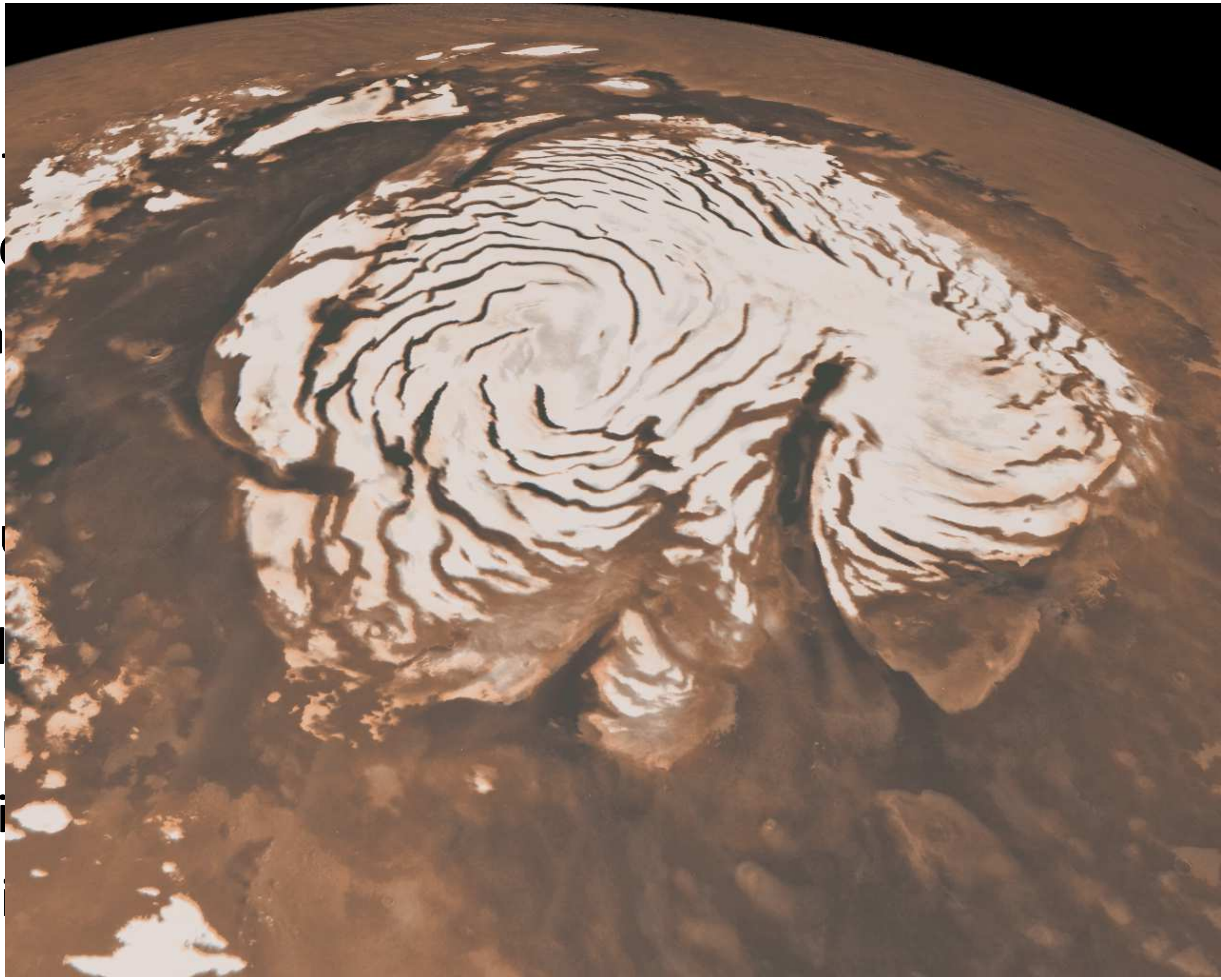
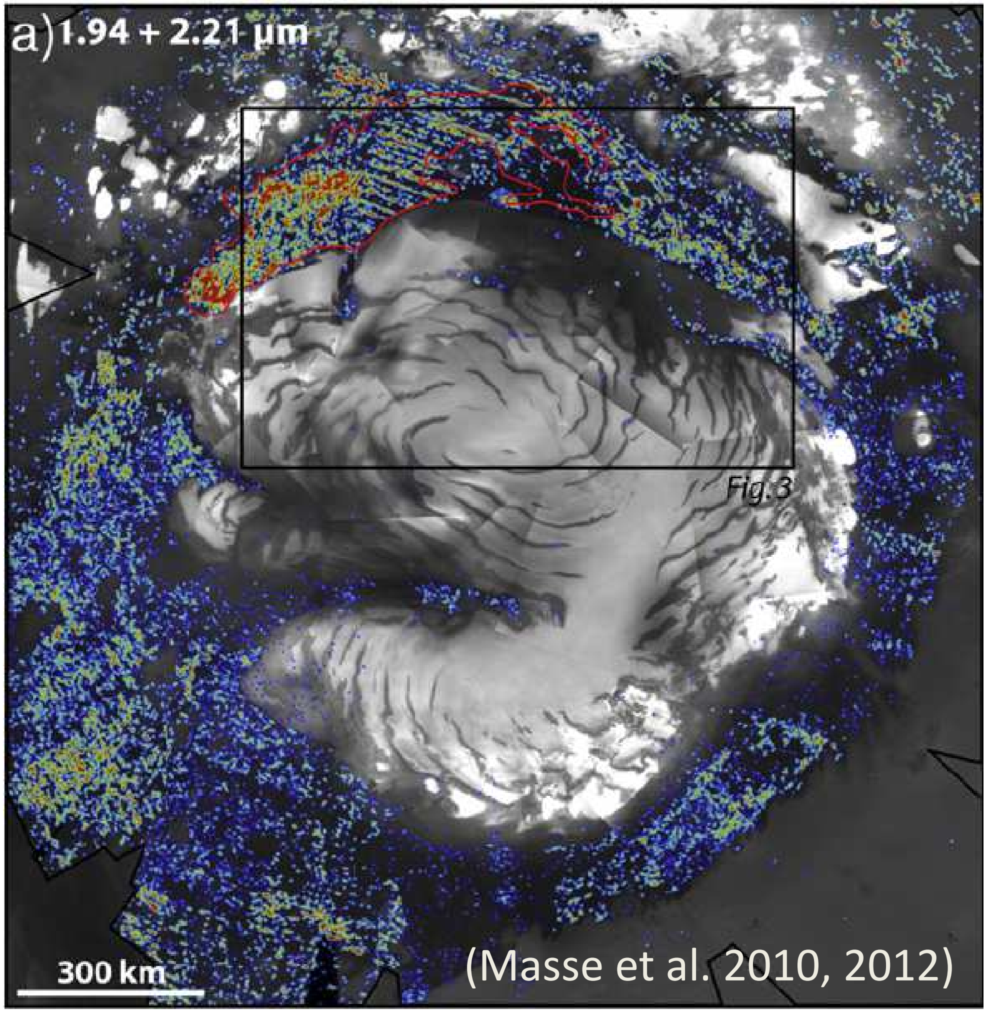


Martian evaporites distribution

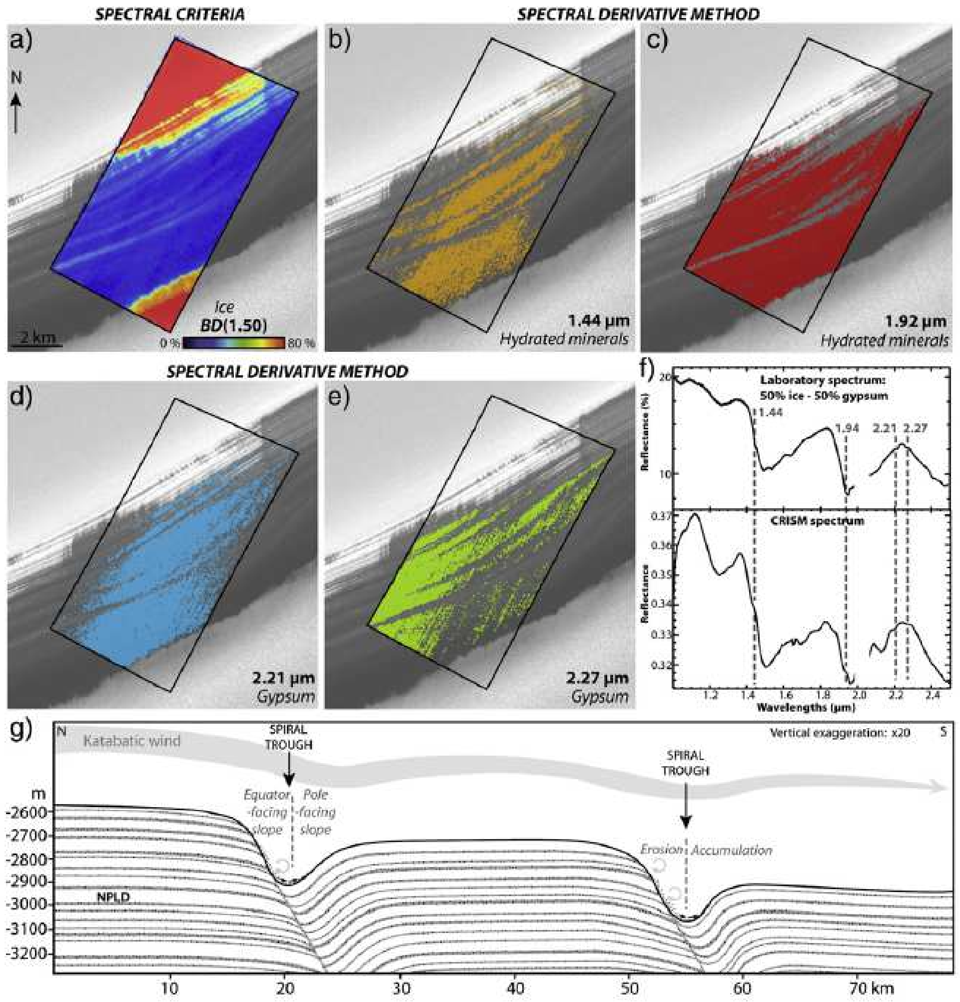
- Evaporites (e.g., gypsum) detected within Olympia Planum region, and Circumpolar Dune Field (Langevin et al., 2005, Horgan et al. 2009, Masse et al. 2010, 2012).
- Formation of evaporites requires liquid water.
- stratigraphically young (Tanaka et al. 2008).



(Masse et al. 2010, 2012)

Evaporites on North Polar Cap

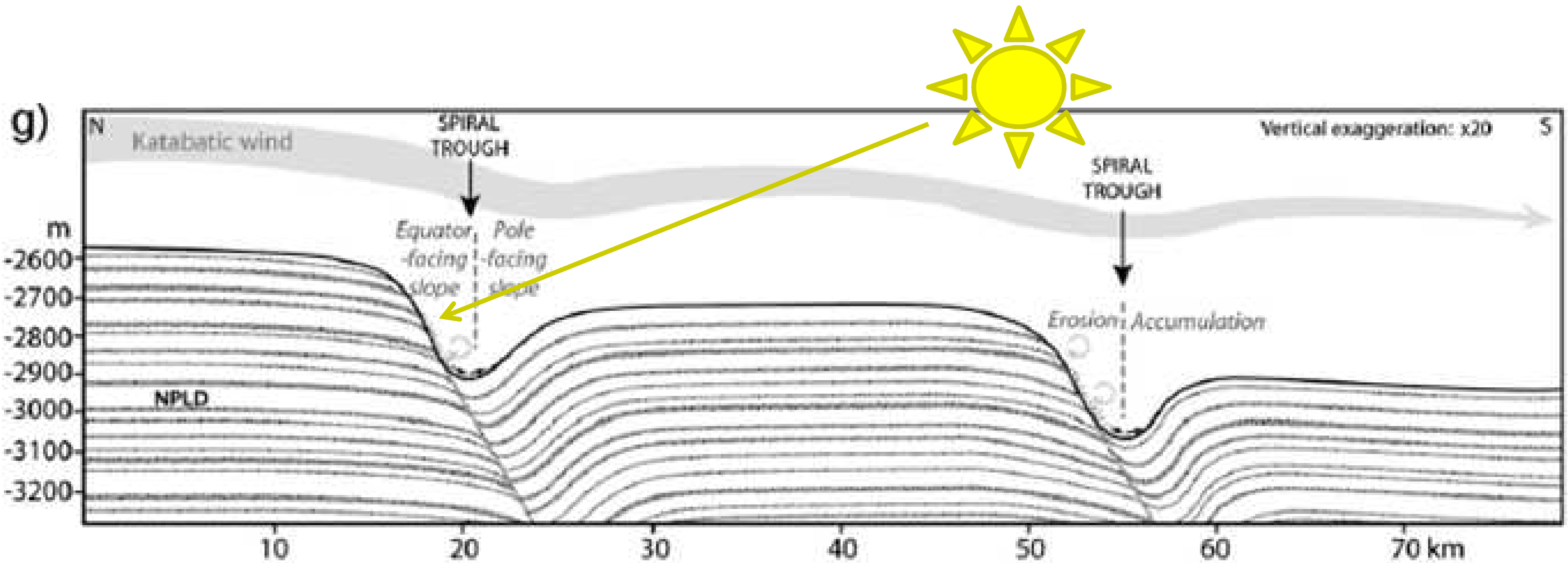
- Evaporites were detected also on the Northern Ice Cap (Masse et al. 2012).
- **How and when was this gypsum formed?**
  - Formation elsewhere and deposition on ice.
  - Formation within ice (Catling et al. 2006, Zolotov and Mironenko 2007, Niles and Michalski 2009).



(Masse et al. 2012)

Numerical modeling

Test if radiant heating is sufficient to melt a thin layer of ice below a mono-layer of dust grains exposed within the south facing side of the Martian North Polar Cap trench.



Numerical modeling

Test if radiant heating is sufficient to melt a thin

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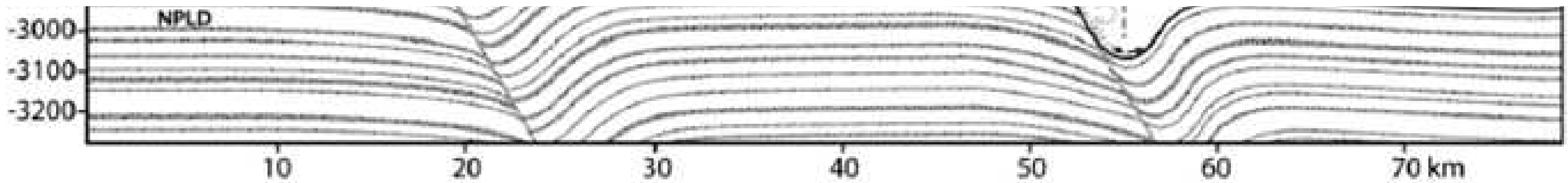
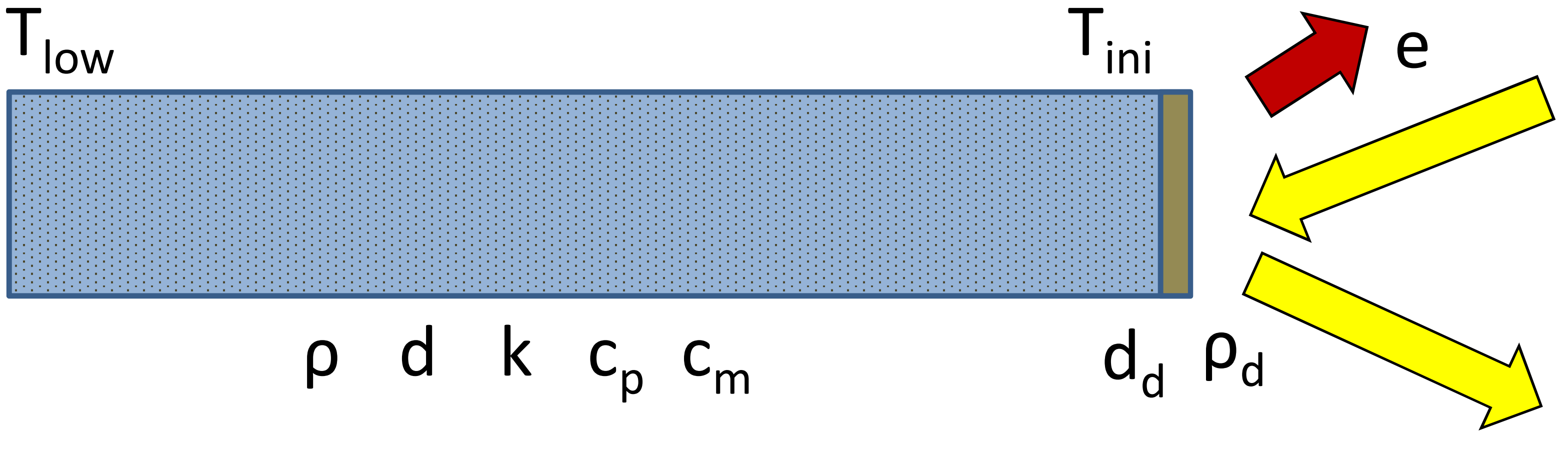
Ephemeral liquid water at the surface of the martian North Polar Residual Cap: Results of numerical modelling

Anna Losiak [a,*], Leszek Czechowski [b], Michael A. Velbel [c]

[a] Institute of Geological Sciences, Polish Academy of Sciences, ul. Podwale 75, 50-449 Wrocław, Poland
[b] Institute of Geophysics, Faculty of Physics, University of Warsaw, ul. Pasteura 7, 02-093 Warszawa, Poland
[c] Department of Geological Sciences, Michigan State University, 288 Farm Lane, 206 Natural Science Building, East Lansing, MI 48824-1115, United States



The model



A numerical model based on the equation of the heat transfer (Czechowski 2012):

$$\rho c_p \frac{\partial T(x,t)}{\partial t} = \frac{\partial}{\partial x} k(x) \frac{\partial}{\partial x} T(x,t) + Q(x,T,t)$$

where symbols are explained in Table 1. The equation is solved for x=[0, D] with the following boundary conditions:

$$-k \frac{\partial T(x,t)}{\partial x} = AS - eCT^4$$ for $x = 0$ (the surface)

$T = T_{low}$ for $x = D$ (the lower boundary).

Table 1
Information on values of parameters used in this study.

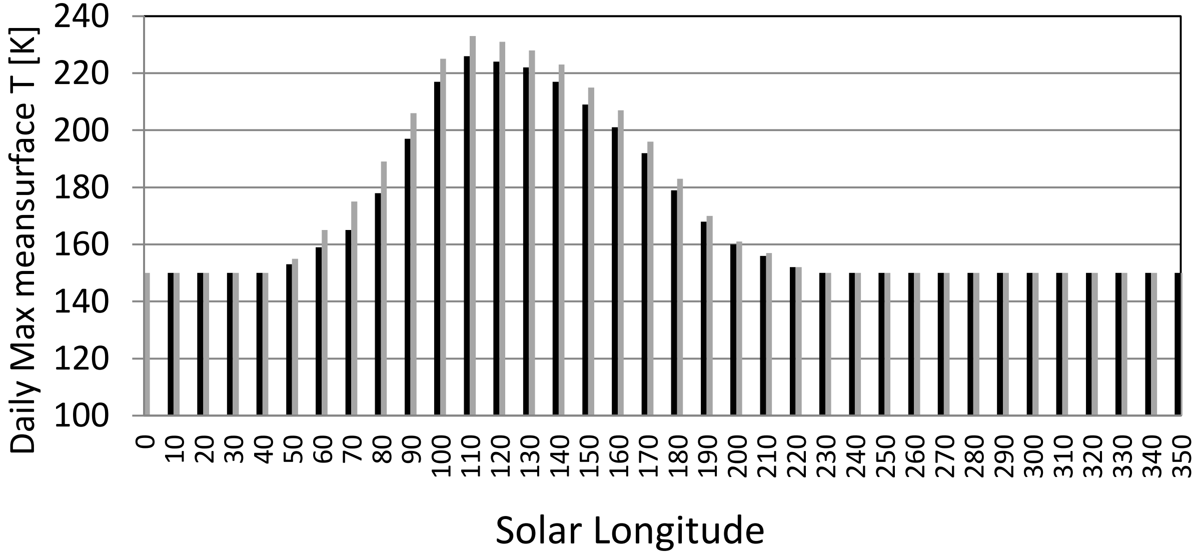
Name	Symbol	Unit	Range or values	Comment
Properties of the environment				
Solar irradiation	S	$W\ m^{-2}$	265–450	Summer conditions on equatorially inclined slopes at the edge of North Polar Residual Cap (Mars Climate Database: Millour et al., 2014)
Initial temperature at the surface	T_{ini}	K	215	Summer conditions at the edge of North Polar Residual Cap (Mars Climate Database: Millour et al., 2014)
Initial temperature at 1 m depth	T_{low}	K	165	Larsen and Dahl-Jensen (2000)
Dust layer properties				
Thickness	d_d	µm	2, 20, 200	2 µm: an average size of dust gains on Mars (Lemmon et al., 2004), 20 µm: upper size limit for suspension, 200 µm: upper size limit for saltation (Vaughan et al., 2010)
Density	ρ_d	$kg\ m^{-3}$	3000	
VR Albedo	A		0.13	Albedo of the Olympia Planum region dunes (Massé, personal communication; Paige et al., 1994)
IR Emissivity	E		0.70, 0.8, 0.87	The IR emissivity of basalt (Le Guern et al., 1979; Mustard and Hays, 1997; Burgi et al., 2002; Donaldson Hanna et al., 2012)
Specific heat of dust grain	c_{pd}	$J\ g^{-1}\ K^{-1}$	0.7084	Specific heat of basalt at temperature of 271.21 K (Hemingway et al., 1973)
Thermal conductivity of dust grain	k_d	$J\ m^{-1}\ K^{-1}\ s^{-1}$	2.34	Value (Clauser and Huenges, 1995) representative of framework silicates forming most of martian dust according to Hamilton et al. (2005). This value lies within the range of possible values for basalt
Porous-dusty firn properties				
Thickness of layer	D	m	1	
Composition		%	10% basalt 75% ice, 15% air	Values assumed based on terrestrial ice-sheets (Lipenkov et al., 1997), and radar measurements of the North Polar Residual Cap (Phillips et al., 2008)
Density of porous-dusty firn	ρ	$kg\ m^{-3}$	987.75	It was calculated by assuming a 1 m^3 of porous ice–silicate consists of 10% silicates (basalt $\rho_b = 3000.00\ kg\ m^{-3}$) and 75% water ice ($\rho_i = 916.75\ kg\ m^{-3}$) and 15% pore space ($\rho_p = 0.017\ kg\ m^{-3}$) is $\rho = 987.75\ kg\ m^{-3}$ ($\rho_b * 0.10 + \rho_i * 0.75 + \rho_p * 0.15$)
Specific heat of porous-dusty firn	c_p	$J\ kg^{-1}\ K^{-1}$	2050	
Thermal conductivity of porous-dusty firn	k	$J\ m^{-1}\ K^{-1}\ s^{-1}$	0.02–1.0	Values based on laboratory experiments (Lange, 1985; Clifford, 1987; Seiferlin et al., 1996) and measurements of thermal inertia of North Polar Residual Cap (Paige et al., 1994; Putzig and Mellon, 2007)
Specific heat for melting of pure water ice	c_m	$J\ kg^{-1}$	333,480	
Heat source/sink	Q	$W\ m^{-3}$	$Q < 0$ $Q > 0$ $Q = 0$	For melting For freezing Otherwise

Losiak et al. 2015 Icarus

Model

Input parameters: temperature & pressure

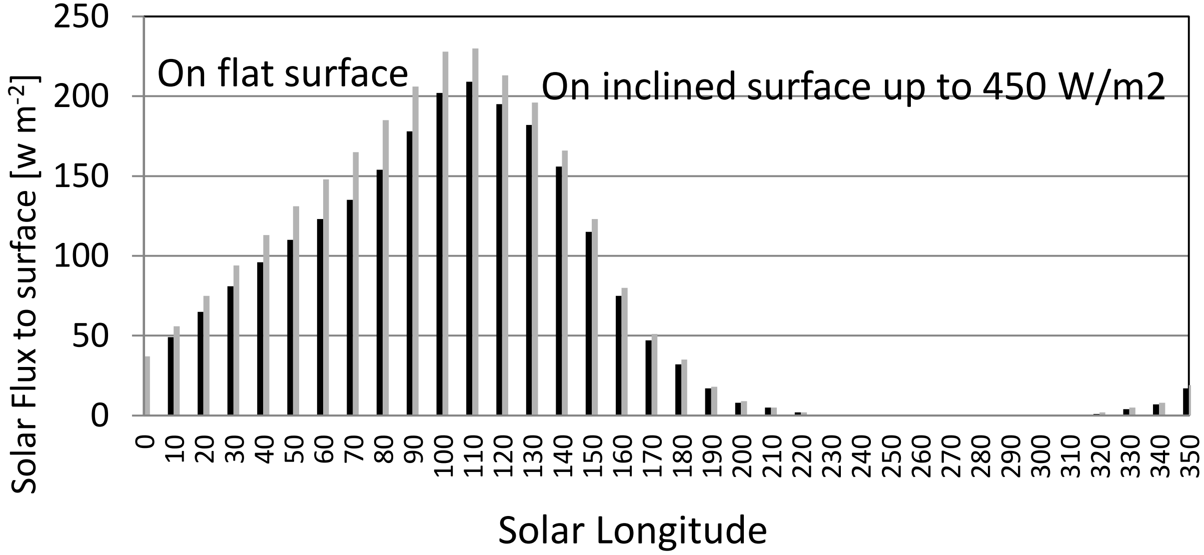
Mars Climate Database

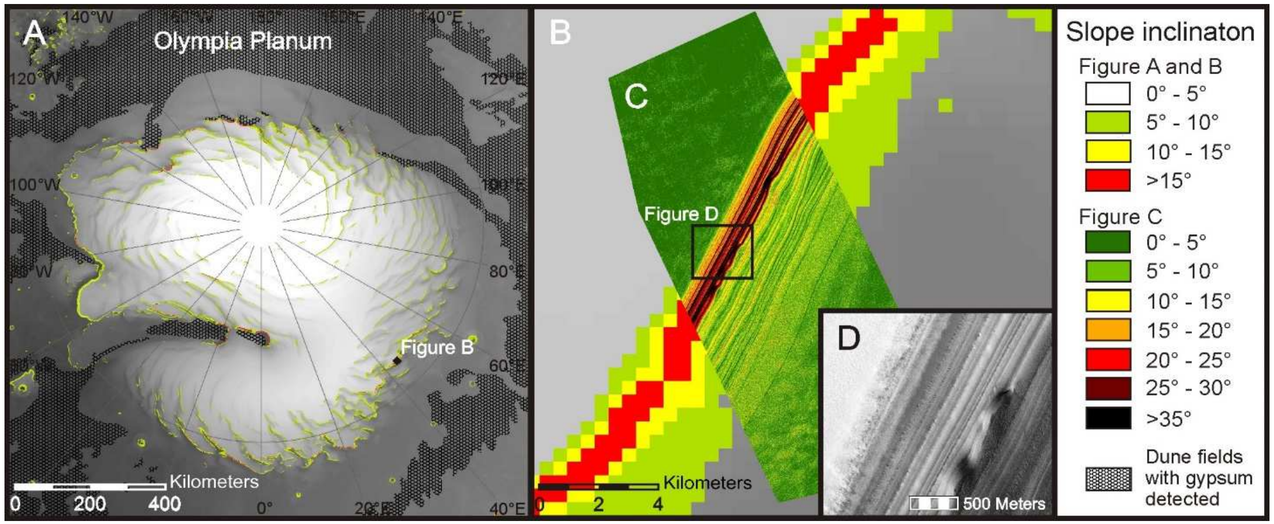


Summer pressure **>700 Pa**
(above triple point of water)

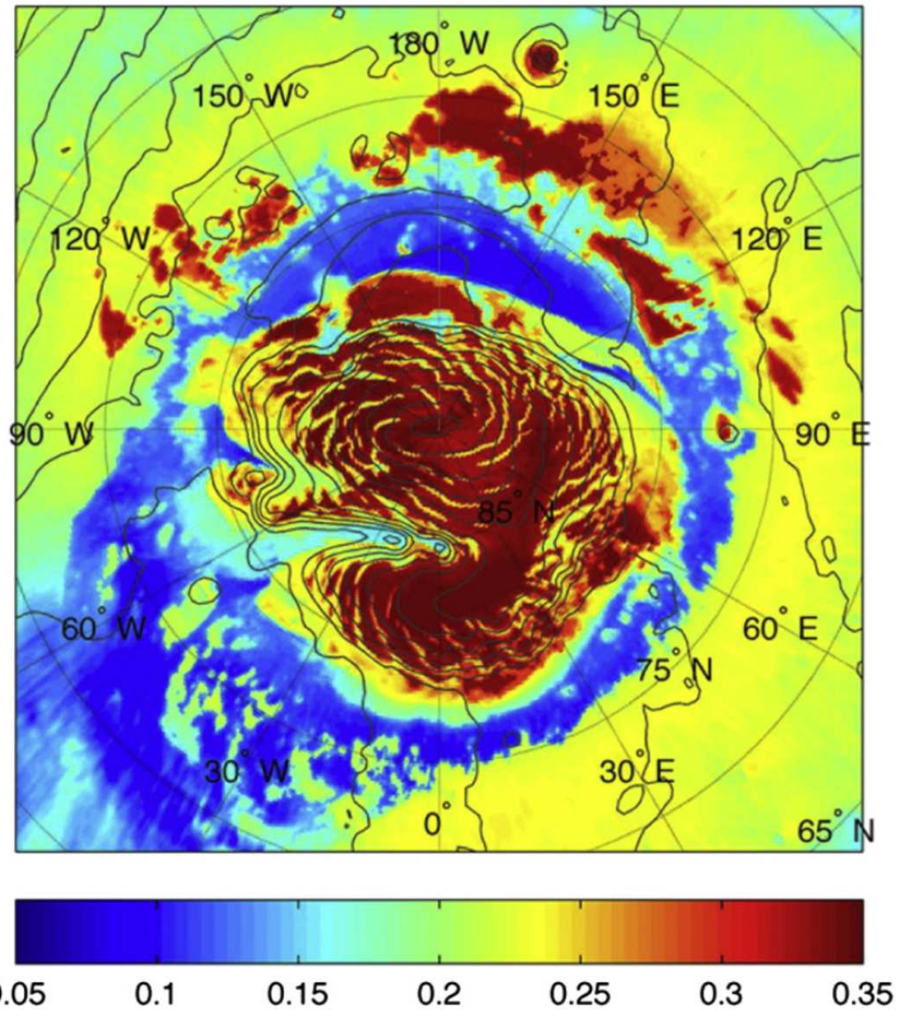
Parameters: solar irradiation

Mars Climate Database





Parameters: albedo



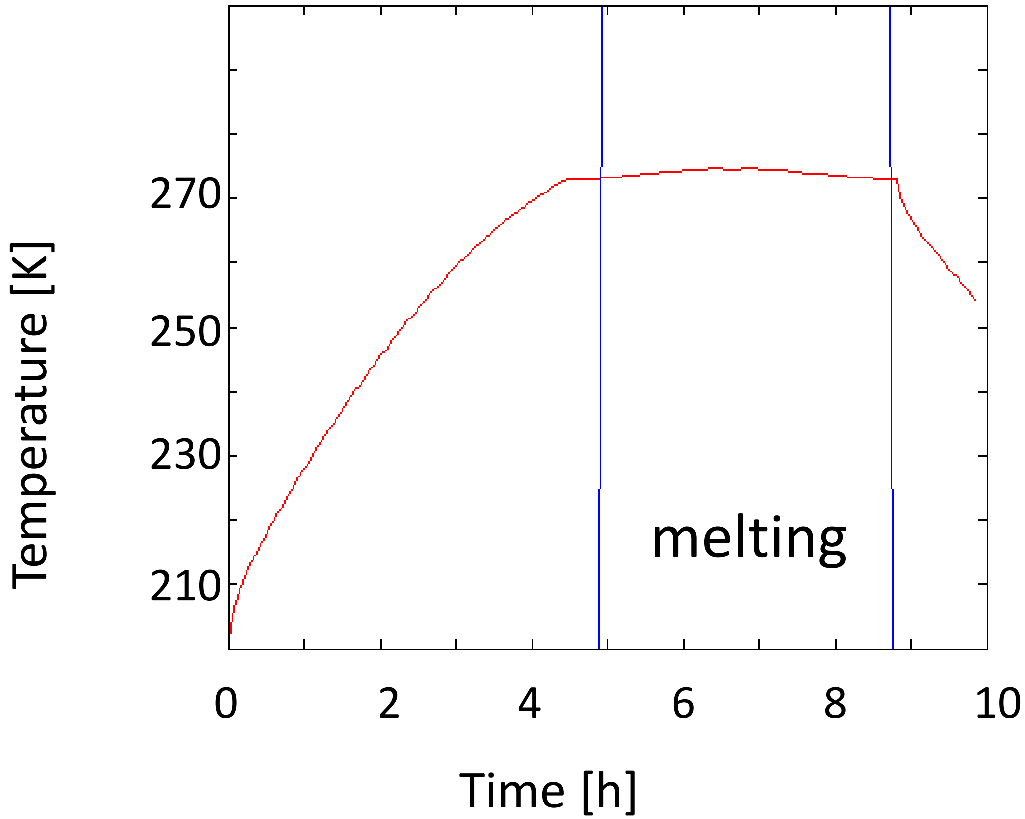
Albedo = 0.13

- measured from OMEGA by M. Massé (personal communication)
- in agreement with Paige et al. 1994
- In agreement with Tyler and Barnes (2014).

The average (over eighth degree resolution) albedo of the dune field is ~0.1 and locally it can be as low as 0.05 Tyler and Barnes (2014).

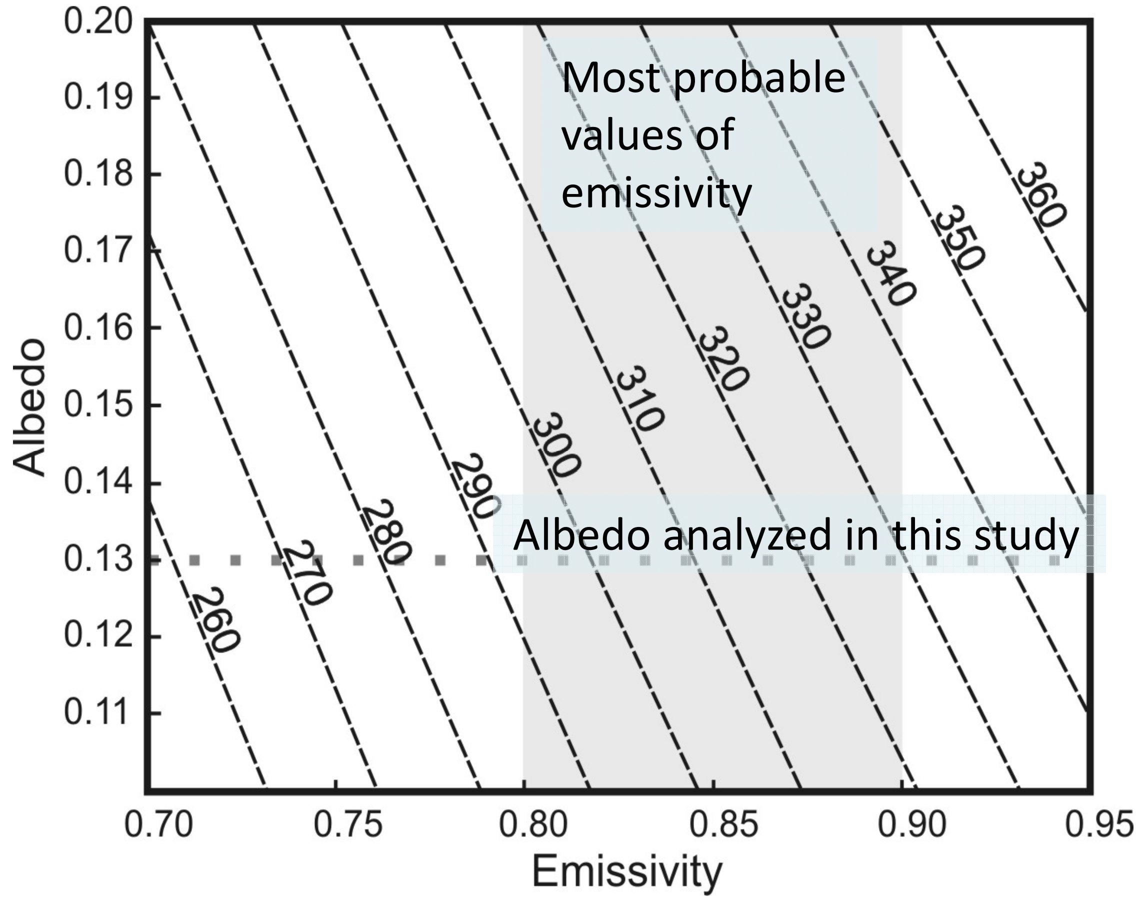
Melting of ice on Mars

S=492 W m^{-2}
k=0.09 W K^{-1} m^{-1}
A= 0.13



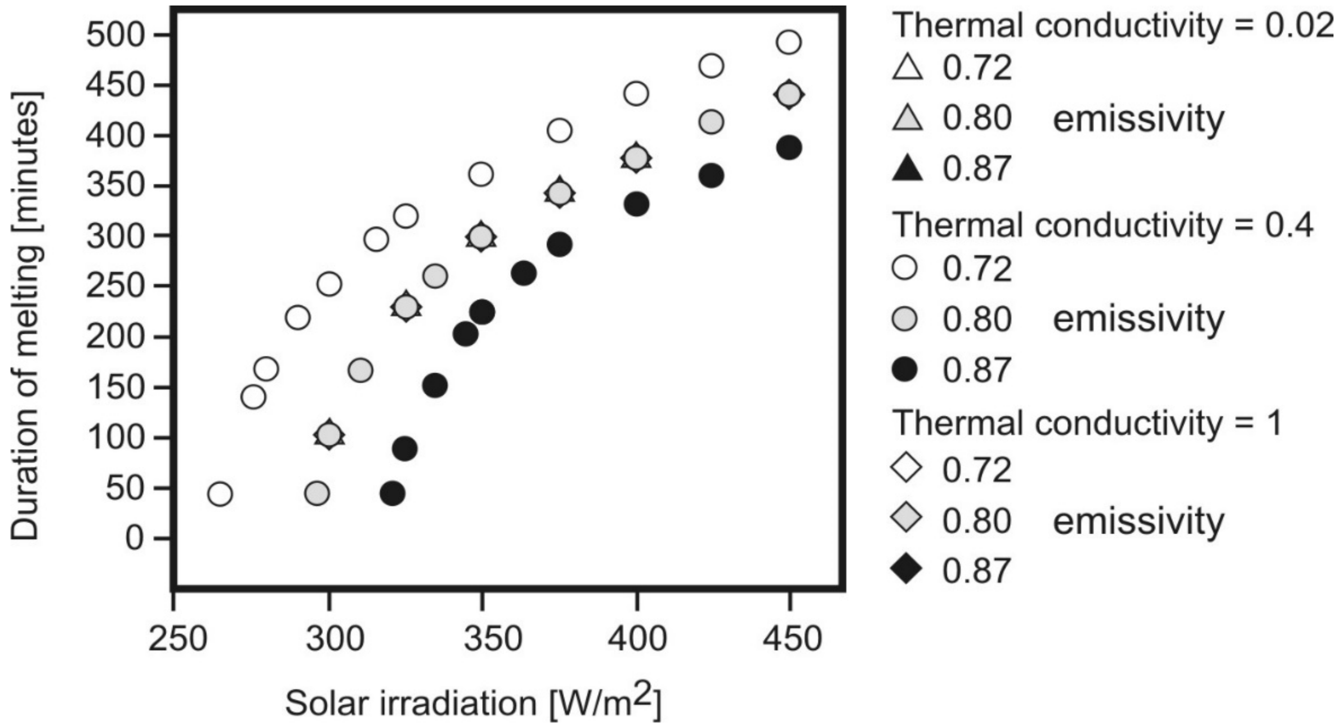
Temperature profile **below the grain (200 µm)** vs. time. Simulation covers 0.4 Martian day. The local noon is approximately at time = 5 h.

Min Solar irradiation required for melting



Minimum solar irradiation (S) required for heating the surface of dust layer (laying on a porous-dusty firn exposed within equatorial facing slopes of NPRC spiral troughs), to 273.15 K as a function of albedo A and emissivity E of the dust grains.

Duration of melting

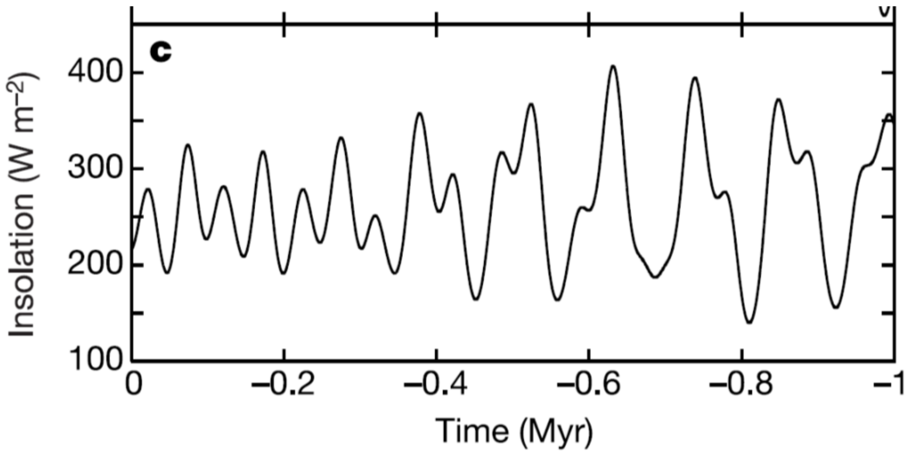


Duration of melting for different values of solar irradiation, dust layer emissivity and thermal conductivity of a porous-dusty firn. The duration of melting increases with increase of solar irradiation and decreases with increasing emissivity.

Curent ephemeric liquid water on NPRC

Liquid water present for up to few hours

- Rate of melting sufficient to sustain rate of evaporation measured by Hecht 2002
  - Not free Surface!
  - Protected by dust or ice lid (Mohlmann 2010)
- Brines
  - Duration (Mohlmann 2010, Mohlmann and Kereszturi 2010)
  - Probability of occurrence
  - Decrease evaporation rate
- Changes in solar irradiation (Laskar et al. 2002).

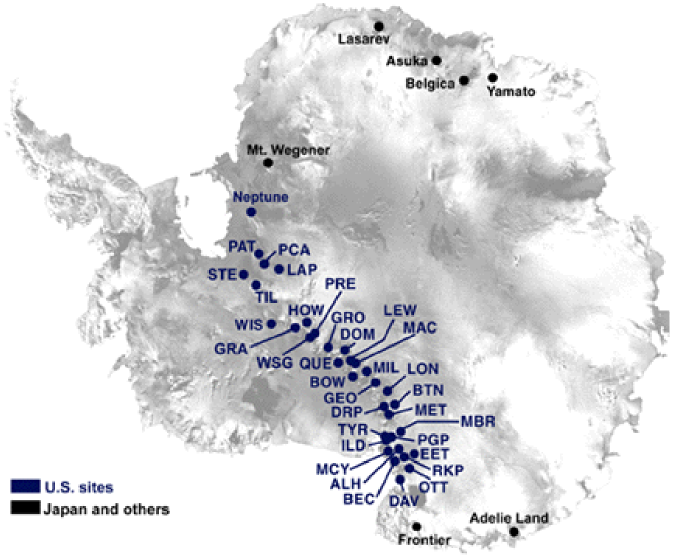


Why would that be enough for evaporites formation?

Discussion

- 5% ANSMET meteorites have evaporites visible in hand sample (Losiak and Velbel 2011)
- Others have evapirites visible under microscope
  - Nesquehonite $Mg(HCO_3)(OH)\cdot 2H_2O$
  - Hydromagnesite $Mg_5(CO_3)_4(OH)_2\cdot 4H_2O$
  - Epsomite $MgSO_4\cdot 7H_2O$
  - Starkeyite $MgSO_4\cdot 4H_2O$
  - Gypsum $CaSO_4\cdot 2H_2O$
  - Jarosite $KFe_3(OH)_6(SO_4)_2$
  - Smectites

  (Yabuki et al. 1976, Marvin 1980, Gooding 1986, Jull et al. 1988, Velbel et al. 1991)
- Rapid formation of evaporites
  - ^{14}C dating (Jull et al. 1988)
  - Meteorites enclosed within ice (Harvey and Score 1991, Krahenbuhl and Langenauer 1994)
- Up to few occurences every season of liquid water (Harvey 2003)



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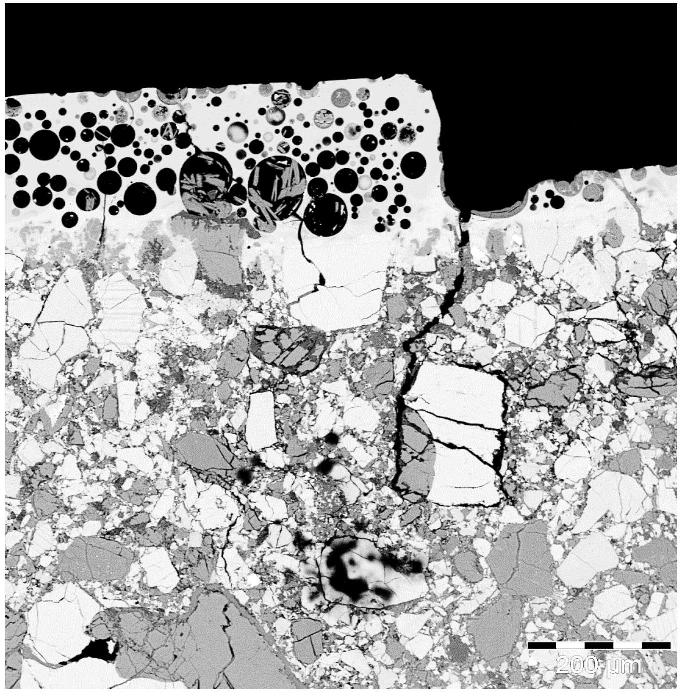

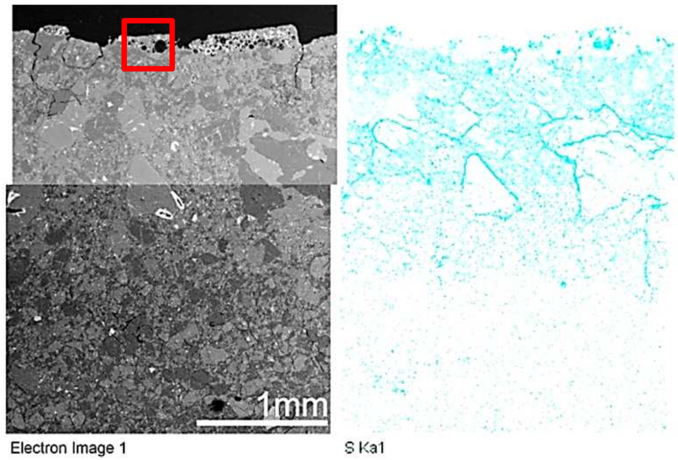

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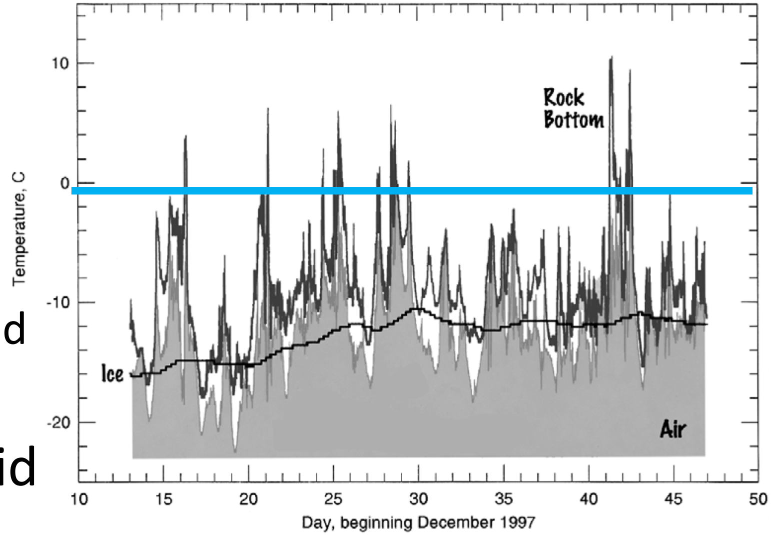


Harvey 2003

Why would that be enough for life formation?

Discussion

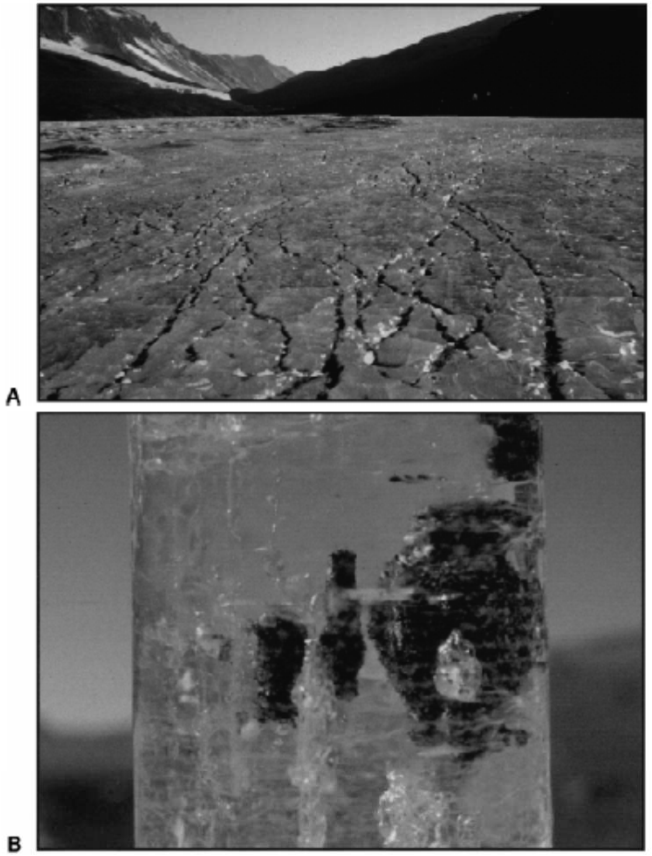
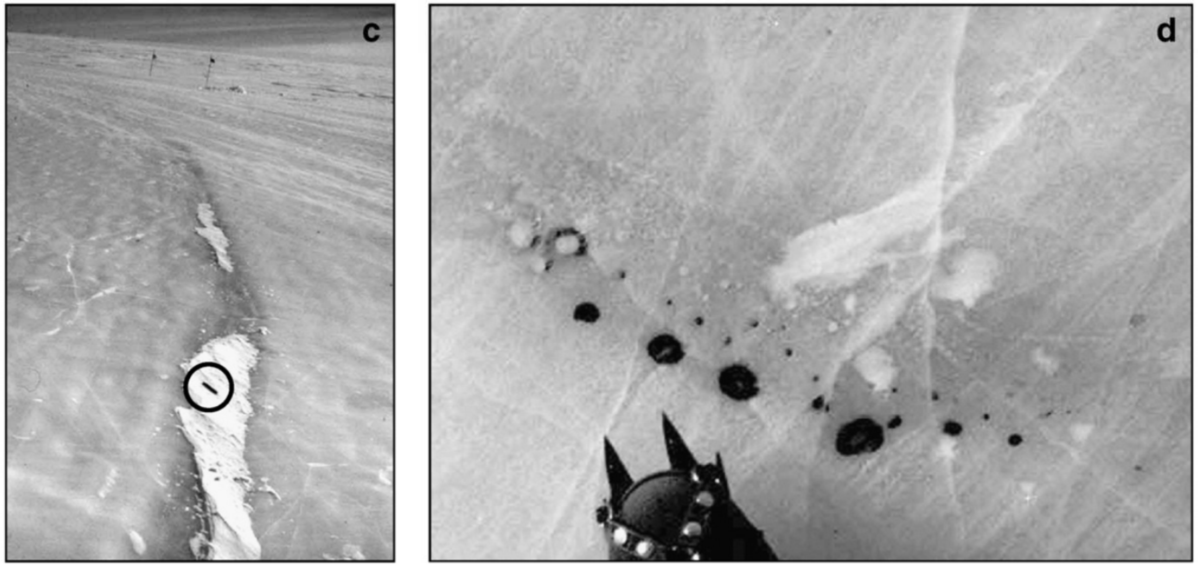
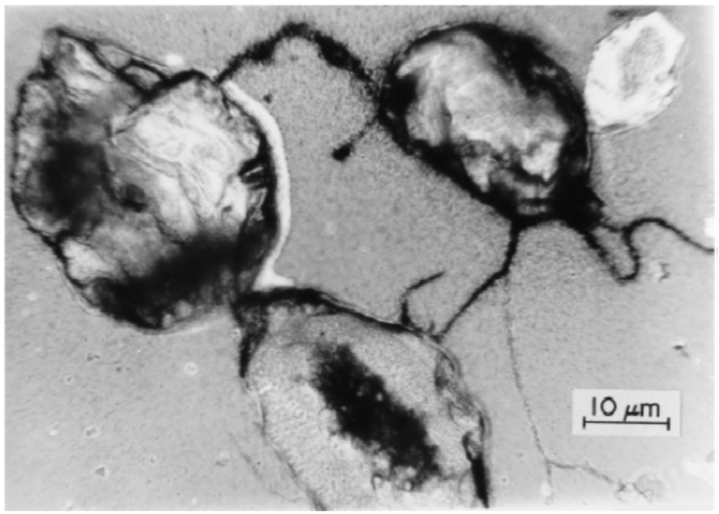


Fig. 1. (A) The permanent ice cover on Lake Bonney, McMurdo Dry Valley Lakes Region, Antarctica. Note ridges and depressions in the ice cover, which trap wind-blown soil particles as aggregates. (B) Side view of an ice core taken from 1.5 m depth in Lake Bonney's (East Lobe) ice cover. Soil aggregates (1–2 cm across) can be seen embedded in the core.



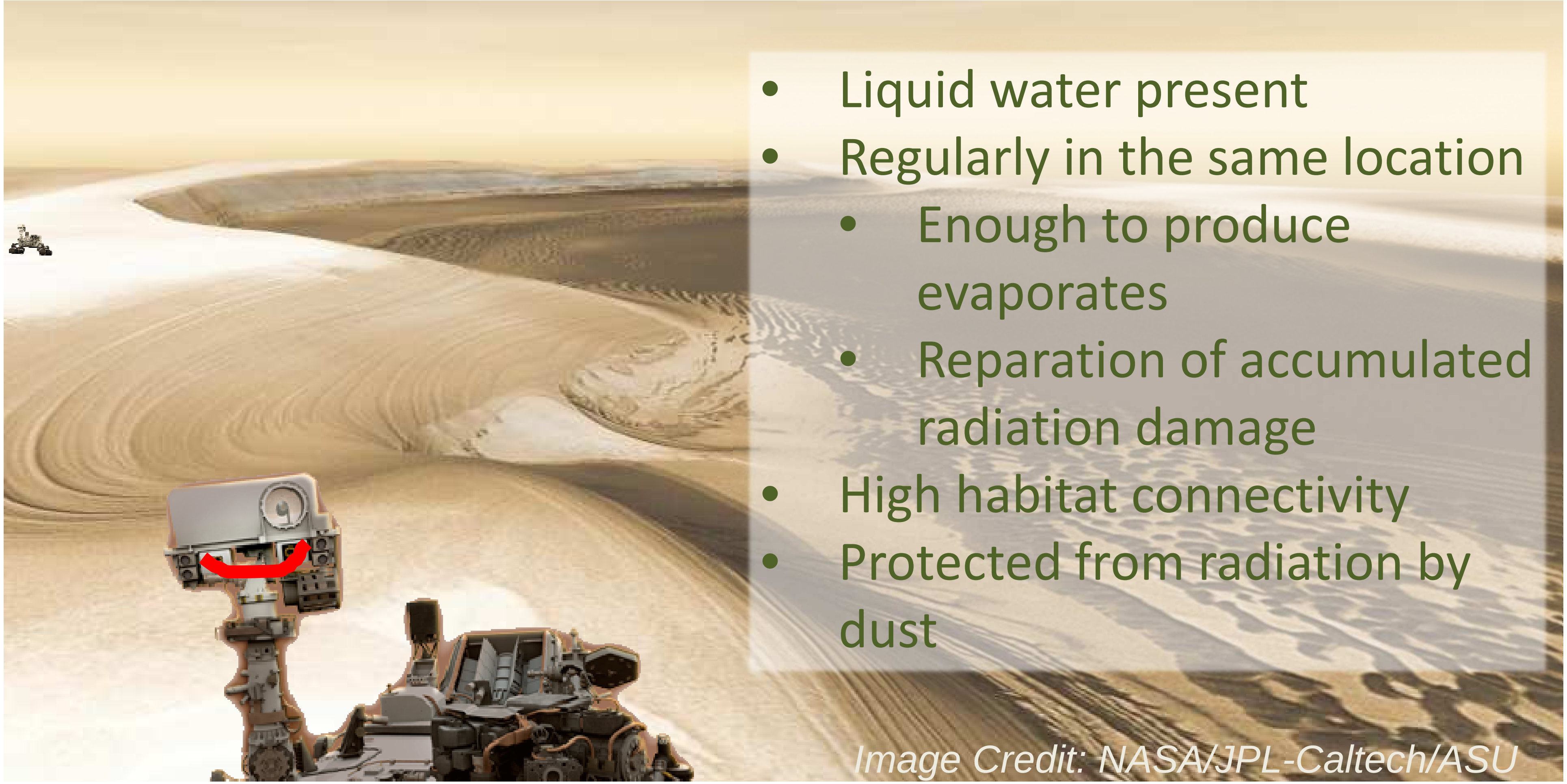
(Harpel et al. 2008)



(Paerl and Priscu 1998)

Astrobiological mission to the North Polar Residual Cap

Conclusions



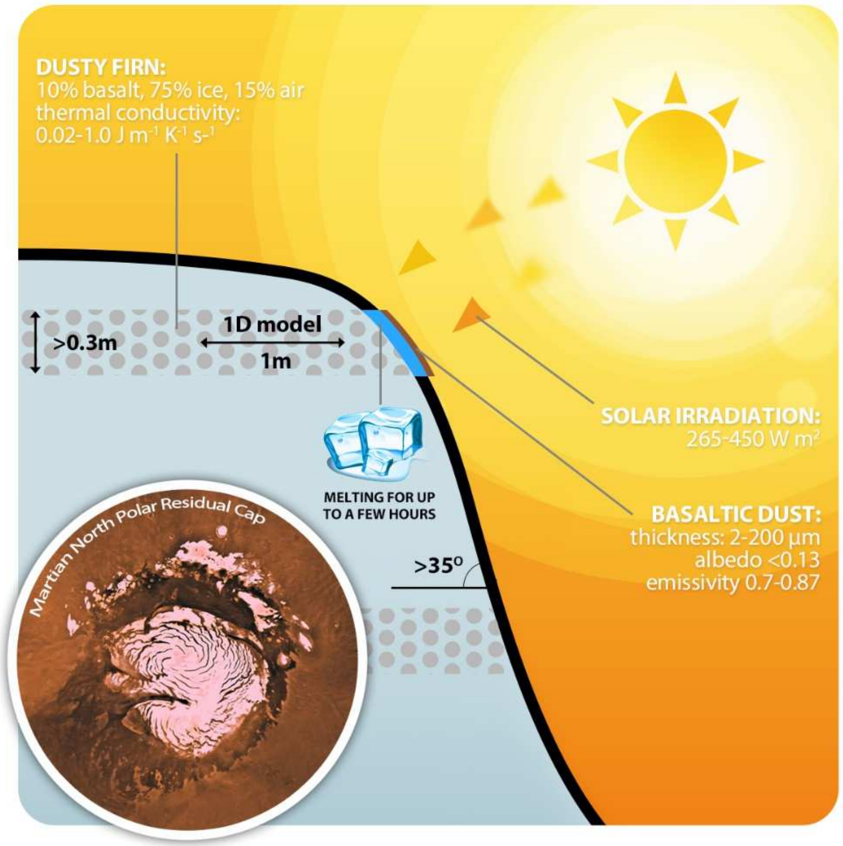
- Liquid water present
- Regularly in the same location
  - Enough to produce evaporates
  - Reparation of accumulated radiation damage
- High habitat connectivity
- Protected from radiation by dust

Image Credit: NASA/JPL-Caltech/ASU

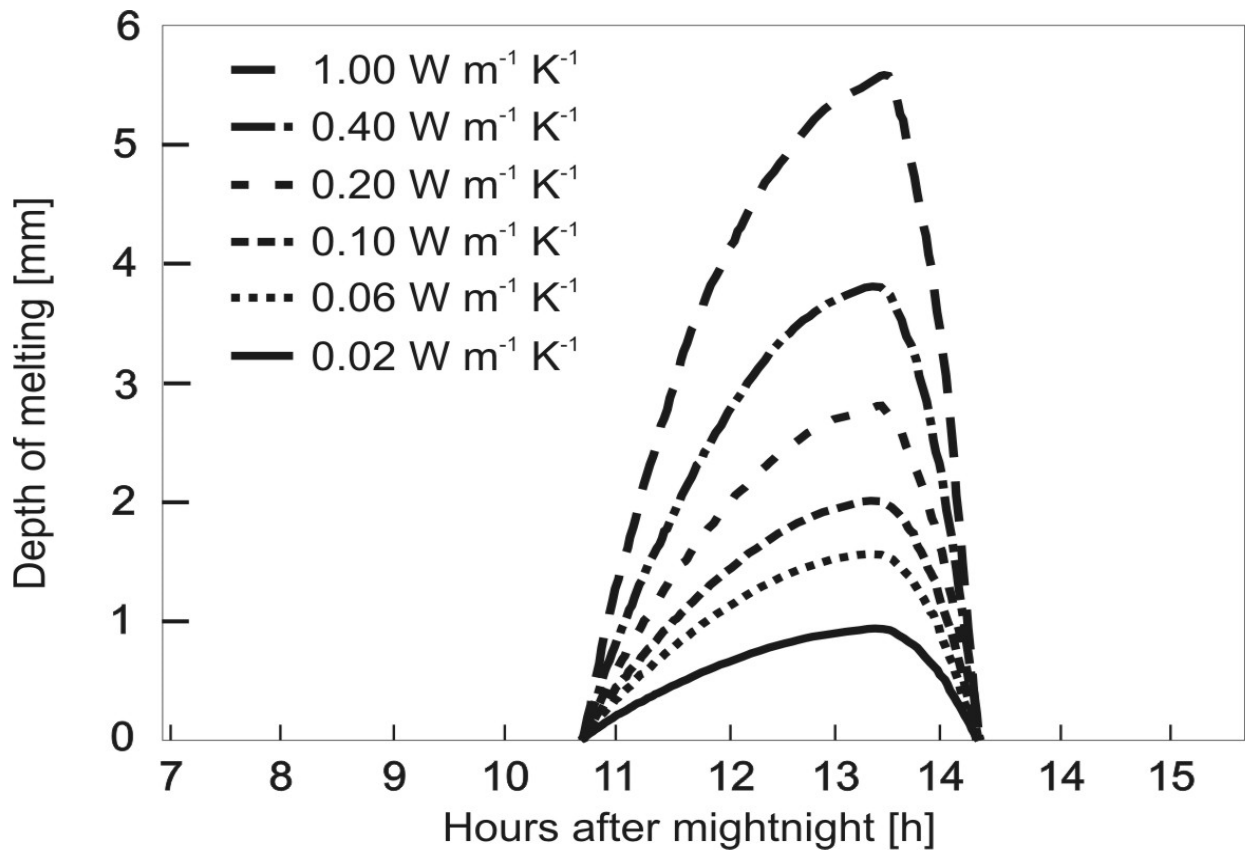
Conclusions

Current Ephemeral liquid water on the surface of Martian NPRC

- Melting depends on
  - solar constant
  - heat conduction of dirty ice
  - IR emissivity of a grain
  - NOT on grain size
- Ice melting for up to few hours.
  - Possibly sufficient to form evaporites and sustain life

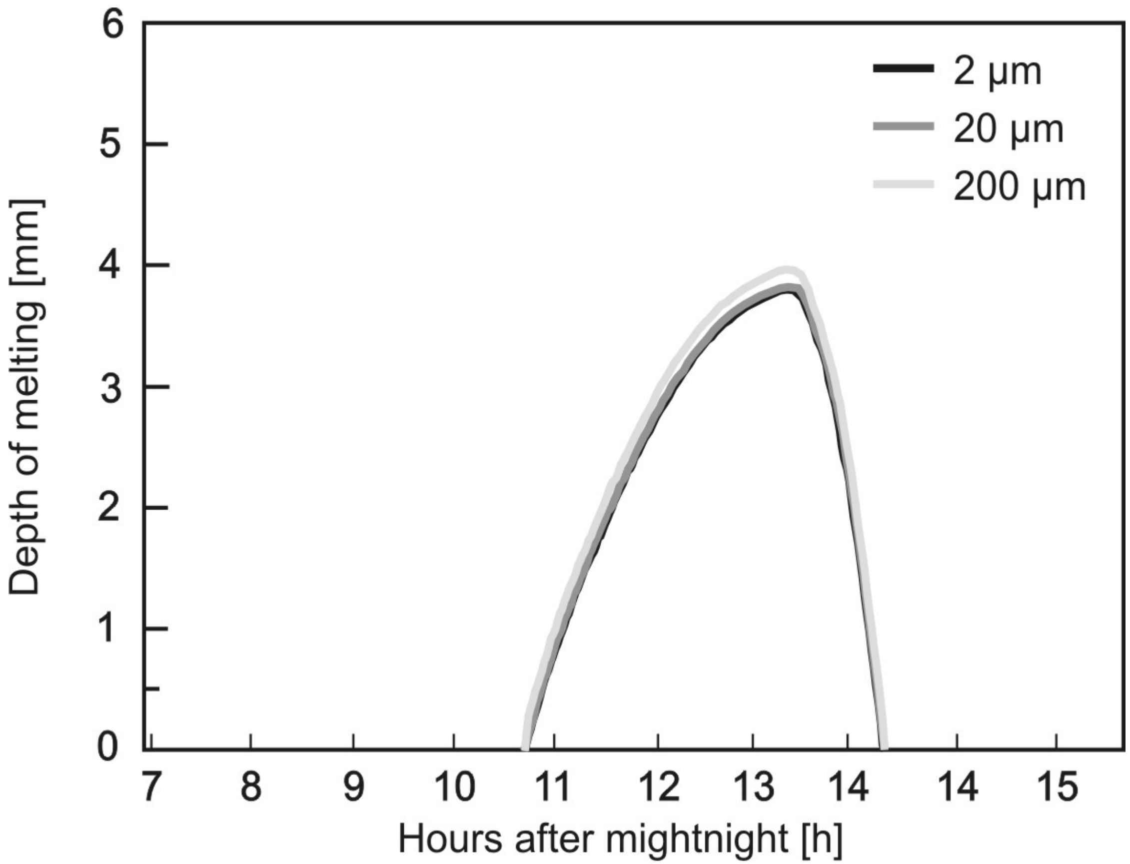


Influence of thermal conductivity



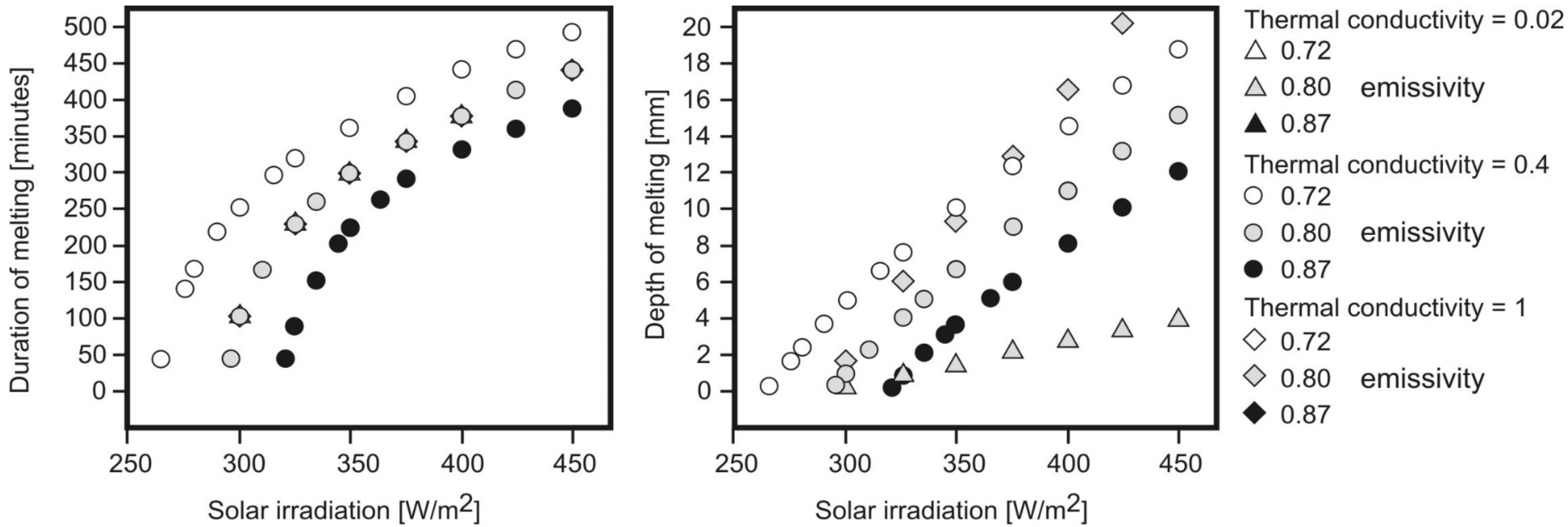
Depth and duration of melting for the range of thermal conductivities used in this study for the same value of S = 350 W m-2 and E = 0.87. Depth of melting increases with thermal conductivity, while the duration of melting does not change.

Influence of dust layer thickness



Depth and duration of melting for different dust layer thickness and the same value of S = 350 W m-2 and e = 0.87, k = 0.4 W m-1 K-1.

Duration of melting



Duration of melting for different values of solar irradiation, dust layer emissivity and thermal conductivity of a porous-dusty firn. The duration of melting increases with increase of solar irradiation and decreases with increasing emissivity.