Influence of subsurface properties on water ice and methane clathrate stability on Mars

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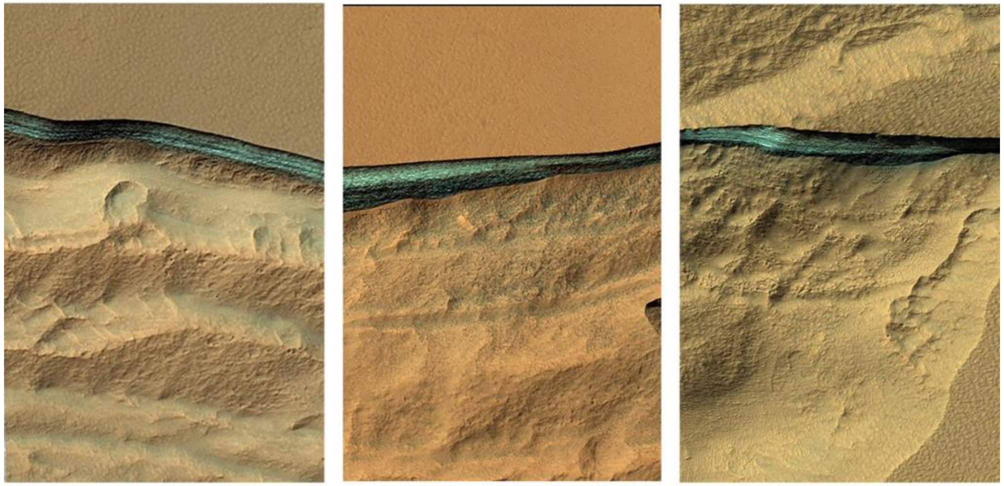

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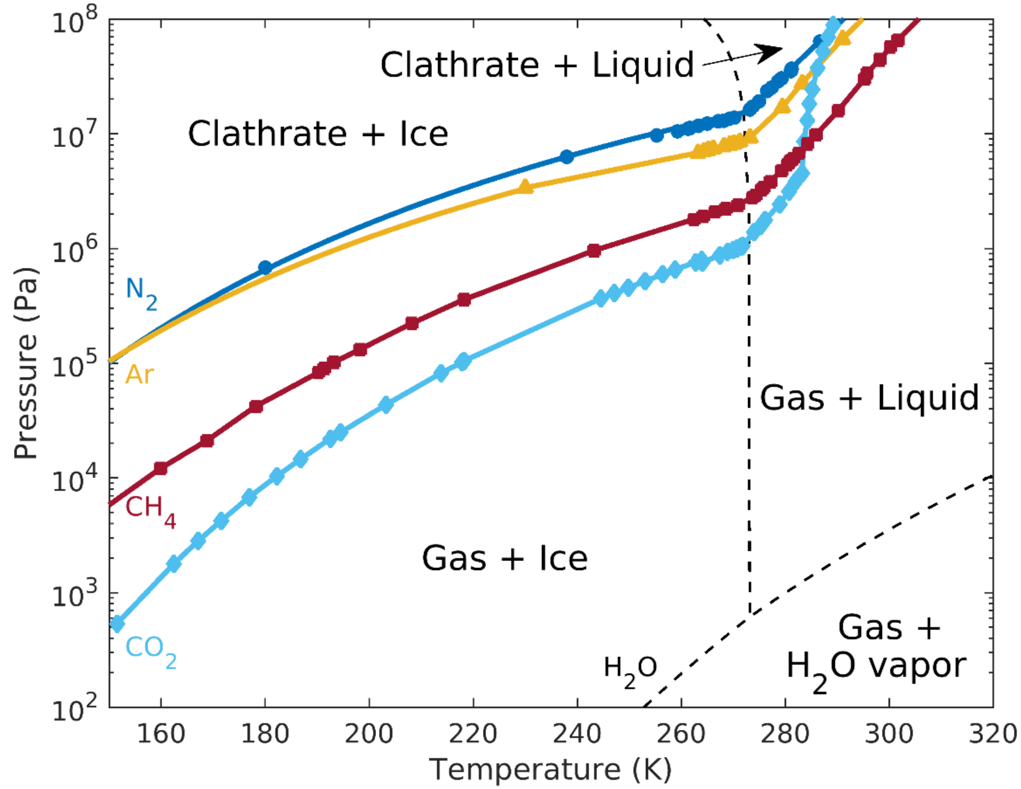
Models

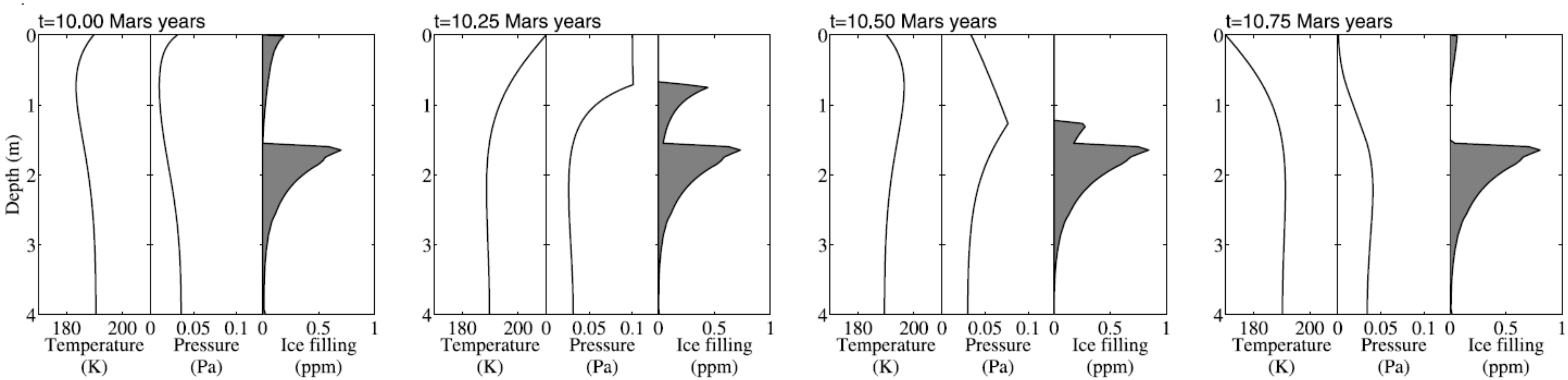
1. Clathrate stability conditions determined using an approach similar to Thomas et al. (2009).

   → This model is coupled to a 1D thermal model to obtain clathrate stability zone variations in the subsurface of Mars.

2. The diffusive model used to study water ice stability is based on the work of Schorghofer and Aharonson (2005).

Phase diagram of H_2O (black dotted line) and stability curves of CH_4, CO_2, N_2 and Ar clathrate hydrate.

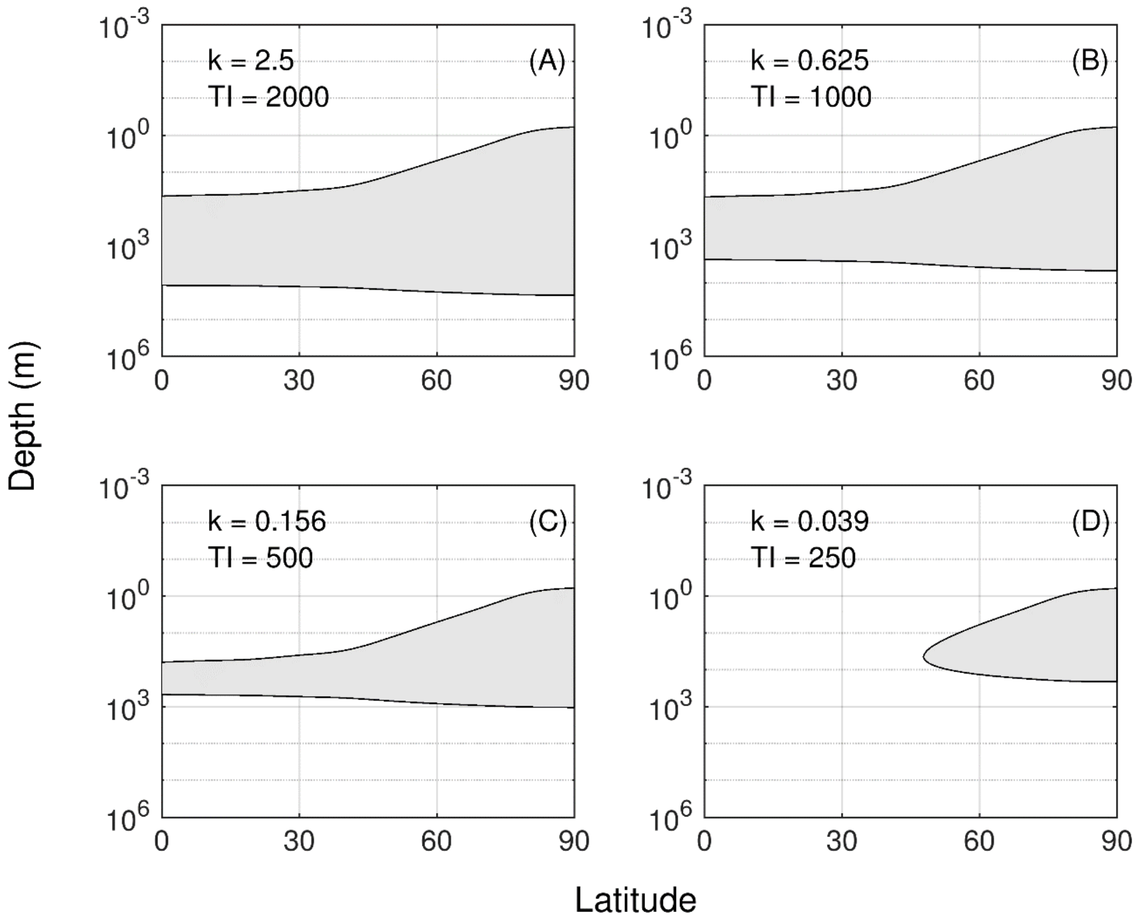




Schorghofer and Aharonson (2005)

Methane clathrate: variation of thermal inertia

- Methane clathrate stability zone can significantly vary depending on the subsurface composition.



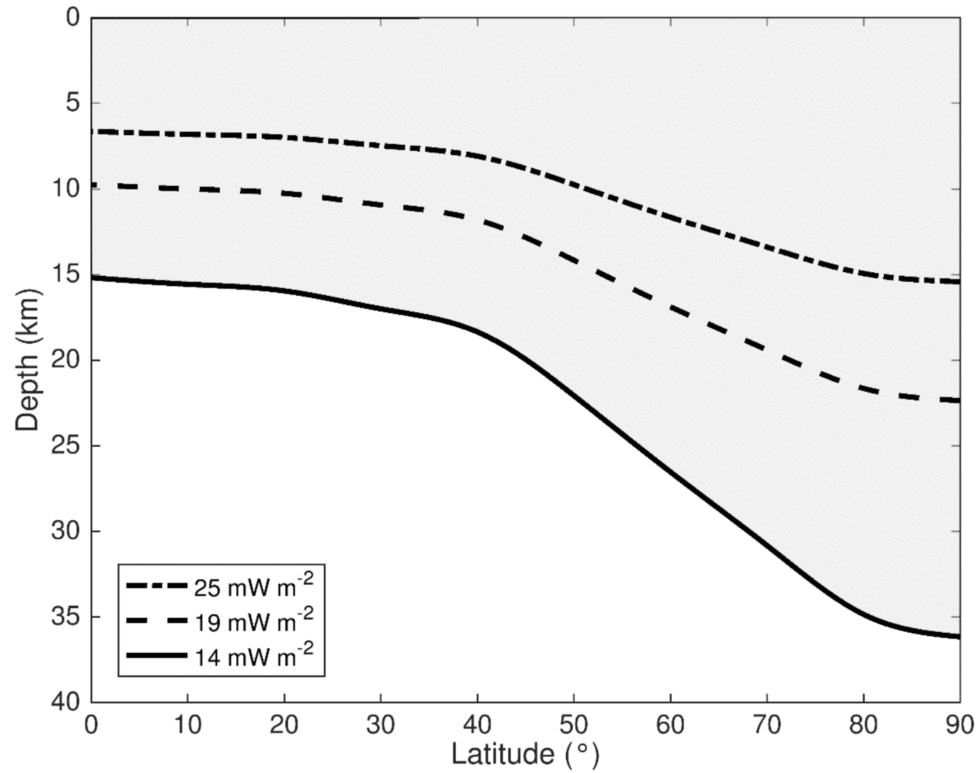
- Stability zones are calculated using mean annual surface temperatures and assuming a surface heat flow of 19 mW m^{-2}, the present-day average value (Parro et al., 2017).

Hydrate stability zone of simple CH_4 clathrates in the martian subsurface for different thermal properties in the subsurface model corresponding to thermal inertia (TI) ranging from 250 to 2000 J m^{-2} K^{-1} s$^{-1/2}$. The volumetric heat capacity is kept constant (1.6 x 10^6 J K^{-1} m^{-3}) while the thermal conductivity *k* is changed to 2.5 (A), 0.625 (B), 0.156 (C) and 0.039 W m^{-1} K^{-1} (D) respectively.

Methane clathrate: variation of heat flow

- The heat flux also controls the depth of hydrate stability zone and mainly affects its base.

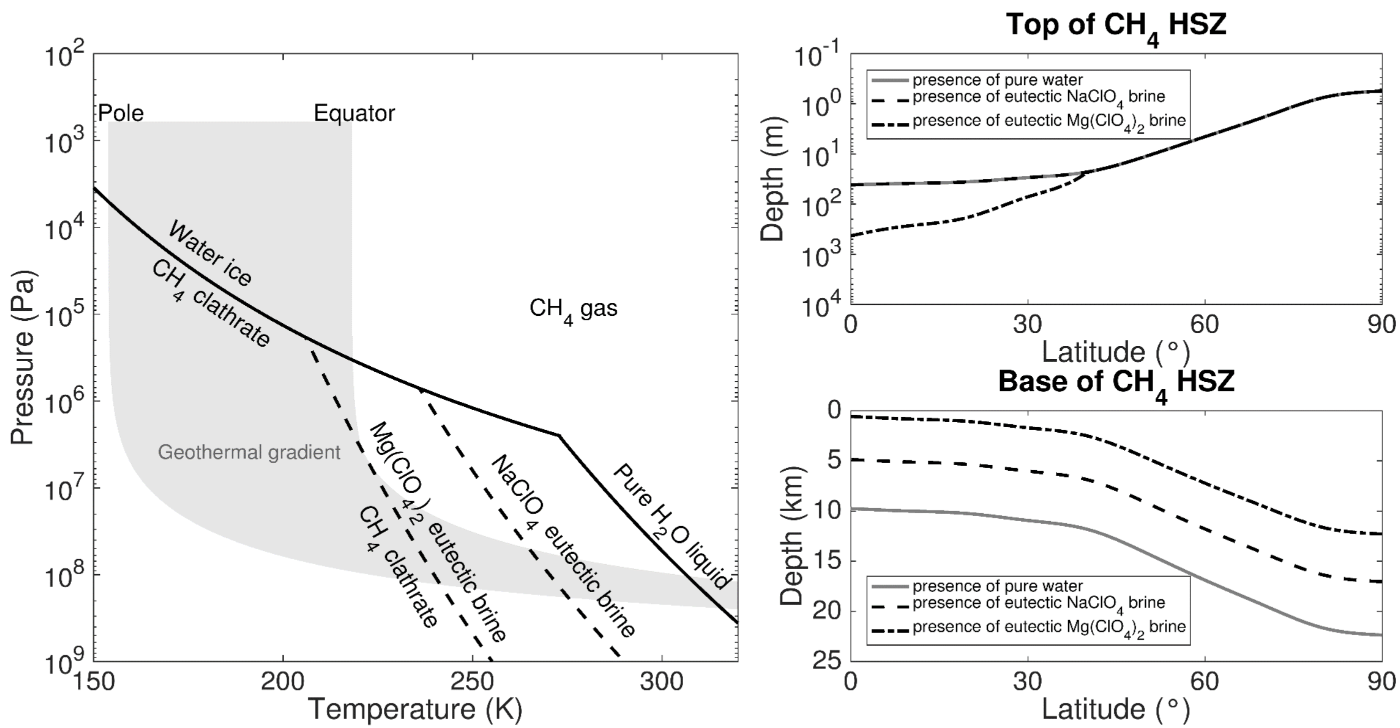
- The crust composition for this simulation was assumed to be basalt with CH_4 clathrates filling the pore spaces.



Variations in the depth of the base of methane hydrate stability zone as a function of latitude for different values of the heat flow (14, 19 and 25 mW m^{-2}).

Methane clathrate: formation in the presence of $Mg(ClO_4)_2$ eutectic brine

- When salinity increase, the dissociation curve of clathrate hydrates is shifted to lower temperature and higher pressure → upward shift of the base of the hydrate stability zone (HSZ).

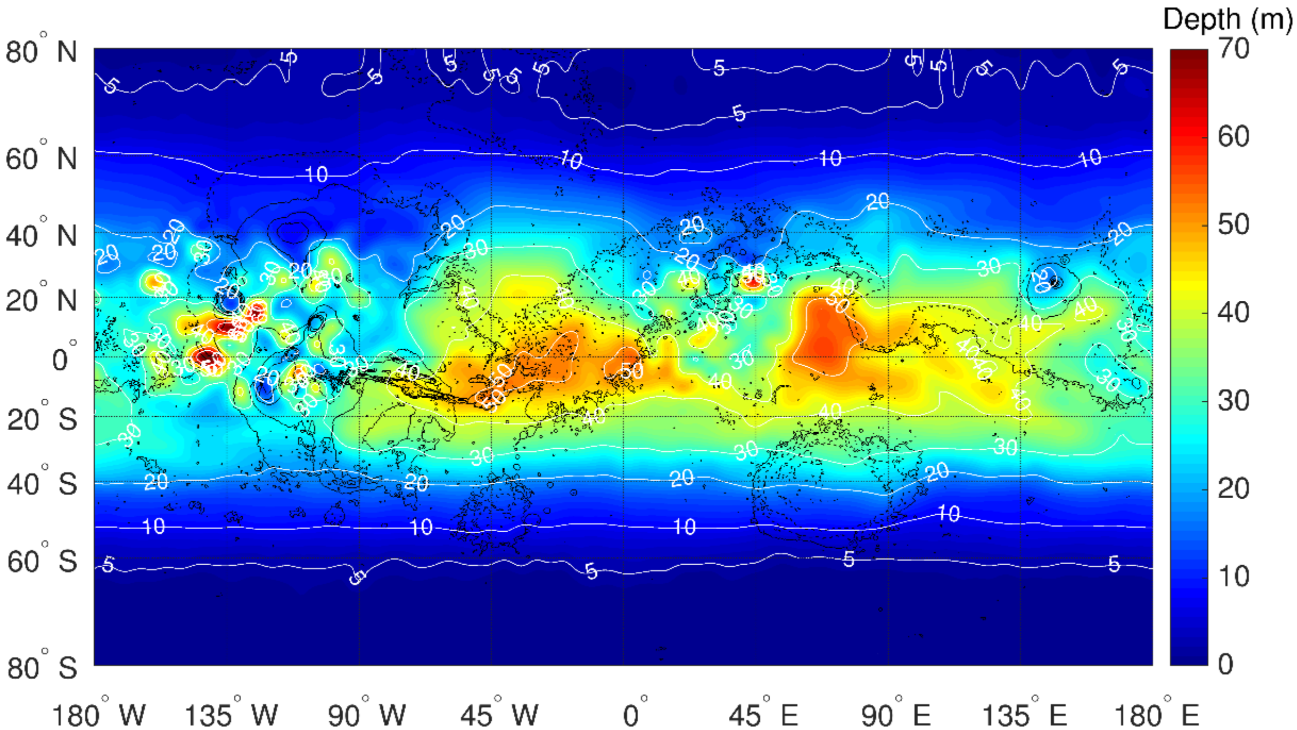


- $Mg(ClO_4)_2$ exhibits one of the lowest eutectic temperature of all salts (206K) and its presence, in addition to shift the base of HSZ, significantly affects the top of HSZ at low latitudes.

Methane clathrate: global map

Layers in subsurface model (0 → 100m)

- Between 50°N and 50°S: 1st layer (1m) = TI derived from TES MGS observations, 2nd layer = dry basalt
- From 50° to poles: 1st layer (50cm) = TI derived from TES MGS observations, 2nd layer = ice-cemented soil

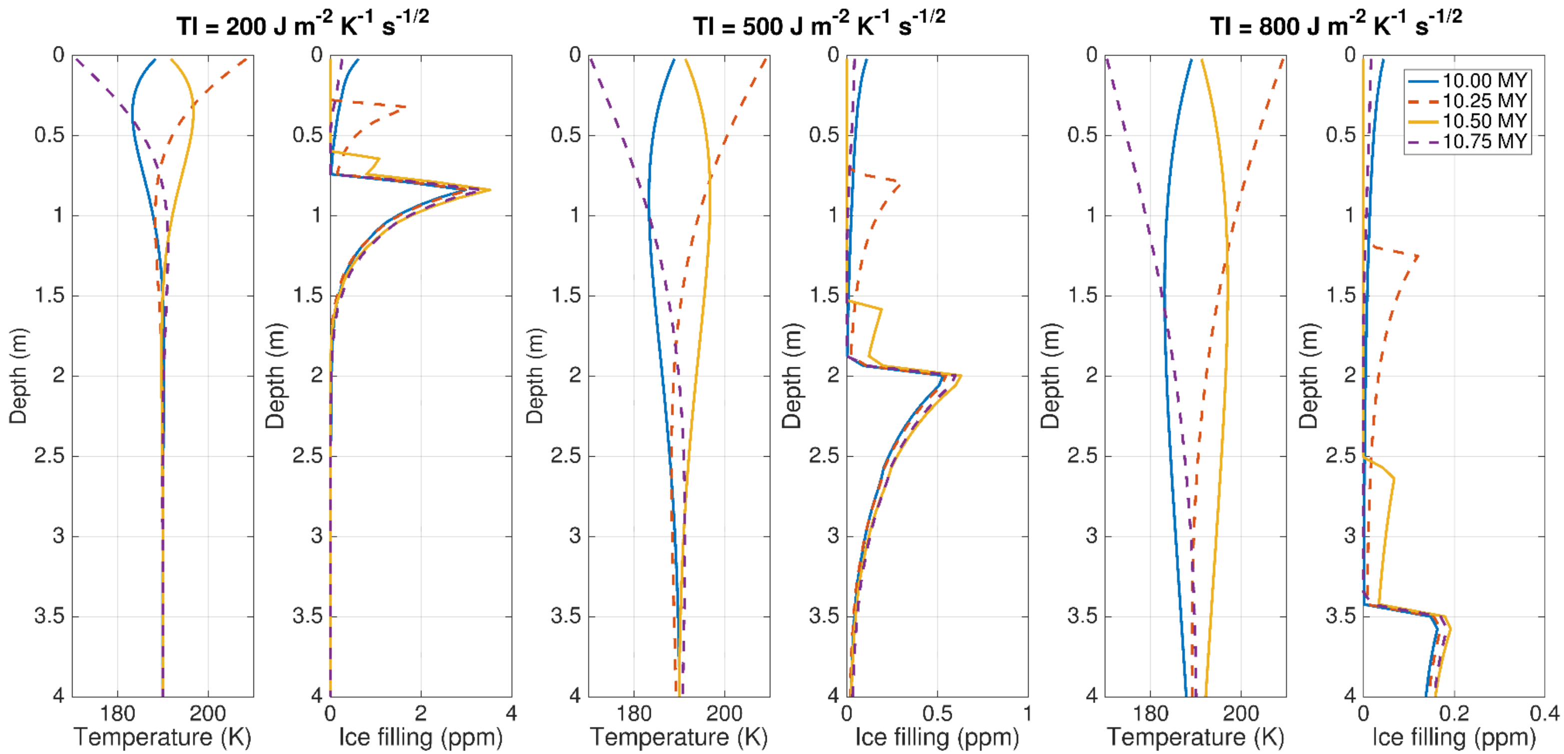


Depth (m) of the top of hydrate stability zone in present-day martian subsurface for CH_4-rich clathrates formed from a gas phase with 90% of methane.

- ➢ CH_4-rich clathrates are stable close to the surface with a stability zone strongly dependent on the average annual surface temperature.

Water ice: variation of thermal inertia

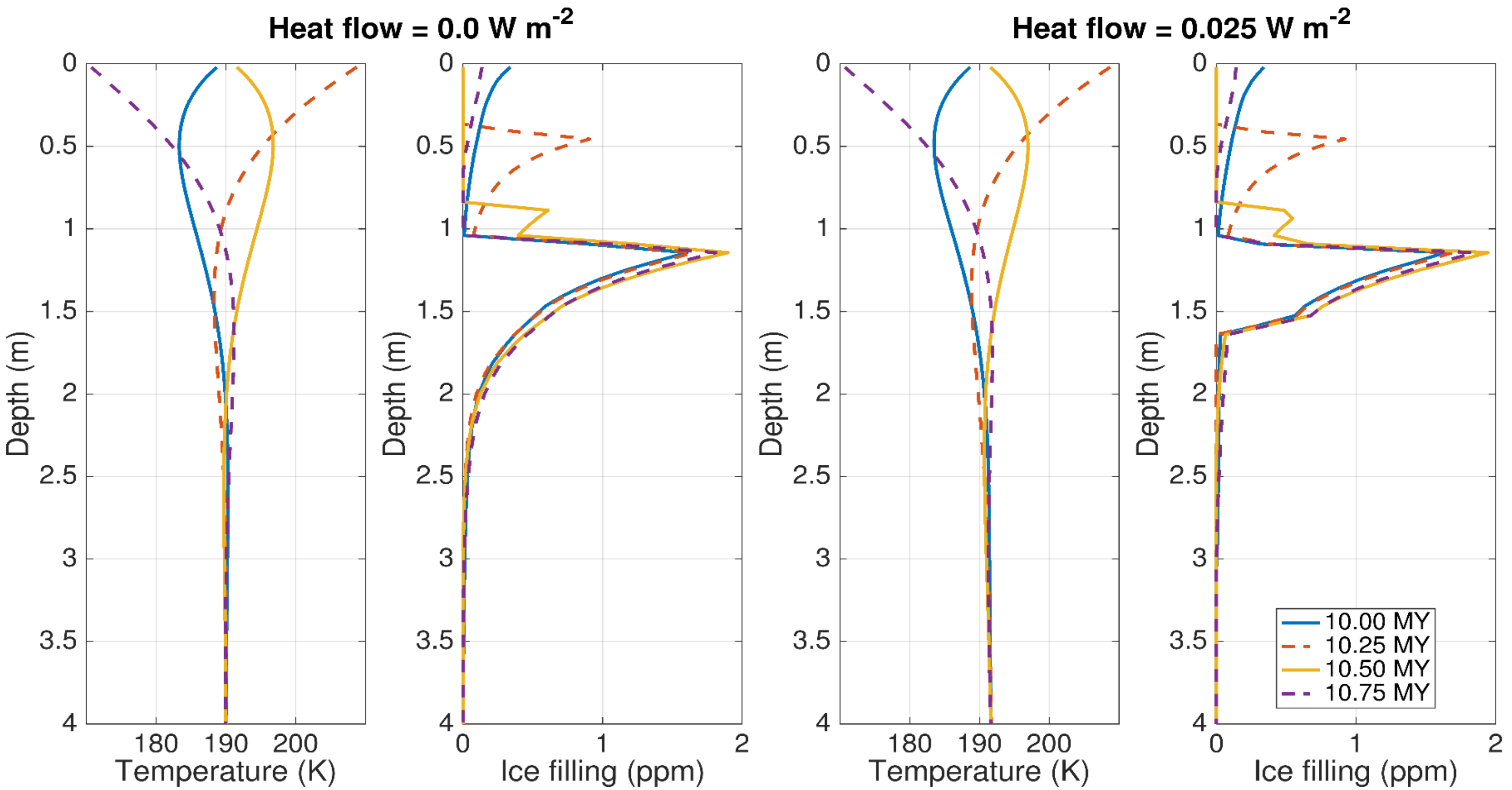
- Thermal inertia has a large influence on both the ice table depth and the amount of ice in the regolith.



Subsurface temperatures and fraction of pore space filled with ice after 10 Martian years for different thermal inertias.

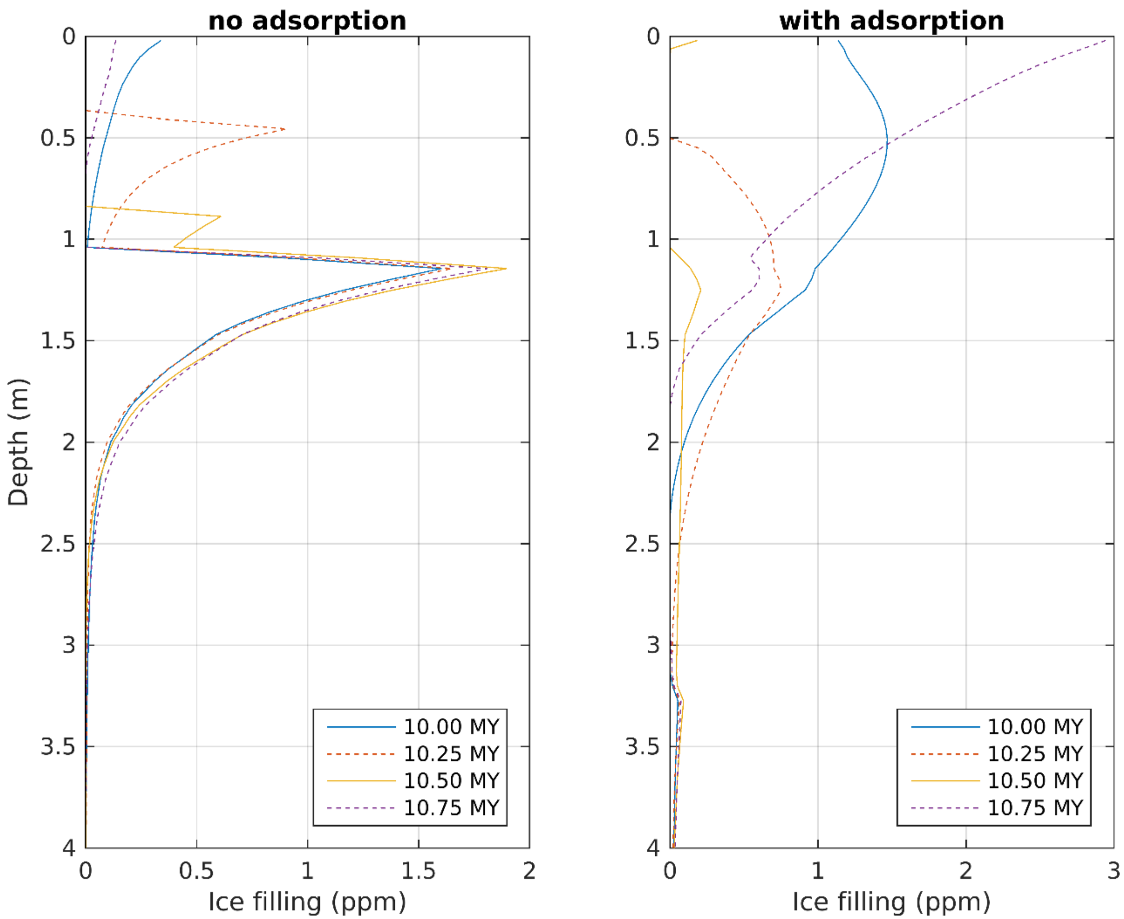
Water ice: variation of heat flow

- The ice distribution is affected by the heat flow due to the increase of the temperature.



Subsurface temperatures and fraction of ice in pore space after 10 Martian years, calculated with a heat flow of 0.0 W/m^2 (left) and 0.025 W/m^2 (right).

Water ice: adsorption



Ice filling profiles after 10 Martian years calculated without adsorption (left) and with adsorption (right).

With adsorption:

- Much larger variations in the amount of ice.
- No direct pattern of the downward migration of ice.
- The amount of ice increases with the specific surface area.

The temporal change in the surface flux of water vapour and in the total mass of ice in the subsurface has a larger amplitude when adsorption is taken into account.

Conclusions

- The presence of CH_4-rich clathrates on Mars depends on many factors:
  - Thermal history and composition of the crust
  - Obliquity variations
  - Dissociation rate of clathrates
  - Amounts of methane available in the subsurface or in the early martian atmosphere

  → The current stability zone of CH_4-rich clathrate hydrates is close to the surface and the destabilization of these reservoirs could provide methane releases in the atmosphere of Mars.

- Dynamics of atmospherically derived ground ice has been investigated under idealized conditions:
  - The ground ice table forms in depths above the annual skin depth, as a function of the thermophysical properties of the soil.
  - The quantity of water exchanged periodically is strongly affected by adsorption.

- These results have strong implications on subsurface gas transport and methane outgassing scenarios on Mars that is among the main objectives of ExoMars Trace Gas Orbiter.