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Surface processes on Mars with the potential for episodic trace gas release

M. R. Patel, A. H. Stevens, S. R. Lewis
Department of Physical Sciences, The Open University, UK (manish.patel@open.ac.uk)

Abstract

We model the transport of gas through the martian subsurface in order to quantify the timescales of release of a trace gas with a source at shallow depth using a Fickian model of diffusion through a putative martian regolith column. The model is then applied to the case of methane to determine if diffusive transport of gas can explain previous potential observations of methane in the martian atmosphere.

We investigate which parameters in the model have the greatest effect on transport timescales and find that diffusive transport is very sensitive to the pressure profile of the subsurface, but relatively insensitive to the temperature profile. Uncertainties in the structure and physical conditions of the martian subsurface also introduce uncertainties in the timescales calculated.

Mass wasting events are shown to have the potential for the sudden destabilisation of clathrates in the shallow martian subsurface. Clathrate destabilisation is one potential mechanism for the release of large masses of trace gases into the martian atmosphere, with a resulting outgassing flux of >12 × 10^{-4} kg m^{-2} s^{-1} over <1 martian year.

1. Introduction

The aim of this study was to determine the timescale of trace gas transport in the martian subsurface, identify and quantify which controlling parameters have the biggest influence, and determine whether surface processes can have an influence on the emission of trace gases in the subsurface. In particular, we will quantify how relevant parameters alter the time it takes a trace gas to be transported to the surface-atmosphere interface. Investigating these properties will allow us to determine whether the source scenarios presented are compatible with recent observations of the martian atmosphere.

2. The model

Diffusion of gas through the martian subsurface is modelled here using a modified form of Fick's laws. The diffusivity is calculated at each depth grid space using

$$D_z = \frac{\phi(z)}{\tau(z)} D_{12} \left(\frac{T(z)}{T_{ref}} \right)^{\frac{3}{2}} \frac{P_{ref}}{P(z)} \tag{1}$$

and applied to give

$$\frac{\partial C_{bulk}}{\partial t} = \frac{\partial}{\partial z} \left(D_z \frac{\partial C_{pore}}{\partial z} \right) \tag{2}$$

where $\phi(z)$ is the porosity at depth, $\tau(z)$ is the tortuosity at depth, D_{12} is the free gas diffusivity of gas 1 in gas 2, T is temperature, P is pressure, C_{bulk} is the concentration in the geometric volume and C_{pore} is the concentration in the pore space within that volume. Using this equation, which is equivalent to the diffusive part of the model proposed by [1] but in this case neglects Knudsen diffusion, requires the concentration to be scaled between bulk geometric and pore volume.

Equation (2) is discretised using a Crank-Nicolson finite difference scheme. The boundary conditions of the system use a constant zero value condition in the layer of atmosphere above the top of the regolith column to simulate the effect of having a well-mixed atmosphere above that moves diffused gas away at timescales shorter than the diffusion from the surface. As the diffusion timescale across one grid space is of the order $\Delta z^2/D$, the trace gas is transported from the top layer of the subsurface to the bottom of the atmosphere in the order of 100 days. We consider any atmospheric concentration to be well mixed over timescales of more than 10^7 s, as 6×10^7 s is approximately one Mars-year [2-4].

3. Application

The model can provide timescales of release by defining a threshold amount of trace gas in the lower levels of the atmosphere (set to be equivalent to 1 ppb) and shows that for deep sources of trace gases such as methane (among others), release from sources such as serpentinisation or biogenesis could take many thousands of years to reach the surface and would be incompatible with observations of transient methane ‘plumes’ in Mars’ atmosphere [6].

However, clathrate hydrate deposits could exist close to the martian surface [5] and mass wasting events could act to destabilize the deposits, releasing the trace gas (such as methane) incorporated within them. Short lived mass wasting events such as avalanches or debris flows would be sufficient to provide the flux required to create a plume such as the one described by [6] over timescales of less than a martian year, as shown in Figure 1.

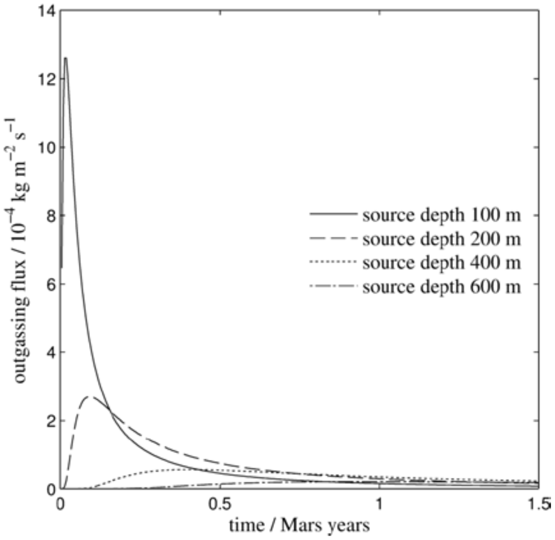

Figure 1 – The effect on source depth on outgassing flux over time for deposits of methane clathrate hydrate at 100, 200, 400 and 600 m being destabilised by discrete mass wasting events.

Simulations of seasonally varying sources can reproduce release into the atmosphere that is cyclic, tying well with observations such as [7]. However, it is difficult to reconcile subsurface sources that are influenced by seasonal temperature changes, though seasonal cycles of erosion and deposition could be responsible.

6. Summary and Conclusions

Results from simulations of release from methanogenesis or serpentinization at realistic depths, with a production rate based on geochemical modelling of serpentinization, show a large variation in the potential timescale, with the major controlling parameters being the source depth and subsurface pressure profile chosen. All of the timescales calculated are too long to account for short timescale variations in the atmosphere, as observed by ground based and orbital spectroscopy, though short period release into the atmosphere is possible from very shallow sources.

Simulations show that release of methane from destabilising clathrate hydrate sources due to transient mass wasting events can provide a short lived flux of methane into the atmosphere that could feasibly create a ‘plume’, as observed by [6]. Similar release caused by continuous erosion provides a slow and steady methane flux from the surface that reaches a steady state value and therefore cannot explain methane observations that show variable abundance over time.

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