Laboratory simulation of Martian atmospheric chemistry

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Laboratory simulation of Martian trace gas chemistry

Maria K. D. Duffy, Stephen R. Lewis, Nigel J. Mason & Manish R. Patel

Department of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, United Kingdom.
Contact: m.k.duffy@open.ac.uk

Introduction

Recently there has been a great deal of interest in the concentration and distribution of gases within the Martian atmosphere due to the observation of trace species such as methane [1,2] that could hold clues to currently unobserved processes such as volcanism or perhaps even life.

Mars Global Circulation Models (MGCMs) can predict both the seasonal and spatial variability of trace gases on Mars. Current models are very effective at predicting the variability due to transport (dynamical) processes [3] though there are only two MGCMs in the world that can model the effects of the chemical reactions that act on the gases [4,5].

To improve the accuracy of these models more must be learnt about the mechanisms and rates of these reactions under Martian environmental conditions.

The Laboratory Set-up

The UK-LMD MGCM is a state of the art MGCM developed by researchers from the Laboratoire de Météorologie Dynamique (LMD), France; the Instituto de Astrofísica de Andalucia, Spain and Oxford University and The Open University in the UK. The UK-LMD version utilises a spectral dynamical core [6] and a semi-lagrangian advection scheme [7,8] developed in the UK along with physical sub-models developed by researchers at LMD [9]. These sub-models include radiative transfer, cloud microphysics and a water cycle [3].

The chemical sub-model contains 16 species (CO₂, CO, O₃, O/², O/D, O₃, H, H₂, OH, HO₂, H₂O₂, CH₄, Ar, N₂, H₂O and H₂O vapour) undergoing 42 chemical reactions [4]. The concentration of each gas species is calculated every 30 minutes taking into account advection,vertical diffusion, convection and chemistry plus any effects of the CO₂ and water cycles.

The Problem

The reaction rates and mechanisms used are assumed to be the same as those for reactions occurring in the Earth's atmosphere but this might not be the case. Important differences between Earth and Mars:

- The average temperature of Mars is much lower and so reaction rates must be extrapolated to these lower temperatures.
- The bulk constituent on Mars is CO₂ experiments using CO₂ rather than N₂ or O₂ have been shown to increase the efficiency of certain three-body reactions by ~2.5 times [10].
- Basalt dust is an important constituent in the Martian atmosphere but not on Earth so it is possible that some reaction mechanisms haven’t yet been observed.

To characterise these effects on rates and mechanisms we must measure reactions under Martian conditions.

The UK-LMD MGCM

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An example: The effect of heterogeneous reactions on ozone

Heterogeneous chemistry involves reactions between species in different phases. In the Earth's atmosphere reactions that occur on the surface of liquid aerosols and solid particles in the air can be very important, particularly to reactive species such as ozone.

The figures to the right show zonally-averaged seasonal plots of ozone column density (µm-atm) on Mars. Figure A is a run using purely gas-phase chemistry in the chemical sub-model while in Figure B a suite of heterogeneous reactions have been added. These simulations were run using the UK-LMD version of the MGCM and agree with the published results for similar conditions from the LMD MGCM [4,11].

The model predicts the qualitative distribution of ozone well. In both Figures the maximum value of ozone column density occurs during polar winter (Winter solstice is at L=90° in the South and L=270° in the North). The maxima occur when the concentration of water vapour in the atmosphere is lowest. This is because species that form from the photolysis of water (HO₂=H₂O₂) catalyse the destruction of ozone.

However, the LMD team found that the predicted ozone distribution did not agree quantitively when compared with observations from the IR spectrometer aboard SPICAM [11]. The model underpredicted the maximum concentration at aphelion (L=71°) and in late summer where the ozone did not increase quickly enough to match the observations. This was remedied by the addition of heterogeneous reactions involving HO₂ occurring on the surface of water ice cloud particles seen in Figure B.

These are unlikely to be the only heterogeneous reactions of interest. Indeed, reactions that occur on the surface of dust particles will likely be important on Mars though laboratory simulations are required to characterise them as they are not currently well understood.

Summary

The study of trace gas chemistry on Mars is interesting as it offers clues into underlying active processes such as volcanism.

To understand observations of trace gases they must be modelled by MGCMs that are capable of predicting their seasonal and spatial distribution because of both transport and chemical processes.

Laboratory simulations of chemistry under Martian environmental conditions are needed both to improve the accuracy of current MGCM reaction schemes but also to identify possible new reactions of interest such as ones occurring on the surface of basalt dust particles.

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Background image: A Viking image showing the low thermal radiation atmosphere around Galle crater. Credit: NASA