Assimilating Martian atmospheric constituents using a global circulation model

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Assimilating martian atmospheric constituents using a global circulation model

Stephen R. Lewis, Liam J. Steele, James A. Horne, and Manish R. Patel
Department of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (stephen.lewis@open.ac.uk)

Introduction

The technique of data assimilation is employed in a novel way for a planetary atmosphere to perform a complete spatial and temporal reconstruction of martian atmospheric constituent data over periods of several Mars years. Observations of martian atmospheric constituents, generally made from orbiting spacecraft, are often sparse and incomplete. A global circulation model can be used to predict the transport, phase changes and chemical reactions that these species undergo. If constrained by observations, it can then provide a consistent interpolation to unobserved regions and, in principle, a useful a priori for future retrievals. Furthermore, any consistent mis-fit between the model predictions and new observations can be used to identify potentially important physical processes that are missing from the model, including inferring the presence and location of sources and sinks.

Data Assimilation

Data assimilation is the combination of observations and models, which provide physical constraints and propagate the observational information that is introduced. This offers some significant potential advantages for the analysis of atmospheric data from other planets [4]. Thermal and dust opacity observations have been successfully assimilated over a period of about eight Mars Years (MY), including data from the Thermal Emission Spectrometer (TES) aboard NASA Mars Global Surveyor (5, 6) in MY24–27 and Mars Climate Sounder (MCS) data from NASA Mars Reconnaissance Orbiter (MRO) in MY32–31. Previous work has focused on assimilation of temperature and total column dust opacity into a Mars global circulation model (MGCM), which includes the option of a coupled photochemical model [2, 3]. We now add assimilation of water vapour, water cloud aerosol and chemical species. Results shown in this paper for water vapour are for MY24–25 and for water ice and ozone for MY30.

Below: dust absorption optical depth at 9.3 μm, normalised to 810 Pa and averaged over longitude. This should be multiplied by about 2.6 to get a broadband visible dust total extinction. The data here are from [7]. assimilation gives similar zonally- and diurnally-averaged results.

Water Vapour Assimilation

The MGCM can include a full water cycle, coupled to the model radiation scheme. Retrievals of water vapour column data from TES [6] were assimilated into the model [9], resulting in the global water vapour column error in the MGCM changing from 2–4 μm-2 per grid point depending on season.

Left: zonal-mean water vapour mass mixing ratios for the two hemispheres. The left side shows the cloud-laden regions. Black contours show the mean integrated vertical column (10^9 kg/cm^2) and solid, dotted lines representing fixed vertical column (10^9 kg/cm^2) at 500 mbar. Dashed lines show the values for the northern and southern hemispheres. The right side shows the cloud-free regions. Black contours show the mean vertical column (10^9 kg/cm^2) at 500 mbar. Dashed lines show the values for the northern and southern hemispheres. The right side shows the cloud-free regions.

Below: water vapour column field in northern hemisphere summer (a) and (b) a model with outflowing ice deposits around the north pole, and (c) a model with the only the mean ice cap accounted for. The impact of outflowing ice deposits on the north pole ice cap increases between 75° and 120° E.

Observations

Assimilation

Ozone Assimilation

The Mars Color Image (MARCI) [1] observations provide near-deck global mapping of ozone column concentration. These data were used alongside MGCM temperature and dust opacity observations, which help to ensure a realistic atmospheric dynamical structure.

Ozone has been successfully assimilated into the MGCM and can be shown to improve the model’s predictive capability, although the system generally retains information from observations over only a short period. This is because the model is constrained with various observations of ozone in daylight. This is less of a problem in polar regions around winter, and assimilation of ozone is able to highlight differences in the structure of the Martian polar vortex when compared to a control model run.

Water Ice Assimilation

We have assimilated MGCM-typical data from a variety of sources. The model can be shown to improve the model’s predictive capability, although the system generally retains information from observations over only a short period. This is because the model is constrained with various observations of ozone in daylight. This is less of a problem in polar regions around winter, and assimilation of ozone is able to highlight differences in the structure of the Martian polar vortex when compared to a control model run.

Conclusions

The data set resulting from a constituent assimilation allows a detailed study of the atmospheric state that is not possible using observations or models alone. The MGCM has the ability to transport many independent tracers, so a wide variety of photochemically active and passive trace species can be assimilated simultaneously as observations become available.

Chemical data assimilation is a relatively new area of Mars research. Assimilation of even a single chemical species can provide constraints on other observed constituents and provide estimates for unobserved constituents. Chemical rate coefficients, primarily from laboratory experiments, can be tested by reconciling observational datasets and theoretical models. The assimilation of such observations should lead to improved in martian chemical models and better use of present and future observations, such as those from the 2016 ESA ExoMars Trace-Gas Orbiter.

References


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Background Image: Mars Exploration Rover Mission, Cornell, JPL, NASA.