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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 analysis 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 prior 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’s Mars Global Surveyor (6, 7), in MY24–27 and Mars Climate Sounder (MCS) observations from NASA’s Mars Reconnaissance Orbiter (MRO) in MY28–31.

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 poster for water vapour are for MY24–25 and for water ice and ozone are 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.

Ozone Assimilation
The Mars Color Imager (MARCI) [1] aboard MRO provides near daily global mapping of ozone column concentration. These data were used as Truth to assimilation and used to constrain the New Model of Atmosphere (NGM) used in this analysis. The assimilation uses the model to simulate the impact of the proposed observations on the model state, using the new observations to provide information on the model’s current state. The model’s output is then assimilated into the model, using a combination of observational and model-based information. This results in a more accurate and complete representation of the martian atmosphere, allowing for improved predictions and understanding of atmospheric processes.

Water Vapour Assimilation
The NGM can include a full water cycle, coupled to the model radiation scheme. Retrospective of water vapour column data from TES [6] were assimilated into the model [9], including the global water vapour column produced by the NGM in to around 2–4 µm per day on average. Left: zonal mean water mass mixing ratios for the southern hemisphere (a) winter, (b) summer, (c) autumn, and (d) winter. Right: zonal mean water ice mass mixing ratios for the southern hemisphere (a) winter, (b) summer, (c) autumn, and (d) winter. Contours show the mean zonal wind direction. These figures show the impact of assimilation on the model state, with improved agreement between the model and observations.

Water Ice Assimilation
The NGM can include a full water cycle, coupled to the model radiation scheme. Retrospective of water vapour column data from TES [6] were assimilated into the model [9], including the global water vapour column produced by the NGM in to around 2–4 µm per day on average. Left: zonal mean water mass mixing ratios for the southern hemisphere (a) winter, (b) summer, (c) autumn, and (d) winter. Right: zonal mean water ice mass mixing ratios for the southern hemisphere (a) winter, (b) summer, (c) autumn, and (d) winter. Contours show the mean zonal wind direction. These figures show the impact of assimilation on the model state, with improved agreement between the model and observations.

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 NGM 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 improvements 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.