

Assimilating martian atmospheric constituents using a global circulation model

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Introduction

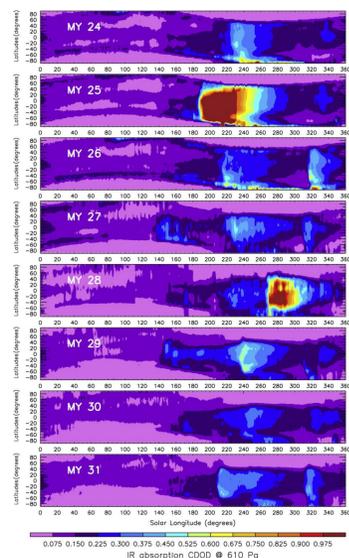
The technique of data assimilation is employed in a novel way for a planetary atmosphere to perform a complete spatial and temporal analysis of martian atmospheric constituent data over periods of several Mars years. Observations of martian atmospheric constituents, generally made from orbiting spacecraft, 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 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

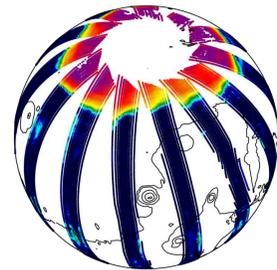
Data assimilation is the combination of observations and models, which provide physical constraints and propagate the observational information that is introduced. This offers some significant potential advantages for the analysis of atmospheric data from other planets [4]. Thermal and dust opacity observations 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) observations from NASA Mars Reconnaissance Orbiter (MRO) in MY28–31.

Previous work has focussed 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.

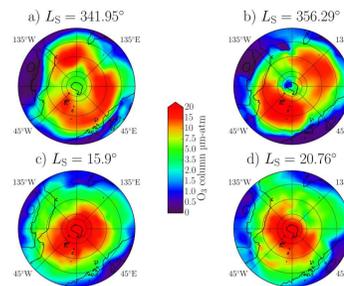
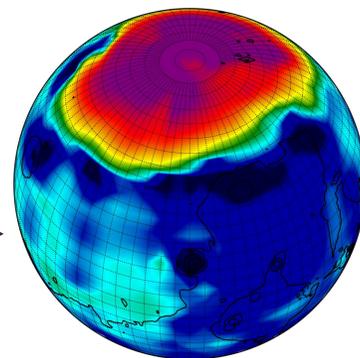
Below: dust absorption optical depth at 9.3 μm , normalised to 610 Pa and averaged over longitude. This should be multiplied by about 2.6 to get a broadband visible dust total extinction. The data here are from [7], assimilation gives similar zonally- and diurnally-averaged results.



Observations

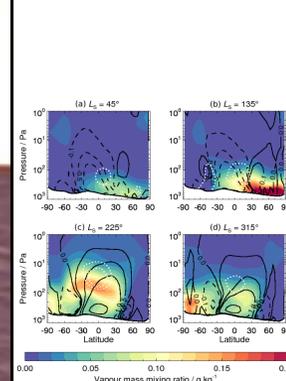


Assimilation

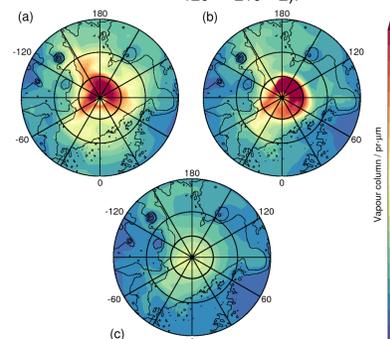


Model

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 [8] were assimilated into the model [9], reducing the global water vapour column error in the MGCM to around 2–4 μm depending on season. **Left:** zonal-mean water vapour mass mixing ratios for the midpoints of the northern hemisphere (a) spring, (b) summer, (c) autumn, and (d) winter seasons. Black contours show the mean meridional circulation (10^9 kg/s) with (solid, dashed) lines representing (clockwise, anticlockwise) circulation. Dotted white lines show ice mass mixing ratio. Water transport by transient eddies is largest at northern mid-latitudes close to equinox, with a net northward transport of water vapour toward the ice cap. **Below:** water vapour column field in northern hemisphere summer ($L_s = 120^\circ$) from (a) an assimilation of TES water vapour, (b) a model with outlying ice deposits around the main ice cap, and (c) a model with only the main ice cap represented, revealing the impact of outlying ice deposits around the north polar ice cap (located between 75° – 80° N and 120° – 210° E).

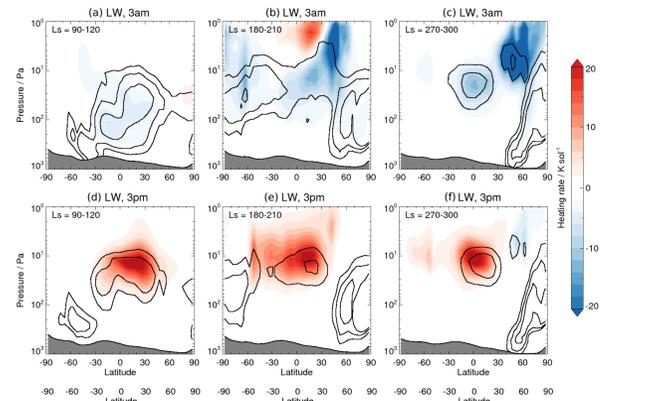
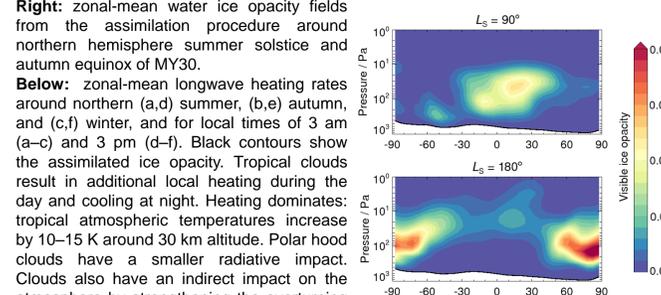


Ozone Assimilation

The Mars Color Imager (MARCI) [1] aboard MRO provides near-daily global mapping of ozone column concentration. These data were used alongside MCS temperature and dust opacity observations, which help to ensure a realistic atmospheric dynamical state. 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 time owing to rapid reactions with water vapour and photolysis 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 MCS opacity data which includes vertical profile information [10]. This can be challenging since the MGCM rapidly converts between water vapour and ice. **Right:** zonal-mean water ice opacity fields from the assimilation procedure around northern hemisphere summer solstice and autumn equinox of MY30. **Below:** zonal-mean longwave heating rates around northern (a,d) summer, (b,e) autumn, and (c,f) winter, and for local times of 3 am (a–c) and 3 pm (d–f). Black contours show the assimilated ice opacity. Tropical clouds result in additional local heating during the day and cooling at night. Heating dominates: tropical atmospheric temperatures increase by 10–15 K around 30 km altitude. Polar hood clouds have a smaller radiative impact. Clouds also have an indirect impact on the atmosphere by strengthening the overturning circulation, leading to an increase in temperatures over the poles by around 6–8 K at 50–60 km altitude, and transporting additional dust, leading to temperature increases in the tropics of around 2 K.



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 improvements in martian chemical models and better use of present and future observations, such as those from 2016 ESA ExoMars Trace Gas Orbiter.

References

- [1] Clancy, R. T., et al. (2011) *Mars Atmosphere: Modelling and Observations* 3, 337–339.
- [2] Lefèvre, F., et al. (2004) *JGR* 109, 7004.
- [3] Lefèvre, F., et al. (2008) *Nature* 454, 971–975.
- [4] Lewis, S. R. (2010) in *Data Assimilation: Making Sense of Observations*, Lahoz, W., et al. (eds.) Springer, 681–699.
- [5] Lewis, S. R., et al. (2007) *Icarus* 192 (2), 327–347.
- [6] Montabone, L., et al. (2006) *Icarus* 185, 113–132.
- [7] Montabone, L., et al. (2015) *Icarus*, doi:10.1016/j.icarus.2014.12.034. (http://www-mars.lmd.jussieu.fr/mars/dust_climatology)
- [8] Smith, M. D. (2004) *Icarus* 167, 148–165.
- [9] Steele, L. J., et al. (2014) *Icarus* 237, 97–115.
- [10] Steele, L. J., et al. (2014) *GRL* 41(13), 4471–4478.

Acknowledgments

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