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The martian water cycle through assimilation of Thermal Emission Spectrometer data

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Abstract

We present for the first time an assimilation of Thermal Emission Spectrometer (TES) water vapour column data into a global climate model (GCM) of the martian atmosphere, and discuss the seasonal cycle of water vapour and the processes responsible for the observed vapour distribution. The assimilation scheme is shown to be robust in producing consistent reanalyses even with differing initial conditions, and the global vapour column error is reduced to around 2–4 pr-μm depending on season. Wave activity is shown to play an important role in the vapour distribution, and the assimilated vapour field shows evidence of western boundary currents (WBCs) during aphelion season around Tharsis and Syrtis Major.

1. Introduction

In order to understand the ever-increasing number of observations of the martian water cycle, numerous models have been developed over the years which have performed well in reproducing the main features of the observed water cycle, but it is difficult to compare models to observations without first averaging in time or location. This study combines the benefits of both observations and modelling by coupling a data assimilation scheme with a Mars global climate model (GCM), and assimilating TES temperature and water vapour data. The results of the temperature assimilation allow us to diagnose the impact and importance of the changing model dynamics on the water cycle. By additionally assimilating water vapour columns we can investigate any remaining deficiencies, and further understand the role different modes of transport play in the vapour distribution.

2. Modelling and data assimilation

To study the martian water cycle we use a GCM which combines the LMD physical schemes [1, 2] with the UK spectral dynamical core and data assimilation scheme. The assimilation scheme is based on the Analysis Correction scheme of [3] and has already been successfully used to assimilate TES dust opacity and temperature data into the GCM [4], as well as new data being returned from Mars Climate Sounder. Here we assimilate total column water vapour abundances from TES [5], and iteratively scale the model vapour mixing ratios in order for the integrated column value to match observations (see Figure 1).

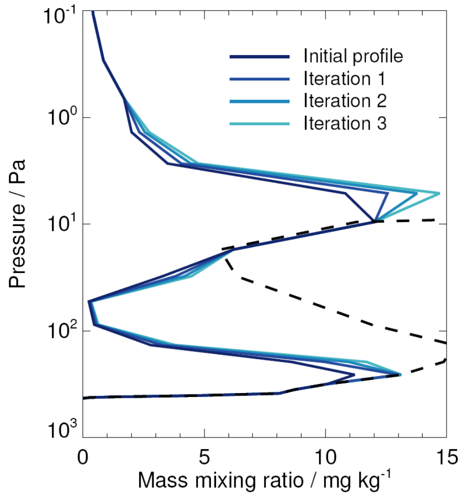

Figure 1: Example of the scaling process, with the water vapour mixing ratio profile scaled each iteration (but not exceeding saturation; dashed line) until the column integrated value agrees with the assimilation.

3. Preliminary results

Results of a year-long assimilation from $L_s = 180°$ of MY 24 to $L_s = 180°$ of MY 25 show that the assimilation of vapour columns reduces the model error to between 2–4 pr-μm (Figure 2). The fluctuation of the error with season is related to the variability of the vapour field in the free-running model, which is at a minimum around northern spring.

Stationary waves around the Hellas and Argyre basins act as regions of increased vapour transport, channeling vapour southwards along their eastern flanks during northern summer and autumn, and northwards along their western flanks during southern summer. Transport of vapour from the north polar ice cap is via a zonal wavenumber 1 wave, while during the remaining seasons zonal wavenumber 2 waves at northern high northern latitudes act to transport vapour northwards, limiting the southerly extent of the vapour minimum. Apart from at high latitudes around the equinoxes, transport by transient eddies has a smaller magnitude than by stationary waves.

The vapour assimilation also provides evidence for WBCs during aphelion season (Figure 3) which extend to around 30°N to the east of Tharsis and Syrtis Major. The assimilated vapour field in these regions is lower than in the free-running model, possibly suggesting winds stronger than those modelled (which average around 12–15 m s^{-1}).

Acknowledgements

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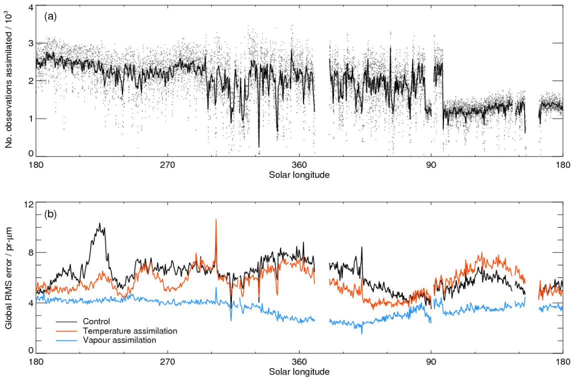

Figure 2: (a) The number of vapour column observations assimilated globally each model time step, with the black line showing a daily average value. (b) Daily average vapour column global RMS errors.

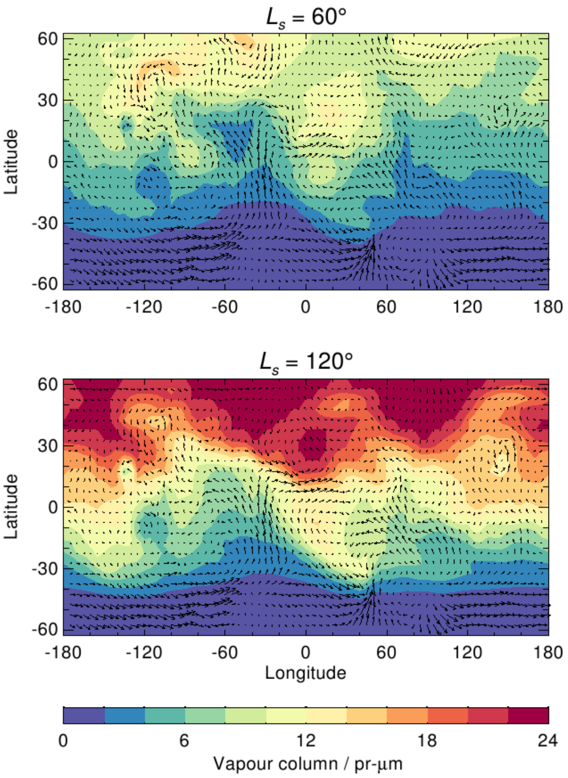

Figure 3: Water vapour column plots from the vapour assimilation, showing evidence for WBCs around 50°W and 70°E. Vectors show the vertically-averaged wind in the lowest 2 km of the atmosphere, and data are averaged over 10 sols centred on the labelled L_s values.

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