Assimilating the martian water cycle

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1. Introduction

- Water ice clouds play a role in the martian water cycle, and through their absorption and emission of infrared radiation, they can produce local heating and cooling effects, which can in turn impact the dynamics of the atmosphere [1,2].
- In order to account correctly for the radiative influence of clouds, and to investigate their effects on both the water cycle and atmospheric dynamics, it is important that we can accurately model their location and properties in the martian atmosphere.
- In this poster we discuss the use of data assimilation in order to better understand the martian water cycle. We are presently assimilating data from the Thermal Emission Spectrometer (TES) aboard Mars Global Surveyor, and will soon move on to assimilate ice, dust and temperature data from Mars Climate Sounder (MCS) aboard Mars Reconnaissance Orbiter.

2. The assimilation scheme

- We use a Global Climate Model (GCM) which uses the most recent version of the LMD GCM physical schemes [3] with the UK spectral dynamical core [4]. For these results, the model resolution corresponds to a 5°×5° grid, with 25 vertical levels ranging from the surface to ~100 km.
- The assimilation scheme used is based on the Analysis Correction scheme [5], modified for Mars [6]. Assimilated fields are updated every model time step, and increments are applied to model grid points that lie within a set radius from the observations (see Fig 1). The increments added to the model are weighted by the distance between the observation and model grid point, as well as the difference between the observation time and the current model time. Observations all have local times ~2pm, and each observation affects the model 3 hours before and 1 hour after its valid time.

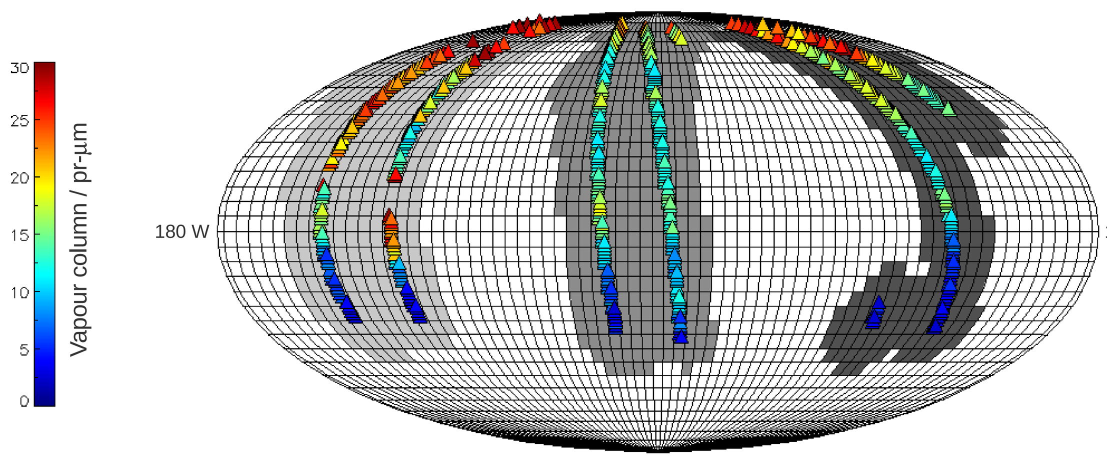

Fig 1. TES observations (△ symbols) and the model grid points they affect after assimilation, at three different times.

■ T + 0 h ■ T + 8 h ■ T + 16 h

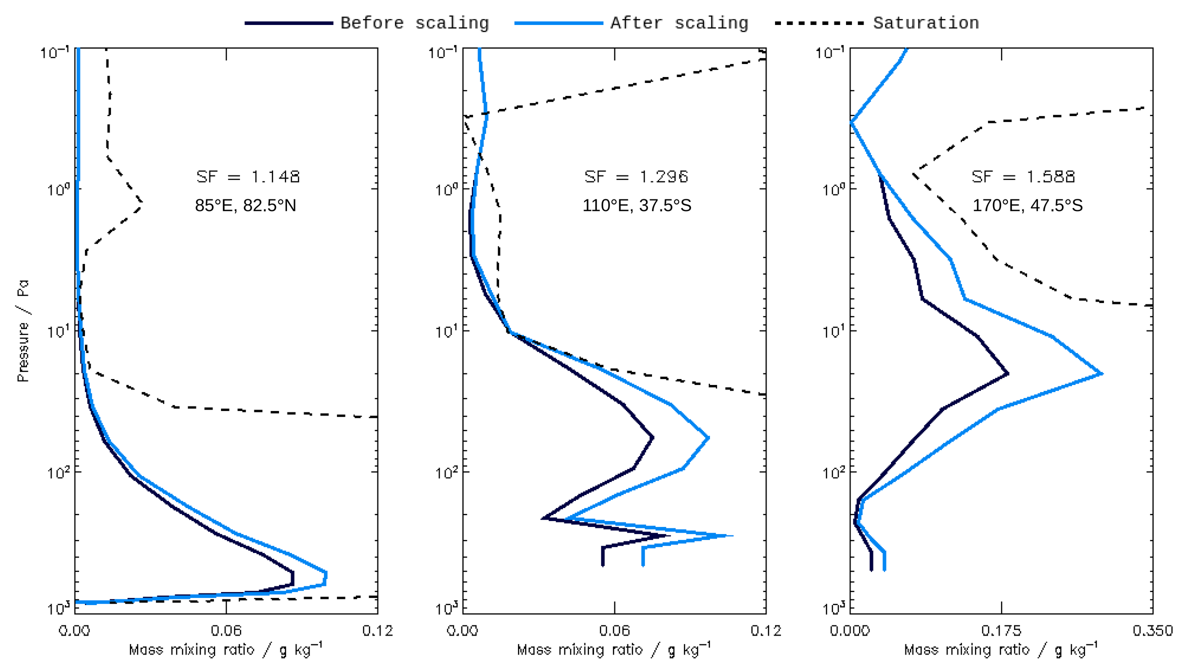

Fig 2. Examples of the scaling of vapour mass mixing ratio profiles due to assimilation. The scaling factors (SF), latitudes and longitudes for each case are shown on the plot. The seasons are; (left) NH summer; (middle) NH autumn; (right) NH winter, all Mars year (MY) 24.

- The TES temperature retrievals used in the assimilation have vertical profiles, but the water vapour retrievals are from nadir observations, so are of total water vapour column. Thus, there is no information on the vapour vertical profile.
- We take the model's predicted vapour profile and apply a scaling factor in order to make the model integrated vapour column match the assimilated TES data. An example of this scaling process is shown above in Fig 2.

3. Assimilation results

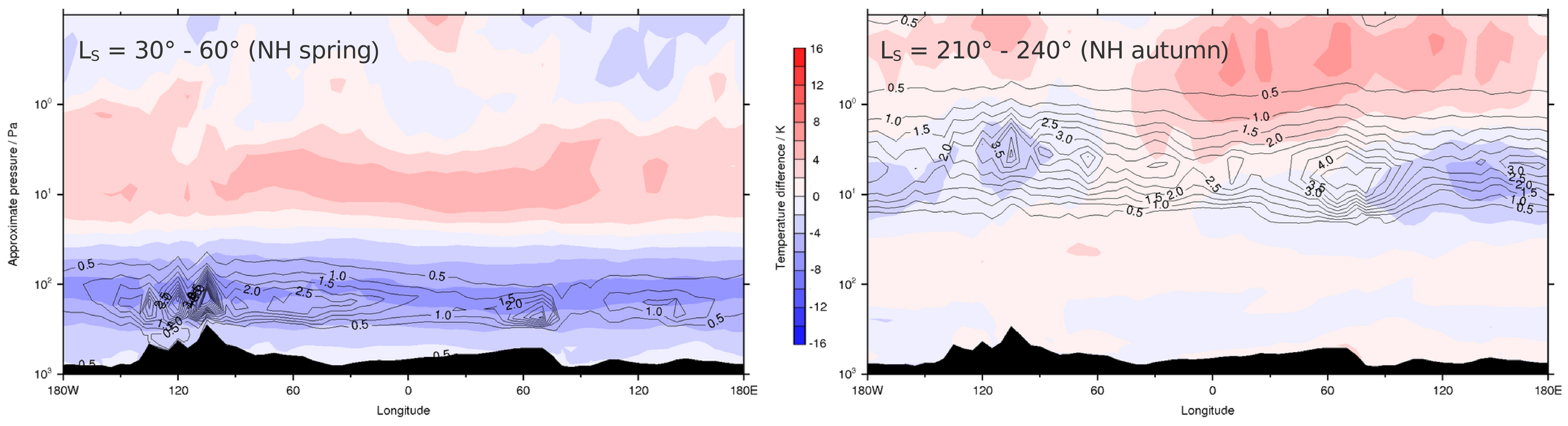

Fig 3. Temperature difference (red/blue shading, K) for two different seasons between an assimilation of temperature and a control run, with water ice mass mixing ratio from the assimilation (contours, 10^{-2} g/kg). Latitude is 12.5°N. Data are averaged over 30° of L_S during MY 25. Black shading represents topography.

- Fig 3 shows the average temperature difference (T_{assim} □ $T_{control}$) for two seasons between an assimilation of TES temperature retrievals and a control run. The control run includes cloud microphysics and tracer transport, but ice is not radiatively active.
- The results show regions of upper-atmosphere warming and cooling that are not accounted for in the control run. These regions correspond to locations where the model predicts clouds, suggesting they may result from the absorption and emission of infrared radiation by the clouds. We therefore need to include cloud radiative effects in simulations.
- In order to improve our modelling of clouds, we are assimilating TES water vapour column data, and will soon move to assimilating MCS ice opacity data.

- Combining assimilation with the ice and vapour transport of the model allows data to be transferred to regions where there are few or no observations. Thus, improvements can be made to the model even in locations between orbit tracks or over the winter poles.
- The assimilation of TES water vapour data enables us to identify regions or times when the model predicted vapour distribution differs from observations, allowing improvements to be made to the model. It allows studies of the vertical profiles of ice and vapour to be made, as well as local and global dynamical processes, which are not available through studying observations alone.
- The middle plots in Fig 4 show the mean vapour column difference between the TES observations and the control run. Red areas are where the control run is too dry compared to observations, and blue areas are where it is too wet. As can be seen, the error in northern hemisphere summer is mainly due to a lack of sublimation from the north polar cap, and hence a lack of vapour transport to mid latitudes. An improvement will be made to the distribution of surface ice around the north polar cap, which should increase sublimation. While the assimilation has improved the vapour field, Fig 4 shows there are still errors over the Tharsis region, which are responsible for the daily peaks in the RMS and mean increments shown in Fig 5. These errors may be due to problems with the modelling of vapour transport in the region, or possibly due to an assimilation error caused by the surface height differences between model and observations.
- The error in southern hemisphere summer is also mainly due to a lack of sublimation at the south pole. As there is no ice cap specified here in the model, the sublimation is of ice that was deposited in the winter, after being transported as vapour from the tropics. Thus, improvements to the north polar cap should lead to increased vapour transport south, and hence a reduction in the model error in southern hemisphere summer. Again, the assimilation has improved the vapour field, but differences still exist, particularly east and west of Hellas and around Alba Patera. These may again be due to problems modelling vapour transport, or due to an assimilation error caused by surface height differences.

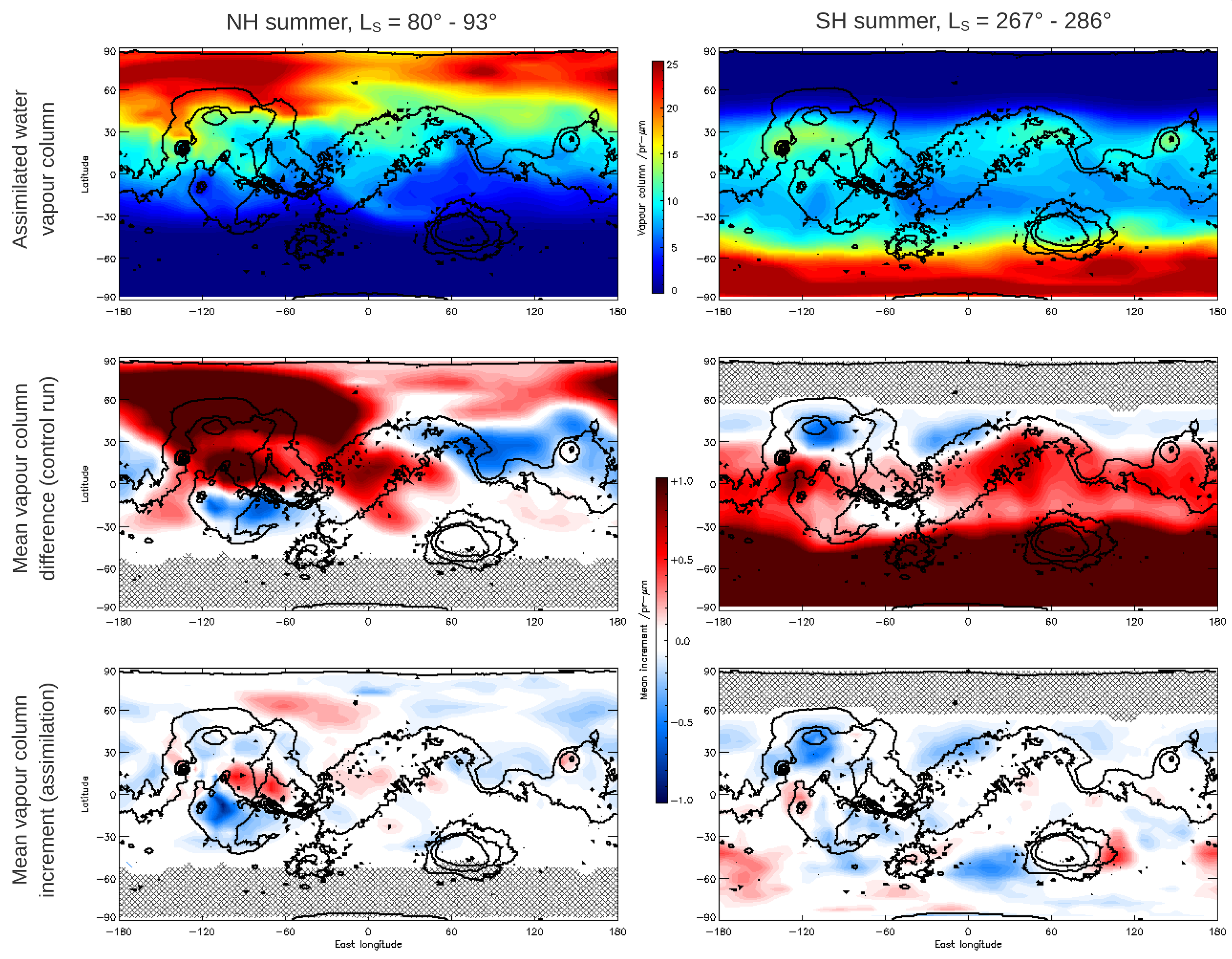

Fig 4. Plots for two different seasons of MY 24 showing; (upper panels) assimilated model total vapour column V; (middle panels) the mean 30-sol increment for the control run, (V_{obs} - $V_{control}$); (lower panels) the mean 30-sol difference for the vapour assimilation (V_{obs} - V_{assim}). All plots are in pr-μm, and are scaled to a reference pressure of 610 Pa. Cross hatching represents regions where there were no TES observations to assimilate.

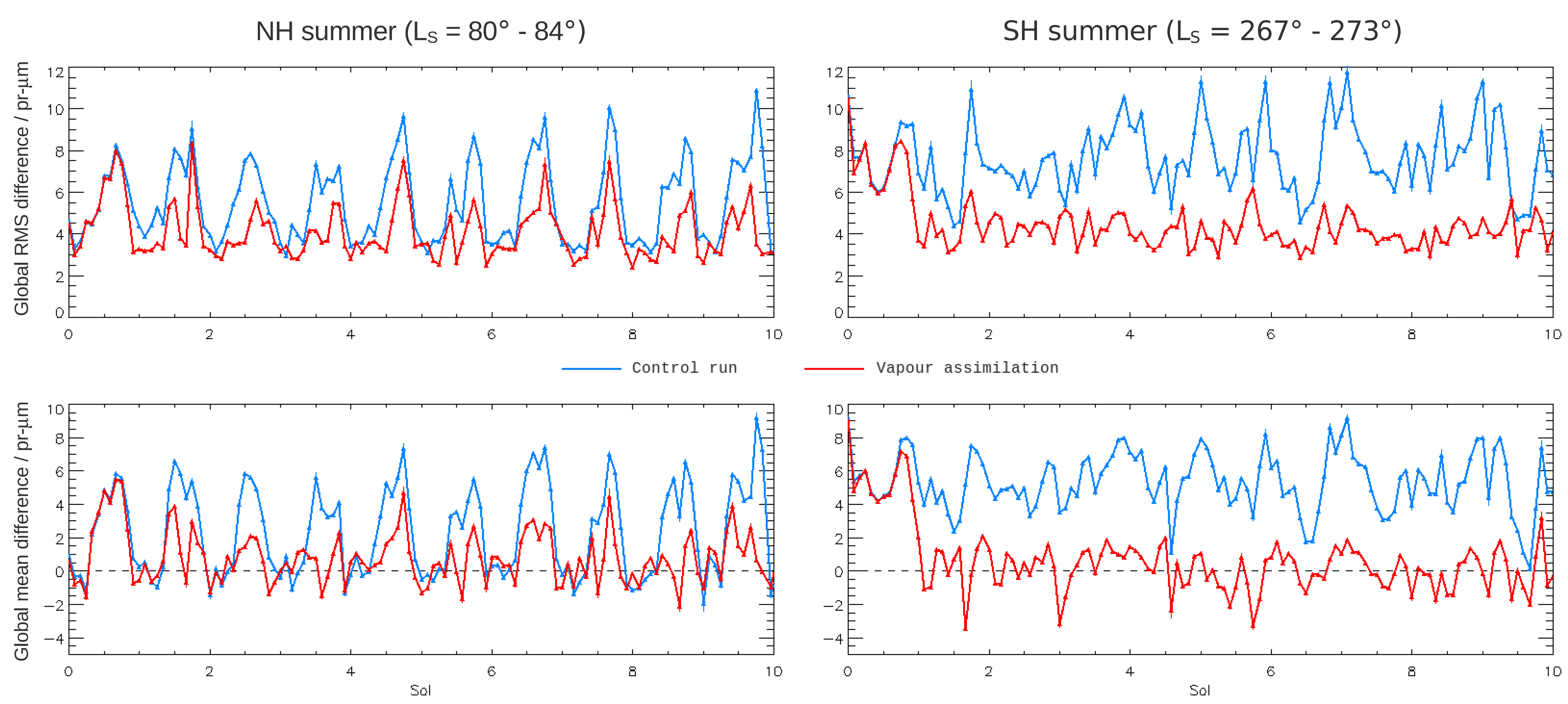

Fig 5. Global RMS vapour column difference (upper panels) and global mean vapour column difference (lower panels) for a control run (blue line) and a vapour assimilation (red line).

4. Discussion and future work

- The temperature assimilation provides evidence of the radiative effects of clouds on the atmospheric temperature.
- The TES vapour assimilation has led to global improvements in the model's vapour field, and highlighted areas where improvements can be made to the model in order to improve water cycle modelling. Additionally, we will soon be implementing a new LMD cloud microphysics routine, which should further improve model performance.
- Assimilation of MCS temperature, dust and ice data will soon be undertaken. This will enable us to better understand the processes involved in cloud formation and evolution, and will allow further improvements to the model to be made. Detailed investigations will be carried out into the effect of clouds on atmospheric dynamics.

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