DATA ASSIMILATION WITH A MARTIAN ATMOSPHERIC GCM: AN EXAMPLE USING THERMAL DATA

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ABSTRACT

Data assimilation is a technique for the analysis of atmospheric observations which combines current information with prior knowledge from previous observations, summarized and forecast in time via the use of a numerical model. A sequential data assimilation scheme has been implemented with a full general circulation model (GCM) of the martian atmosphere for the first time, and has been adapted for the types of atmospheric data which might be expected in the near future, e.g. remote-sensed temperature profiles from a polar orbiter mission such as Mars Surveyor '96 and '98. Tests demonstrate the performance of the scheme using artificial data generated from independent model experiments.

INTRODUCTION

With many new atmospheric observations expected from forthcoming missions to Mars, data assimilation schemes have been proposed (Banfield *et al.*, 1995; Lewis and Read, 1995) as a means to produce a continuous, global, evolving map of atmospheric structure. Data assimilation is particularly valuable where observations are sparse and taken asynchronously, such as when only a single satellite is available. It has the additional advantage of producing a self-consistent analysis of all model variables, not just those directly observed. A similar procedure is performed operationally for numerical weather prediction models; the scheme used here is based on one in current use at the UK Meteorological Office (Lorenc *et al.*, 1991). Lewis and Read (1995) applied this scheme to a martian model with highly simplified physics. Lewis *et al.* (1996) described the scheme in more detail and the processes by which it was adapted and tuned for the martian atmosphere. This paper shows results from the application of the scheme to a martian GCM with surface topography and many complexities absent in the earlier studies. The physical parametrisation schemes now include a realistic radiation scheme with diurnal variation, atmospheric condensation and sublimation, a planetary boundary layer and convection scheme, and a soil model (Hourdin *et al.*, 1993). The model is that described by Collins *et al.* (1996), though with greater vertical coverage in this case.

METHOD

The spectral model was run at a resolution comparable with a 6° horizontal grid and with 20 vertical levels covering the region from the ground to about 90km altitude. Two models were integrated for several years to form the initial conditions for the experiments. In the first case, known as the "truth", the atmospheric dust optical depth, τ, was set to 1.0, corresponding to moderate, but not dust storm, conditions. In the second case the optical depth was set to a constant, relatively clear value, $\tau = 0.2$, and this experiment was used as the "control". It is possible to update the model dust field by assimilation, but the difference between the true and control experiments here was intended to simulate partially the problem of incomplete knowledge of the true physics when real observations are assimilated into a model. Temperature profiles were taken at regular intervals, 90 times per orbit, following a polar orbiter making 12.67 orbits per sol (a martian solar day $\approx$ 24.66hr). Profiles were degraded to 10km vertical resolution and gaussian errors with a standard deviation of 1K were added to each profile layer. Both the models were run independently over a 30 sol period close to northern winter solstice ($L_s = 270°$), a time when there is strong planetary wave activity in the northern hemisphere and large latitudinal temperature gradients near the edge of the

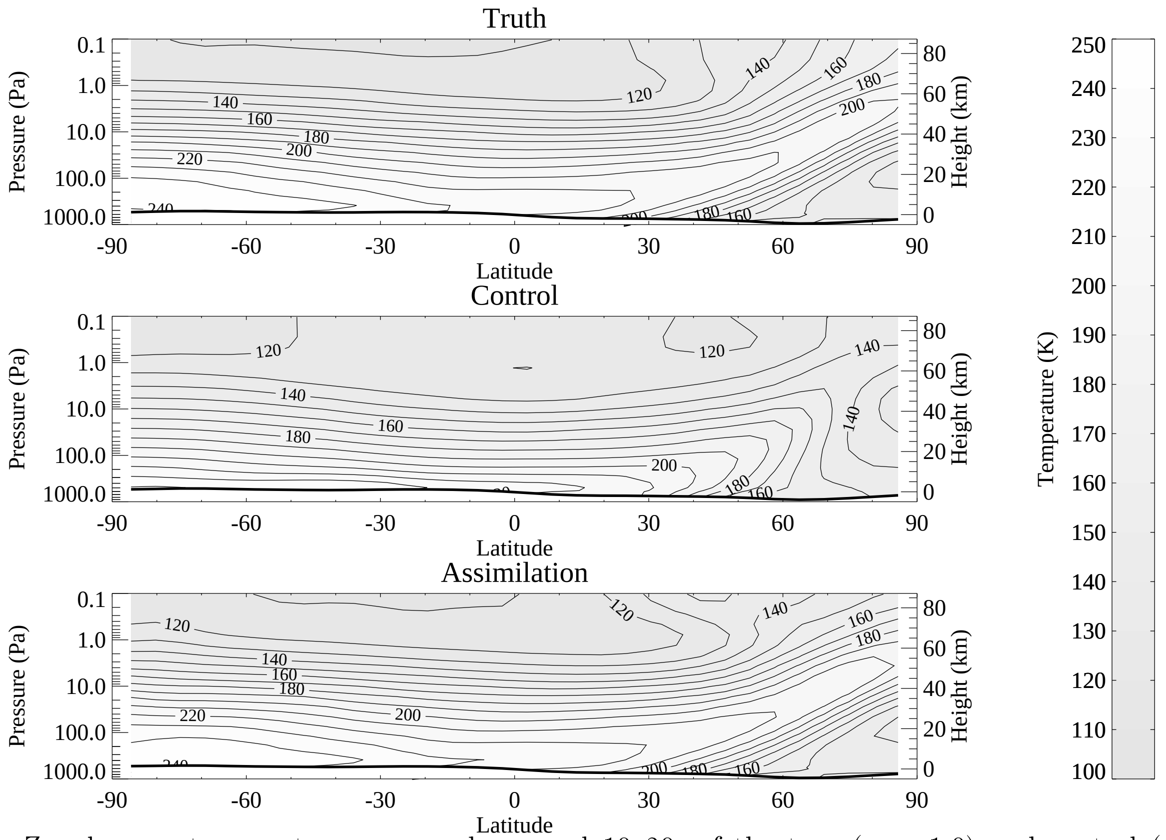

Fig. 1. Zonal mean temperature, averaged over sol 10–20, of the true ($\tau = 1.0$) and control ($\tau = 0.2$) simulations and the results of assimilation into the $\tau = 0.2$ model.

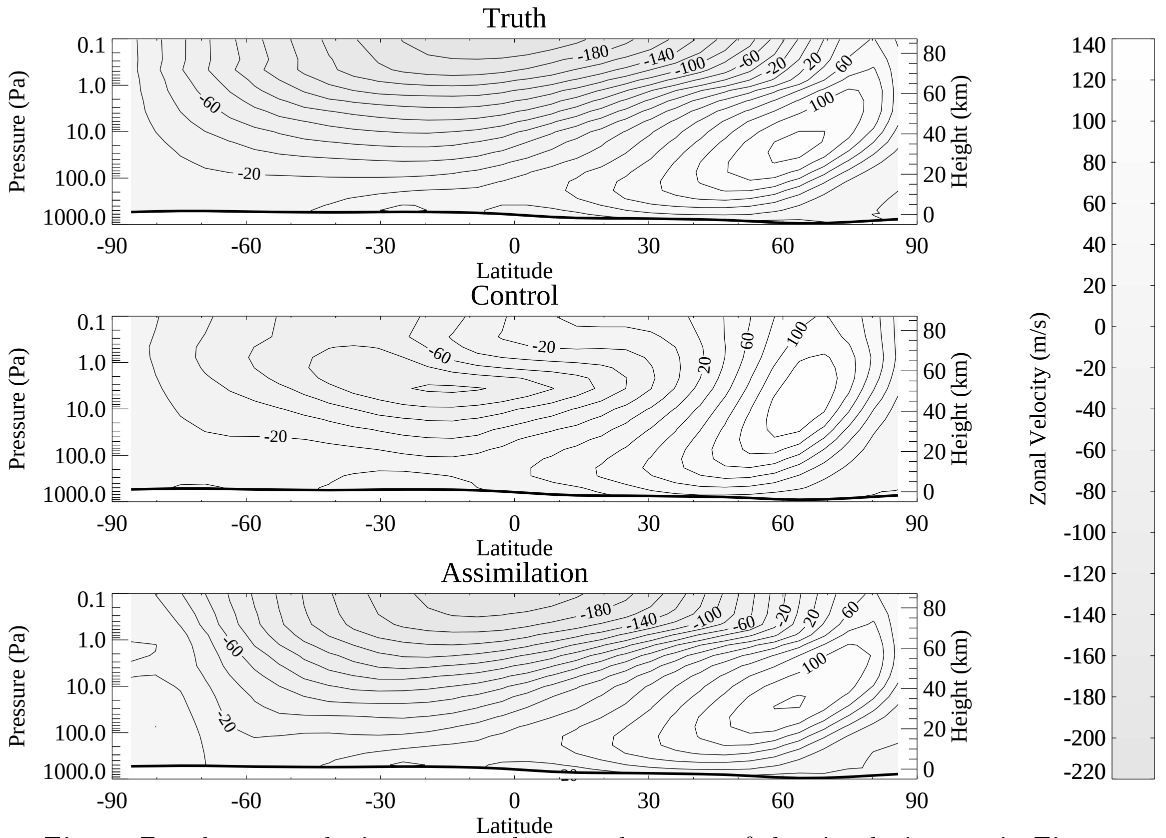

Fig. 2. Zonal mean velocity, averaged over sol 10–20, of the simulations as in Figure 1.

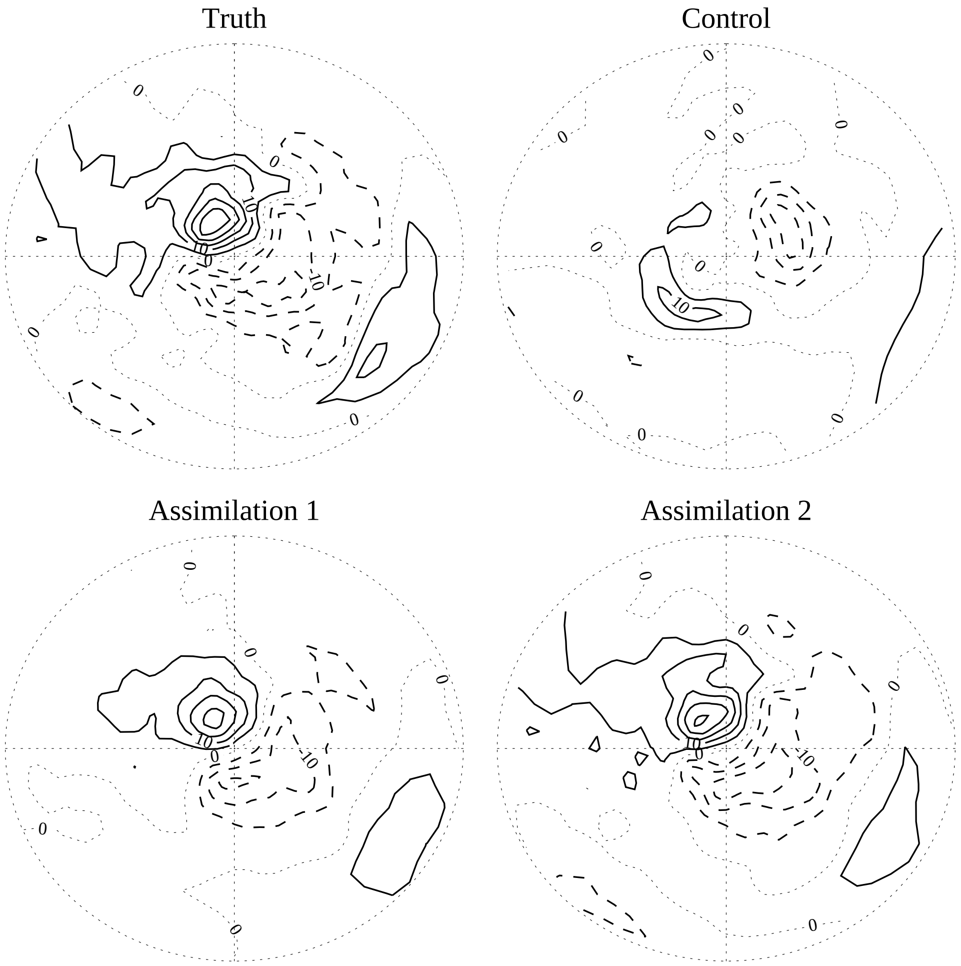

Fig. 3. Transient temperature on the 75Pa surface at sol 20 of the truth run ($\tau = 1.0$), the control run ($\tau = 0.2$) and assimilation results with a low dust ($\tau = 0.2$) model (1) and a model updated to the true dust opacity (2). The transient temperature here is the temperature at sol 20 minus the average temperature over the previous 10 sols, emphasizing time-dependent features. The plots are polar stereographic projections with the north pole in the centre and the equator at the edge. Positive contours are solid, zero is dotted and negative contours are dashed, with an interval of 5K.

polar cap. The initial conditions and dust state from the control were then used for an "assimilation" integration over the same period in which the temperature profiles from the truth run were introduced. Only atmospheric temperature was analysed here, though any other model variables which can be observed, e.g. surface pressure, can improve the assimilation (Lewis *et al.*, 1996).

RESULTS

Figures 1 and 2 show the zonal mean state of the true and control experiments compared to the results of assimilation of data from the true model into the control model. The temperature state of the truth run, including the large latitudinal and vertical gradients near the winter pole and the high-level polar warming are well reconstructed by the assimilation. The zonal mean wind is also recovered well in the assimilation, even though it is not observed directly, as a result of the model balances. The full three-dimensional, mass-weighted r.m.s. temperature and velocity errors in the assimilation (time averaged over sol 10–20) are 2K and 6ms^{-1} respectively, compared to 17K and 14ms^{-1} in the control experiment.

Figure 3 shows the transient temperature on a pressure surface at about 22km altitude. The first assimilation experiment is the procedure used elsewhere with constant low dust; the second has the dust field updated as profiles are inserted, though the experiment was still initialized in the incorrect state. Both assimilations capture the phase and amplitude of the strong wavenumber one disturbance near the pole, with improvements when the true dust state is known. In the case of the second assimilation, however,

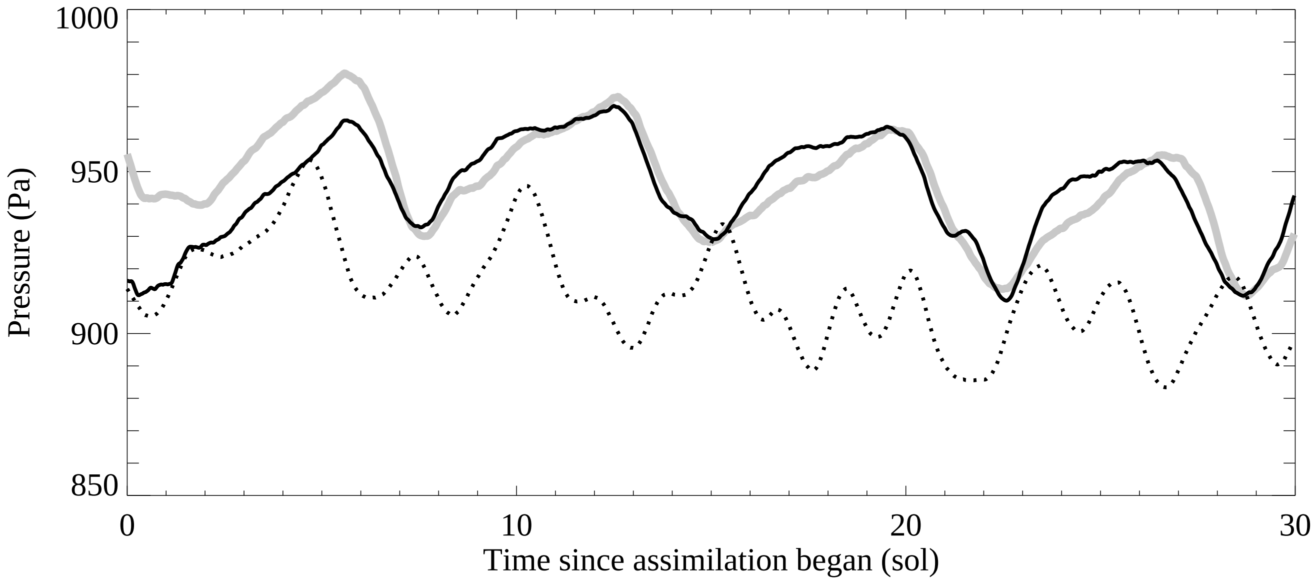

Fig. 4. Surface pressure at the Viking Lander 2 site (134°E, 48°N) over the course of a 30 sol assimilation. The thicker grey line shows the true ($\tau = 1.0$) curve, the dotted line the control ($\tau = 0.2$) experiment and the solid black line the assimilation result using the same model and initial conditions as the control. The curves have been low-pass filtered to remove the strong tidal signals for clarity.

the assimilation increments become much smaller as the model dust field, and so radiative forcing, becomes more accurate; this suggests a method of testing models against real observations.

Figure 4 shows the surface pressure at one site from each experiment. Despite the fact that no surface pressure information has been used it is clear that the assimilation has recovered a regular wave with a period of about 7 sol. This wave has a remarkably similar amplitude and phase in the assimilation and truth experiment, compared to the mixture of shorter period waves in the control experiment. The global, area-weighted r.m.s. surface pressure error averaged over sol 10-20 of the assimilation is 5Pa, compared to 23Pa in the control.

CONCLUSIONS

These experiments suggest that assimilation of spacecraft data of the type expected from future missions to Mars is potentially useful. Temperature profiles from a single satellite can be used to reconstruct the thermal state of the atmosphere and indirectly other fields. Information may be extracted about planetary waves with periods and amplitudes comparable to those in the martian atmosphere. With data of sufficient quality and quantity, the scheme is robust enough to produce reasonable results in the face of substantial model errors. Furthermore, the size of the increments introduced by the assimilation scheme may provide indications of errors in the model itself and thus a procedure for validation.

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