DATA ASSIMILATION WITH THE LMD MGCM AND LETKF

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Introduction:

Data assimilation is a technology widely used in geosciences, especially meteorology and weather forecast. It enables to optimally reconstruct a best estimate of the atmospheric state by combining various instrumental observations and theoretical information provided by a model. In Earth atmosphere science, it is systematically used to provide climatologies derived from space-based observations.

The very first Martian data assimilation project was carried out by [9], who applied the Analysis Correction Scheme to their Mars Global Climate Model (MGCM).

More recently, ensemble methods have been used for Martian data assimilation. The Local Ensemble Transform Kalman Filter (LETKF) has been coupled to the GFDL MGCM [5] and used with observations from the Thermal Emission Spectrometer (TES) [4]. The Data Assimilation Research Testbed (DART) has been used to apply an ensemble Kalman filter to the MarsWRF GCM with TES radiance data [7].The purpose of this work is to develop a data assimilation chain by coupling the Laboratoire de Météorologie Dynamique (LMD) MGCM with the LETKF assimilation framework of the University of Maryland [6].

Motivation:

There are various possibilities and applications presented for data assimilation. In this specific case, the reasons to develop such an assimilation are numerous:

- The reconstruction of atmospheric fields is *per se* a strong motivation. It provides a best estimate of the known atmosphere and could be seen as a useful tool for atmospheric science community.

- Data assimilation could help to characterize the local conditions for landers and rovers on the Martian ground on a daily basis.

- One main objective of the Trace Gas Orbiter (TGO) is to detect the presence and origin of trace gas in the Martian atmosphere. A data assimilation chain using data from the Atmospheric Chemistry Suite (ACS) on board TGO can be used to backtrack winds to locate the sources of such trace gases.

- Another asset of data assimilation is the possibility to point out disagreements between model and observations. It is a very powerful tool to estimate MGCM parameters or characterize instrumental errors.

Atmospheric Model:

The model used in this data assimilation scheme is the MGCM developed at LMD [2]. It includes a semi-interactive dust scheme driven by dust scenarios, a thermal plume model [1], a water cycle that includes radiatively active water ice clouds [10] with interaction between dust and clouds, a photochemical model [8] and an extension to the thermosphere, up to 600 km [3].

Data assimilation Scheme:

The principle of data assimilation is to successively alternate two steps: analysis and forecast. In the analysis step, an *a priori* estimate of the system state, called the background, is used to obtain a new estimate (called the analysis) by being combined to observations. The forecast, or propagation step, consists of applying the forward model to the analysis to get a new background after time integration (of typically 6 hours).

The assimilation scheme used is LETKF, which consists of an approximation of the Kalman Filter. It uses an ensemble, that is to say a set of a large enough number of forecast members that samples the variability of the system. The analysis step then consists of applying the filter to the background ensemble to create a new ensemble, the analysis. Observations are localized, that is to say their influence is limited and weighted in space within an arbitrary range.

Development strategies:

The development of a data assimilation chain is strongly incremental. After the validation of the assimilation with synthetic observations derived from the model itself, the assimilation of temperature from the Mars Climate Sounder (MCS) on board Mars Reconnaissance Orbiter has been initiated. We plan to assimilate data from the Planetary Fourier Spectrometer (PFS) on board Mars Express, thus taking advantage of the combination of the different local times between PFS and MCS measurements. The next goal is to directly assimilate dust and ice from MCS data.

Beyond this preparatory assimilation, the goal is to prepare the real-time assimilation of data from ACS on board TGO whose orbital insertion is expected in the second half of 2016. Ultimately, the direct assimilation of ACS radiances instead of temperatures will be attempted with the help of a direct model.

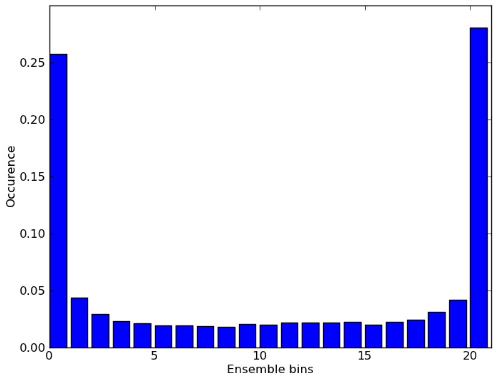

Figure 1: Rank histogram at Ls=0°, MY29 for an ensemble of 20 members. For each observation, if N forecasts are colder that this observation, we increment the value of the N^{th} bin. A balanced ensemble should have a flat histogram. Here, the tails at both ends show that the ensemble is not spread enough. This study finds that, for Mars, this behaviour does not depend on the size of the ensemble, or the type of observations (synthetic or real).

Assimilation of MCS data:

Assimilation of MCS temperature profiles indicates a bias in the analysis (figure 2), up to 20 K. Moreover, the ensemble of MGCM simulations are not spread enough to surround observations (figure 1), especially in the case of strong bias. Hence, the assimilation is overconfident with the model, rather than observations.

Despite the use of an adaptive inflation of the spread of the ensemble [11], this filter divergence seems very likely to occur in the Martian case. The use of fast varying inflation, that quickly adapts to new information, can reduce this divergence, though the inflation multiplicative factor can be up to 100, giving possible unrealistic atmospheric states. This behavior is not specific to MCS observations, as it occurs with synthetic observations generated from the model. This is a motivation to bring more variability in the simulations of the Martian atmosphere thanks to an ensemble with different dust loadings [4].

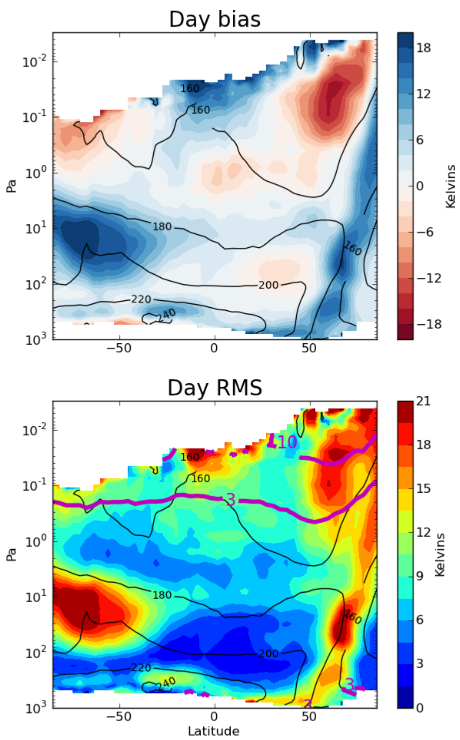

Figure 2: Bias (top) and standard deviation (bottom) of observations minus forecast of dayside temperatures, for the period Ls=310°-315°, MY29. The MGCM uses a guiding scenario for dust opacity. A regional dust storm in the southern hemisphere causes the strong cold bias observed in the southern latitudes. Observations are contoured in black, and observation errors in purple.

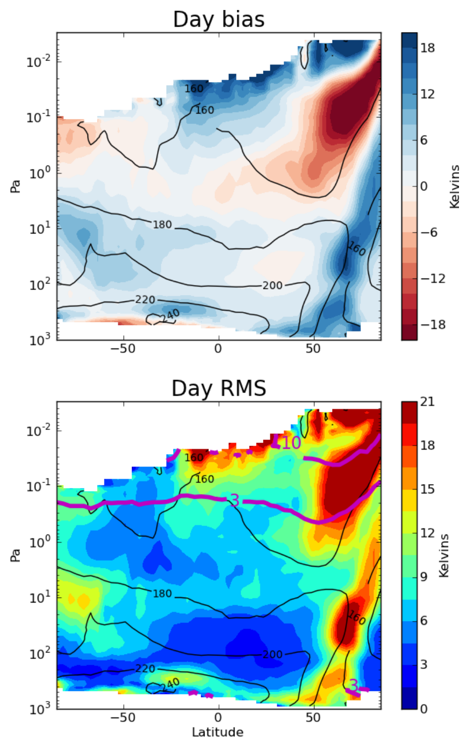

Figure 3: As figure 2, but with the update of dust in the analysis, that freely evolves in the MGCM, without any guiding scenario. The forecast is clearly improved at level 1 Pa, where the regional dust storm occurs.

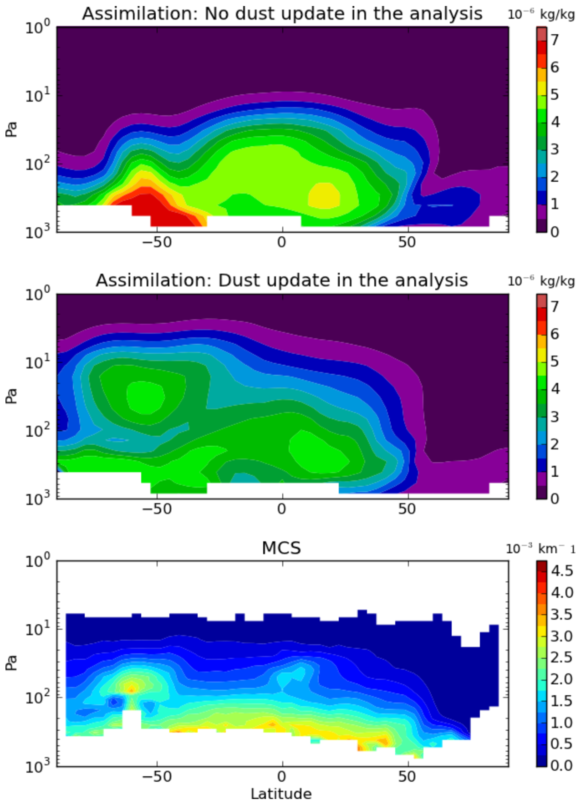

Figure 4: Daytime zonal mean of the dust mass mixing ratio of assimilation analysis during the same period as in figures 2 and 3, without dust update in the analysis (top), with the dust update (middle), compared to the dust opacity as seen from MCS during the same period.

Thanks to the semi-interactive dust scheme of the LMD MGCM, it is possible to update the atmospheric dust in the atmosphere at the analysis step, taking into advantage correlations between temperature and dust. This update of dust is done so that the dust particles size is kept constant between the background and the analysis states. It helps to increases the variability in the ensemble forecast, though not enough to surround all the observations, and decreases the forecast bias in the tropics below 1 Pa (figure 3), at locations where dust controls the atmospheric temperature. The reason is that the dust vertical distribution is more realistic due the presence of a dust detached layer (figure 4) that helps to have a more consistent atmospheric state, suggesting that its signature in MCS temperature profiles is strong enough to constrain it.

However, this signature of the aerosol in the observed temperatures does not tell which of the dust, the water ice, or both is the cause. This ambiguity is a call to directly assimilate aerosols. Assimilating aerosols could also help to assess the coherence between aerosols and their effects on atmospheric temperatures in models as well as in observations.

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