ON THE ASSIMILATION OF MARTIAN TOTAL OZONE RETRIEVALS

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Introduction: The technique of data assimilation gives us an opportunity to further our understanding of important photochemical processes in the Martian atmosphere, through the creation of a reanalysis product that can be used to investigate the temporal and spatial agreement between model and observations and determine any possible causes of identified differences. In this study [1], we have assimilated, for the first time, total ozone retrievals into a Mars Global Circulation model (GCM) to study the ozone cycle.

Model setup and assimilation: We use the UK version of the Laboratoire de Météorologie Dynamique (LMD) Mars GCM. This 4D-model uses the physical parameterisations [2] and LMD photochemical module [3] shared with a recent version of the LMD Mars GCM coupled to a UK-only spectral dynamical core and semi-Lagrangian advection scheme [4]. It has been developed in a collaboration between the LMD, the Open University, the University of Oxford and the Instituto de Astrofisica de Andalucia. For the case study detailed here, the model was run at T31 resolution in the horizontal, corresponding to a resolution of 5° latitude by 5° longitude, with 35 vertical levels in the range 0–105 km. Future simulations are planned at higher model resolutions, with the parameters defining the assimilation technique potentially needing to be optimised as a consequence. The Mars GCM includes the latest sub-models to provide the most realistic modelling of the planetary boundary layer and water and dust cycles [5,6,7]. The photochemical module provides multiple photolytic and chemical reactions with up-to-date reaction rates between 16 advected species including carbon dioxide, water vapour and ozone. It also includes heterogeneous processes removing odd hydrogen radicals, a process which has been shown to improve the agreement between models and observations [8].

The assimilation is performed using a form of the Analysis Correction scheme [9] converted to martian conditions and has been shown in the past to be a computationally inexpensive and robust method [10]. Using this methodology, observations of short-lived (and long-lived) species can be supplemented by knowledge of the transport and atmospheric chemistry from a Mars GCM.

SPICAM retrievals: The ozone retrievals that have currently been assimilated are displayed in Figure 1a) and come from the SPICAM instrument on Mars Express. Maximum total ozone values are seen around northern hemisphere spring equinox at northern polar latitudes, as a result of polar night conditions in the recent past and a lack of odd hydrogen species. The SPICAM instrument is able to observe large ozone abundance before water vapour and associated odd hydrogen species are transported into the northern polar regions resulting in destruction of ozone.

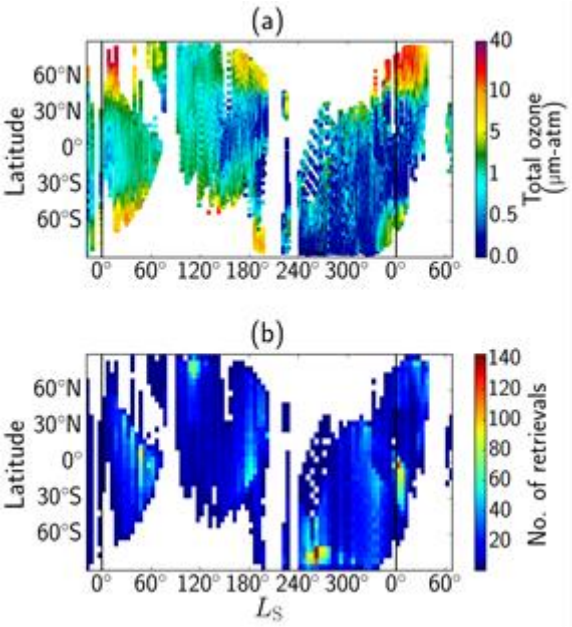

Figure 1: SPICAM nadir retrievals for L_S = 341° MY 26 to L_S = 69° MY 28 as a function of latitude and solar longitude displaying a) the total ozone abundance and b) number of retrievals. The number of SPICAM retrievals are binned every 5° L_S and 5° latitude.

For the first assimilation of ozone for Mars, the dynamically determined wind field from the Mars GCM is used to transport ozone and all other chemical species, but future investigations could potentially also assimilate thermal profiles alongside ozone retrievals. This highlights another benefit of data assimilation, in that data sparse regions are potentially influenced by SPICAM retrievals of total ozone being advected into the local unobserved region.

Results & Discussion: To investigate the effect of total ozone assimilation on the seasonal cycle, we ran a 'control' simulation with no assimilation and a second simulation in which total ozone retrievals from SPICAM were assimilated (hereafter the SPICAM ozone reanalysis). Differences in the modelled and

observed ozone cycle (Figure 2b) are efficiently identified by the assimilation process, with the largest total ozone percentage differences identified between 45°S–10°S from L_S = 135–180° and at northern polar (60°N–90°N) latitudes from L_S = 150–195°, at the onset of northern polar winter. An asymmetry in the magnitude of total ozone percentage differences in northern fall (L_S = 150–195°) and early northern spring (L_S = 0–30°) at northern polar latitudes is also identified. Through investigation of the water cycle, underestimated amounts of total ozone in the control simulation were found to be due to excessive northward transport of water vapour west of the Tharsis region and over Arabia Terra throughout northern polar winter resulting in increased increments in total ozone necessary in the SPICAM ozone reanalysis. Neither modelling biases in water vapour or heterogeneous processes on water ice clouds can explain outstanding differences in total ozone between the SPICAM ozone reanalysis and the control simulation at northern polar latitudes from L_S = 150–195°. In this region in particular, investigation of the vertical profiles of water vapour/ice and ozone are needed to try and explain the difference in total ozone between the control simulation and SPICAM ozone reanalysis and determine whether it is a further unidentified process which is not adequately represented.

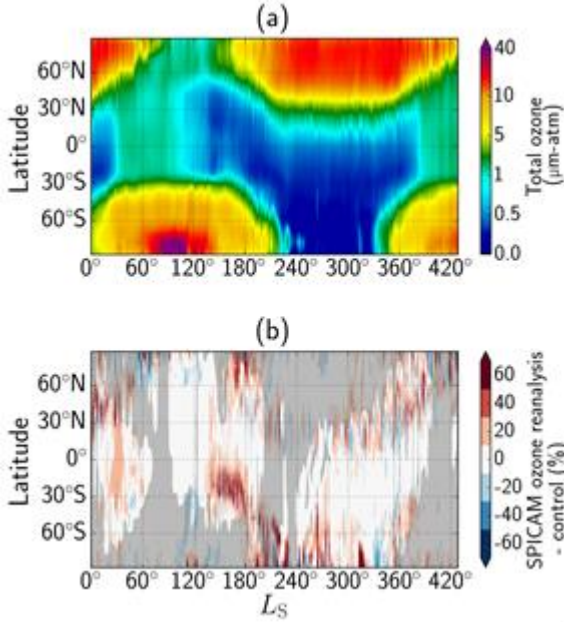

Figure 2: (a) Assimilated zonally averaged ozone column at 12 p.m. everywhere and (b) the percentage difference between the SPICAM ozone reanalysis and control simulation for MY 27 and start of MY 28. Shading indicates regions where there are no nearby SPICAM retrievals at the corresponding time and space.

The assimilation of SPICAM retrievals can also provide potential information on the polar maximum, with chemical changes as a result of the assimilation process shown to affect the southern polar high-altitude ozone layer. For a more realistic study of the polar dynamics, assimilation of total ozone, and ideally water vapour too, would provide a more accurate ozone spatial distribution. How best to combine two datasets that show a distinct anti-correlation with one another is currently open for debate.

In the future, observations from NOMAD [11] on the ExoMars TGO spacecraft, will provide a more comprehensive dataset to assimilate, with the SPICAM observational dataset extremely useful also for cross-validation purposes. Assimilation of vertical profiles of ozone and water vapour/ice alongside column retrievals, such as will be possible from the NOMAD instrument on the ExoMars TGO, will also be of great use to further study the origin of differences in total ozone between the SPICAM ozone reanalysis and global circulation models. There is also the possibility of assimilating multiple different ozone datasets at the same time, but how best to optimise this reanalysis when they are at different spatial and temporal resolutions needs to be considered carefully.

Moving forward, the chemical assimilation is being tested for other chemical species and ozone datasets, with each one posing a unique challenge because of the high variability in their spatial and temporal distribution when compared to one another. For instance, water vapour is far less localised and reactive than ozone abundance, and so different parameters for the assimilation technique have been found to be optimum for this particular chemical species.

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