Global Analysis and Forecasts of Carbon Monoxide on Mars

Conference or Workshop Item

GLOBAL ANALYSIS AND FORECASTS OF CARBON MONOXIDE ON MARS. J. A. Holmes[1], S. R. Lewis[1], M. R. Patel[1,2] and M. D. Smith[3], [1]School of Physical Sciences, The Open University, Milton Keynes MK7 6AA, UK, james.holmes@open.ac.uk [2]Space Science and Technology Department, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX, UK, [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States

Introduction: Carbon monoxide (CO) plays an important role in the chemical stability of the martian atmosphere [1] and has now been observed by a number of ground-based telescopes [2,3,4] and spacecraft in orbit around Mars [5,6,7]. The long chemical lifetime of CO of around 6 years [4] means that for any given annual cycle CO can effectively be treated as a passive tracer. CO can also potentially be used as a tracer of the middle atmosphere dynamics, since the CO distribution is largely determined by the dynamical state of the atmosphere.

Furthermore, CO is a non-condensable gas, and hence a relative enhancement in abundance during polar winter is to be expected, as has previously been seen for argon [8]. The relative enhancement of CO and other non-condensable gases is directly linked with the condensation of carbon dioxide, and so constraining the CO abundance can be used to study and constrain the sublimation/condensation processes of carbon dioxide. Overestimation of the modelled CO distribution during summer at polar latitudes when compared to retrievals of CO could perhaps be as a result of excessive condensation of carbon dioxide during the preceding winter for example.

The statements above indicate that a good understanding of the spatio-temporal distribution of CO provides a powerful tool for constraining multiple elements of the photochemical and dynamical processes that occur in the martian atmosphere. To make optimal use of the available information, however, it would be ideal to have the ability to synthesize the models and retrievals of CO in a self-consistent way. This process would allow for investigation of the evolution of the retrievals that is difficult to deduce using retrievals alone as they are generally separated by at least one sol in time and include a 'snapshot' of the atmosphere at the exact spatio-temporal location.

The above approach provides a much more in-depth investigation of the underlying chemical and physical processes and is one of the primary goals of data assimilation, a technique that combine a global circulation model (GCM) and retrievals to provide the best estimate of the global atmospheric state.

Other benefits of data assimilation over direct comparison between GCM simulated and observed quantities include providing estimates for parameters which are not directly observed, investigating interactions between chemical species such as CO and water vapor and the ability to combine observational datasets (including of different observations such as CO column mixing ratio and temperature profiles) to optimize the value of the resulting data set.

Methods: The model simulations conducted as part of this investigation use the UK version of the Laboratoire de Météorologie Dynamique (LMD) Mars GCM (hereafter MGCM). The MGCM is comprised of shared physical parameterizations [9] and the LMD photochemical module [10] with a recent version of the LMD Mars GCM coupled to a UK-only spectral dynamical core and semi-Lagrangian advection scheme [11] and has been developed in a collaboration between LMD, the Open University, the University of Oxford and the Instituto de Astrofisica de Andalucia.

The assimilation package associated with the UK version of the LMD GCM is now capable of assimilating multiple different trace gases and other meteorological variables such as temperature and dust. This unique capability provides an invaluable tool for investigating links between the different components and transport processes in the martian atmosphere and for combining future observations from multiple different spacecraft currently in orbit around Mars, including the ExoMars Trace Gas Orbiter spacecraft

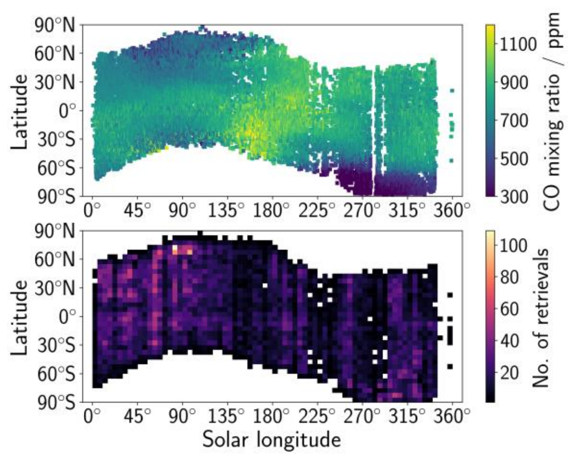

Figure 1 - CRISM column integrated CO mixing ratio retrievals covering multiple Mars years as a function of latitude and solar longitude displaying (a) the column integrated CO mixing ratio and (b) number of retrievals. The number of CRISM CO

retrievals are binned every 5° L_S and 5° latitude. White indicates no retrievals.

The MGCM is combined with CRISM hyperspectral CO retrievals [12], shown in Figure 1, and MCS temperature profiles [13] using a form of the Analysis Correction (AC) scheme [14], and has been shown in the past to be a computationally inexpensive and robust method [15]. Through the AC scheme, observations of long-lived species such as CO are combined with the MGCM through successive corrections at every dynamical timestep, resulting in an evolving CO distribution that is supplemented by knowledge of the transport and atmospheric chemistry from a GCM.

The simulations are conducted for MY 29 as it provides the greatest number and also spatio-temporal coverage of CRISM CO retrievals and MCS temperature profiles for any of the MY covered by the CRISM retrievals.

Global results: The first global reanalysis of CO on Mars is shown in Figure 2. Through comparison with the standalone MGCM simulation, we find the northern summer solstice CO minimum between 10°–50°S is found to be caused by suppression of CO-enriched air leaking from the northern edge of Hellas basin and strongly linked to carbon dioxide condensation during this time period . The MGCM is the first model capable of simulating the northern summer solstice CO minimum and can match in time the annual maximum CO at northern polar latitudes seen in CRISM CO retrievals.

The reanalysis indicates that the MGCM is within the CRISM retrieval error (40%) for a large majority of the time period investigated. The primary region in which differences in column integrated CO mixing ratio are seen between the reanalysis and MGCM that are outside the CRISM retrieval error is at southern polar latitudes around perihelion, where CO is depleted as carbon dioxide sublimates from the southern polar cap. The reanalysis suggests that the MGCM possibly under-predicts the strength of carbon dioxide sublimation, but coincident vertical profiles of CO are warranted to confirm the result.

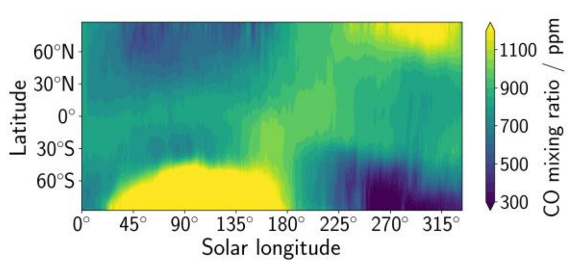

Figure 2 - Zonally-averaged column integrated CO mixing ratio at 3 p.m. everywhere in the reanalysis for L_S = 0-332° MY 29.

Inclusion of MCS temperature profiles alongside CRISM CO retrievals in the assimilation process leads to a more accurate representation of the temperature structure and circulation of the atmosphere that can alter the distribution of CO in unobserved regions, alongside alterations to the condensation/sublimation of carbon dioxide. This is a powerful method to provide constraints on predictions of CO in regions that are unobserved due to instrument limitations. The modelled vertical distribution of CO is also found to be altered through additional assimilation of MCS temperature profiles, and will be the focus of future observations and reanalysis.

Forecasting CO on Mars: We have also investigated the potential to forecast the CO abundance using the data assimilation method, by comparing forecasts initiated from the reanalysis at different times of year with withheld CRISM CO retrievals. 30-sol forecast simulations starting at L_S = 9° and L_S = 282° MY 29 (Figure 3) had a lower root mean square error (reduced from 120 ppm to 60 ppm) when compared to the control simulation for the whole 30 sol time period, indicating that there is significant skill in the global forecasting of column integrated CO mixing ratio during southern summer and early northern spring. Further details will be presented at this meeting.

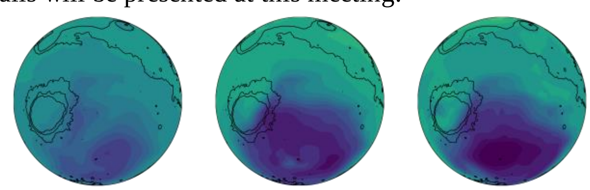

Figure 3 - The simulated column integrated CO mixing ratio in the control (left), forecast (middle) and reanalysis (right) at L_S = 297° MY 29 after 30 sols of withheld CRISM CO retrievals. Black contours indicate topography.

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