Global Analysis and Forecasts of Carbon Monoxide on Mars

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Global analysis and forecasts of carbon monoxide on Mars

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Introduction

- Constraining the spatio-temporal distribution of carbon monoxide (CO) provides a way to explore photochemical and dynamical processes that occur in the martian atmosphere such as the stability of the atmosphere, middle atmospheric dynamics and the condensation/sublimation of CO2
- We have investigated the CO cycle on Mars using data assimilation techniques to combine a Mars Global Circulation Model (GCM) with observations of CO and temperature from Mars Climate Sounder
- An in-depth analysis of the CO cycle is conducted [1] by combining observations of chemical species with multiple other observations (temperature, dust) and a Mars GCM. This process is also applicable to other chemical species [2,3]

Methods

- We use the UK version of the Laboratoire de Météorologie Dynamique (LMD) Mars GCM to simulate the martian atmosphere. Shared physical parameterizations [4] are coupled to the LMD Photochemical module [5] and a UK-only spectral dynamical core and semi-Lagrangian advection scheme [6]
- The Mars GCM is combined with CRISM hyperspectral CO retrievals [7], shown in Figure 1, and MCS temperature profiles [8] using a form of the Analysis Correction scheme [9], and has been shown in the past to be a computationally inexpensive and robust method [2,3,10]
- Through the AC scheme (Figure 2), observations of CO are combined with the Mars GCM resulting in an evolving CO distribution that is supplemented by knowledge of the transport and atmospheric chemistry from a Mars GCM

Results

- Assimilation (Figure 3) improves a standalone GCM simulation by indicating corrections in the local dynamics after the observed northern summer solstice CO minimum, a feature that is maintained for an extended time period in the assimilation by suppressed transport of CO from the Hellas and Argyre basins
- Global analysis shows that the GCM simulated CO cycle is within the CRISM retrieval error (40%) for the majority of the Mars year (Figure 4)
- Even when CRISM CO retrievals are not found nearby information from the past is carried forward in the assimilation, with increased levels of CO still found in the assimilation from 50-70°N when nearby CRISM retrievals are available again as Ls = 330° after 200 sols with no nearby CRISM CO retrievals (Figure 5)
- A free-running forecast from an assimilated initial state shows significant predictive skill out to at least 30 sols (Figure 6)

Vertical distribution of CO

- Changes to the vertical structure of CO are also seen as a result of the assimilation of MCS temperature profiles altering the condensation/sublimation of CO2 (Figure 7)
- These results will be used as validation for future CO vertical profiles taken by the ExoMars Trace Gas Orbiter [11,12]

Conclusion

- We have been able to determine the cause of the observed northern summer solstice CO minimum as suppression of transported CO leaking from Hellas and Argyre basin, through use of a data assimilation technique
- The assimilation provides initial states that can be used to demonstrate significant predictive skill using the GCM
- A combined assimilation of chemical and dynamical data (as performed in this work) is an invaluable tool to explore unexplained features of the martian atmosphere found in satellite retrievals

References


Figure 1: CRISM CO retrievals (top) and number of retrievals (bottom) over Ls = 330° as a function of latitude and solar longitude

Figure 2: Example of the data assimilation process with sample retrievals (left) influencing the Mars GCM (right) in space and time

Figure 3: Zonally averaged column integrated CO mixing ratio at 3 p.m. from the past to be a computationally inexpensive and robust method [2,3,10]

Figure 4: The percentage difference in column integrated CO mixing ratio between assimilation (Figure 3) and a control GCM simulation for Ls = 330° MY 29

Figure 5: Comparison of the column integrated CO mixing ratio in the assimilation (Figure 3) and a control GCM simulation for Ls = 330° MY 29

Figure 6: The simulated column integrated CO mixing ratio in the control (left), forecast (middle) and assimilation (right) at Ls = 297° MY 29 after 50 sols with an assimilated CRISM CO retrievals (boxed at northern latitudes for Ls = 297° MY 29)

Figure 7: The simulated column integrated CO mixing ratio in the control (left), forecast (middle) and assimilation (right) at Ls = 297° MY 29 after 50 sols with an assimilated CRISM CO retrievals (boxed at northern latitudes for Ls = 297° MY 29). Black contours indicate topography

Figure 8: The assimilation improves a data assimilation process with sample retrievals (left) influencing the Mars GCM (right) in space and time

Figure 9: Example of the data assimilation process with sample retrievals (left) influencing the Mars GCM (right) in space and time

Figure 10: Zonally averaged column integrated CO mixing ratio at 3 p.m. from the past to be a computationally inexpensive and robust method [2,3,10]