SIMULATING ATMOSPHERIC CHEMISTRY AND D/H DURING THE 2018 GLOBAL DUST STORM ON MARS

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Introduction:

The atmospheric spectrometers on the ExoMars Trace Gas Orbiter (TGO), NOMAD and ACS, witnessed dramatic changes in the distribution of water vapor during the 2018 Global Dust Storm (GDS) on Mars (Vandaele et al., 2019; Aoki et al., 2019; Fedorova et al. 2022). This phenomenon was simulated with the GEM-Mars General Circulation Model (GCM, Neary et al., 2020). In addition, NOMAD could also witness how semi-heavy water ascended with H_2O, and the D/H ratio in water vapor remained constant to much larger altitudes than in normal conditions (Villanueva et al., 2021). This process was also simulated with the GEM-Mars GCM (Daerden et al., 2022a).

Impact on Atmospheric Chemistry:

The GEM-Mars GCM could also demonstrate how the redistribution of water vapor affected the atmospheric chemistry. In particular, we found that ozone on Mars was destroyed in the middle atmosphere on a planet-wide scale. The UVIS channel of NOMAD allows to retrieve ozone vertical profiles (Patel et al., 2021; Khayat et al., 2021). Patel et al. (2021) described a decrease in ozone during the 2018 GDS. By applying dedicated filtering to the NOMAD ozone observations during dusty conditions, the GCM simulations could be compared in detail to the NOMAD ozone profiles taken during the GDS (Daerden et al., 2022b). We will present model-data comparisons in various ways to demonstrate that the combination of NOMAD observations and GCM simulations confirm that the middle atmospheric ozone on Mars was destroyed by up to 95% at all latitudes, including the polar maxima. In contrary, the model predicts that the near-surface ozone (and hence total column ozone) at low latitudes is increased during the GDS.

As water vapor is ascending to large altitudes and latitudes during the GDS, and as the water vapor photolysis rate coefficient increases with height, this causes a strong increase in odd hydrogen radicals (HO_x, i.e. OH and HO_2) in the Martian middle and upper atmosphere. We demonstrate using the GCM that it is not the increased HO_x that destroys ozone directly, but the resulting decrease in atomic oxygen rather suppresses the formation of ozone.

Impact on Atmospheric Escape:

The model also computes the increase of atomic hydrogen in the middle and upper atmosphere as a consequence of the redistribution of water vapor. We find enhancements of almost 2 orders of magnitude during the GDS, which is consistent with enhanced hydrogen escape observed in the upper atmosphere during the GDS (e.g., Stone et al., 2020). Odd hydrogen species have only been sparsely observed in the past on Mars, and were to present day not observed by TGO instruments. Nevertheless they are key species that drive the Martian atmospheric chemistry, and form the link between middle atmospheric water vapor and upper atmospheric escape. Our model simulations are constrained by middle atmospheric water vapor and ozone observations (two end points in the photochemical cycles), and the overall good comparison supports the simulated odd hydrogen abundances. This is an important requisite to quantify the enhanced escape and understand the connection with lower atmospheric processes.

References:

Aoki et al. (2019), https://doi.org/10.1029/2019JE006109; Daerden et al. (2022a) https://doi.org/10.1029/2021JE007079; Daerden et al. (2022b), GRL, in review; Fedorova et al. (2020) https://doi.org/10.1126/science.aay9522; Khayat et al. (2021) https://doi.org/10.1029/2021JE006834; Neary et al. (2020) https://doi.org/10.1029/2019GL084354; Patel et al. (2021) https://doi.org/10.1029/2021JE006837; Stone et al. (2020) http://doi.org/10.1126/science.aba5229; Vandaele et al. (2019) https://doi.org/10.1038/s41586-019-1097-3; Villanueva et al. (2021) https://doi.org/10.1126/sciadv.abc8843