Differential Ablation of Meteoric metals in the LMD-Mars-Metals and NCAR CESM2-Metals models

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1 Abstract:

Observing and modelling of mesospheric metal layers can be used to provide information on how cosmic dust ablates as it enters the atmosphere from space. The metal layers are also very useful for testing transport and chemistry processes in the MLT region. We have developed the first global meteoric atmospheric metals model in the NCAR's Whole Atmosphere Community Climate Model (WACCM) and updated the meteoric metals with several significant changes (termed as CESM2-Metals), see Fig 1. A layer of Mg^+ produced by meteoric ablation, occurs in the range 70-130 km, which is peaking ~90 km in the Martian atmosphere, has been observed by NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft IUVS (Imaging Ultraviolet Spectrograph, Fig 5) . MAVEN's Neutral Gas Ion Mass Spectrometer (NGIMS) has also measured Mg^+, Fe^+ and Na^+ in the Martian upper atmosphere during deep dip campaigns (Fig 5). Therefore, it is necessary to develop a global meteoric metals model for the Martian atmosphere to investigate the processes controlling the metal layers. Here we have used a similar method as CESM2-metals (Fig1) to develop the Martian's atmospheric meteoric metals in the Laboratoire de Météorologie Dynamique (LMD) Mars global circulations model (Fig 2).

2 Mars-MIF (Meteoric Input Function):

Meteoric ablation is the source of metal layers, when the cosmic dust particles enter the atmosphere. The Leeds Chemical ablation MODel (CABMOD) is combine with other astronomy model (Zodiacal Cloud Model) to produce the meteoric input function (MIF) (injection rate profiles of the main meteoric chemical species into the atmospheres of Earth, Mars and other planets), including three main cosmic dust sources: Jupiter-Family Comets, main-belt asteroids and Halley-Type Comets). Meteoric ablation occurs above 50 km up to 100 km with different peak injection rate of Mg for different latitudes in the Martian atmosphere (Fig 3).

3 LMD-Mars-Metals model:

- σ-p coordinate from surface to ionosphere (up to 250 km) (Chaufray et al., 2013);
- Dynamical core: continuity, momentum, energy equation of Mars atmosphere;
- Physical core: Sources/loss terms and the subgrid processes (boundary layer turbulence, convection, gravity waves (orographic) and low level drags);
- Radiative transfer: CO_2 gas absorption/emission, heating due to CO_2 and dust, cooling due to thermal IR of CO_2, non-LTE, UV and EUV heating;
- CO_2 condensation, Surface thermal conduction;
- Tracer transport and detailed photochemistry scheme (González-Galindo et al., 2013);
- Mg, Fe and Na chemistry module and their injection rates are included (Fig 2)

4 LMD-Mars-metals Performance:

- ➢ Mg^+ layer in the tropical region occurs in the altitude range of 70-130 km, peaking ~90 km with a concentration up to 500 cm^{-3} (Fig 5);
- ➢ 1-D model (Plane et al., 2018) simulates well the observed Mg^+, 3D LMD-Mar-metals overestimates Mg^+ density with some improvements using the updated chemistry (Marsh et al., 2022) in terms of Mg^+ layer and peak altitude (Fig 5);
- ➢ NGIMS measurements showed the metallic ions and CO_2 had very similar scale heights (i.e., the distance over which the concentration changes by a factor *e* (Fig 5);
- ➢ LMD-Mars-metals is able to simulate the larger observed Fe^+ than Mg^+, Na^+ above 130 km.

5 Annual mean Mg^+ profile

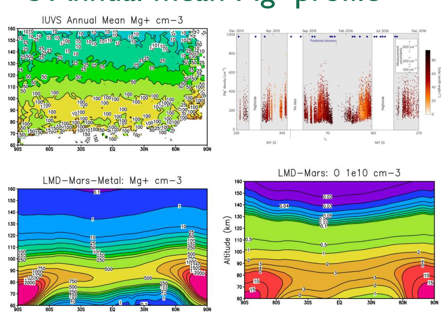

Fig 6: Annual mean Mg^+ from IUVS and the model. Top right: Observed Mg^+ concentration (90-100 km, Crismani et al., 2017). Large discrepancies of Mg^+ at high latitude, which is caused by very high modelled atomic O.

6 Seasonal variation of Mg^+

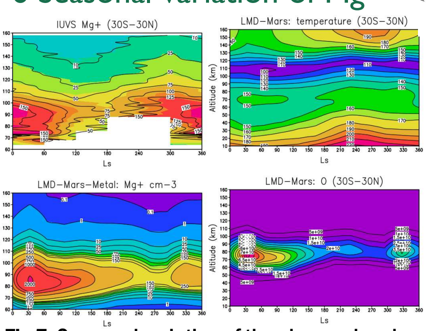

Fig 7: Seasonal variation of the observed and modelled Mg^+, T, O in the tropical region. Model seems to capture the larger observed Mg^+ for some seasons. Again large discrepancies of Mg^+ at Ls=30 is caused by very high O density.

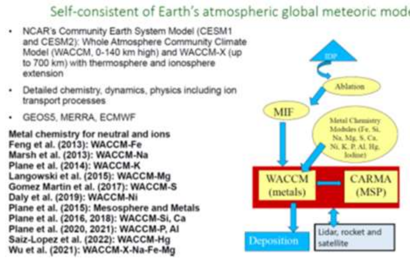

Fig 1: CESM2-Metals Model

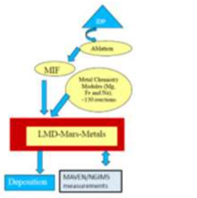

Fig 2: LMD-Mars-Metals model

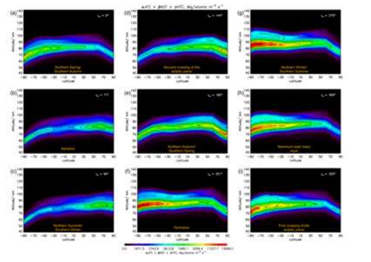

Fig 3: Injection rates of Mg weighted over a Martian day as a function of latitude and height for the orbital positions (Carrillo-Sanchez et al., 2022)

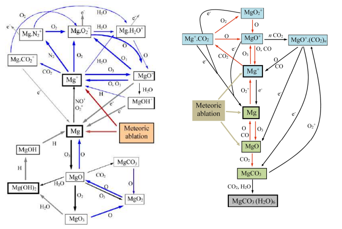

Fig 4: Magnesium chemistry: Earth's (left, Plane et al., 2015) and Martian (right, Plane et al., 2018) upper atmosphere.

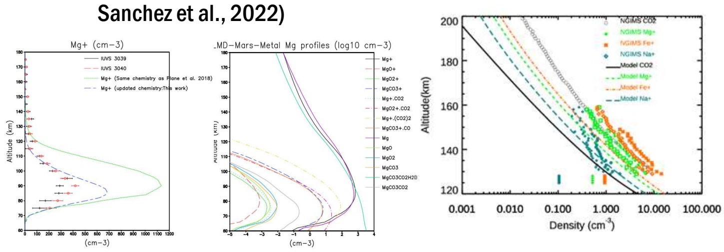

Fig 5: Mg^+ profile in the tropical region from the IUVS (Crismani et al., 2017), 1D (Plane et al., 2018) and 3D LMD-Mars-metals model simulations using the same Mg chemistry (Figure 4) and some updates (Marsh et al., 2022). Also shown the all Mg species and Mg^+, Fe^+ and Na^+ vertical profiles between LMD-Mars-metals results and NGIMS observations during the deep-dip campaigns (Grebowsky et al., 2017).

7 Diurnal variation of Mg^+

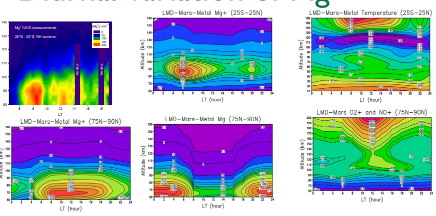

Fig 8: Time series of observed and modelled Mg^+, T or the total of O_2^+ and NO^+ at low/high latitudes. Model captured the Mg^+ peak well. Tides dominates the Mg^+ diurnal variation at low latitudes. Peak Mg^+ concentration occurs at lower altitude in the high latitude, mainly caused by the charge transfer (bottom).

8 Earth's Mg^+

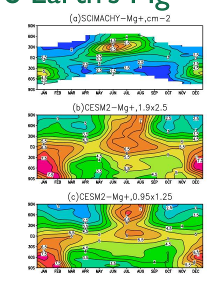

Fig 9: Mg+ total column in the Earth's atmosphere from SCIAMACHY/Envisat satellite (Langowski et al. 2015) and CESM2-metals results.

Summary

- Successful developed the first self-consistent model of mesospheric meteoric metals in the state-of-the-art Laboratoire de Météorologie Dynamique (LMD) Mars global circulations model and NCAR's Earth System Model (CESM2) including the latest updated MIF and metal chemistry, which allow us to better understand the astronomy, chemistry and transport processes that control the different metal layers in the MLT for Martian and Earth's atmosphere.

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