Introduction

The Global Environmental Multiscale model for Mars (GEM-Mars) has undergone considerable improvements and now simulates Mars atmospheric chemistry in reasonable accordance with available datasets and with the LMD model [Lefèvre et al., 2004]. Model innovations include an update from GEM 3.3.0 to GEM 4.2.0, inclusion of radiative effects of water ice clouds, and a parameterization for non-condensable gas enrichment. The diurnal and seasonal variations are compared to observations and to other models.

1. The GEM-Mars GCM

The GEM-Mars General Circulation Model (GCM) is based on the Canadian Global Environmental Multiscale (GEM) model for weather forecasting on Earth [Côté et al., 1998; Daerden et al., 2015]. The model is typically operated on a grid with a horizontal resolution of 4°×4° and with 103 hybrid vertical levels reaching from the surface to ~150 km. Processes that were added to the model since older versions include lifting of size-distributed dust by saltation and in dust devils, and dust radiative heating using the refractive index of Wolff et al. [2006, 2009], an interactive CO₂ cycle with surface exchange, a multi-layered thermal soil model, turbulent transport in the atmospheric surface layer, convective transport inside the PBL, convection in the free troposphere through mixing of dust-generated instabilities, low level blocking, gravity wave drag, and a full water cycle with ice and surface frost formation, sedimentation of monodisperse particles, a subsurface ice table and radiative effects of clouds and surface ice. The geophysical boundary conditions include topography [Smith et al., 1999], albedo [Christensen et al., 2001], thermal inertia [Putzig et al., 2005], and roughness length [Hébrard et al., 2012]. The integration timestep was 1/48 of a sol (Martian solar day).

2. The dust cycle

The implementation of saltation in the model uses the “KMH” method of Kahre et al. [2006] with the application of a detailed roughness map [Hébrard et al., 2012; Daerden et al., 2015]. The mass flux from dust devils is implemented by the parameterization of Renno et al. [1998]. Both methods require tuning of proportionality factors to match observations. The resulting simulated seasonal dust cycle (Fig. 1) compares qualitatively to observations, e.g. from THEMIS on Mars Odyssey [Smith, 2009] (note that dust inside the polar nights remains largely unobserved). Settings were applied for a year with minor dust storm activity.

![Figure 1: Zonal mean optical depth of dust simulated in GEM-Mars for a year with minor dust storm activity, compared to dust optical depth observations from THEMIS on Mars Odyssey for Mars year 31.](image1)

![Figure 2: Seasonal cycle of the zonally averaged total water column (in pr-µm) as observed by CRISM in Mars year 30 (top) and simulated by GEM-Mars (bottom).](image2)
3. The water cycle

Together with the global circulation patterns, the Mars water cycle is the principle driver of the Martian photochemistry. The simulated water cycle is compared in Fig. 2 to the observations by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument [Smith et al., 2009] on the NASA Mars Reconnaissance Orbiter (MRO).

4. The ozone cycle

The seasonal cycle of ozone is strongly controlled by the water cycle. The simulated cycle is shown in Fig. 2 and compared to the observations by the Mars Color Imager (MARCI) instrument [Clancy et al., 2016] on MRO. The results shown here do not include heterogeneous chemistry processes, as was suggested in Lefèvre et al. [2008].

Figure 3: Seasonal cycle of the zonally averaged total ozone column (in µm-atm) as observed by MARCI in Mars year 31 (top) and simulated by GEM-Mars (bottom). Elevated values at nonpolar latitudes in the second half of the year in the MARCI data are due to dust contamination in the retrieval process [Clancy et al., 2016].

5. Seasonal cycle of noncondensable species

Because CO₂ as major atmospheric constituent is subject to dramatic condensation during the polar winters, the resulting effect on the mixing ratios of species that do not condense with CO₂ is considerable [Sprague et al., 2004; Smith et al., 2009]. In GEM-Mars a parameterization was developed to simulate this process based on the local pressure change upon CO₂ condensation or evaporation. The resulting seasonal cycle of carbon monoxide (CO) is shown in Fig. 4 and compared to CRISM data from Mars year 30 [Smith et al., 2009].

Figure 4: Zonal mean column-averaged volume mixing ratio of carbon monoxide observed by CRISM in Mars year 30 (top) compared to the simulation in GEM-Mars (bottom).

References

Clancy, R. T., et al. (2016), Icarus 266, 112–133
Lefèvre, F. et al. (2008), Nature 454, 971–975
Smith, M. D. (2009), Icarus 202, 444–452.