SENSITIVITY OF RADIATIVELY ACTIVE WATER ICE CLOUDS ON GRAVITY WAVE DRAG IN THE GEM-MARS GCM

L. Neary, **F. Daerden,** *Royal Belgian Institute for Space Aeronomy, Brussels, Belgium. (lori.neary@aeronomie.be)*

Introduction:

It has been shown in several modeling studies that radiatively active water ice clouds (RAC) are key to simulating the thermal structure of the Mars atmosphere (e.g. Madeleine et al., 2012, Wilson et al., 2008). Mid-altitude (~20-30 km) temperatures observed in the equatorial region during the northern summer season around aphelion are best explained when this effect is included in general circulation models (GCMs). Another thermal feature during the winter solstice at each pole is an inversion or polar warming, with temperatures around 50-60 km increasing significantly compared to the levels below (McCleese et al., 2008). The inversion is a result of strong down-welling of the Hadley circulation over the pole. The magnitude, slope and shape of this polar warming are also affected by the inclusion of RAC in GCM simulations, as it increases the overall strength of the circulation.

This region of the atmosphere during the solstice period is also affected by orographic gravity wave drag (GWD). The large topographic features of the Martian surface lead to excitation of gravity waves that propagate upwards and break in the upper atmosphere away from the source regions. These waves are typically of the scale below the horizontal resolution of most GCMs and must be parameterized.

In this study, we are interested in quantifying the effect of RAC on the GWD parameterization and the general circulation patterns in the GEM-Mars GCM.

Methodology:

We use the GEM-Mars model (Daerden et al., 2015, Viscardy et al., 2016) for this study, at a horizontal resolution of 4°x4° with 103 vertical levels. The model includes a gravity wave drag parameterization (McFarlane, 1987) and a low level blocking scheme (Zadra et al., 2004). Model topography and subgrid-scale parameters are taken from higher resolution (0.25°x0.25°) data from the Mars Orbiter Laser Altimeter (MOLA).

The model has an active dust lifting scheme but for this experiment, the total optical depth of dust is scaled to climatological values for Mars Year 31 (Montabone et al., 2015), while the vertical profile from the dust lifting scheme is maintained.

RAC is implemented in the model, assuming 4 μm spherical particles with optical properties computed using Mie code and refractive indices from Warren and Brandt (2008).

We compare temperatures with the Mars Climate Sounder (MCS) (McCleese et al., 2007, Kleinböhl et al., 2013) for MY31 and examine the tendency of the wind fields due to the GWD parameterization for two simulations, with and without RAC.

Results: Figures 1 and 2 compare zonal mean modeled temperature profiles with MCS for noRAC and RAC simulations respectively. The inclusion of RAC improves temperatures for all seasons in general with the largest effect occurring during the northern summer solstice period (L_s=90°) when the equatorial aphelion cloud belt occurs.

Figure 3 shows the difference between the 2 simulations, showing a warming of ~15-20K during this period, and warming of ~5-15K in other seasons in the mid-altitude range.

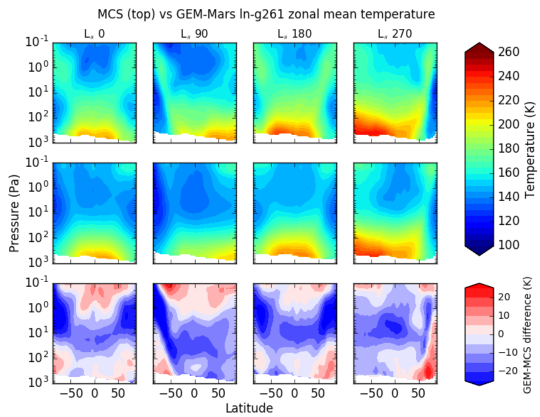

Figure 1 Seasonal average MCS (Top) and GEM-Mars noRAC simulated temperatures with their differences.

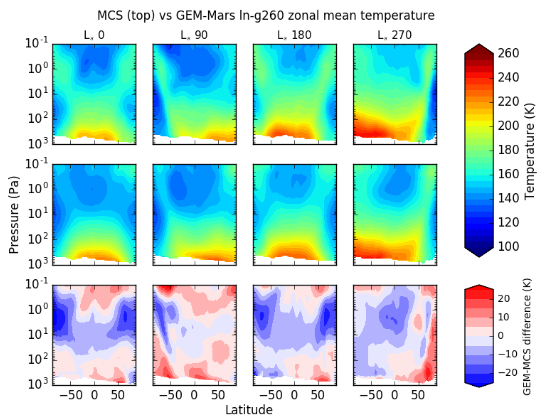

Figure 2 Same as above but with GEM-Mars RAC simulation.

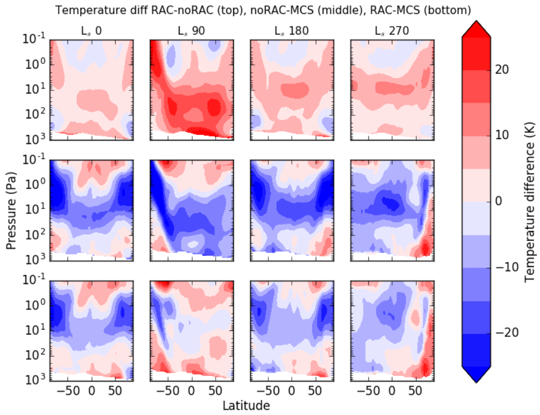

Figure 3 Zonal mean temperature differences for 4 seasons. Top row is difference of RAC-noRAC simulations, the middle row is noRAC-MCS, bottom row is RAC-MCS.

For the same two simulations, we look at the GWD induced changes to the zonal and meridional winds in m/s/sol, for the L_s=90°-120° period, shown in figure 4. The background contours show the model zonal mean temperature profiles with the wind tendencies shown with black (zonal, on the left) and white (meridional, on the right) contours. A negative tendency means that the winds are slowed and a positive tendency indicates an increase in wind speed. The inclusion of RAC has the effect of reducing the drag, whether it be deceleration in the case of zonal winds, or acceleration of meridional winds in the south polar winter region.

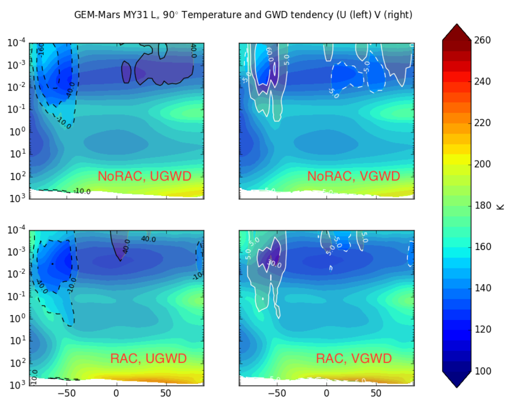

Figure 4 L_s=90°-120° zonal mean temperatures for noRAC (top) and RAC (bottom) simulations, overlaid with contours showing the tendency of zonal (left) and meridional (right) winds due to GWD in m/s/sol.

Discussion and conclusions: The addition of radiatively active water ice clouds in the GEM-Mars GCM improves the comparison with observations of temperatures in the middle atmosphere. It has the overall effect of increasing the strength of the Hadley cell circulation, which in turn strengthens the winter polar warming.

The change in circulation and temperature structure has an impact on the amount of drag induced by gravity waves as calculated by the parameterization. In the south polar winter, the amount of drag on both the zonal and meridional wind fields is reduced by more than half in the region just above the location of the polar warming.

Further tests are underway to better quantify and understand the indirect effects of RAC on the general circulation.

Acknowledgements:
The research presented here has received support from the European Union Seventh Framework Program (FP7/2007-2013) under grant agreement no 6071777, the CROSS DRIVE project.

References:

Daerden, F., Whiteway, J.A., Neary, L., Komguem, L., Lemmon, M.T., Heavens, N.G., Cantor, B.A., Hébrard, E., Smith, M.D., 2015. A solar escalator on Mars: Self-lifting of dust layers by radiative heating. Geophysical Research Letters 42, 7319–7326. doi:10.1002/2015GL064892

Kleinböhl, A., John Wilson, R., Kass, D., Schofield, J.T., McCleese, D.J., 2013. The semidiurnal tide in the middle atmosphere of Mars. Geophys. Res. Lett. 40, 1952–1959. doi:10.1002/grl.50497

Madeleine, J.-B., Forget, F., Millour, E., Navarro, T., Spiga, A., 2012. The influence of radiatively active water ice clouds on the Martian climate, Geophysical Research Letters 39. doi:10.1029/2012GL053564

McCleese, D.J., Schofield, J.T., Taylor, F.W., Abdou, W.A., Aharonson, O., Banfield, D., Calcutt, S.B., Heavens, N.G., Irwin, P.G.J., Kass, D.M., Kleinböhl, A., Lawson, W.G., Leovy, C.B., Lewis, S.R., Paige, D.A., Read, P.L., Richardson, M.I., Teanby, N., Zurek, R.W., 2008. Intense polar temperature inversion in the middle atmosphere on Mars. Nature Geoscience 1, 745–749. doi:10.1038/ngeo332

McCleese, D.J., Schofield, J.T., Taylor, F.W., Calcutt, S.B., Foote, M.C., Kass, D.M., Leovy, C.B., Paige, D.A., Read, P.L., Zurek, R.W., 2007. Mars Climate Sounder: An investigation of thermal and water vapor structure, dust and condensate distributions in the atmosphere, and energy balance of the polar regions. Journal of Geophysical Research 112. doi:10.1029/2006JE002790

McFarlane, N.A., 1987. The effect of orographically excited gravity wave drag on the general circulation of the lower stratosphere and troposphere. Journal of the atmospheric sciences 44, 1775–1800.

Montabone, L., Forget, F., Millour, E., Wilson, R.J., Lewis, S.R., Cantor, B., Kass, D., Kleinböhl, A., Lemmon, M.T., Smith, M.D., Wolff, M.J., 2015. Eight-year climatology of dust optical depth on Mars. Icarus 251, 65–95. doi:10.1016/j.icarus.2014.12.034

Viscardy, S., Daerden, F., Neary, L., 2016. Formation of layers of methane in the atmosphere of Mars after surface release: Formation of Layers of Methane on Mars. Geophysical Research Letters. doi:10.1002/2015GL067443

Warren, S.G., Brandt, R.E., 2008. Optical constants of ice from the ultraviolet to the microwave: A revised compilation. Journal of Geophysical Research 113. doi:10.1029/2007JD009744

Wilson, R.J., Lewis, S.R., Montabone, L., Smith, M.D., 2008. Influence of water ice clouds on Martian tropical atmospheric temperatures, Geophysical Research Letters 35, doi:10.1029/2007GL032405

Zadra, A., Roch, M., Laroche, S., Charron, M., 2003. The subgrid-scale orographic blocking parametrization of the GEM Model. Atmosphere-Ocean 41, 155–170. doi:10.3137/ao.410204