Review of the manuscript "Influence of gravity waves on the climatology of high-altitude Martian carbon dioxide ice clouds" by Yiğit et al., submitted to Annales Geophysicae

General comments

The manuscript studies the links between the formation of CO2 clouds in the mesosphere of Mars and the effects of gravity waves propagating from the lower to the upper atmosphere. For this purpose, a General Circulation Model (GCM) incorporating a subgrid-scale parameterization of the effects of gravity waves, previously used to study the role of gravity waves on cloud formation for a single season, is run for a full Martian year. Gravity waves produce a global cooling of the upper atmosphere that facilitates the formation of clouds, and in addition induce local temperature perturbations producing cold air pockets. An statistical probability of cloud formation is derived from the model outputs, which the authors find to correlate well with the gravity wave activity in the model. The authors claim that the probability of cloud formation they derive is in good agreement with the observed seasonal and latitudinal climatology of mesospheric CO2 clouds.

The paper is well written and easy to read. The topic is of interest for the Martian community (and also for people studying high altitude clouds on other planets, including the Earth). The introduction adequately summarizes previous works on the topic and sets up the questions raised by them. The figures are appropriate, although some minor improvements could be made to facilitate the comparison with observations (see below). The length of the manuscript is also appropriate. However, I find the discussion about the comparison with the observations to be flawed due to the incorrect assumptions the authors make about the observations in Sefton-Nash et al. (2013) (see details below). This is an essential aspect of the manuscript that absolutely needs to be corrected before publication.

Specific comments

-In order to validate their predicted CO2 cloud formation probability, the authors chose to use the observations by the Mars Climate Sounder (MCS) instrument described in Sefton-Nash et al. (2013), who observed that mesospheric clouds were usually confined to a narrow latitudinal band around the equator during the first part of the Martian year, while during the second half of the year mesospheric clouds appeared in the mid latitudes of both hemispheres. The problem is that the authors are assuming that all observations in Sefton-Nash et al. (2013) are CO2 clouds, which is not the case. Most if not all of the aerosol layers observed by MCS in the mid latitudes during the second half of the year are not CO2, but H2O clouds or even dust, which has very different implications for the mesospheric temperatures involved. This is proven by MCS temperature measurements simultaneous to the cloud observations, showing that the mid-latitude clouds formed after Ls=150 occur at layers with atmospheric temperature generally >40K above the CO2 frost point. Quoting Sefton-Nash et al. (2013), pages 351-352 "Retrievals for features detected during dust storm season generally shows temperatures between 30 and 80 K higher than CO2 frost poing, suggesting that the formation of CO2 ice at mesospheric altitudes is far less likely during perihelion season". This is in contradiction with the manuscript, e.g. (page 9): " The model reproduces more favorable conditions for CO2 condensation in the midlatitude regions during wintertime. It agrees with observations in that mesospheric clouds occur more frequently during perihelion (Figure 5g)". So, this last statement is not correct for CO2 clouds, which are the ones relevant for this study.

In fact, all the observations of mesospheric clouds able to spectrally discriminate between CO2 and H2O clouds (those made by the OMEGA/Mars Express, PFS/Mars Express and CRISM/MRO instruments) provide a very similar climatology of CO2 mesospheric clouds, with almost all observations concentrating around the equator (and at restricted longitudinal corridors) for the Ls=0-60 and Ls=90-130 periods, with just a couple of clouds observed by OMEGA at latitudes around 50 in both hemispheres during winter (e.g. Aoki et al., 2018; Vincendon et al., 2011; Määttänen et al., 2010). THEMIS/Mars Oddyssey instrument observed a population of mesospheric clouds in the mid latitudes on the Northern hemisphere winter (McConnochie et al., 2010), but they could not discriminate between CO2 and H2O clouds, and their low altitudes (~45-55 km) suggest they are more likely H2O clouds.

This observed climatology of unambiguous CO2 mesospheric clouds presents significant differences with the model predictions summarized in Fig. 5. The most striking one is that the model predicts high cloud formation probability during the second half of the year both at the equator and at the mid-high latitudes of the Northern hemisphere (at 80 km) and at both hemispheres (100 and 120 km). However, CO2 clouds have barely been observed during this period. Given the connection between the gravity wave activity and the predicted cloud formation, this would suggest that the predicted effects of gravity waves are too intense, at least in the mid-high latitudes during the second half of the year.

To summarize, the comparison between the observed cloud climatology and the model predictions should be based only on clouds spectroscopically unambiguously determined to be composed of CO2. The differences between the observed and predicted CO2 cloud climatology should be acknowledged, and the implications for the gravity wave activity in the model discussed.

-Another interesting aspect that deserves further discussion is the altitude variation of the cloud formation probability, predicted to be significantly larger at 120 km than at 80 km. Although the altitude of CO2 mesospheric clouds is not easy to determine for most of the datasets, the current observational knowledge is that, at least during daytime, they are placed at altitudes of about 70-80 km (Schölten et al., 2010; Määttänen et al., 2010). During nighttime SPICAM has detected mesospheric clouds with altitudes around 100 km. No clouds have been detected, to my knowledge, around 120 km or higher, where the model predicts the higher cloud formation probability. I would like to see a discussion about this discrepancy in the manuscript.

-The GCM used in the study is very shortly described, apart from the gravity wave parameterization. While this is mostly OK given that the model has already been described in previous papers, I think the implementation of the physical processes affecting the temperatures in the mesosphere/lower thermosphere needs to be described to some extent. For example, what atomic oxygen distribution are you using among the different possibilities discussed in Medvedev et al., 2015?

-Page 4, lines 8-9. “In the middle and upper atmosphere of Mars, wave damping occurs due primarily to nonlinear wave-wave interactions (breaking and/or saturation) and molecular diffusion and thermal conduction, which are accounted for through the transmissivity”. Eckermann et al., Icarus 211, pp. 429-442 (2011) showed that radiative damping can be a dominant process in the middle atmosphere of Mars. Do you consider it in your model?

-Figure 1. The gravity wave cooling is generally below 60 K/day except for the strong peak at 140 km reaching 120 K/day. Could you provide an the explanation for this strong peak? It apparently affects only one or two model layers, could you confirm this? Can it be due to any boundary effect? Note also that Fig. 1b) horizontal axis is labeled as K/day, but in the caption you state it is in units of K/sol, which is slightly different. Please correct.

-Page 8, lines 4-5: “The model generally reproduces the observed temperature well, except that it overestimates it in the southern hemisphere winter by up to 20 K”. Other data-model discrepancies are evident by comparison of Fig. 4a with Figure 10 in Sefton-Nash et al., (2013). In particular, the temperature at 80 km in the polar regions can be higher than 180 K in MCS observations, while apparently (but this is maybe an artifact of the chosen color scale) do not go much higher than 150 K in the model. Could you please clarify it?

-Page 8, lines 10-11: “It is seen that the coldest temperatures of down to 90-100 K are found around the summer high-latitudes at solstices and during equinoxes”. I do not see those low temperatures during equinoxes, when apparently temperatures do not go below 120 K, as can be seen also in Fig. 2a. Please clarify/correct.

-Page 9, lines 14-16. “Although the vast majority of studies report on cloud observations in the Martian mesosphere below ~80 km, there are some studies that extend their analysis to higher altitudes presenting detections of CO2 clouds at around the mesopause (~100 km) and above (e.g. Sefton-Nash et al., 2013)”. Sefton-Nash et al. (2013) only detected clouds up to 90 km (e.g. their figure 9).

Technical corrections

-Page 2, line 1: “Because the Martian mesosphere is, in average, warmer ...” Warmer than the terrestrial one, or warmer than the CO2 frost point? Please specify.

-Page 3, line 5 “variations variations”. Please remove one.

-Page 3, line 30: “It was developed in detail in the work of Yigit et al. (2008), the general principles of ...”. I think either removing “in detail” or changing to “described in detail” would be more correct. Also please add “and” after the comma.

-Page 4, lines 29-30. “This launch level is around 260 Pa”. Please provide an average altitude for this pressure level.

-The different shades of blue and red in Figs 3, 4 and 5 are not always easy to distinguish (maybe it is a problem with my printed copy). You could consider adding black labeled contours to improve legibility.

-Page 7, line 25. “A more closer examination”. Please remove “more”.

-Figure 4. These temperatures are daily and zonally averaged, or shown instead at a given local time? Please mention it in the figure caption.

-The comparison with the observed seasonal variability would be eased if Figs. 4 and 5 used the solar longitude Ls as a measure of time, instead of the Sol number. At least, please consider adding an additional horizontal axis displaying Ls.

-Page 8, line 29. “During southern winter solstices” → solstice

-The text states (page 5, line 8) that “ instantaneous values of the parameterized (unresolved by the model) temperature disturbances *T’* are impossible to determine” so that an average value |*T’*| is used instead. However, in all later mentions to these temperature perturbations, *T’* is used, and not |*T’*| (e.g. eq. (2), page 7 line 27, page 8 line 18, labels in Figures 3 and 5,...). Please be consistent with the nomenclature across the paper.

-Page 11, lines 5-6: “without subgrid-scale effects effect included”. Please remove “effect”