ICE CLOUD RETRIEVAL IN THE MARTIAN ATMOSPHERE USING SPICAM/UV.


Introduction

The SPICAM instrument on board Mars-Express (MEX) provides valuable data to investigate the Martian atmosphere since 2004. The UV channel, a spectrometer operating in the spectral interval between 110-320 nm, has been in activity during 11 years. The nadir viewing mode records the solar radiation that has been scattered and reflected by the planet and its atmosphere. From these measurements, we can deduce the amounts of several atmospheric species such as dust, ice clouds [Mateshvili et al., 2007, 2009] and ozone [Perrier et al., 2006] but also the surface albedo.

We have developed an improved retrieval algorithm using a more recent and up-to-date parametrisation of the atmosphere and surface characteristics than in previous SPICAM works. The purpose is to deduce simultaneously the following parameters: the ozone column, the dust optical depth (OD), the cloud OD and the surface reflectance. In order to keep independent parameters, the retrieval was limited to 3 parameters. The choice of the non retrieved parameter is made between the cloud OD and the surface albedo for each measurement and depends on the cloud presence. We have therefore developed a cloud detection algorithm from which the results have been compared to those of MEX/OMEGA.

More than 4 Martian years (MY27-30) of SPICAM UV data have been analysed with our retrieval method to produce climatologies of the 4 studied parameters. We will present the results obtained for clouds: the principle of the cloud detection algorithm and the climatology of the retrieved cloud OD obtained using our retrieval method.

Cloud detection method

Clouds appear very bright in the UV compared to the “dark” regolith surface and result in the measurements by an increase of the recorded signal. More precisely, the increase of signal is proportionally more important at longer wavelengths than at shorter wavelengths in the interval considered (220-290 nm). The principle of detection is thus based on the combination of two characteristics: a relatively large increase of the averaged signal ($S_{av}$) and an increase of longer/shorter wavelength ratio (or colour ratio: $R_{av}$). This combination allows to differentiate from the effects due to dust, ozone and Rayleigh scattering. However, the surface reflection also shows such a combination, but as the regolith is strongly absorbing, it induces only limited signal variations and can be differentiated by choosing an adapted (large enough) threshold. On the contrary, ice surface is very bright and can not be differentiated by such a threshold. Area covered by ice, based on the MCD (Mars Climate Database) v5.0 predictions, were therefore excluded in the cloud detection. An “uncertain” area of about 10° latitude is also delimited at the edge of the ice caps, and in which the detections must be considered with caution as it could have been induced by the unpredicted presence of ice.

Each orbit is analysed separately. We simulate an averaged estimate signal $Est_{av}$, analogous to $S_{av}$, using the a priori values (atmospheric parameters from MCD and regolith surface parameters from [Wolff et
al., 2014)]. The idea being that $\text{Est}_{\text{av}}(i_{\text{av}})$ should follow the $S_{\text{av}}(i_{\text{av}})$ variations relatively closely for all $i_{\text{av}}$ measurements wherein no cloud nor ice are present, while for the measurements affected by the presence of clouds or ice, $S_{\text{av}}$ would increase relatively to $\text{Est}_{\text{av}}$.

Figure 1 shows the examples of orbit 2201 and 891. $\text{Est}_{\text{av}}$ is used to select the cloud- and ice-free (CIF) reference measurements (i.e. all the measurements for which $S_{\text{av}}$ remains close or below $\text{Est}_{\text{av}}$). These CIF measurements are then used to build a CIF averaged signal $S_{\text{av}}^{\text{ref}}$ (resp. a CIF colour ratio $R_{\text{av}}^{\text{ref}}$) to which $S_{\text{av}}$ (resp. $R_{\text{av}}$) is then compared in order to determine if the cloud detection threshold $t_{\text{av}}$ (resp. $t_{rb}$) is exceeded. A cloud is detected when both conditions are verified:

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\begin{align*}
S_{\text{av}}(i_{\text{av}}) &> (1 + t_{\text{av}}) \quad S_{\text{av}}^{\text{ref}}(i_{\text{av}}) \\
R_{\text{av}}(i_{\text{av}}) &> (1 + t_{rb}) \quad R_{\text{av}}^{\text{ref}}(i_{\text{av}})
\end{align*}
\]

where $S_{\text{av}}^{\text{ref}}$ (resp. $R_{\text{av}}^{\text{ref}}$) is obtained from $S_{\text{av}}$ (resp. $R_{\text{av}}$) using a weighted average on the nearest CIF measurements (the weight depends on the spatial proximity and surface elevation).

Comparison with OMEGA

We have performed a comparison of our detection results with those obtained by OMEGA, also on board MEX. Their method uses the 3.1 $\mu$m water ice absorption band, considering the slope on the edge of the band between 3.4-3.52 $\mu$m to derive the "cloud index" [Langevin et al., 2007]. OMEGA can make the difference between ice cloud and ice surface (and also between H$_2$O and CO$_2$ ice) which is useful to validate our detection method. The comparison was performed on simultaneous observations of both instruments. This is important for cloud detection as clouds can appear and disappear relatively quickly following the temperature variations.

A detailed comparison was performed with the cloud index maps derived in Madeleine et al., 2012 for the Tharsis region and its vicinity, revealing a very good agreement (in terms of location and extension) for clouds with moderate-to-large OD (retrieved afterwards). For clouds with lower OD, at which the OMEGA method is estimated to reach its detection limit, OMEGA performs still some faint detections that are usually seen by SPICAM (with some additional detections with SPICAM).

Comparisons were also performed in the vicinity of the polar caps where our detection must be considered with caution due to the potential presence of unpredicted ice on the surface. The comparison with OMEGA’s results shows a reasonable agreement between the two methods: the detections (of ice or clouds) correspond, however their spatial extension is not always in perfect agreement. The comparison with OMEGA results tends to validate our detection algorithm.

Cloud climatology

The cloud climatology presented here has been obtained by analysing more than 4 Martian years of SPICAM/UV measurements with the detection algorithm combined with the retrieval algorithm.

Figure 2 shows the seasonal evolution of the cloudiness on Mars, averaged latitudinally and on the 4 MYs. It illustrates the different cloud features that appear on Mars throughout the year. The two main features are: the aphelion cloud belt (ACB) that occurs every year at low latitudes during the aphelion season and the polar hoods that occur above the polar regions of the winter hemisphere.

The spatial and seasonal evolution of the ACB was analysed, showing its different stages as visible in figure 2: the formation starts around $L_s = 20 - 30^\circ$, it shows a maximum extension and intensity between $L_s = 80^\circ$ and $L_s = 140^\circ$ and quickly disappears after $L_s = 140^\circ$. The spatial extension for the ACB maximum activity, when clouds form a belt all around the equator, is shown in figure 3. The highest opacities are observed above the Tharsis region, Lunae Planum and over in the vicinity of Olympus and Elysium volcanoes. These seasonal and spatial distributions are in agreement with the results of Smith et al., 2004 using MGS/TES.

The largest values of cloud OD are often found above the high volcanoes. These orographic clouds form because of adiabatic cooling that occurs with upslope winds arising on these volcanoes. This process makes these locations particularly favourable for cloud formation. As shown in figure 4, we have analysed the seasonal evolution of the cloudiness above the six tallest volcanoes and compared it to the results of Benson et al., 2006 obtained using MGS/MOC: the periods...
where clouds are observed with SPICAM and MOC shows generally a good general agreement indicating a year-to-year repeatability (as the measurements from both instruments do not overlap in time). A correlation between the spatial extension derived by MOC and the OD of clouds obtained from SPICAM is sometimes observed.

The edge of the polar hoods were observed at certain periods as visible in figure 2. For example, the northern polar hood (NPH) was clearly observed with SPICAM between $L_s = 150-200^\circ$. We observe that it starts to form around $L_s = 150^\circ$ and expands progressively equatorward and grows in thickness until $L_s = 200^\circ$. The spatial distribution for this period is shown in figure 5 indicating that all longitudes are covered by the polar hood. The NPH reaches generally latitudes down to 45°N but deviations are visible: the hood extends a little further south in the longitude band going from 170°W to 30°W. This seasonal and spatial behaviours are in agreement with the NPH results of Benson et al., 2011 obtained from MRO/MCS. The edges of the NPH was also observed between $L_s = 220-260^\circ$ and between $L_s = 330-20^\circ$ (see figure 2). The results for southern polar hood were also considered, and were compared those obtained in Benson et al., 2010 using MRO/MCS and shows also generally a reasonable agreement concerning the seasonal and spatial distributions.

Summary

We have shown that the cloud detection method we have developed for our retrieval algorithm using SPICAM/UV is working properly, giving results in agreement with the detection results obtained from simultaneous but independent OMEGA measurements.

The derived 4 MY cloud climatology offers a good representation of the different cloud features (ACB, polar hoods, orographic clouds) observed outside of the winter polar regions. It allows the study of their seasonal and spatial distributions. Our results generally concord with other work results derived from other instruments (MEX/OMEGA, MGS/TES, MGS/MOC, MRO/MCS).

References

Benson et al., 2006, Icarus, 184, doi:10.1016/j.icarus.2006.03.014
Mateshvili et al., 2009, Planet Space Sci, 57, doi:10.1016/j.pss.2008.10.007
Wolff et al., 2014, MAMO 2014