2 July 2009 Arsia Mons Cloud Observed by the MEX-VMC Instrument

Mike Malaska

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The 2 July 2009 Mars Express Visual Monitoring Camera (MEX-VMC) observations of Mars showed a long cloud trailing westward from Arsia Mons (the southernmost volcano of the Tharsis Montes).

For further examination, a single MEX-VMC raw image was selected. (Changing perspective due to spacecraft motion would make stacking of multiple images difficult.) The selected image was 09-183_09.10.51_VMC_Img_No_4.raw. The raw image was first converted to a colorized PNG file using Gordan Ugarkovic's vmc2rgb.exe utility (freely downloadable here: http://www.unmannedspaceflight.com/index.php?s=&showtopic=5415&view=findpost&p=125530). Next, the image was imported into Photoshop CS3 and a Black and White conversion layer added to create a grayscale image for analysis, with the black and white adjustment layer parameters set to 100% yellow. Trial and error showed that this conversion would maximize detail in the cloud structure.

The .celx file provided on the MEX-VMC website was loaded into Celestia 1.6.0 and tweaked slightly to create a view corresponding to the MEX-VMC image (Celestia 1.6.0 is freely downloadable here: http://sourceforge.net/projects/celestia/files/). A planetary coordinate grid was added and creative blending of the two layers in Photoshop CS3 allowed an overlay of the martian coordinate grid onto the MEX-VMC image.

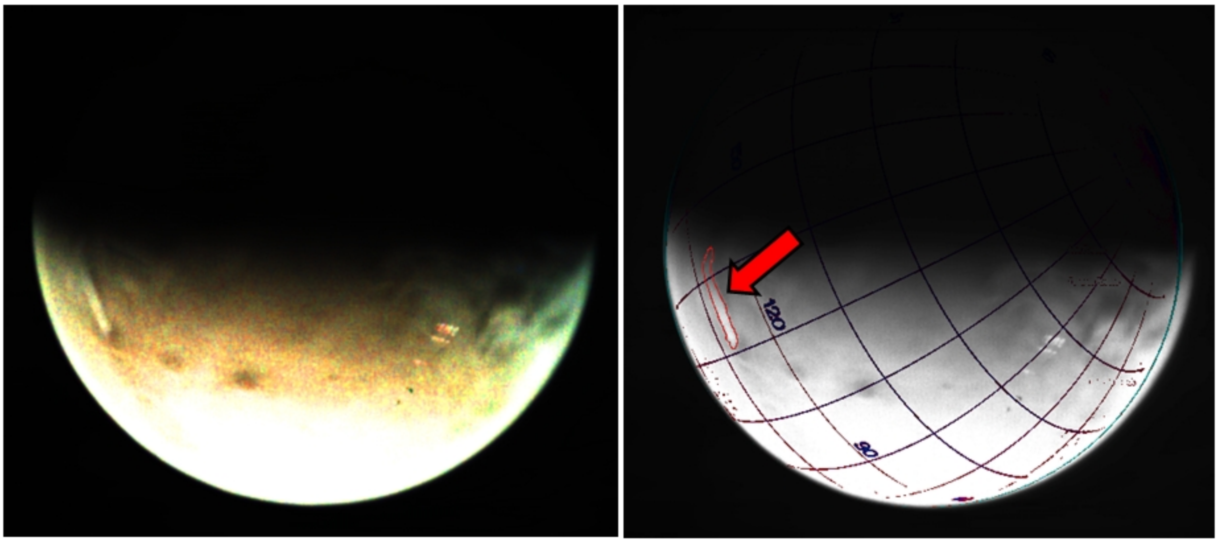

Figure 1 caption: Left: Color saturated and contrast-enhanced version of MEX-VMC Image 09-183_09.10.51_VMC_Img_No_4. Right: Same image, converted to grayscale using 100% yellow B&W conversion layer with an overlaid martian coordinate grid. Cloud is outlined in red and indicated with a red arrow. Image credits: ESA/Mike Malaska

This cloud was also observed by the MARCI instrument on the Mars Reconnaissance Orbiter (MRO) during the 29 June to 5 July 2009 weekly observation. According to the update on the MARCI web page (MARCI Captioned Image Release No. MSSS-90 — 8 July 2009 is available at http://www.msss.com/msss_images/2009/07/08/): "water ice clouds were observed over Arsia Mons and in a few other equatorial locations…" A comparison between the MEX-VMC image and a still from the MARCI weekly movie is shown below:

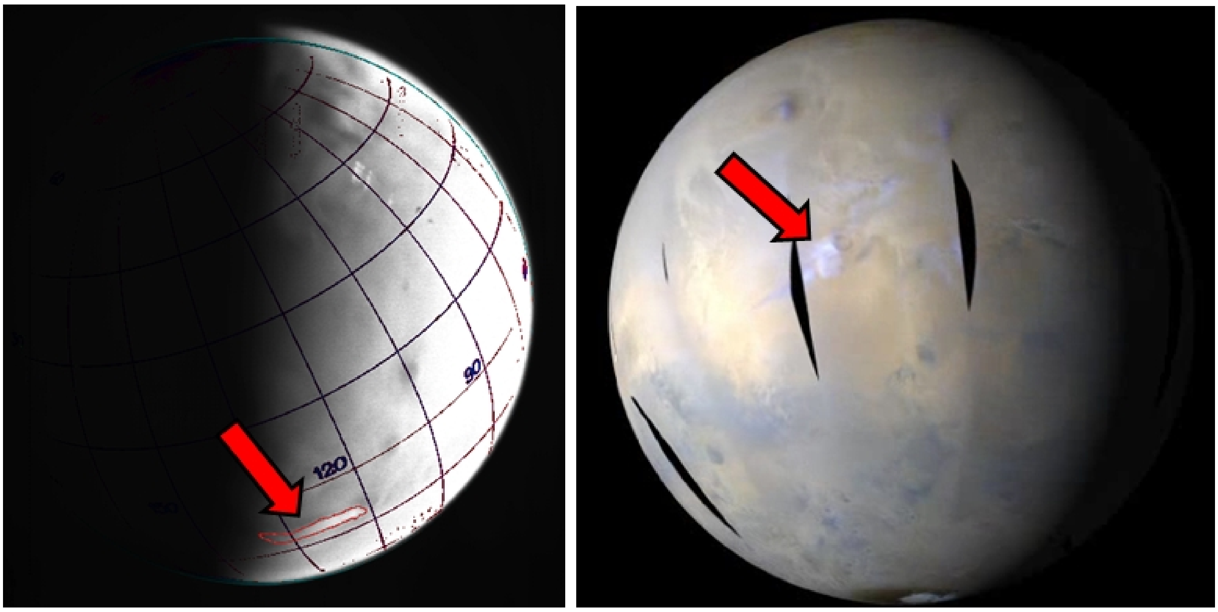

Figure 2 caption: Left: MEX-VMC image rotated so that the martian north pole is up. Cloud near Arsia Mons is outlined in red and indicated by a red arrow. Right: Still from MARCI movie for 2 July 2009. Red arrow indicates Arsia Mons. Image credits: ESA/NASA/JPL/Malin Space Systems/Mike Malaska

From the MEX-VMC image overlaid on the Celestia coordinate grid, the cloud dimensions were estimated. The cloud can be seen to stretch over 15 degrees of longitude to the W from Arsia Mons. The cloud is thus approximately 142 km long. At its maximum width, it spans approximately 2 degrees of latitude, which corresponds to 19 km. The surface coverage of the cloud is estimated at 2700 km^2.

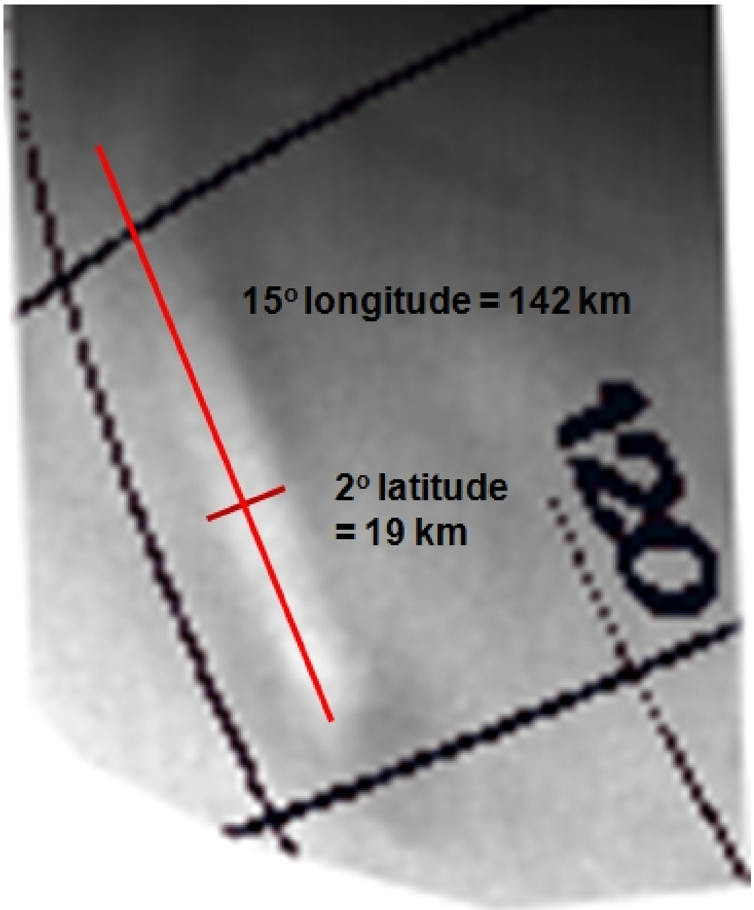

Figure 3 caption: Zoom of processed cloud image. Coordinate grid is shown. Longitudinal and width axes of cloud are shown. Dimensions are 142 km x 19 km. Image credit: ESA/Mike Malaska.

To the N of the cloud, a shadow can be seen on the martian surface. This was used to estimate the altitude of the cloud above the surface using trigonometry. Using Celestia 1.6.0 the illumination angle was determined by highlighting the sun vector. The maximum shadow length is parallel to the sun vector. The thickest part of the cloud shadow falls at roughly [-8^{o}S, 130^{o}W]. Measuring backwards from this point along the sun vector, the shadow length was measured to be 12 pixels. At this location, the MEX-VMC image is approximately 1.9 km/pixel along this latitude line, making the shadow length approximately 22.8 km long. From Celestia 1.6.0, the phase angle at [-8^{o}S, 130^{o}W] was determined to be 78.5 degrees. This corresponds to an elevation of the sun above the surface of 12 degrees – early morning on the Arsia Sulci. The height of the cloud is related to the shadow length and phase angle by the equation:

Height above surface = cot(90°-sun elevation angle) x shadow length along illumination vector

Using this relationship, the cloud is estimated to be approximately 4.6 km above the local martian surface. The Tharsis bulge is topographically high. At the location of the shadow [-8^{o}S, 130^{o}W], the elevation is 3.5 km above mean Mars radius. From the shadow calculation, the absolute elevation of the cloud is therefore 8.1 km above the martian mean radius.

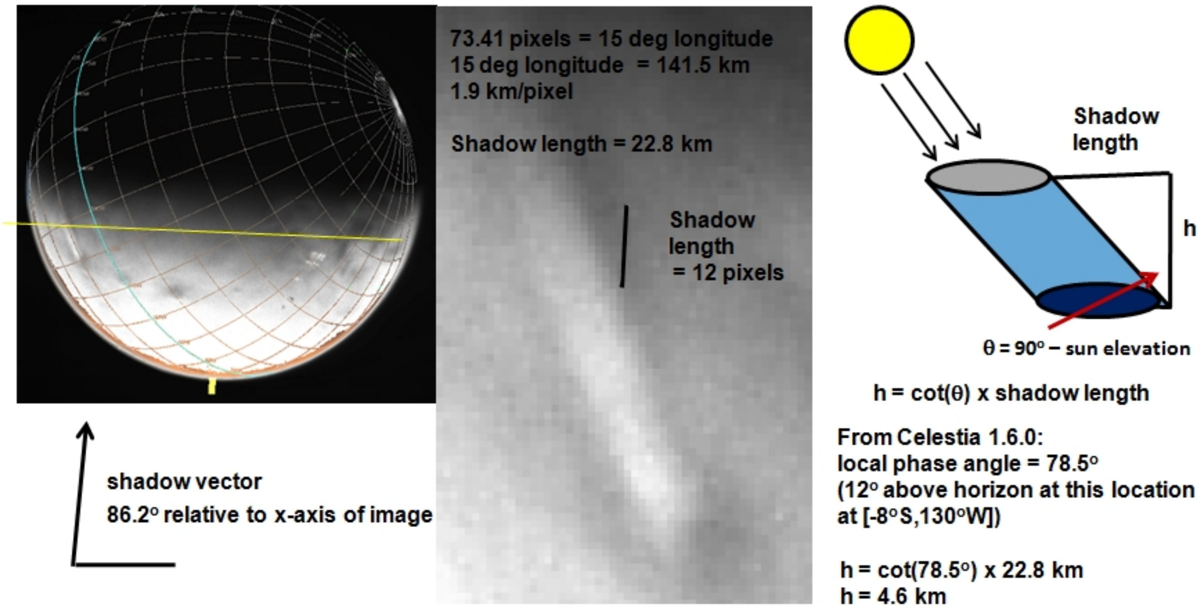

Figure 4 caption: Estimation of cloud height by shadow length. Left: Determination of shadow vector (black arrow) from sun vector (yellow peg at bottom). Middle: Measurement of shadow length. Right: Graphic showing determination of height of cloud. Image credit: ESA/Mike Malaska..

Using another method, the elevation of the cloud was estimated by determining the elevation where the cloud touched the volcano flank. (MEX-VMC Image No 3 was used since it showed better detail in the volcano calderas). From the Google Earth image and topographic data, the cloud was determined to touch the flank at 9 km elevation above the martian mean radius. The estimated cloud height from topography agrees with the elevation derived from the shadow length.

For comparison, the summit of Arsia Mons (bright pixel just visible in the image) is approximately 16 km high, so these clouds are well below the summit.

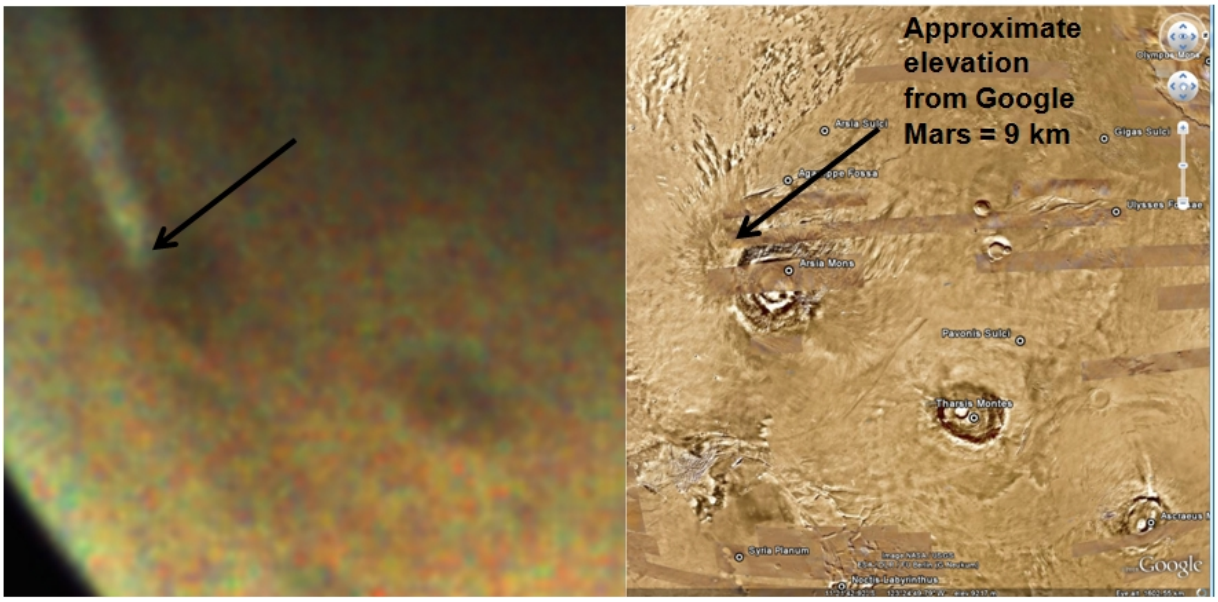

Figure 5 caption: Estimation of cloud height by topographic features. Left: Color and contrast-enhanced MEX-VMC MEX-VMC Image 09-183_09.09.59_VMC_Img_No_3. Right: Google Mars image of corresponding region. Black arrow in both images indicates location where cloud touches Arsia Mons flank. This is at elevation 9 km in Google Mars image. Image credits: ESA/Google/Mike Malaska.

The grayscale converted image of the cloud was converted to pseudocolor using the stock "Spectrum" color table in Photoshop CS3 using the Indexed Color mode. As can be seen from the pseudocolor image, some "clumpiness" is evident in the cloud structure.

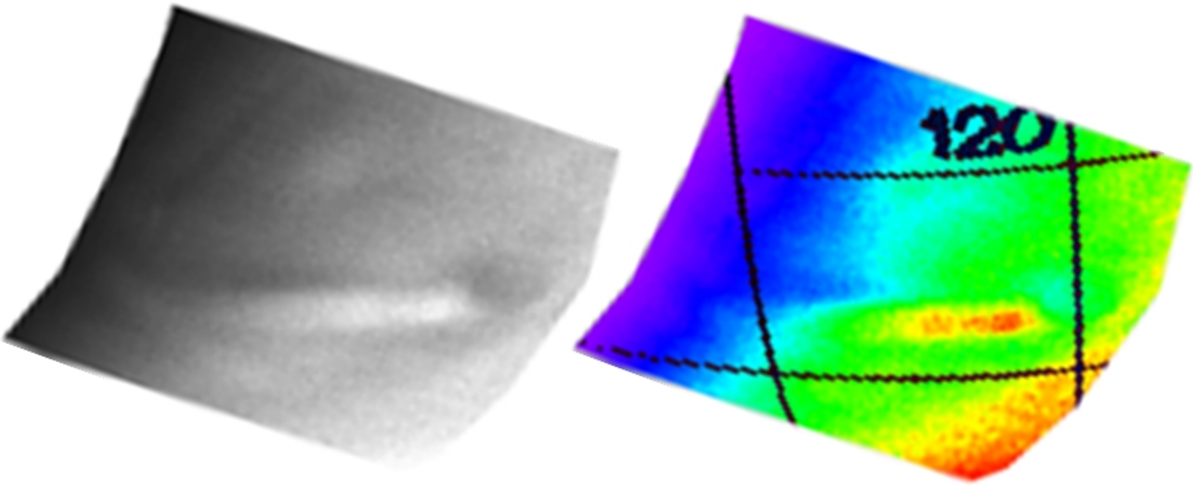

Figure 6 caption: Left: Zoom of cloud near Arsia Mons from original converted grayscale MEX VMC image No. 4 rotated so that N is up. Right: Same image, pseudocolorized using "Spectrum" with martian coordinate grid overlaid. Image credits: ESA/Mike Malaska

A series of transects across the cloud width were made by graphing converted grayscale pixel brightness along a series of transects perpendicular to the longitudinal axis of the cloud streak. These show that the cloud is roughly symmetrical about the longitudinal axis.

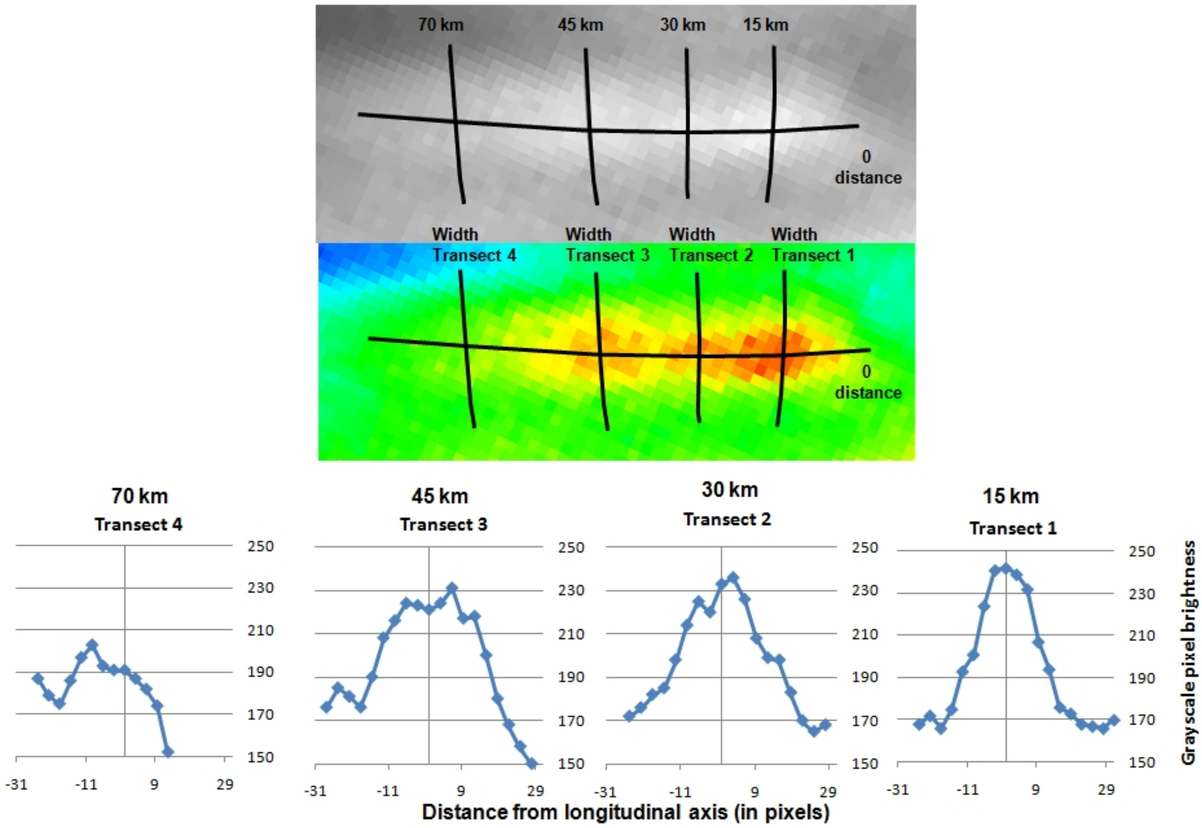

Figure 7 caption: Top image: Grayscale zoom of cloud showing longitudinal axis and width transects at 15, 30, 45, and 70 km. Middle image: Same zoom pseudocolorized. Lower graphics: Transects at different distances W from edge of cloud closest to Arsia Mons. Lower axis is pixel distance from longitudinal line of cloud. Vertical axis is the grayscale pixel brightness of converted MEX-VMC Image No. 4. Image credits: ESA/Mike Malaska.

Similarly, a longitudinal transect was made by graphing the pixel brightness along a line going down the length of the cloud. Pockets of brighter reflectivity can be seen going downwind (to the W) from the flank of Arsia Mons. It can be seen from the graph that there appear to be several clumps. Most notable is a dip in reflectivity at about 40 km. The drop in reflectivity at the far western end could be attributed to the cloud tapering out, or it could also be due to this portion of the cloud being poorly illuminated in the predawn sky as it approaches the sunrise terminator.

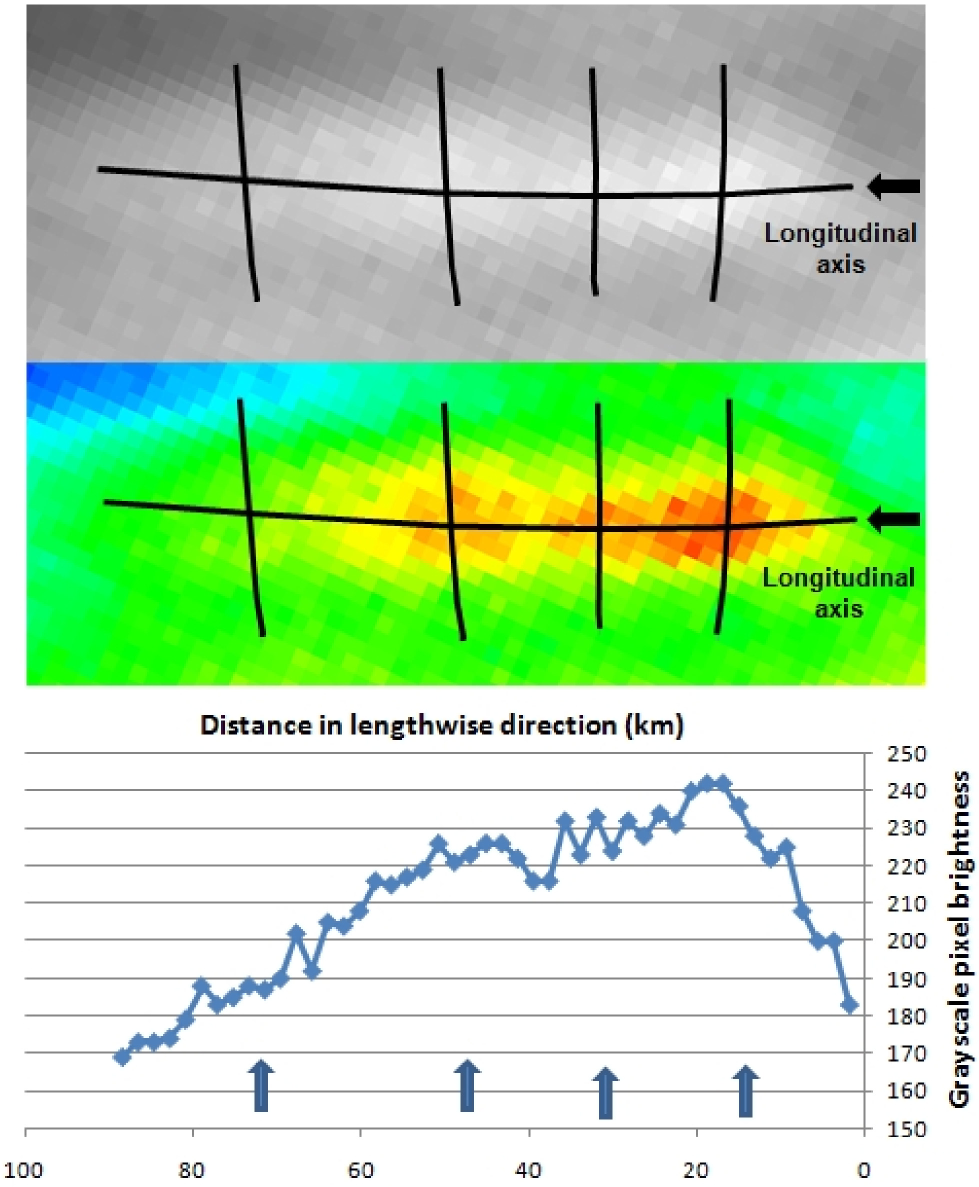

Figure 8 caption: Longitudinal transect along westward length. Top image: Grayscale zoom of cloud showing longitudinal axis and width transects locations at 15, 30, 45, and 70 km. Middle image: Same zoom pseudocolorized. Lower graphic: Graph of converted MEX VMC Image No. 4 grayscale pixel brightness (y-axis) vs. distance W in km from edge of cloud closest to Arsia Mons (x-axis). Locations of width transects in Fig 6 are indicated by blue arrows. Image credits: ESA/Mike Malaska.

Discussion

Water ice clouds above the martian volcanoes, particularly on the Tharsis bulge, have been well documented in the scientific literature (see references below).

These clouds are composed of water ice crystals that are on the order of 2 microns in diameter (Benson et al., 2003a). Most clouds over the big volcanoes occur in late spring and early summer seasons in the northern hemisphere with a peak at about $L_s = 100°$, with almost no cloud activity between between $L_s = 200°$ and $L_s = 350°$ (Benson et al., 2006). (For Mars, the seasons are described using the solar longitude or L_s: this is the angle of the Mars-Sun line to the Mars-Sun line at the northern hemisphere vernal equinox. $L_s = 0°$ is the northern hemisphere vernal equinox, while $L_s = 90°$ is the northern hemisphere summer solstice, $L_s = 180°$ is the northern hemisphere autumnal equinox and $L_s = 270°$ is the northern hemisphere winter solstice. More information on seasons on Mars can be found here: http://www.msss.com/http/ps/seasons/seasons.html; a calculator for converting Earth dates to

Mars dates (L_s values) can be found here: http://www-mars.lmd.jussieu.fr/mars/time/martian_time.html). The MEX-VMC observation date of 2 July 2009 date corresponds to L_s = 296°, so we would expect minimal cloud activity around the big volcanoes.

However, Arsia Mons appears unique in that it has the most continuous cloud activity of all the Tharsis volcanoes. While there is a slight decrease in cloud activity between L_s = 230° to L_s = 350°, there is a small peak in activity during the "quieter period" near L_s = 320° (Benson et al., 2006). The cloud activity around Arsia Mons is especially prevalent on the southwest flank of the rise, although it is not exactly clear why this particular location is such a cloud factory (Dobrea et al., 2003).

From observations from multiple spacecraft, many of the Tharsis topographic clouds first appear in late morning above the summit calderas, then extend westward to form plumes stretching several hundred kilometers by late afternoon (Michaels et al., 2006). In addition to being topographically high, volcanic areas have a very low thermal inertia. This means they heat up quickly during the day, and cool down quickly at night. Extensive modeling of these clouds has indicated that the daytime clouds result from thermally driven upslope flow and downwind mountain wave circulation (Benson et al., 2007; Michaels et al., 2006).

Mountain waves (lee waves, or gravity waves) result from a parcel of air being forced up due to a topographic high, condensing out as a cloud, then dropping back down. As the now drier air descends, it warms up quickly. As the air continues to descend, it "overshoots" and becomes warmer relative to its surroundings and becomes unstable. It rises again, sometimes condensing to form a new cloud. This effect can continue to create a repeating pattern of clouds extending downwind from the topographic obstacle in the form of a series of standing waves. However, other effects can create more complicated patterns (Hunt et al., 1980). This can cause complex patterns of "clumpiness" in daytime clouds or nighttime fogs.

Typically, daytime clouds over Arsia Mons have an altitude of 16-17 km or more above the martian mean radius and are near the summit of Arsia Mons (Benson et al., 2003b). These clouds are typically at higher altitudes and thicker in the afternoon, thought to be due to increased convective daytime heating (Benson et al., 2003a; Benson et al., 2003b). During the mid to late northern summer, daytime clouds over Arsia Mons can have a unique morphology: these clouds sometimes take on the form of rays around a central disk and are referred to as "Aster clouds" (Wang and Ingersoll, 2003). The Aster clouds are thought to form under weak atmospheric static stability and weak background flow, and are probably related to the local upslope winds associated with the volcanoes (Wang and Ingersoll, 2003).

The atmospheric flow over the mountains of the Tharsis bulge pumps significant amounts of water and dust into higher levels of the atmosphere. The pumping effect of the big volcano clouds on Mars is analogous to the effect of thunderstorms on Earth, both serve to pump large amounts of material (water, dust) and energy into the atmospheric circulation pattern (Michaels et al., 2006). Interestingly, when there is a regional dust storm cloud activity shuts down (Benson et al., 2003a., Dobrea and Bell, 2003). Presumably, this is due to dust storms heating the atmosphere, lowering the relative humidity and suppressing cloud activity (Benson et al., 2003a).

At nighttime, the situation changes. The low thermal inertia allows a rapid radiative cooling of the volcanic rocks. This radiative cooling, coupled with downslope winds, creates colder denser air at lower elevations which makes radiation fogs in the early hours of the morning (Hunt et al., 1980). The morning clouds that often crowd the flanks of the big volcanoes are significantly lower than afternoon clouds which are above the summit caldera (Pearl et al., 2001; Hunt et al., 1980). Theoretical modelling of clouds on nearby Olympus Mons (elevation 20 km), predicted daytime clouds to be centered at 25 km elevation above the martian mean radius, while the nighttime fogs are predicted to be centered at 15 km elevation (Michaels et al., 2006). This is a 10 km difference between the daytime and nighttime clouds on Olympus Mons.

Recent observations using Thermal Emission Spectrometers (TES) instruments have hinted that nighttime clouds in the Tharsis region may be thicker and more significant than their daytime counterparts (Wilson et al., 2007). Early morning fogs can also show strong lee mountain wave effects (Hunt et al., 1980). Nighttime fogs may be an important player in the atmospheric energy budget of Mars' atmosphere.

A graphic showing the process involved in daytime and nighttime cloud formation over martian volcanoes is shown below in Figure 8:

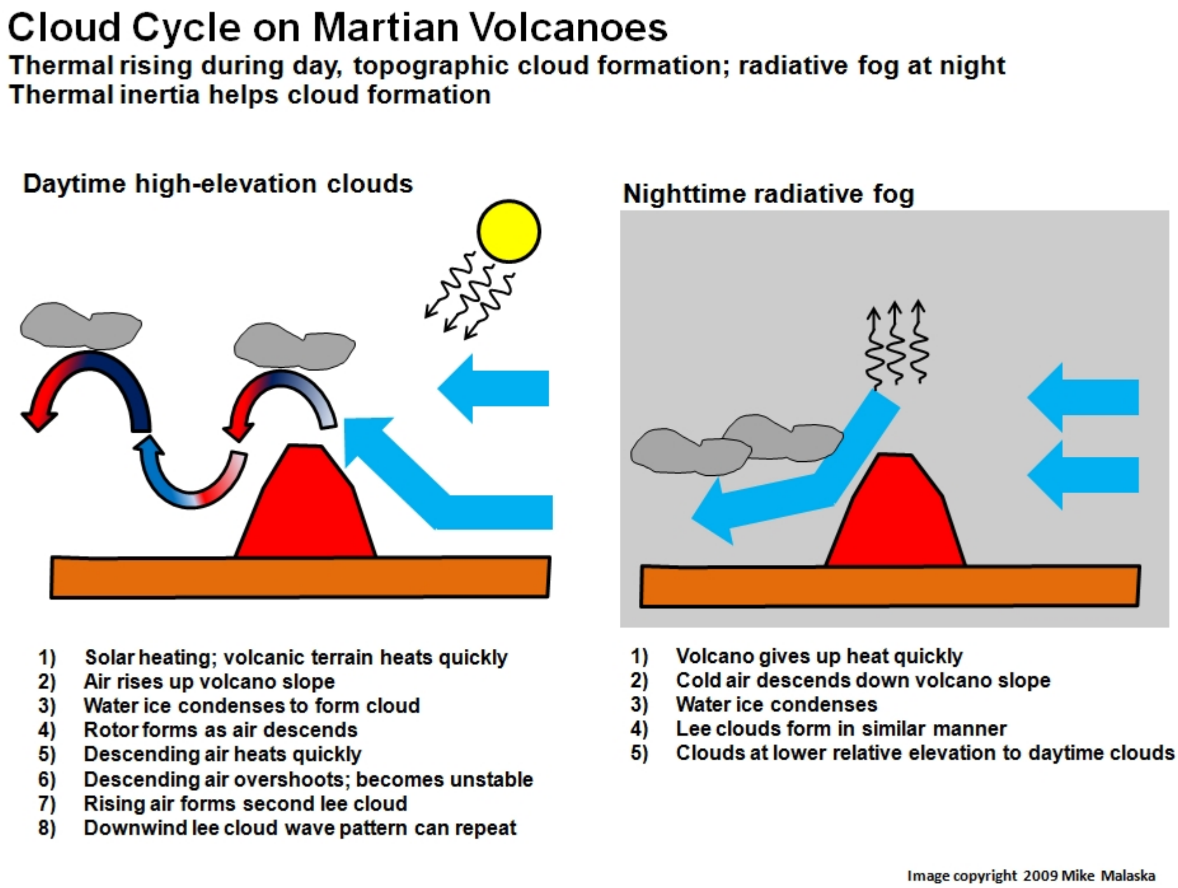

Figure 8 caption: Graphic showing processes responsible for forming daytime (left) and nighttime (right) clouds over Tharsis volcanoes. Image credit: Mike Malaska.

The estimated altitude and form of the 2 July Arsia Mons trailing cloud observed by the MEX-VMC instrument is consistent with an early morning radiation fog of water ice with a strong background westward flow. The downwind direction shows hints of lee mountain waves causing clumpiness in the cloud structure. This is similar to early morning observations of Ascraeus Mons previously described by Hunt et al., 1980.

It will be interesting to see if future early morning observations by the MEX-VMC "dawn cloud patrol" show similar features near Arsia Mons and the other Tharsis volcanoes. In this manner, the MEX-VMC camera can help shed light on the transition of nighttime fogs to daytime clouds.

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Detailed abstract freely available at:

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