MARS' SNOWFALL AND SAND AVALANCHES.

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Introduction: Every year Mars' north polar erg is covered with a seasonal layer of CO_2 ice. The Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) images of ice-free dunes show that from one Mars year to the next new alcoves appear on the dunes, shown in Figure 1. HiRISE image campaigns carried out over multiple Mars years show that the formation mechanism is a puzzle – the alcoves form when it is difficult or impossible to image the dunes due to the polar hood that forms in the fall, followed by polar night [1].

In order to study this process and understand the driver for the sand avalanches that result in new alcoves on the dunes HiRISE images have been taken every year for 6 Mars years. Monitoring sites are spread longitudinally around the north polar erg and at different latitudes. We found that the number of new alcoves that appear each year is variable with some dramatic swings from year to year. The variability is not uniform – the particular year that a lot of alcoves form in one site is not the same at the other sites [1, 2]. This rules out simple explanations such as global dust storms, which would likely affect the entire polar region.

This led us to pose the hypothesis that regional snowstorms, which provide up to ~20% of the seasonal CO_2 cap [3], could be the source of the variability.

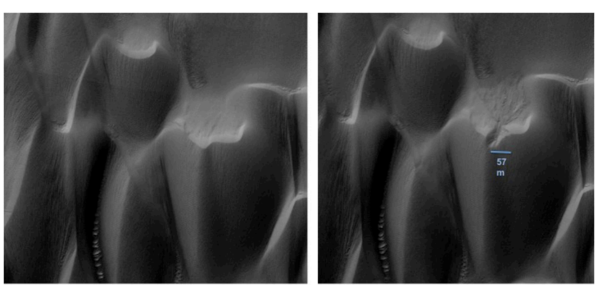

Figure 1. These two images in "Buzzel" were taken one Mars year apart. Examination of ice-free images ESP_027394_2640 (Mars Year MY31) compared to ESP_036387_2640 (MY32) shows a large new alcove on the dune. In the fall / winter of MY31 92 new alcoves formed at the Buzzel site, an area ~4.7 x 13 km in size.

Experimental Data: To investigate this hypothesis we selected 4 of our routine monitoring sites – three approximately equally spaced in longitude at ~84N and one at 76N (listed in Table 1) – for more intense study, coordinated with the Mars Climate Sounder (MCS) on MRO. HiRISE images were scheduled to push the seasonal range as late as possible into fall and as early as possible in the spring. The MCS retrieves atmospheric temperature profiles and detects snowfall by combining limb observations which detect clouds, with measurements of the brightness temperature at nadir [3], which reveals ongoing or recent snowfalls [4].

Table 1. Monitoring Sites (names are informal)

Site	Latitude	Longitude
Buzzel	84.0	233.2
Kolhar	84.7	0.7
Tleilax	83.5	118.6
Palma	76.2	95.4

Preliminary Results: Our initial hypothesis was simply that more snowfall would lead to more alcoves. We looked at the number of alcoves formed at each site compared to snowfall at that site that winter. Although the results from analysis of 4 Mars years of the combined HiRISE – MCS dataset seemed to qualitatively agree the correlation was not as close as we had anticipated.

Furthermore, a single late image taken in Buzzel, acquired at L_s 192 required a re-examination of this hypothesis. That image, shown in Figure 2, already had a light dusting of frost. The contrast afforded by this bright frost showed that the new alcoves identified had already formed. At least in this time at this place a lot of snow had not yet fallen. (This is normally a very difficult time to image the dark polar dunes, as the presence of the polar hood that forms in the fall usually reduces the signal-to-noise ratio to a useless level. The presence of the bright frost really enables analysis of this image.) The time of formation of the new alcoves is constrained by presence in this image taken at L_s 192 and the previous image, ESP_037521_2640, taken at L_s 169, that did not show the new alcoves [1].

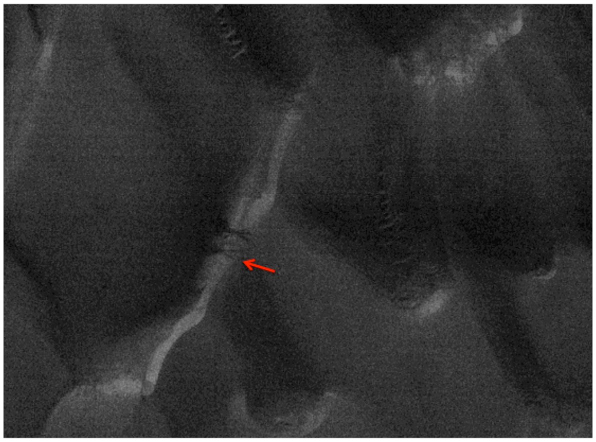

Figure 2. This cutout from image ESP_038035_2640, acquired in the fall (L_s 192) of MY32, already shows the formation of new alcoves. The arrow points to one of the new alcoves, 20m wide at the dune brink.

A new analysis direction. This image suggests that it is events associated with late summer / early fall that trigger the sand avalanches. What events that occur in this timeframe could be the source of the interannual variability?

Turning again to the MCS data there is interannual variability in exactly when the CO_2 begins to condense, the amount of time between condensation and the first snowfall, and how great the first snowfall is at a given site. These are factors that could influence the stability of the dune brink – for example, a significant amount of ice build-up would armor the dune against fierce autumn winds and may stabilize it against a later mass loading of snowfall that otherwise could oversteepen the slope. Figure 3 shows the relevant MCS data for Buzzel.

At Buzzel the standout year for alcoves was MY32. Examination of the plot in Figure 3 for what was different in MY32 relative to other years shows the condensation temperature was reached later and that substantial snowfall came earlier relative to other years. We might expect MY30 to have the fewest alcoves since the ice had the longest time to build up relative to the first snowfall, and this is indeed the year with the fewest new alcoves.

In Kolhar the standout year was MY31 however this year shows a long time between onset of CO_2 condensation and the first snowfall. MY30 had the fewest, yet the profiles are very similar. So, in both years there was plenty of time for the dunes to become armored before significant snowfall arrived.

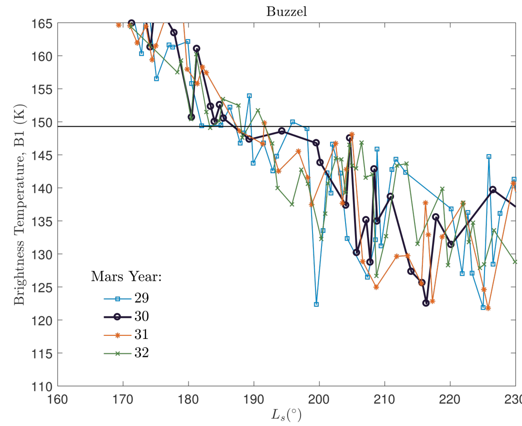

Figure 3. The temperature at which CO_2 frost will start to condense is indicated by the straight line across the MCS data shown here for Buzzel (adjusted by atmospheric pressure). Four Mars years are plotted. Departures well below the frostpoint line are indicative of snowfall, which has a brightness temperature 20 – 30 K below the condensation line. Different years show that the first snowfall occurs at different times with different amounts from year to year. In MY30 the line stays flat and close to the condensation point, suggesting that there is time for ice to form and armor the dunes before the first large snowfall.

Conclusions: The complexity of the regional meteorology has not yet revealed a clear “smoking gun” to explain why there is so much variability in alcove formation, however it does suggest that perhaps a combination of factors could be responsible. In the meantime, instruments on the MRO spacecraft are collecting another year of data which will be analyzed for answers to the question of what process is driving the sand avalanches creating new alcoves.

References: [1] Dinega, S. et al., (2017) in: Conway, S. J., Carrivick, J. L., Carling, P. A., De Haas, T. & Harrison, T. N. *(eds) Martian Gullies and their Earth Analogues. Geological Society, London, Special Publications,* 467, doi:10.1144/SP467.6.
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