FROSTING AND DEFROSTING OF MARTIAN POLAR DUNES. M. C. Malin and K. S. Edgett, Malin Space Science Systems, P.O. Box 910148, San Diego, CA 92191-0148, USA.

Synopsis: It appears from high resolution images that sand (certainly as expressed in dunes, and potentially in sheets or intermixed with other particle sizes) controls both the initial location of frost formation during fall and winter, and defrosting during the spring and summer. Dunes are the first surfaces to frost in the fall and the first to show evidence of defrosting during the late-winter/early-spring. Despite starting to defrost early, frost may persist on dunes long after surrounding terrains have defrosted in late spring and early summer. The reason for these relationships is not clear, but may have to do not only with the thermophysical properties of sand, but with the trapping and release of volatiles within sand deposits.

Observations: During its first Mars year of operation, the Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) observed late-winter/early-spring conditions in both polar regions. Fall and winter observations were not made owing to the evolution of the MGS orbit before finally reaching the near-circular, polar orbit near the end of northern summer. Subsequently, observations have noted changes in both hemispheres that, combined with earlier seasonal views, shed light on frosting and defrosting processes that (while specific to dunes) may have broad implications.

It has been known since Viking that some polar dunes retain frost long into polar summer. What was not fully appreciated until high resolution (<<10 m/pixel) imaging was that polar dunes are usually the first surfaces to start defrosting in spring and the first surfaces to exhibit frost during the fall.

Figure 1 shows representative examples of fall frost formation (left) and late-winter defrosting (middle/right). Frost formation has been seen so far only in the north where, despite a dramatic increase in both clouds and dust-storm activity as winter approaches, high resolution camera views of the surface reveal that at or before L_s = 192° in 1999 some polar dunes became brighter than the surrounding surface (having been darker since early summer). As fall progresses, the dunes brighten further; the surrounding surface may also get brighter, but the exact relationships are difficult to make out through the increasing opacity of the polar hood.

The typical pattern of defrosting is shown in Figure 1 (middle/right): defrosting proceeds from the initiation of small, dark spots typically located at the margins of dunes; these spots individually enlarge, others generate, and eventually all coalesce. The pattern the enlargement follows is distinct and characteristic: a dark nuclear spot enlarges slowly, often with a bright outer zone or "halo." Initially, the areal enlargement of the dark spot and the areal enlargement of the bright halo appear linked. After some time, the spot develops two distinct zones—a darker interior and a gray exterior—while the bright outer zone narrows until it is no longer present. As these are progressive, centripetal phenomena, each location of the light zone is overtaken by an expanding dark zone. Although initially developed along dune margins, spot formation quickly spreads onto and between dunes. As spring progresses, fan-shaped tails develop from the central spot. These tails initially demonstrate strong directional elements, wherein many spots display one or more streaks of identical orientation and relative length. Observations especially of the south polar dunes show patterns highly suggestive of wind flow-lines over and around the dune topography.

As spring progresses, an interesting phenomenon occurs—the surrounding terrain defrosts faster than the dunes, despite the fact that dunes showed the first signs of frost removal. Viking images also showed frost persisting on dunes into summer in some parts of the south high latitude region.

Interpretations and Speculations: The MGS observation that dunes in the polar region are the first surfaces to frost in the fall and to defrost in spring, along with the observations that some dunes retain their frosted surfaces well into summer while others are completely defrosted, suggest that the physical properties of martian polar sand—and something else—are responsible for the attributes seen. One speculative view may be that frost/vapor interactions are responsible for what is observed. In this view, defrosting occurs as the low albedo polar sand heats beneath an optically thin layer of frost, causing the frost to evaporate. This is the dark nucleus of the spots seen on dunes. As the vapor moves laterally, it encounters cold air and reprecipitates, forming the bright halo. This reprecipitated frost is again vaporized as the uncovered zone of sand expands; the cycle repeats many times. Eventually, as the season progresses and the ground and air temperatures increase, the zone affected by whole or partial vaporization of the frost grows more rapidly than the zone of reprecipitation. Indeed, at some point the ground may be too warm to permit reprecipitation, leading to the loss of the bright halo and the advent of the outer gray zone. Of course, once a zone of sand is uncovered, no matter how small, occasional wind gusts will splay sand across the surface, creating dark streaks that enhance sublimation.

It is not clear what attribute of the dunes, and perhaps their constituent sand, create the conditions for early frosting and defrosting. One possibility is that volatile materials react as much to the interior properties of the dunes as they do to their surface properties. For example, the interiors of terrestrial dunes are almost always wet, even in the driest deserts, as the combination of low thermal inertia and high porosity keep them cool and permit moisture to accumulate protected from surface conditions. Perhaps the phase lag between the seasonal temperature wave and surface temperature mobilizes interior volatiles late in the summer, just as surface temperatures fall to the "dew point" for the volatile. Alternatively, perhaps the surfaces react in spring to the increasing insolation and create conditions of sintered or metamorphosed ice, concentrating heat at the surface of the sand and leading to the process described in the preceding paragraph.

It is not clear exactly which frost—CO_2 or H_2O—is participating in this display. Certainly, broad surfaces show temperatures that indicate that CO_2 frost is on the surface, but the details of the temperature of the sand, and the potential for water frost to participate as well, are not known. Perhaps CO_2 is the frost that disappears in early spring, and H_2O is the material that allows dune frost to persist well into the summer season.

Directions for Future Research: Defining the observed relationships quantitatively will be extremely important in determining the frost composition and processes involved. For example, detailed measurements of the area of each zone of each dark spot as a function of time, combined with a model of heating, can test the qualitative impression that the areas are correlated early in the defrosting season. This may be related to how insolation is translated to latent heat. Such studies might then be used to distinguish between water and carbon dioxide frosts. Other studies, for example of atmospheric water content, might indicate if the defrosting dunes are the source of the seasonal increase of water vapor; perhaps their re-frosting in the fall is marked by a decrease in water vapor. Alternatively, thermal modeling of the dunes might indicate that the seasonal thermal wave, propagating into the dunes, releases volatiles previously "cold trapped" into the dunes. Whether such processes occur on seasonal, annual, or longer time-scales dictated by eccentricity or obliquity variations may also be delineated by such observations.

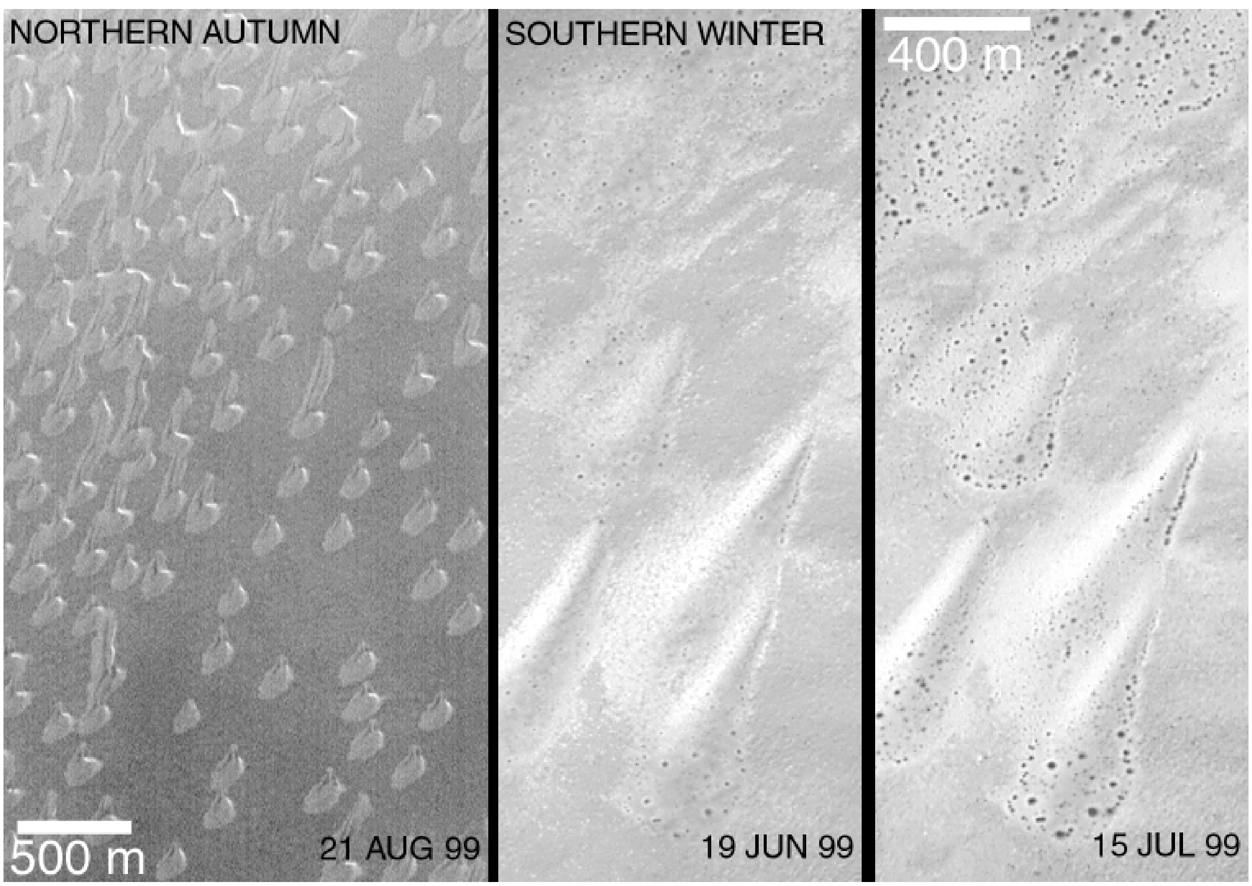

Figure 1: Representative views of frosted dunes in martian polar regions. On left is a view of north polar dunes that have brightened relative to surrounding surfaces in early autumn (subframe of MOC image M04-02215 near 74.7°N, 61.4°W). The center and right images show the same south polar dunes observed about 14° of L_s apart—the development of dark spots is characteristic of defrosting dunes in late winter and early spring. Center image is subframe of M02-02528, right is subframe of M03-02916, both near 59.2°S, 343.6°W.