**SEASONAL VARIATION OF AEROSOLS.** A. D. Toigo, M. I. Richardson, *California Institute of Technology, Pasadena, CA 91125, USA, (toigo@gps.caltech.edu, mir@gps.caltech.edu)*.

**Introduction.** Dust has a profound impact on Martian atmospheric temperatures and circulation. Thus the repeatability of the seasonal dust cycle is of prime importance in understanding the current Martian climate. A number of different observation platforms have been used to measure the amount of aerosols suspended in the atmosphere over the course of the past 25 years. These instruments measure the optical depth of the atmosphere, which is a gauge of the amount of suspended aerosols. The most widely reported measurements are those derived from the Viking Lander camera [1]. These are show in Figures 1a and 2a. The graphs show a relatively clear northern spring and summer ($L_s$ 0 to 180) with visible optical depths of 0.4–0.7 (slightly smaller for Viking Lander 2). A more dusty southern spring and summer (northern fall and winter) included two great dust storms, during which optical depths reached values in excess of 3. Measurements of optical depth in the infrared (9 $\mu$m) were also made by the Viking Orbiters [2,3], using the Infrared Thermal Mapper (IRTM). The general cycle of opacity followed that of the landers, with a ratio of optical depths (visible to infrared) of 2.5 derived during the dusty southern summer period.

This then has been the standard picture of the seasonal dust cycle. More recently Clancy *et al.* [4,5], using microwave measurements of atmospheric temperature as a measure of dustiness, have suggested that this cycle may not be representative of every, or even most, Martian years. Their observations suggested that Mars is typically cooler, and hence clearer of dust, than observed during the Viking era. The opportunity to test this suggestion came with renewed spacecraft missions to Mars. The Mars Pathfinder measured the atmospheric optical depth in a similar way to that of the Viking Landers [6]. Their results were found to be in good agreement with the Viking Lander values. However, more recent infrared opacities derived from the Thermal Emission Spectrometer (TES) on Mars Global Surveyor (MGS) show the northern summer to be clearer than suggested by Viking Lander observations [7], if a ratio of optical depths of 2.5 is used. In addition the TES atmospheric temperatures have been found to be in good agreement with the cool microwave observations [8]. In this study, we have reexamined the full seasonal cycle of optical depth during the first two Martian years of the Viking mission in order to reconcile these apparently contradictory views.

**Data.** The retrieval of optical depth from IRTM has been described by Martin [2,3]. While these values were compared with the Lander measurements during southern summer, comparison during the rest of the annual cycle was not pursued. In Figures 1a and 2a we show IRTM-derived infrared optical depths for $5^\circ \times 5^\circ$ bins centered on the Viking Landers. While the seasonal trends are similar, the infrared optical depths are lower during northern spring and summer than the Viking Lander values even after scaling the values by the canonical factor of 2.5. Interestingly, the IRTM values are in good agreement with the TES observations. It is clear from these figures that

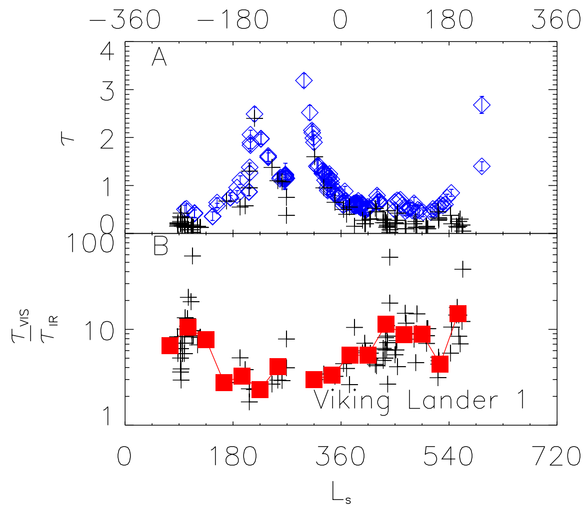


Figure 1: **A.** Plot of optical depth vs. $L_s$ for the Viking Lander 1 location. $L_s$ values range from 0 to 720, with 360 through 720 representing the second Martian year of Viking observations. The labels above the upper axis show the equivalent $L_s$ values with the second year starting at 0. Viking Lander derived values are shown in blue diamonds, with their associated error bars. The IRTM derived values are shown as black crosses. The IRTM values have been scaled by a factor of 2.5 to show their good agreement during dusty periods ($L_s$ 180–360) and their lack of agreement during the clear periods ($L_s$ 0–180). **B.** Plot of the ratio of visible to infrared optical depths vs. $L_s$ for the Viking Lander 1 location. The red boxes and lines are a boxcar average of all values in a 30° $L_s$ box.

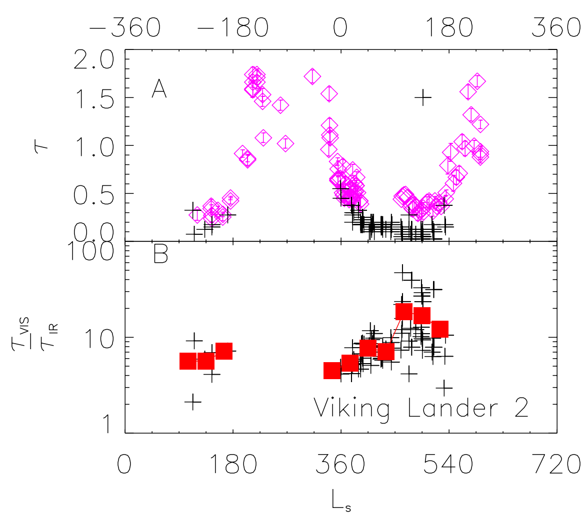


Figure 2: Same as Fig. 1, except for the Viking Lander 2 location. Viking Lander 2 visible optical depth values in (A) are show as magenta diamonds. Other symbols and (B) are the same as for Fig. 1

while a visible to infrared ratio of 2.5 is good for dusty periods (southern summer), the ratio must increase significantly during the clearer periods (northern summer). The visible to infrared ratios derived by comparing our infrared observations with those from the Lander are shown in Figures 1b and 2b. A strong anti-correlation can be seen between the dusty and clear periods. The ratio reaches its minimum near 2.5 during the extremely dusty periods, and the ratio increases both in value and in its variation during the clear periods.

In order to rule out the role of noise, we calculated a boxcar average of the values of the ratio, using a box width of 30° in $L_s$. Although it is probable that noise is making some contribution to the scatter in the ratio values, the mean (shown in red in Figs. 1b and 2b) shows that the increase in ratio during clear periods is robust. We also investigated the role of the proposed errors in the IRTM 15 $\mu$m brightness temperatures [9] on the retrieval process, and found the changes to have negligible impact on our results.

**Interpretation.** Two possible explanations for the increased ratios during the clear periods are changes in mean size of the suspended particles, and increased opacity in the visible due to the presence of water ice clouds.

The settling and removal of larger dust particles following dusty periods results in the shrinking of both the mean size of the particle size distribution and the width of the distribution, leading to increased visible to infrared ratios as the smaller particles exert more influence in the visible wavelengths. Mie calculations suggest that a decrease of a factor of 4 in mean particle size is sufficient to account for an increase in the visible to infrared ratio from 2.5 to roughly 10.

Dusty periods lead to increases in atmospheric temperature, preventing the formation of water ice clouds. The clearer periods are colder, allowing water clouds to form more readily. The clouds contribute opacity in the visible wavelengths (and none at the 9 $\mu$m wavelength), making the ratio of opacities increase. For example, the amount of water ice (in the form of suspended, micron-sized spheres) needed to compensate for the infrared opacity "deficit" (relative to visible opacities) during northern spring and summer is roughly a precipitable micron, which appears reasonable [1,10,11]

If the primary reason for the increase in opacity ratio is due to changes in mean particle size, this provides important constraints on dust lifting, transport, and sedimentation processes, as well as dust properties. On the other hand, if the primary reason is water ice clouds, then this implies that the lander (Viking and Pathfinder) values of optical depth are not representative of the seasonal cycle of *dust*. In this case, Mars really is clearer than believed on the basis of Viking Lander observations. However, it is no clearer than observed by IRTM. In either case there is no evidence of significant interannual variations in atmospheric dust amounts during the northern spring and summer periods, and what variation there is during southern spring and summer appears to result entirely from the occurrence or non-occurrence of dust storm events.

**References.** [1] D.S. Colburn *et al.*, Icarus 79, 159–189 (1989). [2] T.Z. Martin, Icarus 66, 2–21 (1986). [3] T.Z. Martin and M.I. Richardson, J. Geophys. Res. 98, 10941–10949 (1993). [4] R.T. Clancy *et al.*, J. Geophys. Res. 95, 14543–14554 (1990). [5] R.T. Clancy *et al.*, Icarus 122, 36–62 (1996). [6] P.H. Smith and M. Lemmon, J. Geophys. Res. 104, 8975–8985 (1999). [7] M.D. Smith *et al.*, J. Geophys. Res., in press [8] R.T. Clancy *et al.*, J. Geophys. Res., in press [9] R.J. Wilson and M.I. Richardson, Icarus, in press [10] P.B. James *et al.*, J. Geophys. Res. 101, 18883-18890 (1996). [11] M.I. Richardson, Ph.D. Thesis, UCLA (1999).