OASIS REVISITED: FURTHER ANALYSIS OF THE SOLIS LACUS RADAR ANOMALY ON MARS.

Introduction: Recent analysis of the 1971 and 1973 12.6 cm Goldstone radar data of Mars has provided additional evidence for near-surface liquid water in the Solis Lacus region (20-30°S, 85-100°W) during local summer (1). This conclusion was based on: 1) the unique, very strong radar signals returned from this area; and 2) a seasonal variation in the returned signal strength, with the same area apparently possessing a smoother, more reflective surface during the summer than that observed during spring. Solis Lacus had earlier appeared to be an unusual area of Mars from its photometric properties (2), the occurrence of discrete white clouds (3,4), and the initiation of major dust storms (4,5). In each case, liquid water within the top meter of the regolith would be one of the possible explanations for these observations, but alternative interpretations also remain viable. We therefore present here additional characteristics of the radar data which further constrain the interpretations and, hence the inferred properties of Solis Lacus. We report on an analysis of data accuracy (estimates of errors), data reliability (coincidence of radar ground tracks), and on the seasonal variability of surface radar properties.

Data Base: The combined 1971/1973 radar data set comprises 32,000 point measurements of altitude, surface roughness (C-factor), and dielectric constant (inherent reflectivity), that gives almost complete coverage between latitudes 14-22°S (6). The resolution of these measurements is approximately 10 km in longitude and 80 km in latitude, and provides 684 point estimates of surface properties for Solis Lacus between 14.2-21.2°S, 84.0-100.0°W. During the derivation of the radar properties of each surface (6,7) estimates of roughness and reflectivity were paired (8), and the "goodness-of-fit" between the returned signal power spectrum and theoretical model surfaces ("templates") derived. The quality of the data, and hence the degree of confidence that can be placed on the interpretations, can therefore be assessed using these attributes.

Figure 1 presents that part of the Goldstone data between longitudes 84 and 100°W, together with a histogram of the estimated errors; and the equivalent data from measurements made at 70 cm wavelength at Arecibo in 1973 (9).

![Figure 1: Cluster diagrams for Solis Lacus radar data between 84-100°W, 14.2-21.2°S. The middle diagram illustrates a histogram of the estimated errors of the Goldstone data, showing that the accuracy of the data is very high. "N" is sample size.](image-url)
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Fig. 2: Plot of elevation (in km) for latitude 15.45°S (horizontal axis) against latitudes 14.49, 15.43, and 17.00°S (vertical axis) between 84-100°W. The slope of the 15.45 vs. 15.43° line is almost exactly 45° and passes through the origin, indicating coincident groundtracks. In comparison, the profiles north and south of 15.45° are irregular and do not pass through the origin.

It is apparent from Fig. 1 that almost all of the Goldstone measurements in this region have coincident values of C-factor above 3000 and reflectivity above 6%. For essentially all of these data, the estimated errors are less than 10%. In contrast, other areas of Mars typically have C-factors between 100-2000, reflectivities as low as 2%, and estimated errors between 20-150% (8,10). Arecibo data for Solis Lacus, although less numerous, show the same general distribution but with less clustering of the data points, and with estimated errors in the 20-80% range. Because of the nature of the reflecting surface, the radar data for Solis Lacus possesses the highest reliability of the entire data set and, in view of the particularly favorable oppositions in 1971 and 1973, probably represent the highest quality data that is obtainable with current Earth-based radar equipment. This argument, of course, refers only to the accuracy of the measured values; it consequently appears that discussion of the Solis Lacus anomaly must center on the interpretation of the measurements and not on the reduction of the original data base.

Seasonal variations: One exception to the above statement lies in the possibility that a minor error exists in the exact location of each radar track across the planet. Under such circumstances, fortuitous pairings of radar ground tracks might offer an explanation for the apparent seasonal variation in the data set, as opposed to a genuine time-dependent effect. Radar data at 15.45, 15.43, and 15.81°S were derived for Solis Lacus at approximately the same local time of day (12 am - 3 pm; Simpson 1980, pers. comm.) for the seasonal period corresponding to $L_s = 258-294$. Although diurnal influences can therefore be ruled out, it is not clear whether the martian ephemeris was known with sufficient accuracy to insure that the radar system was sampling exactly the same area of the surface on each occasion. Nominally, the 1.3° (80 km) north-south extent of the resolution cell would give an overlap of 70-98% between these radar swaths, from which nearly identical surface characteristics should have been derived. Instead, progressively larger smoothness and reflectivity values were observed with the progression from southern spring to summer (1).

It is possible, however, to estimate independently the relative positions of each radar ground track by comparing the altimetry values for different profiles across the area: coincident ground tracks should produce identical topography regardless of the other surface properties. On a regional scale, Solis Lacus is a gently sloping surface elevated to the northwest and low in the southeast (11). Comparing radar altimetry from different east-west ground tracks would therefore produce identical topographic profiles only if the measurements were made across the same terrain, due to the sloping character of the surface. Fig. 2 presents such height estimates for 15.45°S ($L_s = 258°$) vs. 15.43°S ($L_s = 273°$). It is clear that the deviation from a 45°-slope line through the origin (i.e., exact coincidence and no measurement errors) is less than 150 meter peak, with 68% of the data pairs within 50 meters of each other.
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Fig. 3 (left): Cluster diagrams for radar data at latitudes 15.45° S (L = 258°) and 15.43° S (L = 273°) between 84-100° W. Fig. 4 (right): Seasonal variation of mean reflectivity values for Solis Lacus. Error bars are one standard deviation. From left to right, data are for latitudes 17.31, 14.50, 19.41, 15.45, 15.43, 15.92 and 21.20° S. Crosses indicate data within one radar resolution cell.

By interpolation, such an offset would be equivalent to ~0.10° in latitude, or about 2% of the C-factor measured rms slope. This strongly suggests that the altimetry (and hence the surface characteristics) derived for 15.45 and 15.43° S were acquired for essentially the same elements of the martian surface, and that seasonal variations in the radar returns are a consequence of surface changes rather than mislocations of the radar profiles.

The apparent seasonal variability of the radar data can be identified in Fig. 3, which illustrates the radar properties of the individual points on the surface for Ls = 258° and 273°. In almost all cases the reflectivity is higher at the later season; the smoothness also shows a general increase, but not nearly as marked as the reflectivity. Many points, especially for C-factor values less than 6000, exhibit no change or a decrease in smoothness with season. For additional profiles acquired between 14.5 - 21.2° S (Ls = 213-315°), a general trend in average reflectivity is also observed (Fig. 4), providing that the data is divided into two bands between 14.5 - 15.9° S, and 17.3 - 21.1° S. In Fig. 4, however, the latest measurements in the martian season, corresponding to mid-summer (Ls = 315°) and 21.2° S, show a decrease in reflectivity from the earlier lower latitude measurements. The most likely explanation, based on the limited data available, is that the reflectivity values for such widely separated ground tracks are dominated by regional differences in surface characteristics, rather than possible seasonal variations. It is also possible, however, that the supply of volatiles was limited, and that the surface may have already "degassed" by mid-summer. If so, this would suggest an atmospheric source for the apparent water, rather than a ground-circulative source.

Conclusions: The reliability of the radar-measured values of reflectivity and smoothness for Solis Lacus appears to be extremely good. We feel strongly that any question of the existence of liquid water at or near the martian surface must revolve about the interpretation of these measurements, either in terms of the reasonableness of the present interpretation or the availability of an alternative explanation possessing at least an equivalent probability. Diurnal temperature changes do not appear to be important, and ground track uncertainty is well within the resolution cell of the radar system. Although we still favor the liquid water explanation for the radar anomaly, we are currently examining alternative interpretations for the data.