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THE TOPOGRAPHY OF MARS: A RE-EVALUATION OF CURRENT DATA;

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Our present knowledge of the topography of Mars is completely inadequate for addressing a wide range of geophysical, geological, and atmospheric problems. The data acquired to date by several techniques has not provided us with reliable and consistent values for even the equatorial and polar radii and large uncertainties exist in the altitudes of many of the major volcanic constructs. While much of this can be blamed on a lack of reliable data, we feel that much more could be done to improve the analysis of the present data in a consistent global system that would necessarily involve the re-analysis of early spacecraft and Earth-based data in conjunction with more recent models of Mars' gravity field.

Current topographic knowledge of Mars is based entirely on measurements obtained by the early Mariner and Viking spacecraft and on Earth-based radar measurements [1-4]. Radio occultation measurements of the Mariner 9 spacecraft and the Viking 1 and 2 Orbiters are the primary near-global data sets. The principle behind these observations is that knowledge of the time when the signal from a spacecraft is "lost" behind the planet can be used (in conjunction with knowledge of the position of the spacecraft and the planet) to estimate the radius of the planet at the time of occultation. These data have formed the basis of several determinations of global Mars topography [3,5,6] but only about 400 measurements from the primary and extended phases of these missions are available. The principal sources of error in these data are the spacecraft position [4] at the km level, the timing of the actual loss of signal at the hundreds of msecs of time (~1 km) and the actual location of the grazing ray at the time of occultation due to local topography [1]. Depending on the orbital radius of the spacecraft at the time of occultation, the geometry of the spacecraft and planet, and the topography of the limb, these errors can amount to several kilometers in the planetary radius, although this is often not the case. The effect of refraction through the 6 mbar atmosphere contributes up to a maximum of a few tens of meters to the error in radius, even if neglected completely. Figure 1 shows how 300 Mariner 9 and Viking orbiter occultation measurements [1,4] are distributed across the planet, ranging in latitude between approx. 75N and S and spread across all longitudes. If these data were uniformly distributed across the planet they would have a mean separation of approximately 800 km, equivalent to a spherical harmonic representation of degree and order 17. Even if each value only had an accuracy of only 1 km, the basic shape of the planet at the sub-kilometer level would not be in doubt and the mean equatorial planetary radius known to a few hundred meters even in the absence of other data.

The Earth-based radar data [7,8] provide a direct measure of the distance to the surface of the planet from Earth and by inference of the planetary surface from its center. The measurement is the distance to the point on the surface normal to the incoming wave and has a resolution of 10 to 30 km in longitude and 80 to 120 km in latitude, depending the distance of Mars from Earth and on transmitter power [8]. Because of the limitations in the variation in geometry of the orbit of Mars and its spin axis direction from Earth, radar observations are generally limited to 25 degrees of the Mars equator. A typical observation period will produce radar returns from a strip of almost constant latitude [7] with a range precision of better than 100 meters. The primary source of error appears to be the planetary ephemeris which was thought to be at the kilometer level in the late seventies and early eighties when most of the calculations of Mars topography were performed. This error is of particular significance for estimating the global scale topography and must be accounted for when combining radar data with occultation data by the estimation of biases or adjustments to the ephemeris directly. At a lesser level are errors introduced by the solar plasma, which depend on the radar frequency, and are typically at the tens of meters level. The radar data are an orthogonal data set to the occultation data and together provide the strongest measurements of the global shape of Mars.

The third data set that has been used in deriving the global topography is from the infrared and ultraviolet sensors on the Mariner 6, 7 and 9 spacecraft [9-12]. These sensors provided data about the total atmospheric column content of carbon dioxide thus enabling the topography of the planet's surface to be inferred with respect to an equipotential surface (usually the 6.1 mbar surface) based upon a model of the atmosphere. The instrumental precision of the measurements for a clear atmosphere is probably equivalent to a few hundred meters in altitude above the reference surface [9] with a spatial resolution of a 10x30 kilometers for the UV measurements and 125x125 kilometers for the IR. Over thirty thousand measurements were obtained globally by Mariner 9 [11,12]. Systematic effects arising from assumptions about the atmosphere and its constancy over space and time introduce much larger errors on a global scale thus making the measurements of greater value in some local region but limited in their ability to provide geodetic control on a planetary scale. Further, these measurements only provide altitude

deviations from the reference surface and are unable to independently describe the planet in terms of areocentric radii. In contrast to these data providing strong information about the shape of Mars, it is clear [B. Jakosky, pers. comm.] that an improved topographic model would make the atmospheric data from these instruments even more valuable. More recently the infrared spectrometer on board the Phobos spacecraft obtained nine spectral images of Mars [13]. From the measurement of carbon dioxide absorption, topographic data of 150 meter quality has been derived for certain local regions. These results show some systematic differences with both radar and the occultation data at the few hundred meter level and suggest more major discrepancies for the altitudes of some of the major volcanoes which are not easily observed at their peaks by either the occultation or Earth based radar. The most significant limitation of all these instrumental observations is that they are all referenced to the 6.1 mbar surface and therefore are not providing any topographic information on planetary scales of a 1000 km or larger.

On regional and local scales photogrammetric techniques have been used extensively to derive the topography [6,14-18]. Photogrammetry provides precise detailed information on a local level that requires little or no long wavelength control. However, its obvious strength at local scales is its inherent weakness on the planetary scale and, indeed, in nearly all global models the photogrammetric results have been treated as detail that is added to the long wavelength geodetic control provided by other data, usually occultation and radar. Thus, issues of compensation and isostasy are difficult or impossible to address with the photo data and little progress has been made in this respect for over a decade. A further limitation is the lack of validity of the reference areoid on all medium and shorter length scales. Even the most recent models of the gravity field of Mars [19] contain only minimal information at wavelengths less than 500 km. Thus, even regional problems requiring slope information with respect to the areoid cannot be reliably addressed. Further discussion of Mars topography and its limitations can be found in [20-23].

It is our opinion that all the data that contribute to our knowledge of Mars topography should be re-analyzed. This would include the occultation data, which would benefit from significantly improved orbits for the spacecraft now available, the Earth-based radar data, the incorporation of improved global gravity models [19] and planetary ephemerides, the application of a priori information based on the present topographic models, the use of consistent and improved reference models and parameters of the planetary coordinate system, incorporation of lander atmospheric data and position, and the application of computing techniques and facilities not available a decade ago. We might then be reasonably sure of the extent to which our ignorance of Mars topography is limited by the data.

Fig.1 Mariner 9, Viking 1 & 2 Orbiter Occultation Data
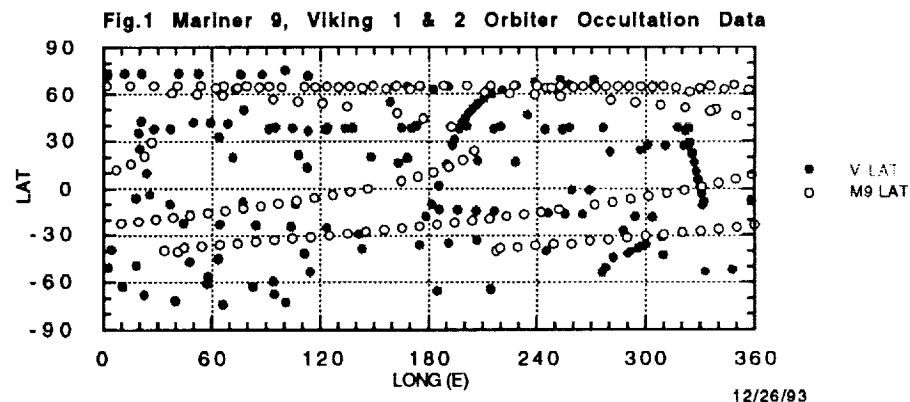
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