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Comparison of microwave and infrared measurements of Martian atmospheric temperatures: Implications for short-term climate variability

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Abstract. This paper presents the first comparison of simultaneous Viking infrared and ground-based microwave measurements of the Martian atmosphere. The data are examined in order to investigate a 15-20 K difference between microwave and Viking measurements of mid-level (10-40 km) air temperature. These data have been used by *Clancy et al.* [1990] to suggest that the Martian atmosphere is generally cooler and clearer than observed during the Viking era. This study suggests that the 15-20 K difference, which is most apparent during the non-"dust-storm" seasons, is not a real temperature difference, but instead results from a disagreement between the measurement techniques. The existence of this instrumental bias implies that the Martian climate has not substantially changed since the Viking era.

1. Introduction

Microwave measurements of Martian atmospheric temperatures constitute one of the most important and extensive Mars climate data sets, with the main period of coverage now extending over more than a decade. The data set shows two distinct portions of the annual cycle: a relatively quiescent and repeatable period, which extends from late northern winter through the year into early northern autumn, and the remainder of the year, which shows greater interannual dispersion of mid level air temperatures [*Clancy et al.* 1996, R.T. Clancy, unpublished figure, 1997]. The former corresponds to the relatively clear and cool "aphelion period" discussed by *Clancy et al.* [1996] (hereafter C96). The latter is the well known southern spring and summer "dust-storm" season, with the variability in temperature reflecting the interannual variability in dust storm occurrence, extent, and magnitude [e.g., *Kahn et al.*, 1992]. From these observations, it is possible to identify a roughly sinusoidal annual variation in mid level air temperatures, phased such that the minimum corresponds to aphelion. Superimposed upon this mean state, for any given year, are perturbations corresponding to fluctuations in atmospheric dust loading.

The majority of the microwave data cover the period 1988 to present, with additional individual observations coming from 1975, 1980, and 1982. This data set thus extends the baseline of observations provided by the Mariner 9 (1971-1972) and Viking Orbiter (1976-1980) infrared observations (Figure 1 illustrates the relative timing of the two spacecraft missions and the first three microwave observations). When this full record of Martian mid level atmospheric temperature is examined (Figure 2) [*Clancy et al.* 1990, C96], a striking difference is apparent between the Viking and microwave data. During the majority of the annual cycle (the non-"dust-storm" portion), the Viking data are typically 15-20 K warmer than the microwave measurements for observations at equivalent times of the year. (It is difficult to determine whether the 15-20 K difference continues during the dust-storm season, as the dust storms themselves can cause temperature perturbations larger than this 15-20 K signal, and are variable from year-to-year in both strength and timing of occurrence.)

On the basis of these data comparisons, *Clancy et al.* [1990] (hereafter C90) have suggested that the Martian climate was distinctly warmer and dustier during the Viking mission (1976-1980) than during the other years for which data exist (1971-present). Additional evidence for this hypothesis come from spacecraft and telescopic measurements of atmospheric dust opacity and water ice cloud properties (C90; C96). Such a transition in climate is of importance for a number of processes including the transport of trace species and the occurrence and nature of water ice clouds (C96). It also presents a challenging climate-dynamics problem, namely, how does the climate jump between interannually stable cooler and warmer states?

A distinction should be noted between the interannual shift in climate suggested by the 15-20 K difference between the Viking and microwave data sets, and the intraannual perturbations in temperature apparent in both data sets. This paper addresses only the former effect, and consequently the phrase "short-term climate variability" in the title of this paper is used in the context of timescales greater than a Mars year.

A question of great importance in the assessment of the proposed climate change is: would the microwave and infrared instruments have measured the same temperatures if observing simultaneously? The majority of Viking orbiter data were collected during two Mars years beginning in July 1976 (corresponding to a Mars seasonal date of L_s=84°, where L_s is the areocentric longitude of the sun, with L_s=0° corresponding to northern spring equinox). As stated above, the microwave data set includes only three observations before 1988. Thus it has not been recognized that simultaneous microwave and Viking data exist, and this has consequently, prevented the question stated above from being satisfactorily answered.

Under the assumption that no simultaneous microwave and Viking observations existed, C90 used Mariner 9 infrared data to infer that no systematic bias exists between the microwave and

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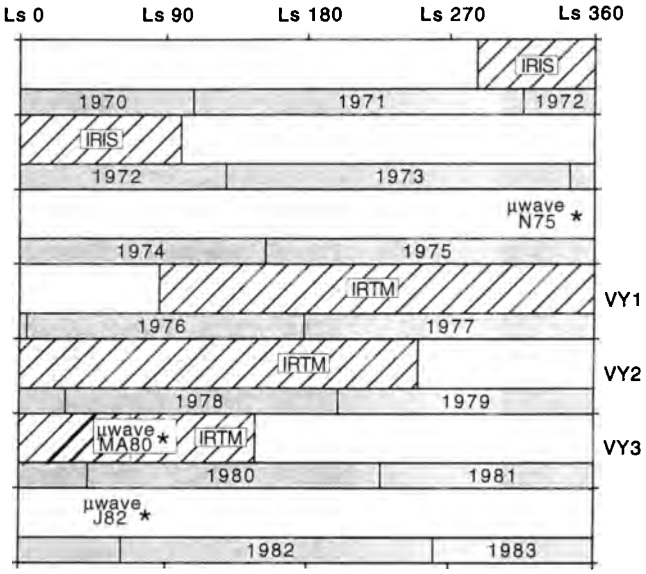

Figure 1. Time line showing the chronology of Mariner 9 IRIS, Viking IRTM, and pre-1988 microwave observations of Mars. Rows correspond to Mars years, running from northern spring equinox at left. Earth years are indicated in the shaded box at the bottom of each row. IRIS and IRTM observation periods are indicated by hatched regions. Note that the IRTM data collection period was not continuous. Microwave observations are indicated by asterisks. The microwave observation labeled MA80 is that of *Good and Schloerb* [1981].

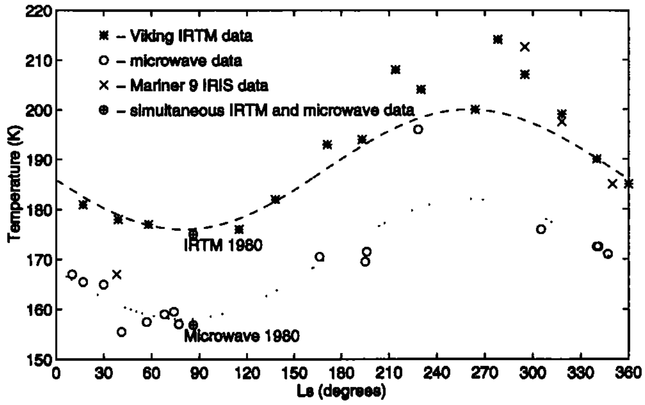

Figure 2. Day-side hemispheric averages of Mars atmospheric temperature at the 0.5 mbar level. Microwave observations are indicated by circles. Averaged IRTM data are indicated by asterisks. Averaged IRIS data are indicated with crosses. The dotted and dashed lines are sinusoids drawn following *Clancy et al.* [1996]. The minima and maxima in these curves concide with Mars aphelion and perihelion respectively. The curves would appear to provide a rough estimate of the unpeturbed, mean atmospheric state for microwave and Viking data. The simultaneous IRTM and microwave data are indicated with crosses enclosed in circles. The IRTM values shown are taken from *Clancy et al.* [1996], save for the data simultaneous with the 1980 microwave observation, for which the hemispheric average value was calculated by the author. Recalculation of the IRTM averages by the author shows good agreement with the values from *Clancy et al.* [1990, 1996].

infrared techniques. The argument is that the Mariner 9 data show a cooling of the atmosphere back to a temperature consistent with microwave observations following the global dust storm of 1971 (Figure 2). If it is assumed that no instrumental bias exists between Viking and Mariner 9 data, then this agreement between microwave and Mariner 9 data suggests that the higher temperatures observed by Viking result from actual differences in air temperature between the years, rather than from an instrumental bias between the Viking and microwave data.

A more comprehensive cross-checking of microwave and infrared data may soon be made possible with simultaneous Mars Global Surveyor (MGS) infrared and ground-based microwave observations of Mars. However, new MGS and microwave data will not necessarily answer the question of whether the Martian climate was generally warmer during the Viking era. For example, in the case of confirmed agreement between microwave and MGS observations, two fundamental possibilities would remain: either the Viking era was warmer, or there exists an instrumental bias between the Viking and the microwave (and MGS) observations.

Simultaneous Viking and microwave data do, in fact, exist and provide the key piece of evidence necessary to answer the climate change question. In this paper, I will present a comparison of the simultaneous Viking and microwave data, which were collected during March and April of 1980. These "year 3" Viking data do not appear in the papers of C90 and C96. Indeed, they do not seem to have been discussed in the context of microwave and Viking data comparison to date. I will also revisit the Mariner 9 measurements to investigate the apparent agreement between that data set and the microwave observations. Finally, I will discuss the implications for the postulated shift in climate which result from this study.

2. Dataset Comparisons

Figure 2 is similar to Figure 15 from C90 and Figure 1b from C96. It shows both microwave and infrared observations at approximately 25 km as a function of seasonal date (L_s). The microwave observations are shown as circles, the averaged Viking orbiter infrared data are shown as asterisks, and the averaged Mariner 9 infrared data are shown as crosses. A comparison of the data, as illustrated in Figure 2, provides the key evidence for a warmer climate during the Viking mission than during the majority of the past 25 years. In order for these comparisons to be valid, the same measured quantity must be extracted from the microwave, Viking, and Mariner 9 data sets. The common quantity is the 0.5 mbar (~25 km), day side hemispheric-average air temperature. Each data set must be processed to provide this quantity, either through spatial averaging, temperature retrieval, or both (C90).

The beam sizes for the microwave observations are somewhat larger than the angular size of Mars, such that atmospheric temperatures measured with this technique are hemispheric averages. The measurements are most representative of the region within 40° of the subsolar point in both latitude and longitude (equivalently ~2.5 hours of local time, C90). Both the Viking and Mariner 9 orbiters provided typical resolution of tens to hundreds of kilometers; thus these data must be averaged to provide values which may sensibly be compared to the microwave data. For the Viking data and the majority of Mariner 9 data shown in Figure 2, sufficient coverage exists to both eliminate longitudinal variations (which can be 5-10 K for Viking) and provide sufficient sampling in latitude and local time to allow good comparison points to be calculated. However, toward the end of the Mariner 9 mission the coverage is sufficiently poor that averaging the available data would not provide a good hemispheric estimate.

2.1. Viking IRTM Comparisons With Microwave

The Viking data discussed in this paper were collected by the 15 μm channel of the Infrared Thermal Mapper (IRTM) orbiter experiments [*Kieffer et al.*, 1977; *Chase et al.*, 1978]. This channel (T_{15}) was centered on the strong CO_2 absorption line and consequently measured air temperatures over a relatively deep portion of the atmosphere, with a weighting function that peaked at roughly 0.5 mbar (~25 km). Because IRTM is limited to sounding this level, while full profiles can be retrieved from Mariner 9 and microwave data, this property of the IRTM T_{15} data determines the choice of 25 km for the intercomparison quantity.

The majority of IRTM data were collected during the period 1976-1979 and are represented in Figure 2. However, some additional data were collected after 1979 (for the purpose of monitoring exposure of the northern residual water ice cap during a third Mars year) which are not represented in that figure. In fact, it does not appear to have been recognized that this portion of the IRTM data set includes measurements which are simultaneous with one of the early microwave observations. Specifically, simultaneous IRTM data exist for an observation by *Good and Schloerb* [1981], which has since been reprocessed by C90, C96. The data comprising the microwave observation were collected between March 24 and April 1, 1980, just before northern summer solstice on Mars (L_s=83°-87°). The timing of this observation relative to that of IRTM data collection is shown in Figure 1.

The IRTM data used in this study derive from the Planetary Data System Viking IRTM CD-ROM. The data have been filtered so that they include only observations flagged as good (quality flag less than 4096) and those at low to moderate emission angles (emission angles less than 60° were used, corresponding to air masses of one to two). The affects of topography were investigated. The IRTM T_{15} weighting function becomes increasingly sensitive to surface emission as surface pressure decreases in association with elevated topography. At 12 km the surface flux contribution is about 8% [*Banfield et al.*, 1996]. Thus, only the taller volcanoes cause a significant signal. Removal of the volcano regions resulted in negligible changes to the binned data presented in this paper.

Plate 1a shows the IRTM data for the period simultaneous with the 1980 microwave observation. The restricted coverage in local time makes it difficult to directly estimate a hemispheric mean for comparison with the microwave measurements. However, this can be overcome by taking advantage of IRTM data for the two previous Viking years, which provide much better coverage, especially in local time. Specifically, information about the behaviour of atmospheric temperatures gleaned from these first two Viking years can be used to extrapolate the year 3 data.

Temperature measurements from the first two Viking years are only useful for the interpretation of year 3 data if a sufficiently simple, repeatable, and predictable pattern emerges. It is then possible to have confidence that the pattern will hold in later years, even if it is not then fully sampled by observations. In the case of T_{15}, a very robust picture emerges when the data are plotted on a latitude and local time figure, having first been zonally averaged to increase coverage and reduce the affects of longitudinal variations and transient features [*Banfield et al.* 1996]. The resulting climatology of T_{15} is dominated by a large, subsolar (tropical noon) temperature maximum. The temperature difference between the subsolar peak and the antisolar trough is roughly 15-20 K for low to moderate atmospheric dust loading [*Martin*, 1981, Plate 1] (Plates 1b-1f). Despite the fact that atmospheric dust loading varied greatly in amount and distribution during the Viking mission [*Martin and Richardson*, 1993], the T_{15} pattern in latitude and local time remained constant, except during global dust storms [*Martin* 1981]. Comparing equivalent seasons for Viking years 1 and 2, it is also clear that there is little interannual variability in the behaviour of T_{15} (away from the dust storm season). It would thus appear reasonable to assume that the same T_{15} pattern holds during the third Viking year as during years 1 and 2.

Although the year 3 data exhibit poor local time coverage (Plate 1a), they provide a much better sampling of longitude. This is important, as we would like to compare zonally averaged quantities in order to reduce data noise by maximizing the number of individual measurements in each latitude and local time bin. It should be noted that the data represented in Plate 1a comprise 2593 individual observations. In order to produce better latitude and local time coverage, year 3 data from a wider range of L_s have been examined. Year 3 data for L_s=60°-90° and L_s=80°-110° are shown in Plates 1b and 1c. In regions of overlap, these expanded samples are very similar to the more restricted, L_s=83°-87° data set. I will therefore use these broader samples in the analysis below to increase coverage and reduce data noise.

The T_{15} climatology discussed above is highly consistent; thus I will assume that the year 3 measurements provide samples of the same latitude and local time temperature pattern observed during the same season in years 1 and 2 (Plates 1d-1f). In this case, differences in temperature between the various years, for individual latitude and local time bins, should be meaningful. Further, an average over these differences should provide a good estimate of the global shift in temperature between the years in question. It is this averaged quantity that is of value for comparison with microwave data.

Figure 3a and Figures 3b and 3c show T_{15} differences between year 3 and years 1 and 2 respectively. Additionally, Figure 3d shows differences between years 1 and 2. There is some spread in the values associated with imperfect longitudinal and daily coverage, yet it can be seen that the temperature differences between individual bins is never greater than 10 K and is less than 5 K in most cases. Averaging the differences between individual bins for each panel results in a difference of -1.1 K for year 1 minus year 3 (L_s=80°-110°), 0.64 K for year 2 minus year 3 (L_s=60°-90°), 0.21 K for year 2 minus year 3 (L_s=80°-110°), and 0.83K for year 1 minus year 2 (L_s=80°-110°). To within a Kelvin, the three years show very similar air temperatures. However, the microwave data for the period L_s=83°-87° in year 3 is 20 K cooler than the IRTM values for years 1 and 2. Thus an offset of about 20 K is implied between the simultaneous microwave and infrared observations.

The error on the microwave observations is about 5 K. The IRTM error is somewhat harder to estimate, combining as it does, instrument error with biases due to imperfect longitudinal and daily coverage. The error can be as high as 10 K for individual bins with few data points. However, the error pertinent to this study is that associated with the average over the bins in each panel of Figure 3. As the error for each bin results mainly from coverage imperfections, which in turn are due to effectively random differences in observation patterns, the averaging process greatly reduces the noise. The error on the averaged differences is

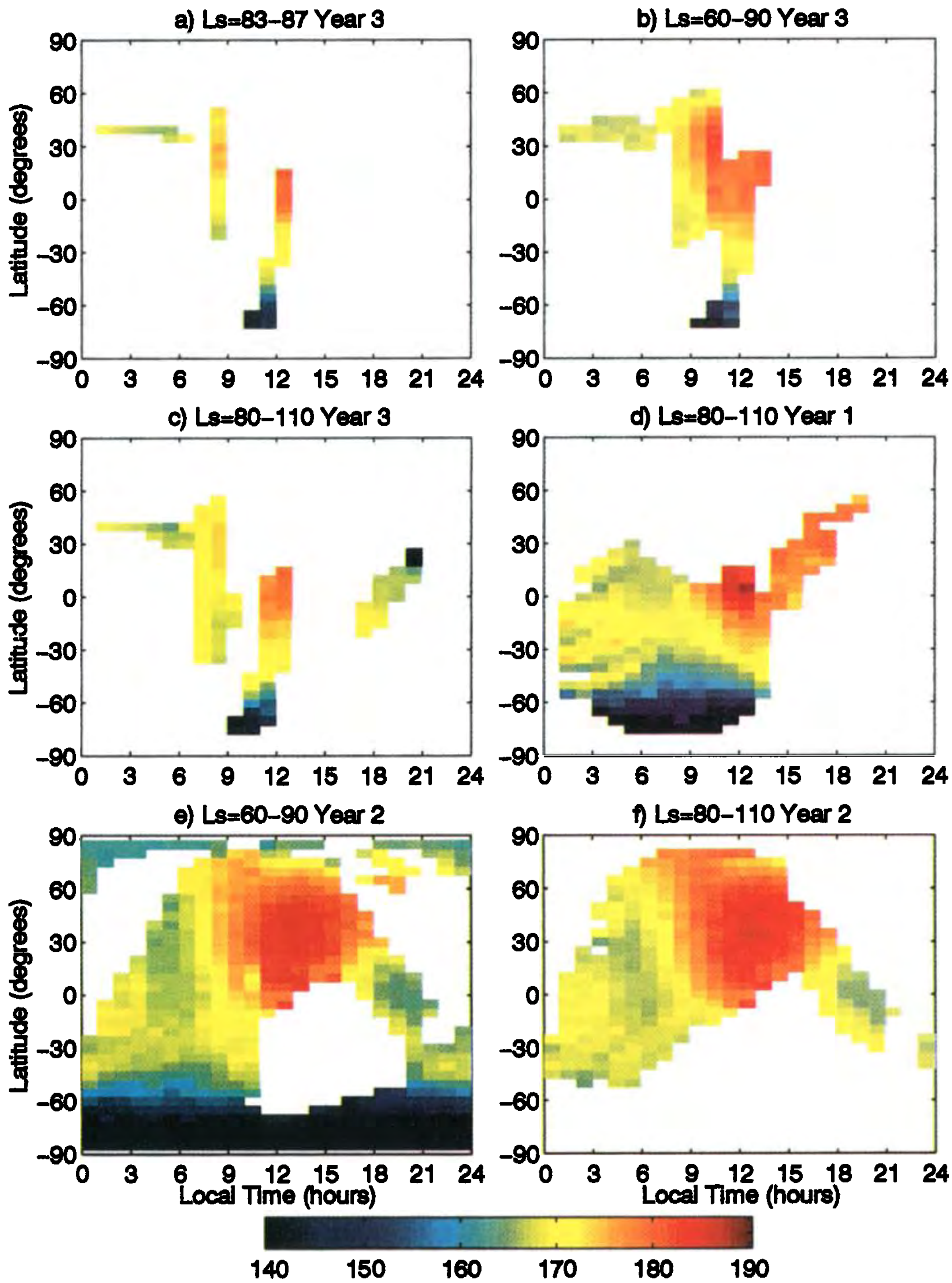

Plate 1. IRTM 15µm channel brightness temperatures (K) for late northern spring displayed in latitude versus local time. (a) Viking year 3 data for L_s=83°-87°, the period concurrent with the March 1980 microwave observation of *Good and Schloerb* [1981]. (b) Viking year 3 data, expanding the period covered in Plate 1a to L_s=60°-90°. (c) Same as Plate 1b but for Ls=80°-110°. The L_s ranges in Plates 1b and 1c have been chosen for ease of comparison with the Viking year 1 and 2 data. (d) Viking year 1 data for L_s=84°-110°. Data for 30° of L_s have been combined to improve coverage. A wider range of L_s is not used as seasonal variations in T_{15} then become important. The L_s range would ideally be centered on L_s=85°, however, the year 1 data do not begin until L_s=84°. (e) Viking year 2 data. The L_s=60°-90° period was chosen because of the good coverage. The tropical noon peak, displaced by roughly 30 degrees in latitude following the sub-solar point, is clearly evident in this compilation, as it is in many other non-dust-storm compilations [*Martin*, 1981, Plate 1]. (f) Viking year 2 data for L_s=80°-110°. These data are provided for direct comparison with the year 1 data in Plate 1d.

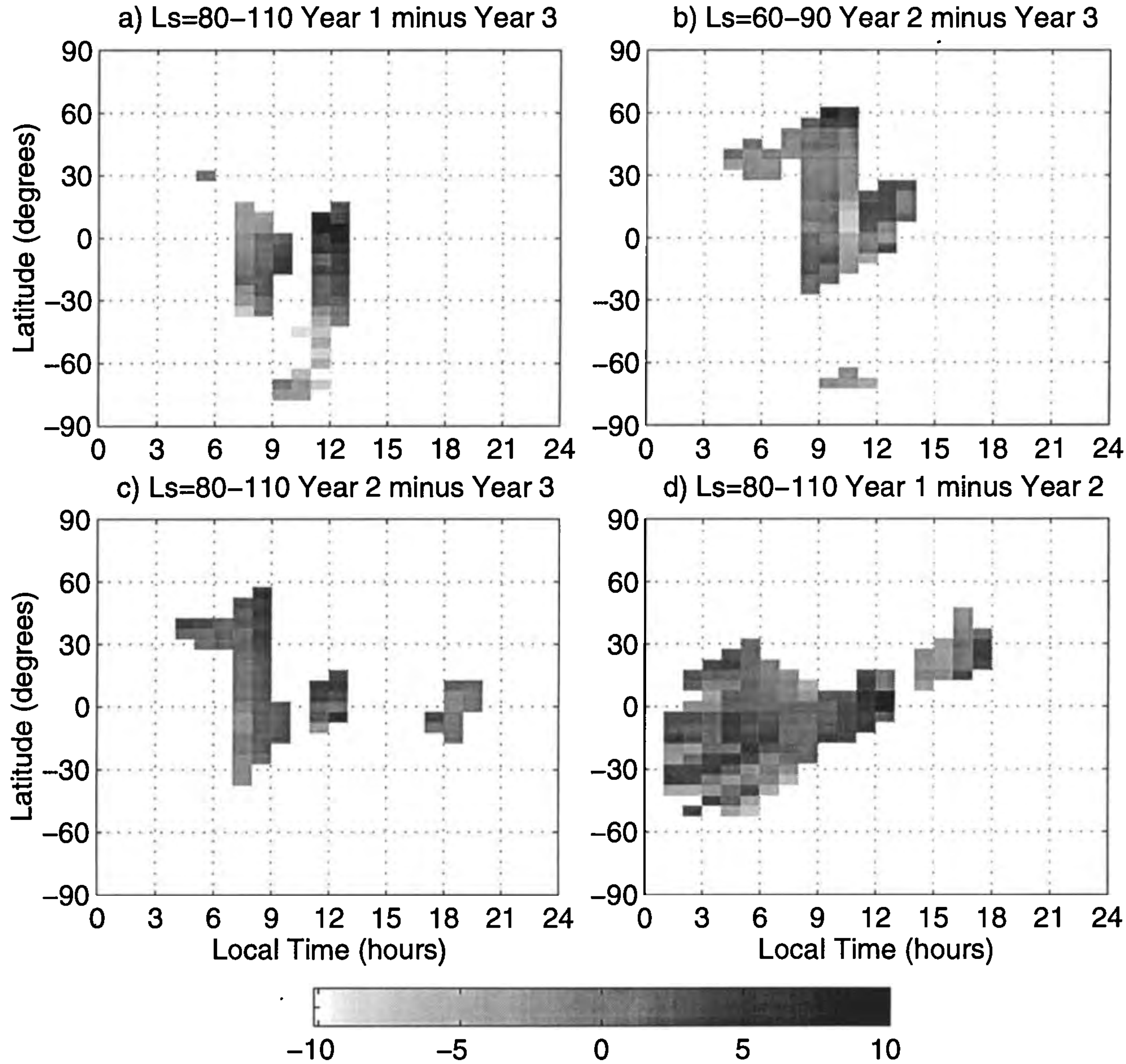

Figure 3. Differences between binned Viking IRTM 15μm channel brightness temperatures (K) for the three Viking years. (a) Year 1 minus year 3 for the period L_s=80°-110°. If the binned differences are averaged, year 1 is found to be cooler by 1.1 K. (b) Year 2 minus year 3 for L_s=60°-90°. Year 3 is 0.64 K cooler. (c) Year 2 minus year 3 for L_s=80°-110°. Year 3 is 0.21 K cooler. (d) Year 1 minus year 2. Year 2 is 0.83 K cooler. Examination of the relative temperatures of years 1, 2, and 3 at L_s=80°-110° should readily convince the reader that the difference values quoted provide more information about error in the differences than about actual differences in mean air temperature between the years. It is, however, apparent that there is little interannual variation in global mean temperatures between the years and, consequently, that the 20 K difference between IRTM and microwave data at L_s=83°-87° in year 3 must result from discrepancies in observational techniques.

less than 2 K. Thus only 7 out of 20 K of the offset can be explained as noise. Additionally, both the IRTM and microwave measurements are very close to their respective typical values for this period in other years. Thus for the offset to be mainly due to noise, not only must the error values discussed above greatly under-estimate the true instrumental error for one or both techniques, but the location of the measurement means must be extremely coincidental. The offset is thus unlikely to be due to random error.

If this result for the 1980 observations can be extrapolated to the other microwave and IRTM data, it suggests that the differences between microwave and Viking infrared observations shown in Figure 2 are due to a systematic disagreement between the two observing systems, rather than being due to a cooling of the climate following the end of the Viking mission.

2.2. Mariner 9 IRIS Comparisons With Viking IRTM

C90 present one other major piece of evidence which suggests that the Viking years were generally warmer than the recent norm. This evidence is provided by Mariner 9 observations of Mars. In Figure 2, the Mariner 9 data suggest a cooling of the

Table 1. Comparison of IRIS and IRTM Data for L_s=41°-53°

Latitude (Degrees)	Longitude (Degrees)	Local Time	L_s (Degrees)	IRIS T_{15} (K)	IRTM T_{15} Average (K)	IRTM - IRIS (K)	IRTM T_{15} Minimum (K)	IRTM T_{15} Maximum (K)	Number of IRTM Points
-8.1	329.0	0900	41.30	168.7	175.0	6.3	166.6	181.0	38
47.9	112.1	1146	41.74	168.3	174.8	6.5	169.1	180.5	9
-35.3	302.5	0801	43.09	168.2	167.4	-0.8	164.7	170.7	53
-33.2	300.7	0809	43.09	169.1	168.0	-1.1	164.7	170.7	46
49.6	80.1	1125	43.53	167.1	170.3	3.2	163.0	178.1	7
-25.2	261.4	0852	44.42	169.0	169.5	0.5	164.4	174.0	213
52.4	51.0	1125	44.87	167.0	169.0	2.0	164.6	173.4	17
53.1	50.4	1129	44.87	166.8	168.9	2.1	164.6	173.4	17
8.2	213.3	0941	46.21	168.8	180.7	11.9	179.4	182.6	4
8.3	215.2	0937	46.21	169.0	179.2	10.2	176.6	180.7	4
9.3	214.9	0938	46.21	169.4	179.1	9.7	176.6	180.7	3
48.7	23.1	1036	46.65	169.4	172.9	3.5	171.7	174.0	2
47.7	355.5	1024	47.98	168.0	172.2	4.2	170.7	175.8	4
-11.8	273.8	0802	52.85	168.5	170.1	1.6	165.3	173.9	65
6.0	267.1	0835	52.85	167.2	170.4	3.2	165.6	174.5	45
8.1	268.4	0832	52.85	167.5	171.4	3.9	168.3	174.5	28
9.3	268.0	0837	52.85	167.2	172.2	5.0	168.7	177.3	23
10.5	267.6	0835	52.85	168.1	172.4	4.3	168.7	177.3	23
20.5	263.2	0857	52.85	168.7	175.7	7.0	169.5	181.3	22

atmosphere back to a temperature more consistent with microwave observations than with IRTM data following the 1971 global dust storm. These data were taken with the Infrared Interferometer Spectrometer (IRIS) which produced infrared spectra between 5 and 50 μm at 2.4 cm^{-1} spectral resolution [*Hanel et al.*, 1972]. It is only the last IRIS data point plotted in Figure 2 (L_s=50°) which provides compelling evidence for agreement between IRIS and microwave observations (although the IRIS data point from L_s=340°-350° suggests some cooling below IRTM values), and thus this final data point is worthy of further examination. The L_s=50° data point includes observations from L_s=41°-53°. This was a period of limited data collection [*Zurek et al.*, 1992, Figure 5]. Only 19 individual measurements contribute to this data point (they can be found by searching the IRIS data set using the following constraints: latitude between 60°S and 60°N, local times between 0600 and 1800, L_s between 41° and 53°, and emission angles between 0° and 60°). Further, all of the IRIS spectra contributing to the plotted point come either from 0800-0930 local time and at tropical latitudes or from 1000-1130 at 40°-50°N. As such, they represent points in latitude and local time which would contribute only weakly to microwave observations. It should also be noted that these points skirt the noon time, tropical temperature peak evident in the IRTM data. Small changes in the location of the IRIS points could thus result in rather large changes in the differences between IRIS and IRTM values.

For comparison with IRTM, it is useful to convolve the IRIS spectra with the IRTM 15 μm channel spectral response to produce equivalent IRTM brightness temperatures (the spectral responses of the two IRTM instruments were slightly different, with the spectral response for the Viking Orbiter 1 (VO1) IRTM being used in this case). Unlike the comparison of IRTM data from different years, insufficient coverage exists to allow zonal-mean quantities to be compared. Account has therefore been taken of latitude, longitude, local time, and L_s for both the IRIS and IRTM data. For each IRIS observation, the IRTM data set has been searched for comparable data points. Table 1 shows the results of a search for IRTM points within ±15° longitude, ±5° latitude, ±24 min local time, and ±7° of L_s, of each IRIS point. Searches with more restricted ranges resulted in no IRTM data points being found for some IRIS observations.

The differences between the IRIS observations (which are consistently between 167 and 170 K) and the IRTM data are shown in Table 1. Also shown are the number of comparable IRTM measurements for each IRIS observation, and the associated minimum and maximum IRTM values. The maximum difference is 11.9 K, with the minimum being 0.5 K. The correlation between the IRTM-IRIS differences and the number of IRTM points should be noted (the maximum difference corresponds to four available IRTM points, while the minimum corresponds to 213). Averaging the differences results in a value of 4.3 K. If the averaging is restricted to the 12 IRIS observations which possess more than 10 comparable IRTM points, the value drops to 2.8 K.

From the analysis above, it can be seen that the IRIS data at L_s=50° do not convincingly show a 20 K difference from IRTM. The data presented in Figure 2 would seem to suggest such a large difference because morning IRIS data are compared with

IRTM data most characteristic of noon and early afternoon. However, the consistency of the IRIS data, combined with the fact that in all but two cases the IRIS observations are cooler than the average of comparable IRTM data, suggest that the atmosphere observed by Mariner 9 was somewhat cooler than that seen by Viking. The difference in dispersion of the two data sets is puzzling and adds to the general concern that the scarcity of data from both missions limits the interpretation of the analysis discussed above. Thus the main conclusion that can be drawn from careful examination of the L_s=50° IRIS data is that the placement of the final IRIS point on Figure 2 (equivalently on figures in C90, C96), and the implications for agreement between IRIS and microwave data that result from it, should be regarded with some reservation.

3. Discussion

This study suggests that the Martian climate, away from periods of dust storm activity and taken on average, was similar during the Viking years to more recent years observed by microwave. Day side average 0.5 mbar (25 km) air temperatures are taken as a gauge of climatic variations due to the availability of data and to the fact that temperatures at these levels are less sensitive to boundary layer phenomena, transient events, and spatial biases than lower level data, and yet are sufficiently well coupled to the lower atmosphere that the effects of variable atmospheric dust heating will be felt.

Absorption of solar radiation by varying amounts of atmospheric dust can produce large changes in air temperature [see *Zurek et al.*, 1992]. In view of this, C90 proposed that the observed 15-20 K difference in non-dust storm air temperatures between the Viking mission and the period of microwave observations could be explained in terms of differences in atmospheric dust loading. Indeed, there exists evidence to suggest that the Martian atmosphere was, in fact, dustier during the Viking mission than during the "average" Mars year [e.g., *Moroz et al.*, 1991; *Martin and Zurek*, 1993; *Zurek and Martin*, 1993; *Jakosky*, 1995].

Taken as a whole, the Viking era was undoubtedly dustier than the average Mars year because two global dust storms, which are not observed to develop every Mars year, occurred during the first year of the mission [*Martin and Zurek*, 1993]. However, an important issue here is how does one define an average Mars year or the mean Mars climate? Global dust storm events are sufficiently large and infrequent that if they are included in the annual-mean temperature and dust opacity calculations, two Mars years which are otherwise very similar would appear different entirely due to interannual variability in dust storm activity. It is well known that the first Viking year exhibited a particularly active dust storm season. However, this study suggests that the rest of the Viking era did not differ substantially from non-dust-storm periods observed by microwave. Specifically, it is implied that variations in dust opacity between the non-dust-storm Viking data and the microwave data were much less than that required to generate a consistent 15-20 K difference in mid level air temperature. This does not rule out relatively large variations in dust opacity if they are associated with localized, transient events such as local or regional dust storms, especially if the dust is not raised high into the atmosphere. Such events can occur at any time during the year [see *Kahn et al.*, 1992] and are possibly responsible for perturbations in the microwave data. It is thus also important that estimates of the global dust loading or global air temperature are derived from observations which provide good sampling in both space and time.

A separate issue touched upon by *Zurek and Martin* [1993] and *Jakosky* [1995] is that there appears to have been a shift in the frequency of global dust storm activity around the middle of this century. This may well have lead to true global mean changes in atmospheric temperature and dust opacity. However, because this paper addresses atmospheric temperatures, for which observations only exist for the last 25 years, it is not possible for this study to address this issue.

4. Conclusion

The principal conclusion of this study is that the Martian climate was not substantially warmer during the Viking era than during the rest of the past 25 years, in contradiction to the suggestion of *Clancy et al.* [1990]. Instead, the simultaneous microwave and infrared observations of Mars during early 1980 suggest that there exists a disagreement between the two techniques for deriving 0.5 mbar (25 km) atmospheric temperatures, at least for periods not characterized by dust storms.

An apparent disagreement between IRIS and IRTM data from mid-northern spring (L_s=50°), which was used by *Clancy et al.* [1990] to support the claim of elevated temperatures during the Viking mission, is found to result mainly from comparing early postdawn IRIS data with IRTM data averages biased toward tropical noon. When compared in local time, latitude and longitude, the majority of the L_s=50° IRIS data points are found to agree with the IRTM data to within 5 K. However, the data are sufficiently sparse that it would be unwise to place too much weight on the comparison of IRIS and IRTM observations around L_s=50°.

Data from other sources, which provide point samples rather than hemispheric averages, provide contradictory suggestions as to which data set better represents the 0.5 mbar air temperature. If the IRTM 15 μm channel weighting function is applied to the Viking Lander and Mars Pathfinder entry profiles [*Seiff and Kirk*, 1977; *Schofield et al.*, 1997], agreement is found with the IRTM data. However, radio occultation data from the second Viking year [*Lindal et al.*, 1979] imply 0.5 mbar temperatures 15-20 K cooler than simultaneous IRTM data. Additional work is clearly required before we can have confidence in estimates of Martian atmospheric temperatures.

It has recently been suggested that the IRTM 15 μm channel brightness temperatures possess a significant surface emission bias (up to 20K) when surface temperatures are high and the atmosphere is relatively clear of dust [R.J. Wilson and M.I. Richardson, manuscript in preparation, 1998]. If substantiated, such a bias may explain much of the disagreement between day side average IRTM and microwave measurements, by reducing or eliminating the tropical noon time peak apparent in Plate 1. The agreement between IRIS and IRTM reported in this paper would not be affected by such a revision of the IRTM data, as the IRIS observations are located at latitudes and local times away from (or on the periphery of) the region of proposed IRTM bias.

While this paper does cast doubt on the climate shift suggested by *Clancy et al.* [1990, 1996], and suggests that a systematic bias exists between microwave and Viking IRTM measurements of 0.5 mbar (25 km) atmospheric temperature, it does not provide an explanation for the bias between the techniques, nor does it provide a judgment on the relative quality of the techniques. Specifically, it would be a misinterpretation of this paper to draw the conclusion that the microwave data have been proven faulty. Further effort will be required to reconcile infrared, microwave, lander descent, and radio sounding measurements of Martian atmospheric temperature. Of particular importance in this regard will be simultaneous microwave and Mars Global Surveyor infrared and radio sounding observations [*Christensen et al.*, 1992; *Tyler et al.*, 1992].

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