Mars Weather Systems and Maps: FFSM Analyses of MGS TES Temperature Data. J.R. Barnes, College of Oceanic and Atmospheric Sciences, Oregon State University., Corvallis, OR, 97331, barnes@oce.orst.edu.

Introduction:

The Martian atmosphere is a highly dynamic environment, characterized by major changes on a daily basis. Transient baroclinic eddies contribute greatly to this variability — the weather — as do thermal tides, and smaller-scale circulations. The MGS TES atmospheric temperature data now permit the daily variability of Martian weather to be seen, globally, for the first time. Fast Fourier Synoptic Mapping (FFSM) is an analysis method that allows synoptic maps to be constructed from the highly asynoptic TES data. FFSM preserves the full space-time resolution of the data, without distorting or smoothing higher frequency pheonomena such as weather systems. During periods when both ascending and descending (2 PM and 2 AM) orbital data is available, the frequency resolution of the TES data is equivalent to two synoptic maps per sol. During periods for which either ascending or descending data are available, but not both, the resolution is only one map per sol. In any case, FFSM readily allows the generation of maps at arbitrary frequencies and times.

A considerable amount of mapping orbit, nadir, TES temperature data have been subjected to FFSM analysis. A wide range of seasonal periods have been analyzed, from more than two full Mars years. The basic product is synoptic temperature maps. From these maps, the geopotential height field can be estimated, along with the horizontal winds. The combination of these products constitute Mars weather maps, which allow the very dynamic nature of the atmosphere to be depicted.

Data Analyses:

MGS TES nadir temperature data have been binned into one-degree wide latitude bins, spaced at 5 degree intervals. Maps have been produced for a number of the TES pressure levels, ranging from the lowest scale height to 30-40 km above the surface. Typically, intervals of data of about 20-40 sols in length are subjected to the FFSM analyses. Space-time spectra are a by-product of the analyses, and these are extremely useful for detailed studies of the circulation. The maps are produced at one-half sol intervals, nominally. For periods with insufficient data, the nominal interval is one sol. For animation or other purposes, the maps are often generated at much shorter time intervals. Several different basic types of maps have been produced. These include maps showing only the transient eddy (non-tidal) portion of the temperature field, and the total (non-tidal) temperature field. Maps including the westward diurnal tide can be produced, but this tide is not fully resolved by TES.

Using the results from the FFSM analyses of temperatures, maps of the geopotential heights can be constructed. At present, these maps are based upon an assumption of a flat geopotential surface at some pressure level near the ground (this is equivalent to assuming zero horizontal winds at this level). Using the geopotential maps, synoptic maps of the horizontal winds can then be produced. A linear balance approach has been used to determine the winds. This approach yields much better wind estimates than geostrophic or gradient wind balance does, when the winds are fairly strong. It also offers some major advantages when combined with the FFSM method. Weather maps combining the height data, the temperature data, and the wind data, are then constructed.

Results:

In the fall, winter, and spring seasons, the synoptic maps evidence a highly dynamic atmosphere. In the summer season, the atmosphere is much less dynamic except at high latitudes (except for the tides). Weather systems grow and decay on short time scales (as short as one sol or less), and can move rapidly both zonally and meridionally. Front-like structures are often prominent. In both hemispheres the weather systems preferentially amplify in certain regions — storm zones (Figs. 1 and 2). At times, the systems have a highly global structure. The systems are of planetary scale, being dominated by zonal wavenumbers 1-3. The larger scale systems have extremely deep structures, with large amplitudes at very high levels. An extreme example of this is a very-large amplitude disturbance which is present during northern winter (Fig. 3). It is dominated by wavenumber one, and has only small amplitudes near the ground. It propagates to the east quite slowly (having a period of ~ 15-25 sols), but this propagation is actually rather complex when viewed in the maps. This disturbance is almost certainly not the same basic kind of weather system as the others in the maps, and it may have no real terrestrial counterpart. It does appear to be quite characteristic of the

Martian northern winter atmosphere under dusty conditions.

Near to the winter solstice season, the weather systems in the northern hemisphere are much stronger than those in the south (Figs. 4 and 5). This is basically in agreement with the results of GCM simulations, and appears to be a result of both the topography of Mars and the eccentricity of the orbit. However, later in southern winter the systems are found to be much more vigorous. They are also more vigorous in early spring in the south. The southern hemisphere weather systems are somewhat different than those in the north, as they are largely confined to the western hemisphere and especially to the vicinity of the southern extension of Tharsis and Argyre (Fig. 6). They tend to have relatively shallow vertical structures, and tend to be characterized by shorter zonal scales than the northern winter systems. They also have shorter dominant periodicities.

The northern weather systems are typically marked by strong storm zones. These storm zones basically coincide with the broad lowland regions in the north: Acidalia and Utopia/Arcadia. They can extend to very high altitudes. Especially within these regions, the weather systems are often seen to penetrate well to the south (Fig. 7). A similar behavior has been seen in the MOC imagery in late winter and spring, when it is associated with dust events. The weather systems near the winter solstice season in the north tend to have very deep structures, while those in the fall and in the spring are much less deep. The systems tend to be located further south in winter, and are located at higher latitudes in the early fall and the spring seasons. They always are located near the region in which the north-south temperature gradients are strongest, which tends to be near the edge of the seasonal polar cap.

The very strong global dust storm which began in early fall in the second MGS mapping year had a strong impact on the weather systems. They were greatly diminished in strength in comparison with the systems in the same season in the first mapping year. This is consistent with observations made by the Viking Landers during the first Viking year. Later on, when this global storm was still raging, the slowly moving, wave-one disturbance was present in the north at very large amplitudes. There are considerable differences in the weather system activity in the two Mars years of MGS mapping, and the bulk of these appear to associated with regional and global dust storm activity.

Summary:

FFSM analyses of MGS TES nadir temperature data have allowed the construction of Mars weather maps: synoptic maps showing temperatures, geopotential heights, and horizontal winds on constant pressure surfaces. The winds have been determined by making use of a linear balance approach, which is much more accurate than geostrophic balance when the winds are fairly strong. It is assumed that the winds vanish at a pressure level near the ground, in the absence of sufficiently accurate surface pressure data. Maps have been produced for a wide range of seasons in both hemispheres, at levels between the surface and ~ 40 km, for more than two full Mars years.

The maps show a highly dynamic atmosphere in the fall, winter, and spring seasons. Weather systems are seen to grow and decay on short time scales, and can move very rapidly. They tend to amplify in certain regions — storm zones — which are strongly correlated with the topography. The storm zones have very different structures in the two hemispheres, presumably reflecting the very different topography in the two hemispheres. The weather systems can have very deep vertical structures, with some of them exhibiting maximum amplitudes at very high levels (~ 30-40 km or above). Near to the winter solstice seasons, the northern weather systems are much stronger than their southern counterparts — much as predicted by GCM studies. The northern systems also tend to be of larger scale and to have deeper structures. They tend to have longer periodicities.

The weather maps allow the highly dynamical nature of the atmosphere to be clearly seen. This is limited by the difficulty that the TES retrievals have in sampling the lowest part of the atmosphere, and by the relatively coarse resolution of these retrievals. Nonetheless, a great deal of complex weather activity is apparent in the periods which have been mapped to date, and this activity differs substantially between the two MGS mapping years. The synoptic maps have considerable potential, in synergy with MOC imagery,and TES dust and water vapor/ice data, to give us a much better picture of the atmospheric part of the climate system of Mars. Such studies are currently underway.

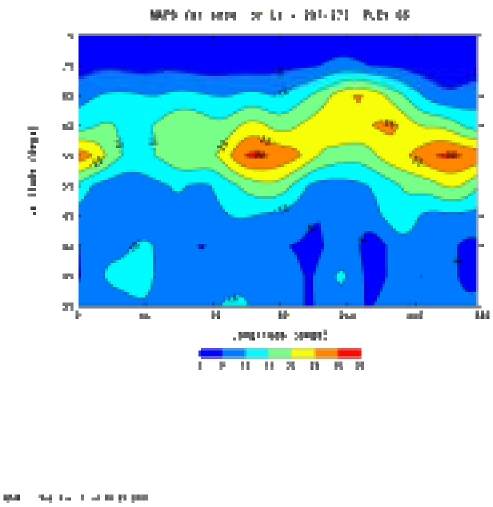

Figure 1: Temperature variance of the weather systems in northern winter, at the 6.1 mb level.

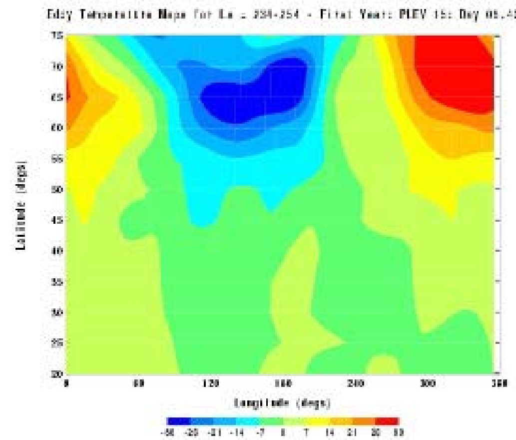

Figure 3: A synoptic map of upper-level temperatures during a northern winter period when the slow, wavenumber one disturbance is dominant.

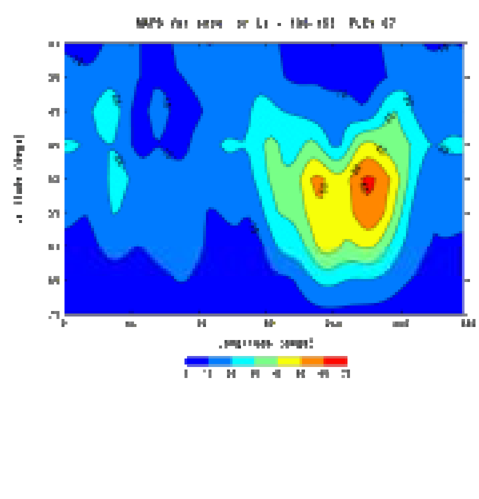

Figure 2: Temperature variance of the weather systems in southern mid-winter, at the 3.7 mb level.

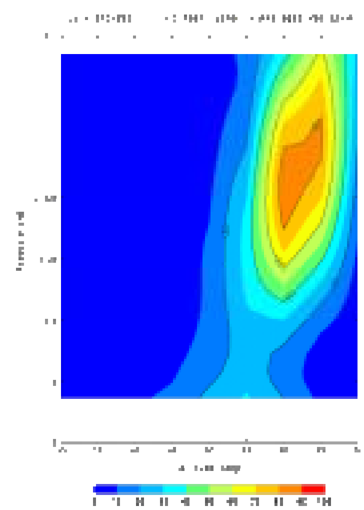

Figure 4: Zonally-averaged weather system temperature variance for a northern winter solstice period.

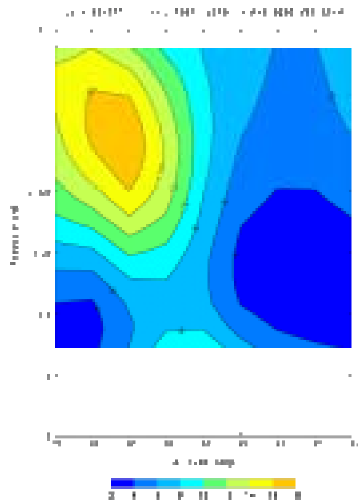

Figure 5: Zonally-averaged weather system temperature variance for a southern winter solstice period.

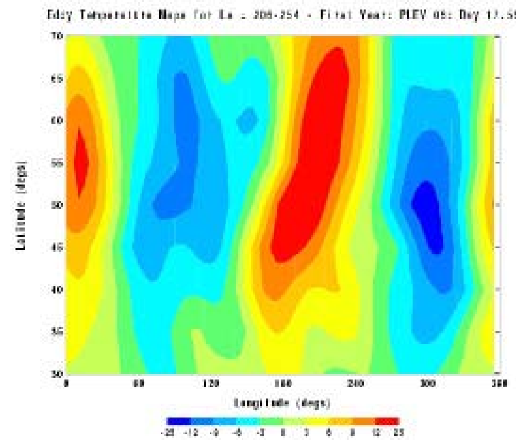

Figure 7: A synoptic map of temperatures associated with northern weather systems during the first mapping year fall season.

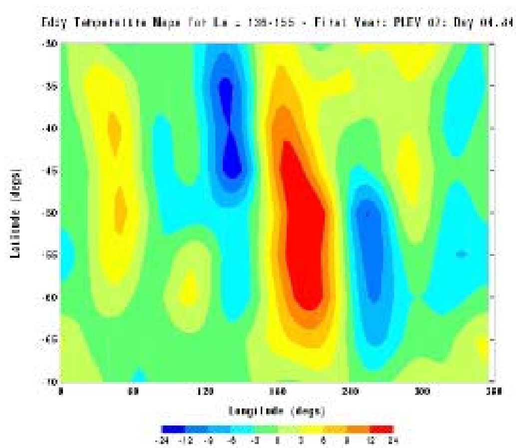

Figure 6: A synoptic map of temperatures associated with southern weather systems during mid-winter.