REMOTE SENSING STUDIES OF THE CURRENT MARTIAN CLIMATE BY THE MARS CLIMATE SOUNDER ON THE MARS RECONNAISSANCE ORBITER.

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A systematic and detailed experimental study of the Martian atmosphere remains to be carried out, despite many decades of intense interest in the nature of the Martian climate system, its interactions, variability and long-term stability. Such a study is planned by the Mars Reconnaissance Orbiter, starting in 2006, using limb-scanning infrared radiometric techniques similar to those used to study trace species in the terrestrial stratosphere. For Mars, the objectives are temperature, humidity, dust and condensate abundances with high vertical resolution and global coverage in the 0 to 80 km height range. The paper will discuss the experiment and its methodology and expectations for the results.

1 Atmospheric Temperature Sounding

Temperature sounding is a well-established technique for the Earth, where it is routinely employed from weather satellites to collect data on the global atmospheric temperature field for forecasting purposes, as well as for research into problems of understanding the climate and climate change. The basic principle is the use of sensitive, calibrated infrared radiometers to measure the thermal emission from the atmosphere. The ÔbrightnessÕ temperatures derived from these measured radiances are then related to different height levels in the atmosphere using spectral and geometric methods and vertical profiles retrieved, which are then built up into global three-dimensional maps. Methods other than infrared radiometry can be used, for example density measurements from the occultation of radio signals, and we return to discuss these briefly later. Following early success from Earth satellites, temperature sounding has been extended to planetary atmospheres, with notable early successes at Venus, from the Pioneer Orbiter in 1979, Jupiter, from Voyager in 1980, and Mars, with Mariner 9 in 1971. Further coverage was possible at Mars using instruments on the Viking orbiters, and, more recently, on Mars Global Surveyor, with the Thermal Emission Spectrometer (TES, Hinson et al., 2004), and Mars Express, with the Planetary Fourier Spectrometer (PFS, Formisano et al., 2005). However, these were primarily nadir measurements, in which the radiometer looks vertically down and vertical layers are distinguished by measuring in different spectral regions of varying opacity. The vertical resolution obtained in this way, at about 15 km, is insufficient to resolve the detailed structure that is known to be present in the Martian temperature profile, for example from direct measurements made during the entry of probes which landed on the surface, like Viking and Pathfinder

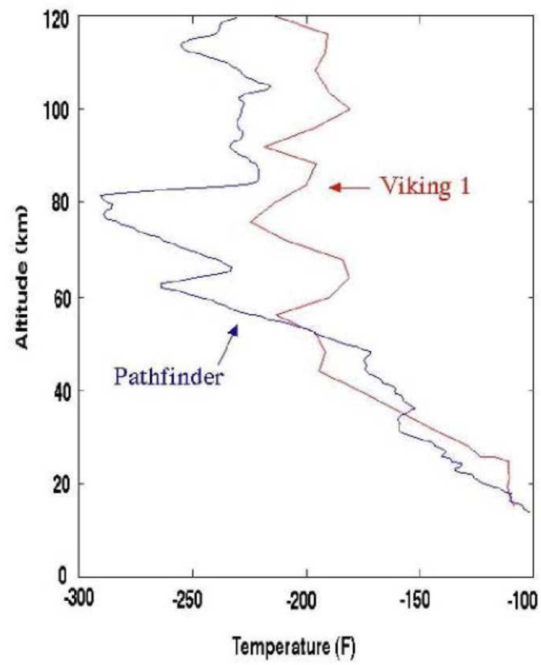

Figure 1: Measured temperature profiles for the atmosphere of Mars, measured during the descent of the Viking 1 and Pathfinder landers in 1976 and 1996 respectively (NASA).

Radio occultation measurements have been used with great success to obtain temperature profiles on Mars with high vertical resolution (e.g. Hinson and Wilson, 2004), while Mars Express includes a radiometer, SPICAM (Bertaux et al., 2000), which is capable of temperature profile measurements above 20 km altitude by observing stellar occultations from Mars orbit. However, like entry profiles, the global and temporal coverage obtainable by occultation measurements is naturally very limited, and, particularly for studies of atmospheric dynamics and circulation, there remains a need for data that achieve high vertical resolution and optimal coverage in space and time simultaneously. A limb-viewing instrument in close polar orbit determining temperatures from observations of thermal emission from the atmosphere can meet this requirement, and such a device, the Pressure Modulator Infrared radiometer (PMIRR), was flown on Mars Observer and Mars Climate Orbiter, both of which reached Mars (in 1993 and 1999 respectively) but then were lost due to technical problems with the spacecraft. A similar instrument, of revised design but with the same objectives, called Mars Climate Sounder (MCS), has now been developed for Mars Reconnaissance Orbiter, and was launched in September 2005. In this presentation we describe the MCS experiment and what it is hoped to achieve with it.

2 Mars Reconnaissance Orbiter Climate Sounder

2.1 Science Goals

The science goals of MCS are the same as they were for PMIRR (McCleese et al.,1992). Once global 4-D data has been acquired we can seek to understand the present climate in detail, including the whole range of Martian meteorological phenomena, such as the water and carbon dioxide seasonal cycles, and the important but puzzling global dust storms. One obvious aim will be to make detailed comparison to the Earth, and thereby understand the atmospheric behaviour on both planets better. This is probably best achieved by first validating and improving models of the current climate on Mars, using existing general circulation models for Mars that were themselves developed from terrestrial GCMs, as further discussed below. Better models for the modern atmosphere are an essential prerequisite for modeling the palaeoclimate more reliably than is possible at present. Another important benefit of better models will be the ability to soft-land spacecraft more safely on Mars, by reducing the uncertainty in predictions of the surface wind field.

2.2 Measurement Objectives

To make progress in understanding the structure and circulation of the atmosphere we need to map the three-dimensional and time-varying thermal structure of the atmosphere from the surface to the highest possible altitude with a vertical resolution of better than a pressure scale height. A reasonable practical goal for the latter is 5 km, about half the scale height and about three times better than existing nadir sounding data. With this choice determining the field of view, spacecraft-driven constraints on the size of the aperture, and using the best available uncooled detectors, measurements with useful precision are possible up to an altitude of about 80 km, or somewhat higher if the measurement time is increased, which degrades the horizontal resolution. Given the large seasonal and spatial variability of atmospheric pressure on Mars, it is necessary to design the measurements to obtain, not just temperature vs. pressure as is common in Earth observation, but both parameters separately as a function of geometric altitude. Limbviewing measurements are particularly suited to this, but require carefully-chosen spectral channels.

Next, we seek to determine the time and space distribution, abundance, sources and sinks of volatile material and dust over a seasonal cycle. This involves mapping the atmospheric dust loading and its global, temporal and vertical variation and the seasonal and spatial variability of the vertical distribution of atmospheric water vapor to an altitude of 35 km, possibly higher during global dust storms when dust concentrations are high up to around 50 km. Since clouds of both water ice and carbon dioxide ice, as well as dust, are found on Mars, the instrument must be designed to distinguish between condensates as well as to map their individual spatial and temporal variations.

Finally, infrared sounding experiments can investigate the polar radiative balance on Mars, and its seasonal cycle. During the course of this, some ten trillion tonnes of CO2 condense on the winter pole, where of course it is dark and the processes involved, which prevent the entire atmosphere from condensing, are difficult to observe. Important constraints, at least, are placed by the atmospheric temperature cycle, and the flow of energy as radiation into and out of the region over the year. The latter requires good coverage across the thermal spectrum, and albedo measurements for the part of the year when the seasonal polar cap is illuminated by the Sun and its volatiles are retuning to the atmosphere.

2.3 Measurement Techniques

The successful implementation of a remote sounding experiment with the above goals depends on obtaining daily coverage, day and night, over at least one complete Martian seasonal cycle, and preferably (since Mars shows marked interannual variability) over more than one. During this time the instrument has to be able to stare at the atmosphere at the limb of the planet, at al latitudes, and the orbit has to be such that a wide range of latitudes (preferably pole-to-pole) can be observed. It helps to fill in the coverage between orbits if the instrument has commandable pointing that allows nadir and intermediate, as well as limb, scanning. The instrument that can achieve this is described by the parameters listed in Table 1 and the selection of spectral channels in Table 2. The instrument has two telescopes, each serving half of the complete set of spectral channels, and containing relay optics, optical filters, and detector arrays. This simple and compact design is possible because of the recent development of sensitive room temperature thermopile detectors in the USA, and miniature high-resolution interference filters in the UK.

Table 1: Mars Climate Sounder Instrument Specifications.

Parameter Property	**Performance**
Spectral Range	0.3 to 50.0 m in nine spectral channels
Telescopes	Two 4cm aperture, f/1.6 telescopes
Detectors	Nine, 21-element, linear thermopile arrays at 300 K
Detector IFOV:	3.6 x 6.2 mrad , equivalent to 5.0 x 8.6 km at limb
Instrument IFOV:	75 x 75 mrad, equivalent to 105 x 105 km at limb
Instrument Articulation	Two-axis azimuth/elevation
Range/Resolution:	Azimuth: 270/0.1 degree s
Elevation:	270/0.1 degrees
Single Operating Mode,	2 s signal integration period
Observation Strategy	Limb Staring; Limb, nadir & off-nadir scanning
	In-track, Cross-track, and Off-track viewing

Table 2: Spectral Channel Characteristics and Functions. A and B refer to the two telescopes

Channel #	**Bandpass** (cm^{-1})	**Band Centre** (μm)	**Measurement Function**
A1	595 - 615	16.5	Temperature 20-40 km
A2	615 - 645	15.9	Temperature 40-80 km, pressure
A3	635 - 665	15.4	Temperature 40-80 km, pressure
A4	820 - 870	11.8	Dust and Condensate extinction 0-80 km
A5	400 - 500	22.2	Temperature, dust & cloud 0-20 km
A6	3300 - 33000	1.65	Polar radiative balance, albedo
B1	290 - 340	31.7	Temperature, dust & cloud 0-20km
B2	220 - 260	41.7	Water Vapour, dust & cloud 0-40 km
B3	230 - 245	42.1	Water Vapour, dust & cloud 0-40 km

3 Models and Data Assimilation

Even with a dedicated spacecraft, coverage of the planet is limited in both time and space and tends to be restricted in terms of the range of atmospheric variables which can be measured. A numerical model, which is able adequately to simulate observations, provides a means of making intelligent extrapolations and predictions for regions or times that have not yet been observed. The complete, physically consistent set of atmospheric fields generated by a combination of model and observation can then be subjected to detailed diagnosis, in order to test hypotheses in ways that would not be possible with either alone. Thus, data assimilation is a powerful technique by which information from both present and past observations and all of the available knowledge of the physics of the problem, embodied in a numerical model, may be combined to produce an optimal analysis of the current state and long- and short-term behaviour of the climate system. The assimilation of data directly into a model is also an attractive method for the study of time-dependent phenomena using data taken asynchronously. The examination of deviations of observations from model forecasts also helps to identify deficiencies in the model, as well as to extract the most benefit from a relatively sparse observational record (see Lewis et al. this meeting).

References

J. L. Bertaux et al., 2000. The study of the Martian atmosphere from top to bottom with SPICAM light on Mars Express Planet. Space Sci. 48, 1303.

V. Formisano, F. Angrilli, G. Arnold, S. Atreya, G. Bianchini, D. Biondi et al., 2005. The Planetary Fourier Spectrometer (PFS) on-board the European Mars Express mission. Planet. Space Sci, 53, 963-974..

Hinson, D. P., Smith, M. D., Conrath, B. J. 2004. Comparison of atmospheric temperatures obtained through infrared sounding and radio occultation by Mars Global Surveyor J. Geophys. Res., 109, E12, 1-10.

McCleese, D.J., Haskins R.D., Schofield, J.T., Zurek, R.W., Leovy, C.B., Paige, D.A., and Taylor, F.W., 1992. Atmosphere and Climate studies of Mars using the Mars Observer Pressure Modulator Infrared Radiometer. J. Geophys. Res., 97, E5, 7735 - 7758.

Read, P.L. and Lewis, S.R. 2004. The Mars Climate revisited: Atmosphere and Environment of a Desert Planet. Springer-Praxis, 2004.