Anzeiger Abt. II (1999) 136: 19–22

Mars Upper Atmosphere: Response to Solar Activity

By

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(Vorgelegt in der Sitzung der math.-nat. Klasse am 16. Dezember 1999
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Upper atmosphere parameters of planets such as Earth, Venus and Mars that are controlled by absorption of solar euv radiation ($\lambda \leq 100\,nm$) are known to show a variability with solar activity since this radiation can vary by about 100% between low and high solar activity. Although the intensity of solar euv fluxes has been directly measured only intermittently and never on a long term basis, the relative sunspot numbers R_z and, more recently the 10.7 cm (2800 MHz) solar radio flux has served as proxy for solar variability. The 10.7 cm radio flux $F_{10.7}$, however, is not linearly related to the intensity of euv radiation outside the absorbing atmosphere, I_∞ or the related photon flux Φ_∞. Thus it can be assumed that

$$I_\infty(\Phi_\infty) \propto F^n_{10.7} \tag{1}$$

The euv intensity (energy flux) I_∞ is important for the heating of the upper atmosphere and thus its neutral gas temperature T or scale height $H = \mathrm{k}T/\mathrm{mg}$, with the k the Boltzmann constant, m the molecular mass of the atmosphere constituents and g the acceleration of gravity. The photon flux Φ_∞ on the other hand enters into the formation of ionospheric layers of wavelengths equal or lower than the ionisation thresholds for neutral species.

For the subsolar peak electron density N_o of a Chapman-layer holds (e.g. [1])

$$N_o = \sqrt{\frac{\eta_i \Phi_\infty}{eH\alpha}} \tag{2}$$

where in addition to the previously defined quantities η_i is the ionization efficiency e the base of natural logarithms and α the dissociative recombination coefficient. The dependence of scale height H and neutral gas temperature T on solar activity, resulting not only from the solar euv input, but also the heat loss by conduction, can be expressed by

$$H(T) \propto F_{10.7}^{m} \tag{3}$$

Thus using (1) and (3), the dependence of N_o (from Eq. (2) on solar activity can be expressed by

$$\frac{dln\,\mathrm{N_o}}{dln\,F_{10.7}} = \frac{n-m}{2} \equiv \kappa \tag{4}$$

For the Venus ionosphere $\kappa = (n - m)/2$ was derived to be 0.38 [10] while for the Mars ionosphere a value of $\kappa = 0.36$ was found by Hantsch and Bauer [7]. From neutral scale heights determined by matching radio occultation profiles from US and Russian Mars missions with a Chapman layer of scale height H and corresponding neutral temperature T at the ionospheric peak (~130 km), their dependence on $F_{10.7}$ was found to be $m = 0.16$ [4]. The dependence of upper atmosphere temperature of Venus on solar activity $(F_{10.7})$ had previously been determined to be $m = 0.14$ [2, 3]. Combining these results for m with that of κ in Eq. (4) implies a slightly non-linear relationship between solar euv intensity (photon flux) and $F_{10.7}$, corresponding to $n \approx 0.9$.

Although these results clearly show that upper atmosphere parameters (subsolar peak electron density, neutral scale height and temperature) have essentially the same response to solar activity (expressed by $F_{10.7}$), for Venus and Mars, it has been argued repeatedly by theoretical modellers of the Martian upper atmosphere [5, 6, 8] that the upper atmosphere temperature of Mars should have a much stronger response to solar activity than that of Venus.

According to their predictions the upper atmosphere (exosphere) temperature of Mars would be $T \approx 250°$K, for $F_{10.7} = 150$ and as high as 280°K for $F_{10.7} = 206$. In contrast to these predictions the first *direct* determination of neutral gas temperature obtained from the aerobreaking (orbital decay by atmospheric drag) of the Mars Global Surveyor (MGS) by [9] was found to be only about 200°K at slightly elevated solar

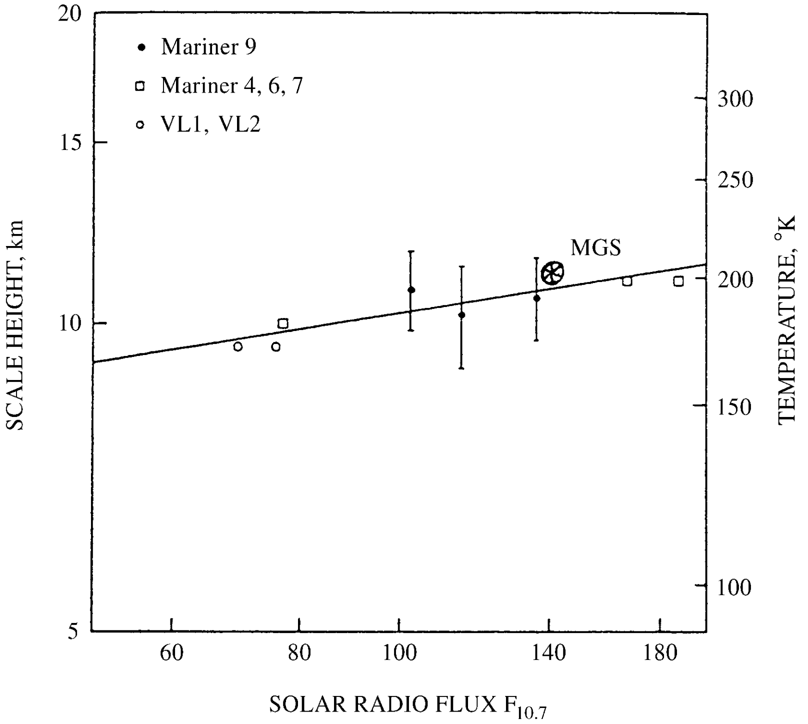

Fig. 1. Scale height of ionizable constituent and corresponding neutral gas temperature vs. solar radio flux following a slope of $m = 0.16$ [4] with the new measurement of neutral gas temperature (MGS) added

activity ($F_{10.7} \approx 140$). Adding this new measurement to the previously derived relationship between $H(T)$ and $F_{10.7}$ by [4] in Fig. 1, lends support to the long standing arguments by the author, that the response of the upper atmosphere temperature of Mars and Venus (both CO_2 atmospheres) to solar activity is essentially the same.

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