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Martian terminator waves

I HAVE suggested that the supersonic motion of the Earth's terminator could generate atmospheric waves[1], and Raitt and Clark claim to have discovered these waves in the terrestrial thermosphere[2]. The Martian terminator will also be supersonic in a wide band of latitudes in the Martian upper atmosphere and may be expected to produce waves if the region's radiative response occurs on a shorter time scale than the dynamic response.

In Martian low and middle latitudes the terminator moves with a speed, V_T, of:

$$V_T = 240 \cos\varphi \text{ m s}^{-1}$$

where φ is the geographical latitude. If we assume a pure CO_2 atmosphere then the speed of sound, C, is

$$C = 16.2\, T^{\frac{1}{2}} \text{ m s}^{-1}$$

where T is the local atmospheric temperature. Supersonic waves may be generated at the equator in regions where $T < 220$ K, and at latitude 30° if $T < 164$ K. If we assume that the minimum temperature in the Martian atmosphere is 140 K at the tropopause[3] then these waves can exist for $|\varphi| < 37°$.

In December 1971 Mariner 9 photographed Mars. There were 10 distinct observations of atmospheric wave structure on or near the terminator between latitudes +40° and −20°. Typical wavelengths were 40 km and the lack of any wave structure when photographed through orange filters indicates that the waves occurred in the atmospheric layer above the dust storms that were blowing during the Mariner expedition[4]. As the dust existed up to 10 km altitude it seems highly reasonable to assume that the terminator waves were generated in the stratosphere (that is, above 15 km) when the stratospheric temperature was sufficiently low. The observed latitudinal extent of the waves agrees well with this hypothesis. There is good reason to believe that the Martian stratosphere is isothermal over a height range of at least 15 km (ref. 3). Provided that the stratospheric temperature is low enough to generate supersonic waves then the resulting disturbances are in phase over that height range. The oscillation produced will, therefore, be evanescent, or very nearly so.

The only waves that will escape destructive interference are those for which the trace of the phase velocity in the direction parallel to the Equator equals the speed of the terminator within the source region of the wave. Only two types of atmospheric oscillations can have supersonic phase velocities[5,6]. First, very low frequency infrasonic waves which satisfy the dispersion relationship

$$k^2 = \frac{\omega^2}{C^2} \frac{\omega^2 - \omega_{an}^2}{\omega^2 - \omega_B^2} \qquad (1)$$

when they are evanescent; and second, the characteristic surface wave[5], which is always evanescent, and obeys the relationship

$$\omega^2 = C \omega_B k \qquad (2)$$

where ω and k are the angular frequency of the wave and wavenumber, respectively, ω_B is the local Vaisala–Brunt frequency, and ω_{an} is the non-isothermal acoustic cutoff frequency, given in terms of the temperature gradient α as[5]

$$\omega_{an}^2 = \frac{\gamma^2 g^2}{4C^2} + \frac{\gamma g}{2T}\alpha$$

where γ (=1.4) is the ratio of specific heats and g(=3.76 m s^{-2}) is gravitational acceleration.

The type of oscillation generating Martian terminator waves can be located by finding α from equations (1) and (2). For example, the waves at +40° latitude occur when $V_T = C$; thus, the wave parameters are given by $V_T = C = \omega/(k \cos\theta)$, where θ is the solar declination. If we assume $\theta = 0°$, then $\alpha =$ 4.26 K km^{-1} from equation (1) and 25.6 K km^{-1} from equation (2). The first of these is the only realistic value.

It is worth studying Revolution 17 of Mariner 9. Terminator waves were observed at −20° latitude, 20°W longitude. Temperature profiles obtained during this revolution[7] indicate that at this latitude the terminator was supersonic from an altitude of 30 km to at least 50 km. The minimum temperature of the tropopause at 38 km is 160 K, and it rises immediately above the tropopause with a gradient of 4 K km^{-1}. These experimental results certainly agree very closely with this theory.

There remains, however, one unusual feature of the Martian terminator wave observations. The tilt of the wavefronts corresponds to that expected during the Northern Hemispheric summer, whereas the latitudinal extent of the wave observations seems to indicate that the Northern Hemispheric stratosphere was at a lower temperature than the southern stratosphere.

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Effects of meridional winds on the interpretation of satellite inclination data

DURING the past decade, the analysis of long term changes in inclination of Earth-orbiting satellites has been used to determine characteristics of the zonal wind field in the Earth's upper atmosphere. As reviewed by King-Hele[1], results of analyses of this type indicate that, on average, the atmosphere between 200 and 350 km rotates faster than the Earth. Average eastward wind speeds of the order of 100 m s^{-1} with respect to the Earth's surface are indicated in the altitude region around 300 km.

The effect of thermospheric winds on satellite inclination is quite small, of the order of 0.1° over a period of several months; as a result long and accurate observations are required to produce useful information. The deduced wind speed applies to a

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