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ACOUSTIC, ATMOSPHERIC, PROPAGATION AND APPLICATIONS

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Rocket grenade studies of the upper atmosphere

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1. Introduction

Since 1957 a U.K. programme of upper atmosphere studies of wind and temperature has been carried out using the rocket grenade technique. Measurements of neutral atmospheric structure are made up to 100 km by analysis of the travel times of acoustical waves from the grenade bursts to the ground. From these and other studies the distributions of mean temperature, pressure, density and winds have been tabulated in several model atmospheres as functions of altitude, season and latitude.

The main features of the variations in the temperature profiles are that at the stratopause (about 50 km) the temperature is greatest near the summer pole and decreases through the equator to the winter pole, and that at the mesopause (about 85 km) the latitudinal temperature gradient is reversed, with highest temperatures towards the winter pole; the latter is contrary to calculations of temperature from radiational heating, and theories of chemical heating and energy transport by dynamical processes have been proposed to explain the anomaly.

The prevailing winds in the stratosphere and mesosphere are driven by the seasonally varying pressure inequalities associated with the temperature variations; these winds are mainly zonal (west-east) with meridional winds being small by comparison. At 50^{o}N and at 60 km there is a maximum westerly wind during winter of about 80 m s^{-1} and a maximum easterly wind during summer of about 60 m s-1.

Superimposed on the prevailing atmospheric motion are various types of disturbance:

(a) Planetary waves with periods of several days and which can be seen as deviations from symmetrical circulation patterns occurring in middle and high latitudes.

(b) Tidal oscillations with periods which are integral fractions of the solar and lunar day and which are global in scale.

(c) Internal gravity waves with periods of minutes or hours and with horizontal wavelengths of a few thousand kilometres.

(d) Infrasonic waves with periods of a few minutes or less.

During summer the stratospheric circulation is symmetrical and centred over the pole. High latitude temperature profiles are smooth up to 100 km and show little deviation from mean values. However at high latitude during winter the deviation from the mean is much greater and the mesospheric temperature profiles are highly structured. These disturbances are thought to be associated with planetary and gravity waves and will be examined with reference to recent rocket grenade experiments carried out from ESRANGE in northern Sweden.

2. Stratospheric warmings and planetary waves

Increases in temperature of 60°C or more occurring over a few days in the winter stratosphere are known as stratospheric warmings. Major warmings may occur during mid-winter when the polar vortex splits into two southward moving parts; warm air replaces cold air over the pole and the latitudinal temperature gradient is reversed. The westerly circulation collapses to be replaced by weak easterly winds, but within a few weeks the wintertime circulation is restored. In the initial stages of a warming a system of warm air moves across the pressure contours towards higher latitudes. As the pressure gradient increases and the warming builds up, winds may increase to as high as 231 m s^{-1}.

These departures from a symmetrical circulation pattern can be described in terms of wave components. Significant correlations have been noted between tropospheric and stratospheric flow by analysis of these wave components. Planetary scale disturbances have been traced upwards to 70 km by analysis of rocket data and have appeared at about 100 km from radar observations of meteor trails.

3. Gravity waves

Temperature profiles in the high latitude winter mesosphere exhibit wave-like features which are commonly connected with changes of temperature of 30 to 40 °K per hour and with large wind shears. The vertical wavelength (10 to 15 km) and period (about 2 hours) of the observed temperature fluctuations are consistent with the gravity-wave theory. Possible sources for these waves may include tropospheric thunderstorms and frontal systems, instabilities in the jet stream, the effects of winds blowing over mountains and volcanic and nuclear explosions. Recent studies show that the stratospheric circulation may also be important both for preventing gravity wave propagation upwards into the mesosphere and as a generator of gravity waves.

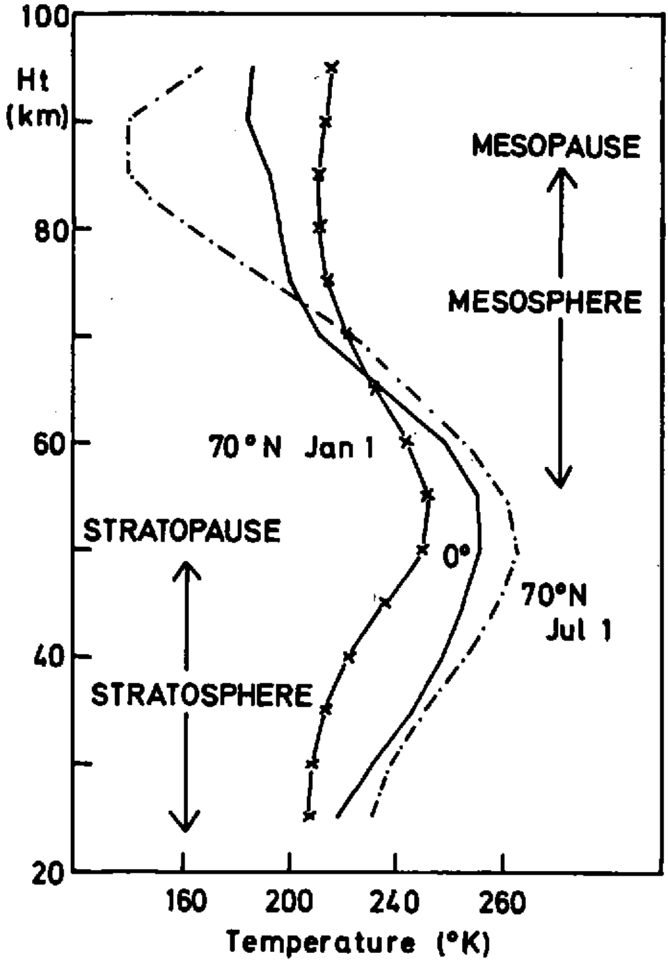

Fig. 1 Mean temperature profiles at 70°N for summer and winter

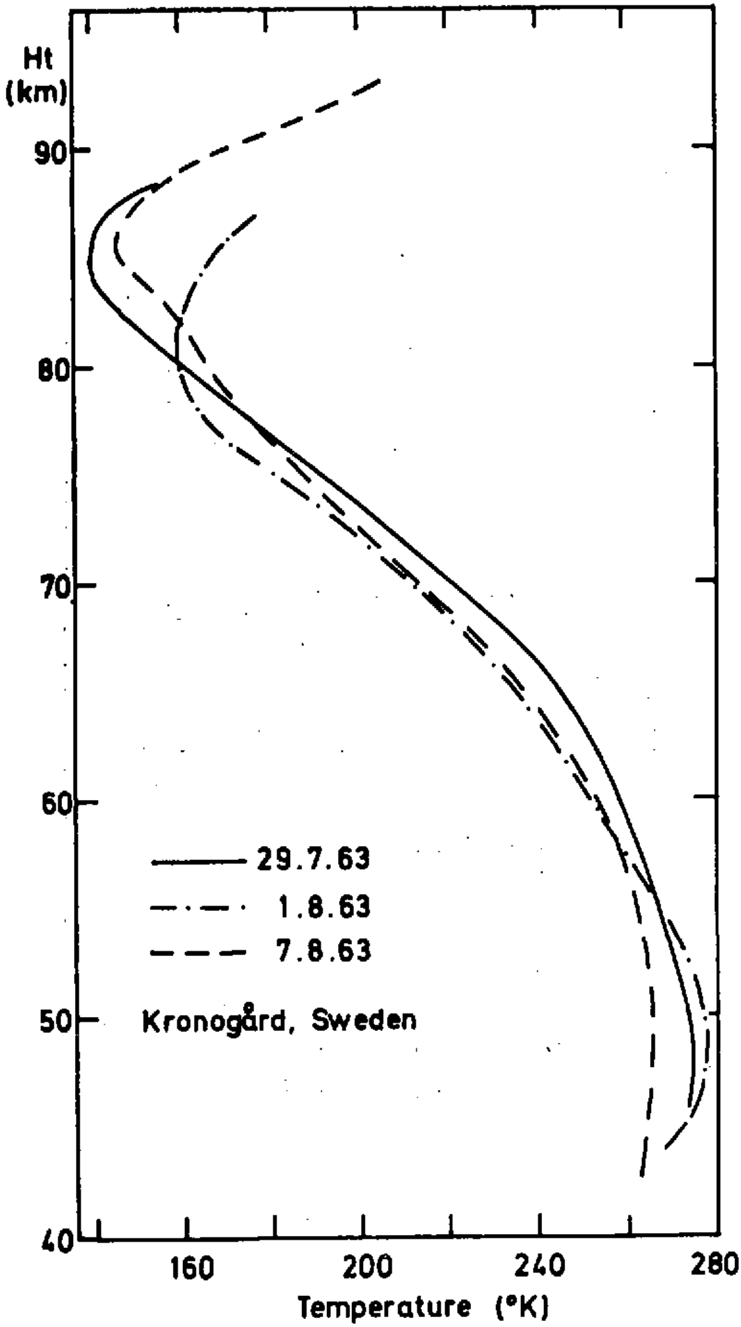

Fig. 2 Summertime temperature profiles from N. Sweden