WAVELET ANALYSIS OF TEMPERATURE PROFILES OBTAINED BY LIDAR OVER A TROPICAL SITE: RÉUNION ISLAND (20.8°S, 55.5°E)

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Abstract

The Rayleigh LIDAR at Réunion Island (20.8°S, 55.5°E) was used to study the temperature and gravity wave structure using wavelet analysis. The mean temperature rises from ~210 K at ~30 km to a peak of ~270 K at about 45 km before declining to ~220 K at ~68 km. Superimposed on the mean structure are upward propagating gravity waves which vary with both height and time. The strongest waves have wavelengths of 5, 10 and 15 km with the first two dominating in the heights above 45 km while the 15 km waves cover the whole height range of ~30-67 km. The estimated phase velocity of the upward propagating waves is ~-2 km/h and periods of ~6-7 h for the 10-20 km wavelength band.

Introduction

Atmospheric gravity waves are a common feature of the stratosphere/mesosphere thermodynamic structure. These waves are generated in the lower atmosphere and propagate upward with their amplitudes increasing with height as the atmospheric density decreases. Eventually, these waves break in the mesosphere/lower thermosphere and by so doing contribute to wave drag in this region.

A LIDAR, with its good time and height resolution, is suitable for studying gravity waves. In this paper we present results obtained using a Rayleigh LIDAR at Réunion Island (20.8°S, 55.5°E). The details of this instrument can be found in Bencherif (1996). The data presented here is for 29 May 1994 and consist of 305 temperature profiles with a time resolution of 100 s and a height resolution of 0.3 km. To decrease statistical uncertainties, each profile was obtained by averaging 18 temperature profiles in a 30 minute (i.e. 1800 s) data window. Of particular interest to us is the behaviour of the temperature above Réunion Island as influenced by gravity waves and the structure of these waves.

Results

In Figure 1 we have plotted the temperature [Figure 1(a)] and the temperature fluctuations [Figure 1(b)] obtained by subtracting the mean temperature profile from the individual profiles. The following features can be observed. The temperature starts off with a relatively low value of about 210 K rising to a peak of about 270 K at a height of about 45 km. Thereafter, there is a general decrease in temperature up to a height of over 65 km. Superimposed on this mean structure are temperature fluctuations that are due to gravity waves. It can be seen, especially in Figure 1(b), that the amplitude of these fluctuations increases with height

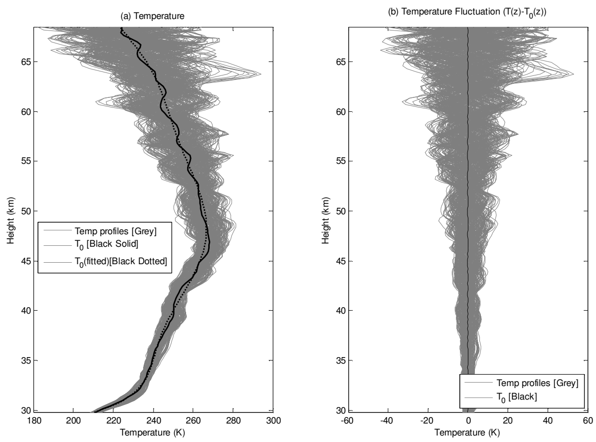

Figure 1. (a) The temperature profiles (grey) together with the mean profile (solid) and the polynomial fit (dotted). (b) Temperature fluctuations.

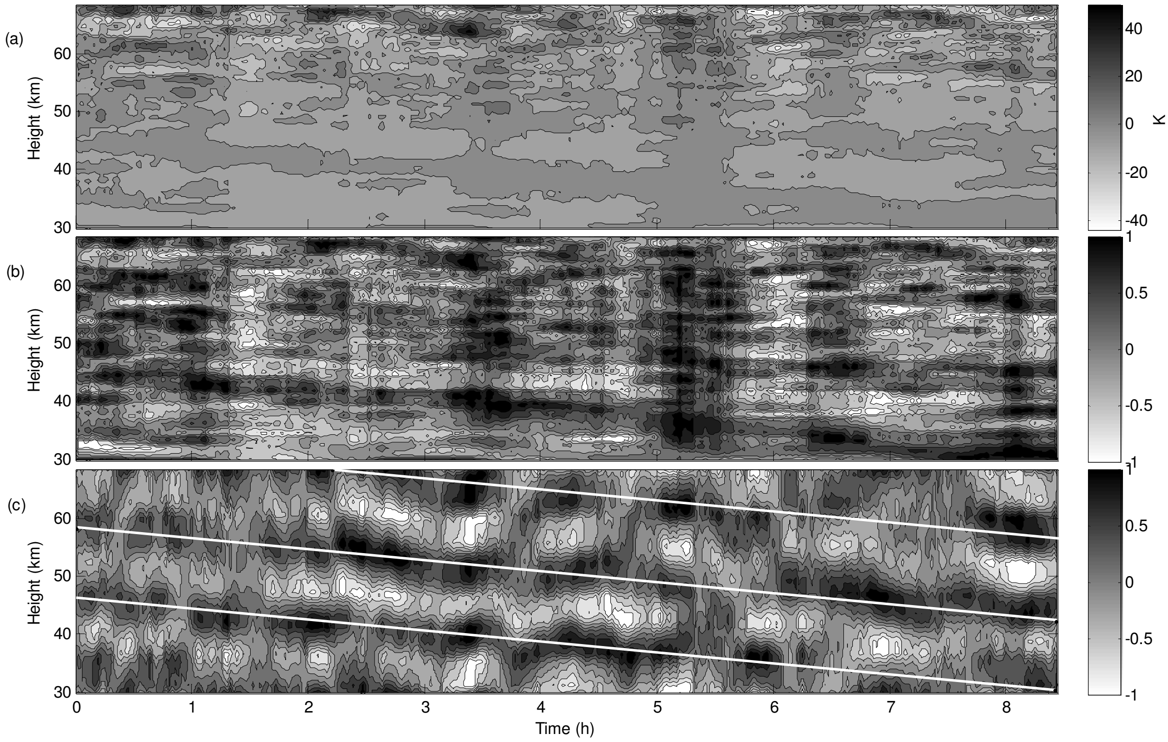

Figure 2. (a) The temperature fluctuations. (b) The normalised temperature fluctuation. (c) The normalised temperature fluctuations filtered with a 10-30 km wavelength bandpass. The time is with respect to the starting time of the data and not of the day.

and this is attributed to the decrease in the atmospheric density with altitude. To investigate the time evolution of the structure of temperature fluctuations we plotted the 2-D contour plots in Figure 2. Figure 2(a) shows the variation of temperature fluctuations with both height and time. Even in this unfiltered data we can see features that are indicative of the presence of gravity waves. However, the vertical extent of this is masked by the increase in amplitude with height. To compensate for this increase in amplitude and hence elucidate the gravity wave structure, we have normalized the temperature fluctuations using the maximum absolute temperature fluctuation for each height as shown in Figure 2(b). In this figure, the presence of gravity waves is clearer but the picture is still complicated by the fact that there is a superposition of gravity waves of different wavelengths.

Preliminary work has shown that the strongest gravity waves have vertical wavelengths of 10-25 km. This being the case, in Figure 2(c) we show normalised temperature fluctuations that have been filtered to eliminate all waves with vertical wavelengths outside a 10-30 km wavelength range. In this particular figure we can clearly see gravity wave features as indicated by the height stratified temperature enhancements. The slopes of the strata, as indicated by the white solid lines, are negative indicating upward propagating waves. The estimated vertical phase velocity from Figure 2(c) is ~ -2 km/h which is larger than the value of -0.8 km/h found by Alpers et al. (2004) at an altitude of 50 km. However, our value compares well with the phase velocity of -1.7 km/h they found at 90 km. The estimated vertical wavelength from Figure 2(c) is ~15 km and wave periods are ~6-7 h. During the time interval 6-7.5 h, the wave structure seems to be partially disturbed especially at higher altitudes. This could be due to the waves breaking at slightly lower altitude than during other times or, alternatively, it symbolises the superposition of waves with different vertical wavelengths during this time.

A more accurate investigation of the vertical wavelength is obtained by partitioning the data into 15 sets each consisting of 20 profiles as shown in Figure 3. The mean profile of each data set, which is shown by the solid black line on the figure, is thereafter spectrally

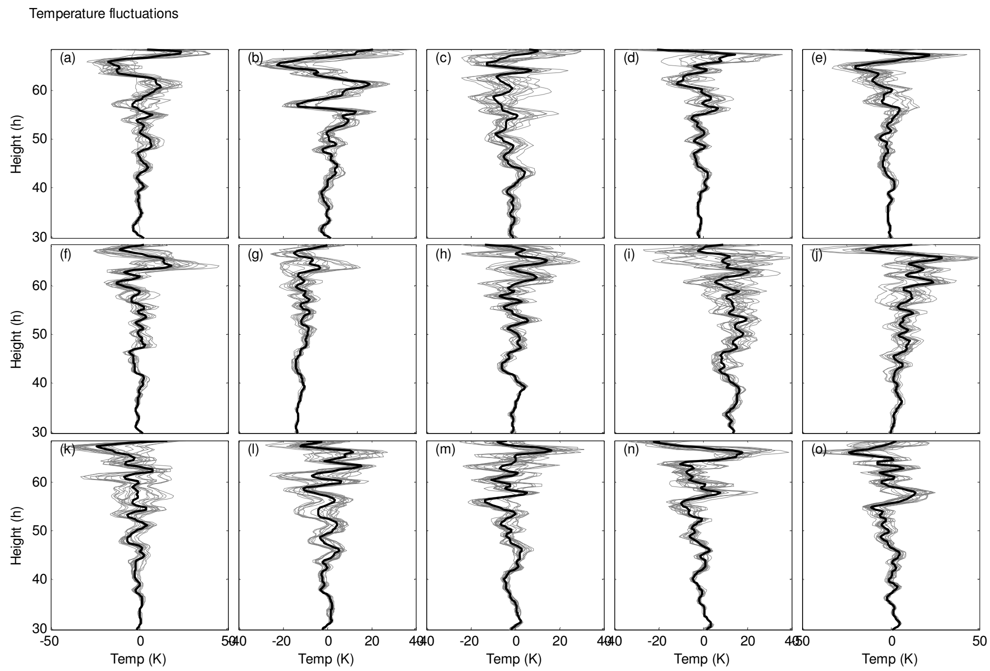

Figure 3. Sets of unfiltered temperature fluctuations (grey) together with the mean profile (solid black line) for a corresponding set of 20 profiles.

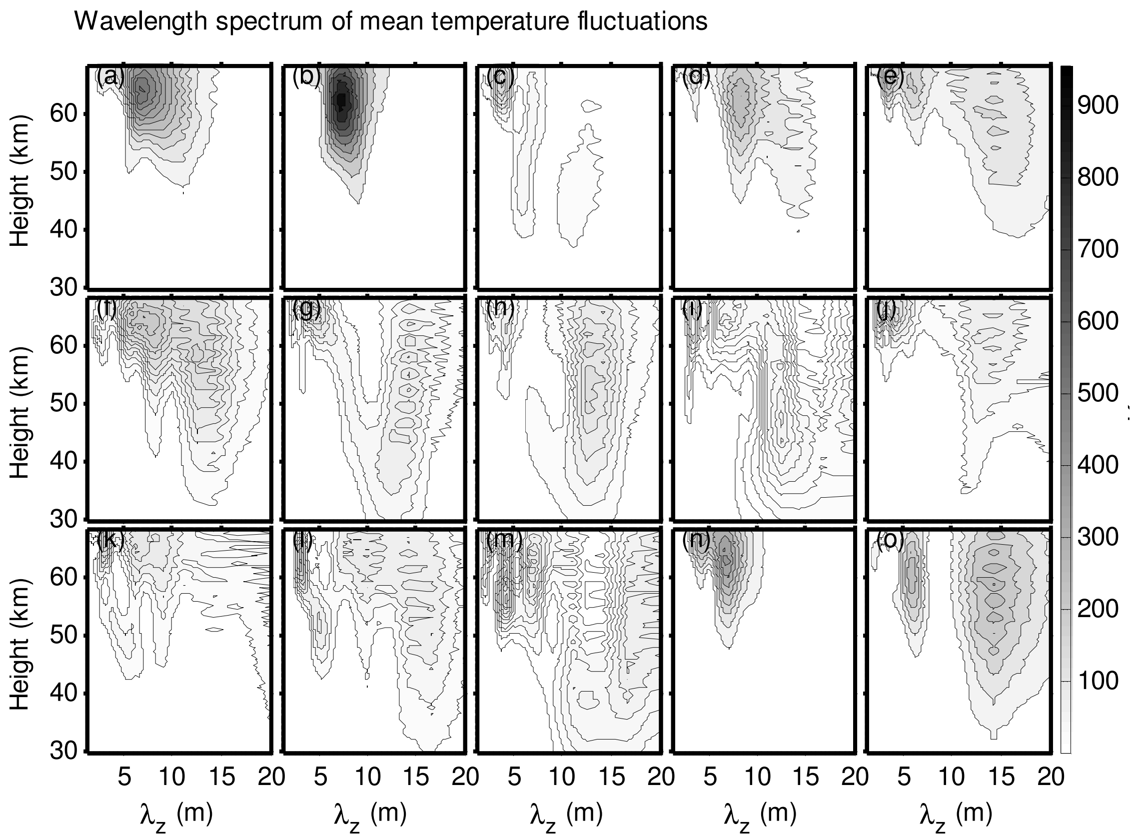

Figure 4. Wavelet wavelength spectrum for the corresponding mean profiles computed in Figure 3 above.

analyzed using wavelet analysis. Wavelets are most suited for studying non-stationary data as we are having here. The superior height-wavelength handling capabilities of wavelets make it possible to investigate the variation of the spectral content of the superimposed waves with height. This is particularly important because gravity waves undergo changes and various processes as they propagate upwards including reflections, dissipation and selective filtering due to changes in the background state. The wavelength spectra of the respective mean profiles are shown in Figure 4. Generally, we see that the wavelength spectra vary both with height and time. The dominant waves have wavelengths of <25 km with strong peaks at wavelengths of about 5, 10 and 15 km. These are consistent with the work of Alpers et al. (2004) who observed dominant wavelengths of 12-15 km. The wavelengths of 5-10 km are more dominant in altitudes that are higher than 45 km while the wavelengths of ~15 km tend to cover the whole height range of ~30-67 km. Higher wavelengths (>25 km) tend to be more intermittent.

Conclusion

Our results show a mean temperature that rises from ~210 K at ~30 km to a peak of ~270 K at about 49 km followed by a decline to ~220 K at ~ 76 km. Temperature fluctuations that are due to gravity waves are superimposed on the mean temperature and their amplitudes increase with height as the atmospheric density decreases. The observed gravity waves propagate upwards and their structures change with both height and time. The strongest waves have wavelengths of 5, 10 and 15 km with the first two dominating in the heights above 45 km while the 15 km waves cover the whole height range of ~30-67 km. For the 10-30 km wavelength band the estimated phase velocity is about -2 km/h and wave periods are ~6-7 h.

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