Investigation of lidar observed gravity wave characteristics over Reunion Island (20.8°S, 55.5°E) from temperature profiles obtained by LiDAR observations from 1994 to 2007

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Abstract

Climatology of the gravity wave characteristics are studied using temperature profiles obtained from Rayleigh lidar located at Reunion Island (20.8 ° S, 55 ° E) over a period of 14 years (Mar. 1994 – Dec. 2007). Gravity wave (GW) analysis is carried out in a height range of 30 – 65 km. The present study documents the GW characteristics in terms of time (frequency) and height (wave number) and GW associated Potential Energy and their seasonal dependences. The frequency and wave number spectra are obtained for about 164 days where timely continuous data sets of about 4½ h are found. Generally, the temporal evolution of temperature profile illustrates the downward phase propagation indicating that the energy is propagating upward. The wave activity is clearly visible with the wave periods ranging from 260 min to 21 min. The dominant components have vertical wavelengths in the range of about ~4 km to 35 km. The potential energy for height range 30-65 km are calculated and analyzed. The potential energy increases with height and the calculated average potential energy value for upper stratosphere (35-50 km) is ~21 J/kg and for lower mesosphere (50-65 km) is ~49 J/kg. The seasonal mean of potential energy is maximum during summer than during other seasons in the upper stratosphere and lower mesosphere.

Main objective and Data Bases:

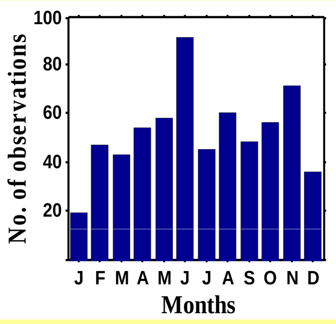

Fig. 1: Histogram showing the details of observational days during 1994-February 2008

➢The paper aims to study GW characteristics over a subtropical site.

➢Histogram represents the total number of observational days where as we have used only 164 days which has 4½ h data sets.

Mean Temperature profile with Standard deviation

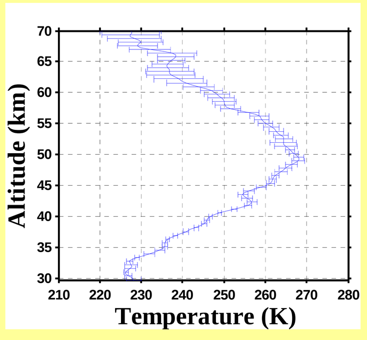

Fig. 2: Mean Temperature profile for 2 hrs obtained by Rayleigh Lidar on May 01 2007.

Methodology

The recorded lidar raw data is in the form of photon count profiles with a height resolution of 300 m and time resolution of 122 s. . We are limiting the height coverage to 65 km due to the low signal-to-noise ratio at higher heights for wave studies. The data frames used for the spectral analysis are of ~4½ h duration and 35.4 km in height range. The temperature perturbations from which the vertical wave number spectra are derived, are extracted by subtracting from the height profile of the temperature a third order polynomial fit applied to the entire height range. In the case of frequency spectra, the temperature perturbations are obtained by removing a linear trend and applying a windowing technique to remove the long-term trend from the time series of the temperature data for a given altitude level. The adaptive filter method is used to remove the noise in the power spectral density by employing hanning window with 95% of confidence level. Therefore, the spectral results are better in accuracy and free from noise.

The potential energy per unit mass is calculated by

$$E_p = 1/2 \, (g/N)^2 \, (T'/T_o)^2$$

Where, N is the Brunt Vaisala Frequency, $N^2 = g/T_p \, [dT_p/dz + \Gamma]$, g is the acceleration due to gravity, "Γ" is the adiabatic lapse rate (=-9.8 K/km), Tp is the temperature value taken from the 3rd order polynomial fit applied to the mean temperature profile, To and T' are the mean temperature and temperature perturbations, respectively.

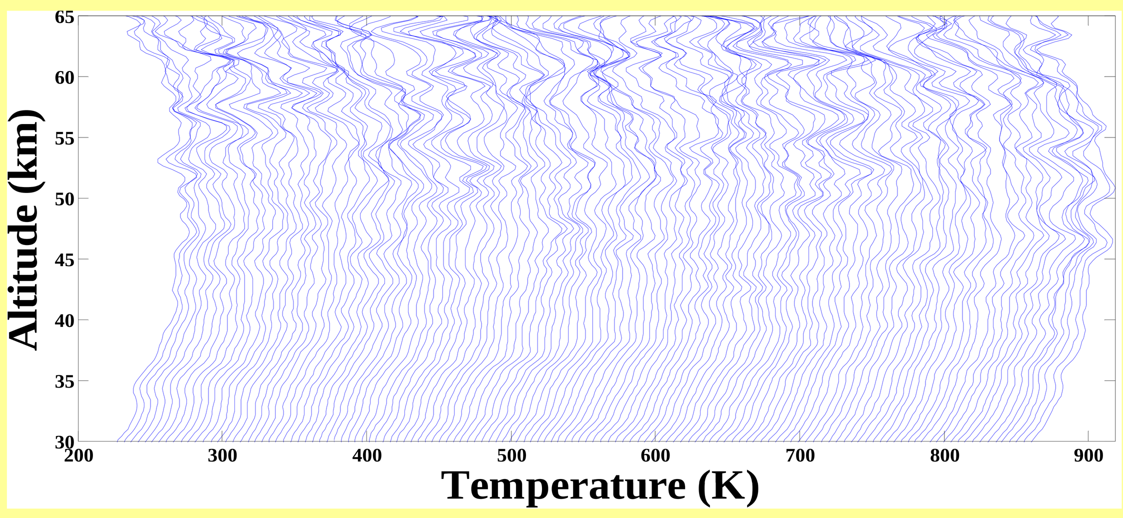

Fig. 3: A Time sequence of 128 profiles observed on the night of 22 July 2003. The successive profiles are offset by 5 K.

✓The profile clearly reveal wave perturbations in temperature.

✓The wave perturbations are characterized by downward phase progression, as expected for upward propagating gravity waves.

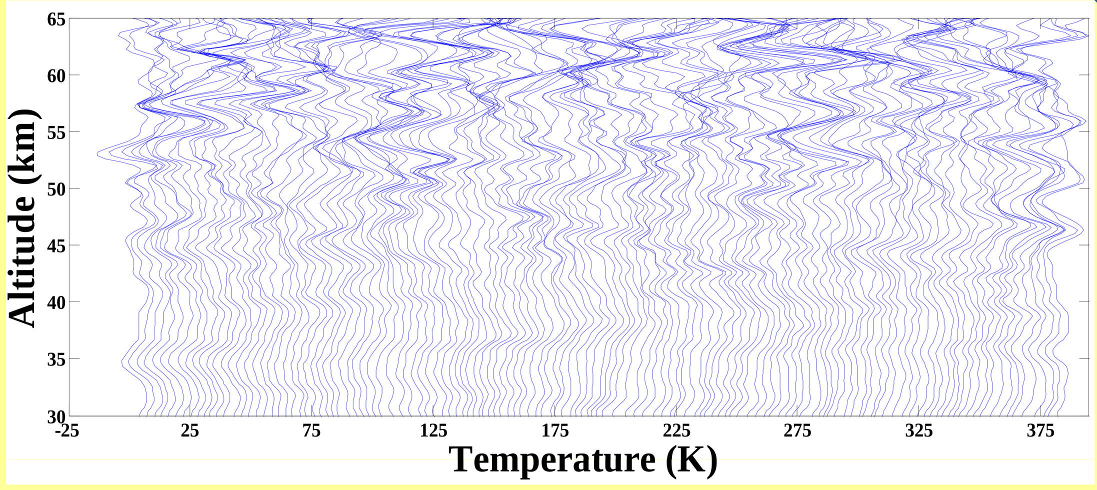

Fig. 4: Time sequence of 128 profiles of temperature fluctuations obtained by subtracting the third order polynomial fit from the observed temperature profiles for the night of 22 July 2003. The successive profiles are offset by 3 K.

➢The wave amplitudes associated with the fluctuations are found to increase with height.

➢The variance of the fluctuations ($(\Delta T')^2$) representing the intensity of the wave activity averaged over the height range 50-60 km, is found 35 K^2 for 22 July 2003.

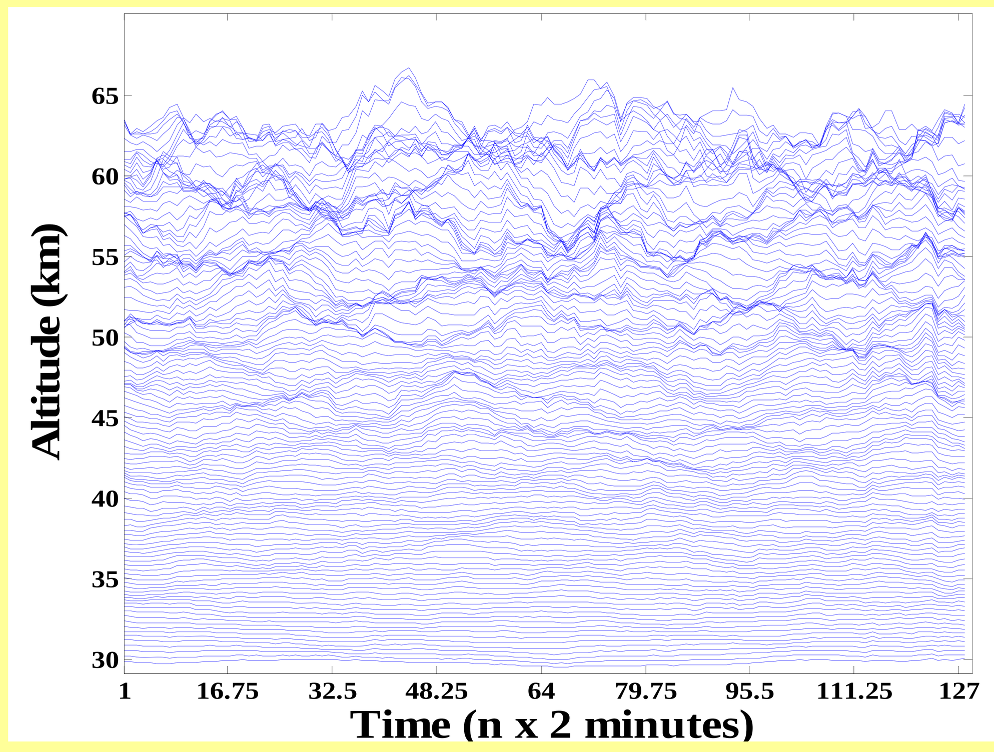

Fig. 5: Height-time variations of temperature fluctuations T' obtained by removing the linear temporal trend at each height for the night of 22 July 2003. The successive profiles are offset by 3 K.

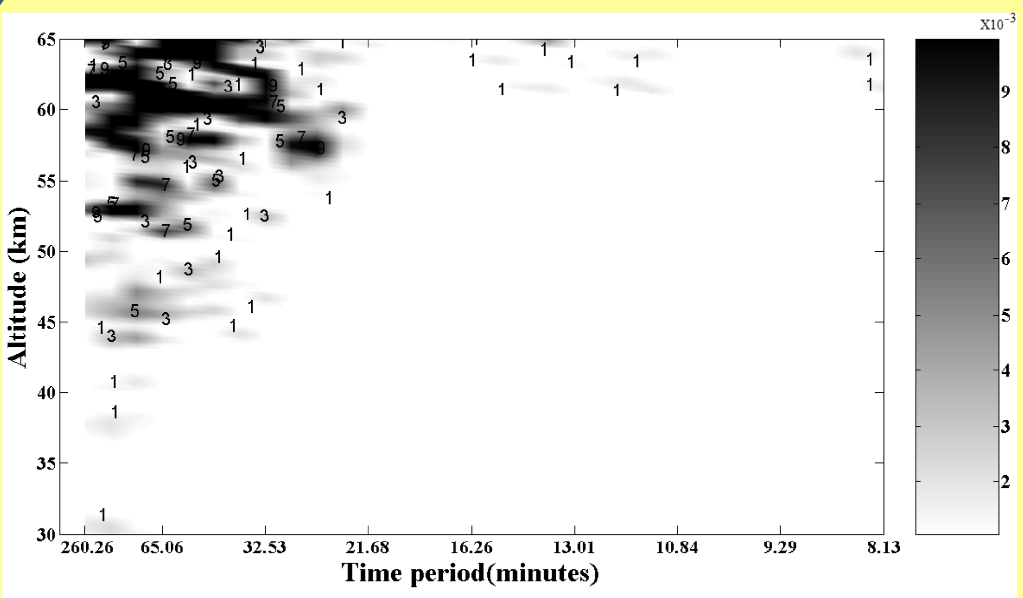

Fig. 6: Frequency-power spectra of relative temperature fluctuation (as shown in figure 5) as a function of height for 22 July 2003.

➢The wave activity is clearly visible with the wave periods ranging 260 min to 21 min.

➢The dominant wave periods observed in the lower mesosphere (50 – 60 km) range from 21 to 260 min and 40 to 260 min in the upper stratosphere(35 – 50 km).

➢The stratosphere shows considerably lesser wave activity compare to the mesosphere.

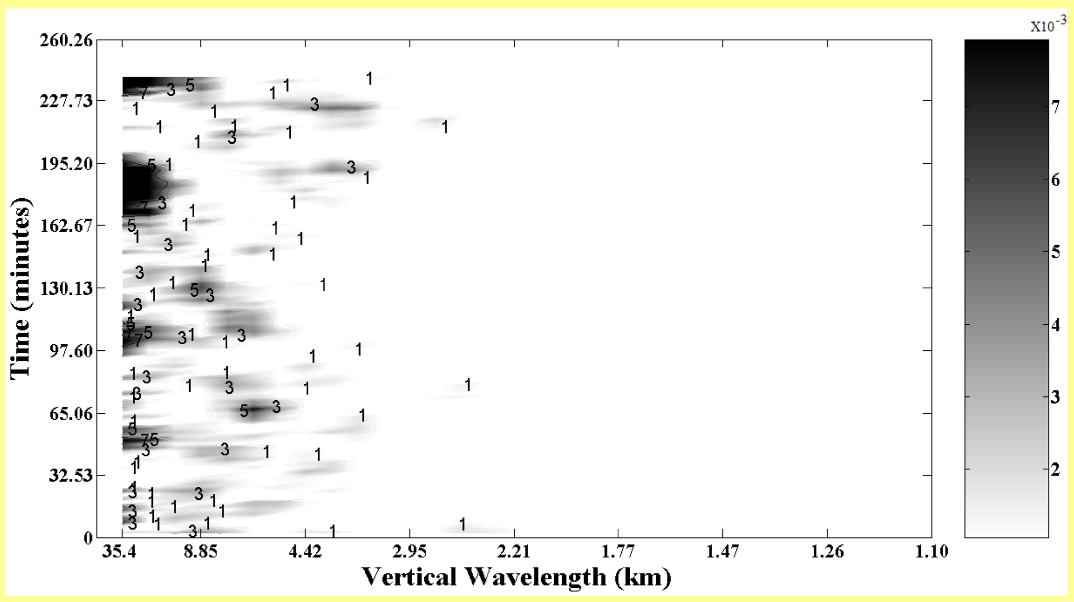

Fig.7: Vertical wave number-power spectra for the 128 profiles of relative temperature fluctuation (as shown in figure 4) for 22 July 2003.

✓The dominant components have vertical wave lengths in the range of about ~4 – 35 km.

✓The dominant wave activity was found at vertical wave lengths between ~4 to 35 km in the lower mesosphere and 6 to 35 km in the upper stratosphere.

Monthly Averaged Potential energy

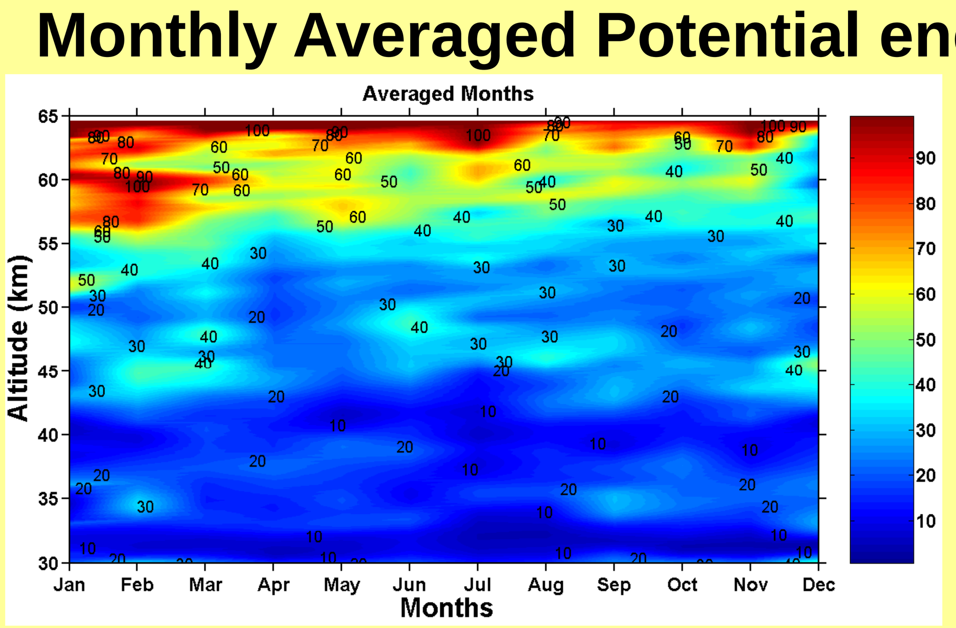

Fig. 8: Monthly averaged potential energy obtained from of 14 years (Mar.1994 – Dec. 2007) of data sets

➢The monthly mean values of potential energy in the upper stratosphere (30-50 km) shows a maximum value of 23 J/kg in the month of February and minimum value of 14 J/kg in the month of July while the monthly mean values of potential energy in the lower mesosphere (50 -65 km) shows a maximum of 67 J/kg in January and minimum of 32 J/kg in December.

Seasonal variation of Potential energy

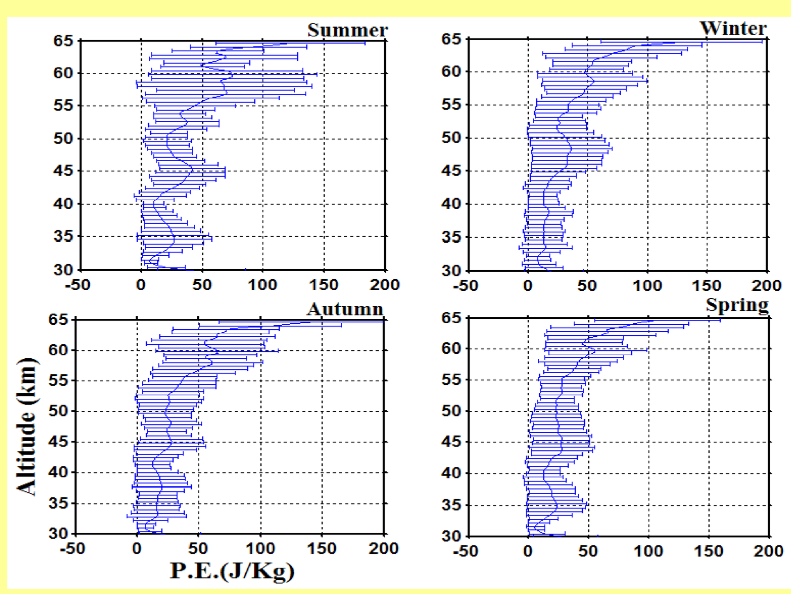

Fig. 9: Height profiles of seasonal mean potential energy per unit mass associated with GW perturbations for the four different seasons

♣The average potential energy value is found in the upper stratosphere (35-50 km) is ~21 J/kg and in the lower mesosphere (50-65 km) is 49 J/kg.

♣The seasonal mean of potential energy in the upper stratosphere (35-50 km) found a values of 24 J/kg in Summer (Dec, Jan, Feb), 22 J/kg in winter (Jun, Jul, Aug), 21 J/kg in Autumn (Mar, Apr, May), 20.5 J/kg in Spring (Sep, Oct, Nov) where as the seasonal mean of potential energy in the lower mesosphere (50-65 km) observed a values of 55 J/kg in summer, 48 J/kg in winter, 51 J/kg in Autumn and 43 J/kg in Spring.

♣The observed Potential energy magnitude is found to be higher in comparison to the mid- and high-latitude results (Wilson et al., 1991a, b; beatty et al.,1992; Gardner et al., 1989).

Summary and Conclusion

1. The high resolution Rayleigh lidar measurements made over March 1994 to December 2007 at Reunion Island are used to study the gravity wave characteristics in the Reunion Island.
2. The lidar observations revealed significant gravity wave activity over the entire observed height range of 30 – 65 km.
3. The obtained wave number spectra and frequency spectra illustrate the wave activity with the vertical wavelength of the order of 4-35 km and the time period ranges from 21 min to 4½ h.
4. The mean potential energy shows increasing gravity wave activity with height.
5. The seasonal mean of potential energy is maximum during summer than during other seasons in the upper stratosphere and lower mesosphere.

Acknowledgements

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