Lidar observations of middle atmospheric gravity wave activity over a southern sub-tropical station, Reunion Island (21ºS ; 55 ºE)

V. SIVAKUMAR*, D. Faduilhe and H. Bencherif

Laboratoire de l'Atmosphère et des Cyclones, LACy, CNRS–UMR 8105,
Université de La Réunion, La Reunion, FRANCE
siva@univ-reunion.fr

***Also at National Laser Centre, Council for Scientific and Industrial Research (CSIR),**
Pretoria, South Africa.
SVenkataraman@csir.co.za

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Plan of presentation

- A brief introduction
- Aim and scope of the study
- Instrument used : LiDAR (System and Specifications)
- Data used and Method of analysis
- Results
  - Gravity Wave characteristics
  - (Time period, vertical wavelength and potential energy)
    - Over all mean characteristics
    - Summer and Winter
    - Relationship with QBO ?
- Summary

Brief Introduction

Hines.[1960] first proposed a theory for the upward propagating internal gravity waves - Universally accepted - foundation for middle atmosphere studies.

- Number of studies are carried out on gravity wave using different techniques in the middle atmosphere, such as : Characteristics of GW, generation of turbulence, wave saturations and its effects and etc.,
- **Major Source :** Convective instability in lower atmosphere.
  Tropical region is dominant.
- **Rayleigh lidar :** Effective technique in the height range 30 - 80 km.
  GW Studies are confined to mid- and high latitudes.
- **Mid- and high latitude results are :**

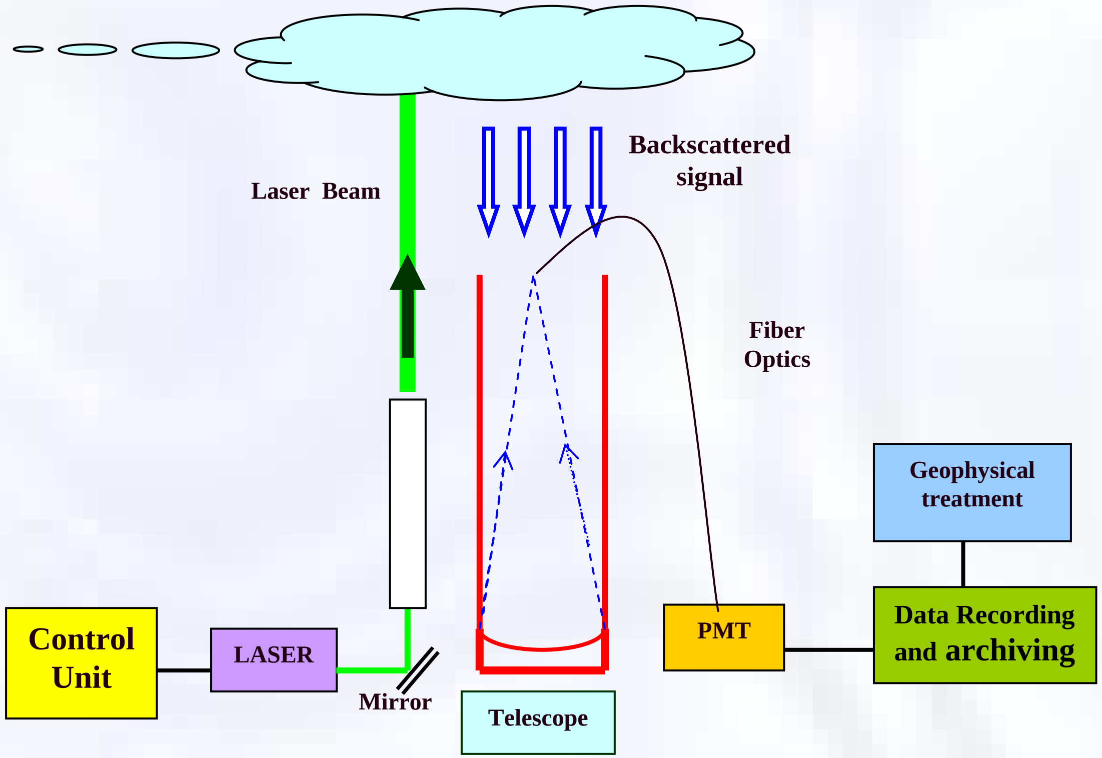
Gravity wave activity maximum during winter and minimum during summer. The dominant wave periods range from 2 to 8 hrs and vertical wavelengths from 2 to 10 km. They have noted wave saturation taking place around 60 - 70 km.

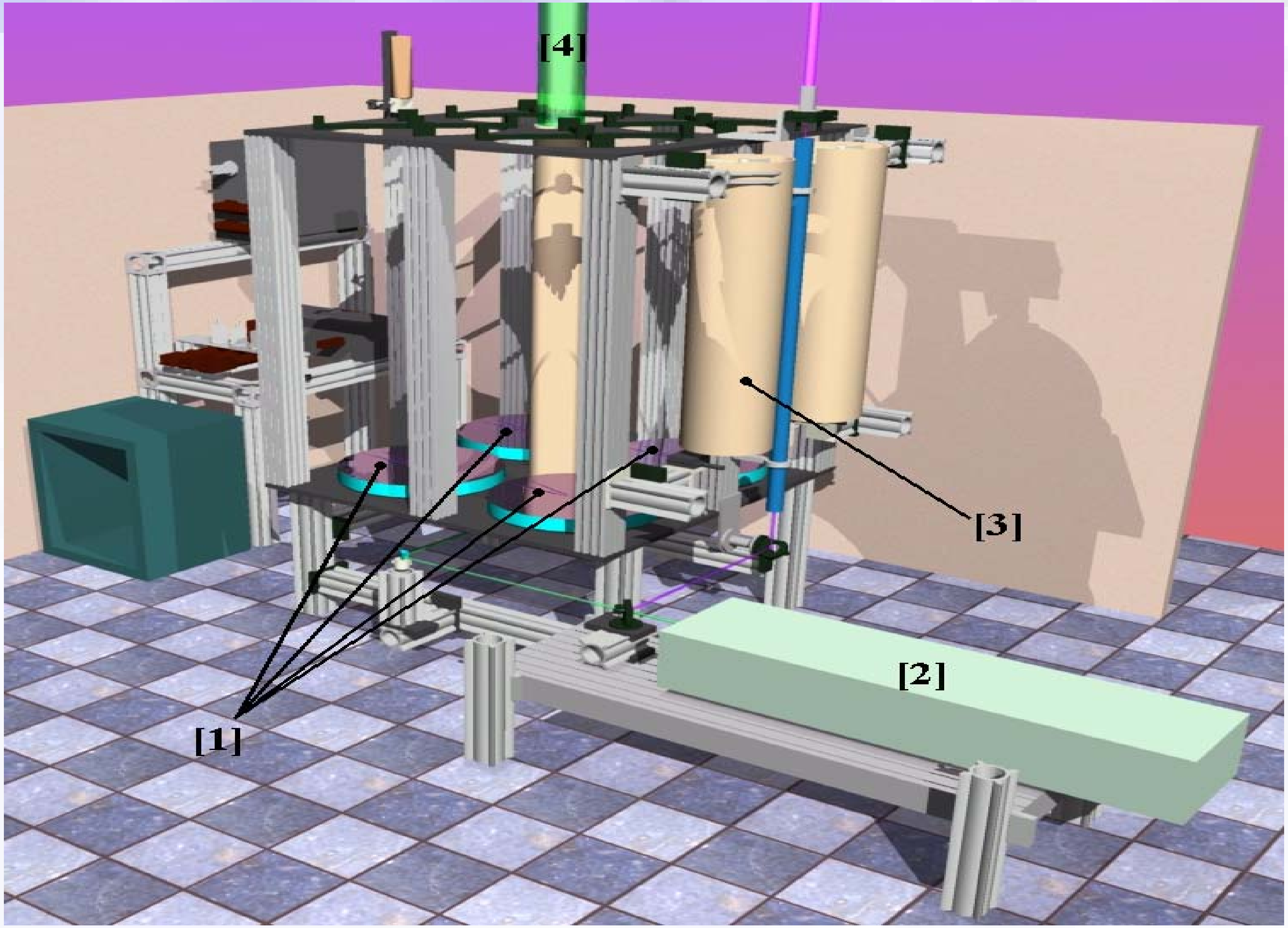
Aim and scope of the study

The prevailing convective activity over tropics and subtropical regions acts as an important source for the generation of GW. Reunion Island (21°S, 55°E) is located in sub-tropics where a large number of convective phenomena occur. Hence, the GW studies at Reunion Island may contribute to a better understanding of middle atmospheric on seasonal and long term scales.

We make use of ~11 years (1994-2004) of recorded high resolution Rayleigh lidar measurements for the present study. Temperature profiles are derived from raw photon count profiles and for the 30-90 km height range, with a vertical resolution of 300 m. The obtained temperature profiles are further subjected to extract and delineate the GW features. The present study documents the GW characteristics in terms of time (frequency) and height (wave-number), associated Potential Energy and their seasonal dependences.

LIDAR BLOCK DIAGRAM





Representation of lidar in Réunion : (1) Receiving Mirrors (2) Laser (3) Telescope for troposphere measurements (4) Laser beam

Lidar Specifications

Laser	Nd:Yag
Wavelength	1064/532
Energy	1 J at 532 nm
Beam Divergence	0.05 mrad
Pulse Width	10 ns (1064 nm)
	7-8 ns (532 nm)
Frequency	30 Hz
Telescope	53 cm (x4), 20 cm (x1)
Aperture	Channel-A (0.3 mrad)
	Channel-B (0.6 mrad)
Fiber optics	Channel-A (400 μm)
	Channel-B (600 μm)
Photomultiplier	Hamamatsu
Detection	Photon counting mode
Integration time	3600 laser shots

Data Used :

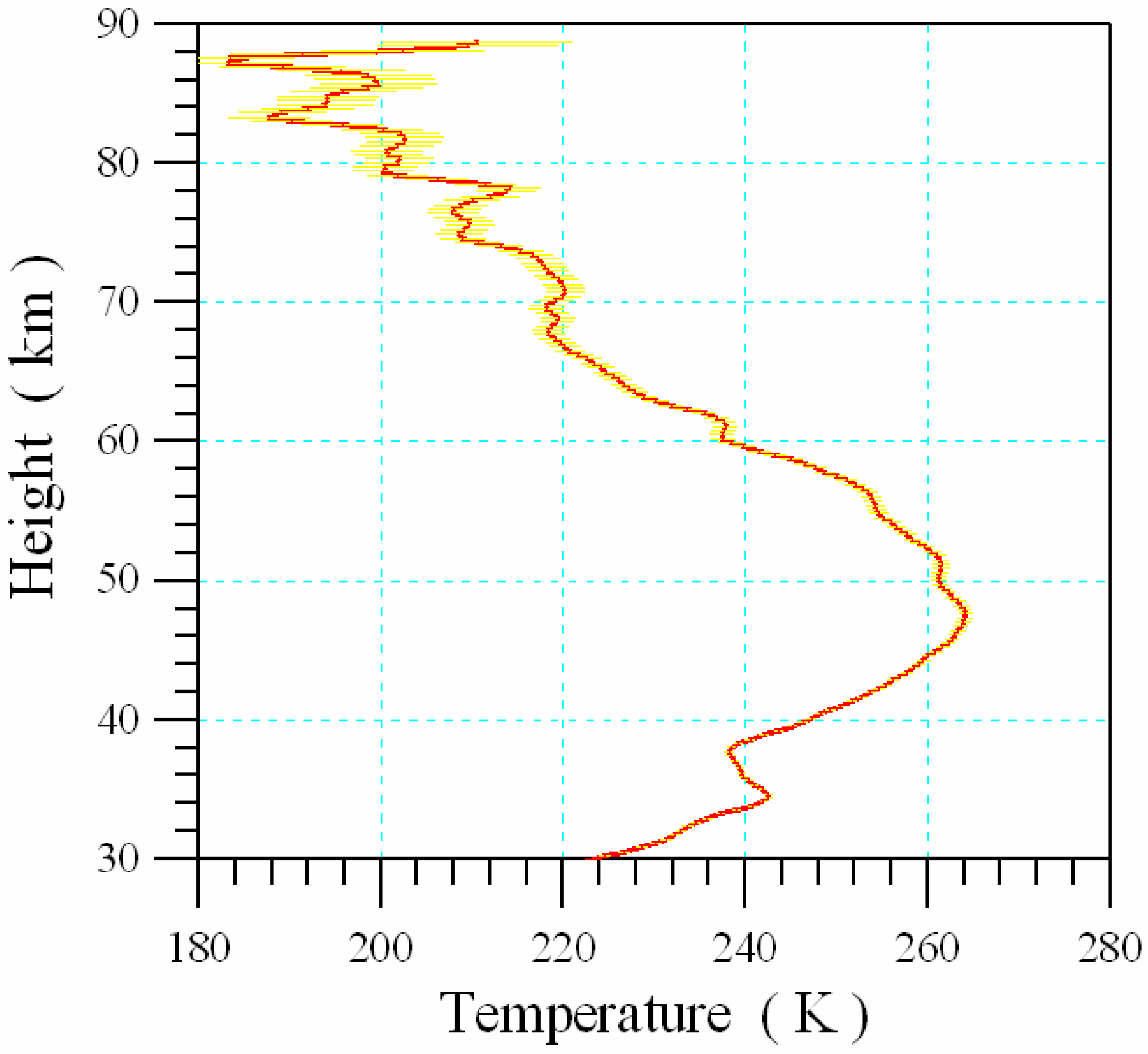
Rayleigh lidar temperature profile for a period from 1994 to 2004.

Height resolution	**: 300 m**
Time resolution	**: 2 min**
Observational period	**: 4 to 7 hrs (Night)**
Number of data used for GW study	**: 122**
	(minimum ~4 hrs of data)
Height Range	**: 30 – 65 km**

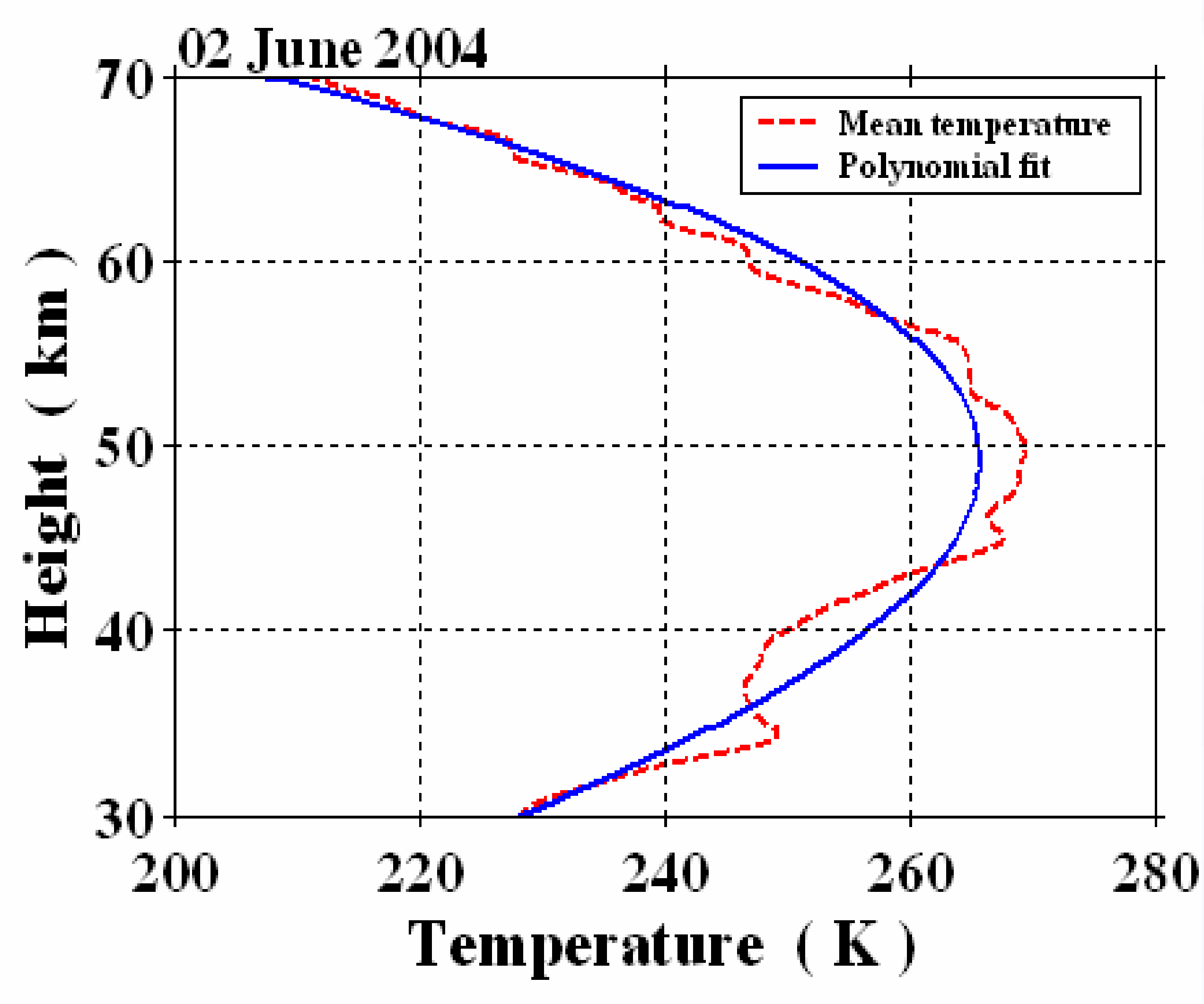
Seasonal characteristics are presented for Summer and Winter

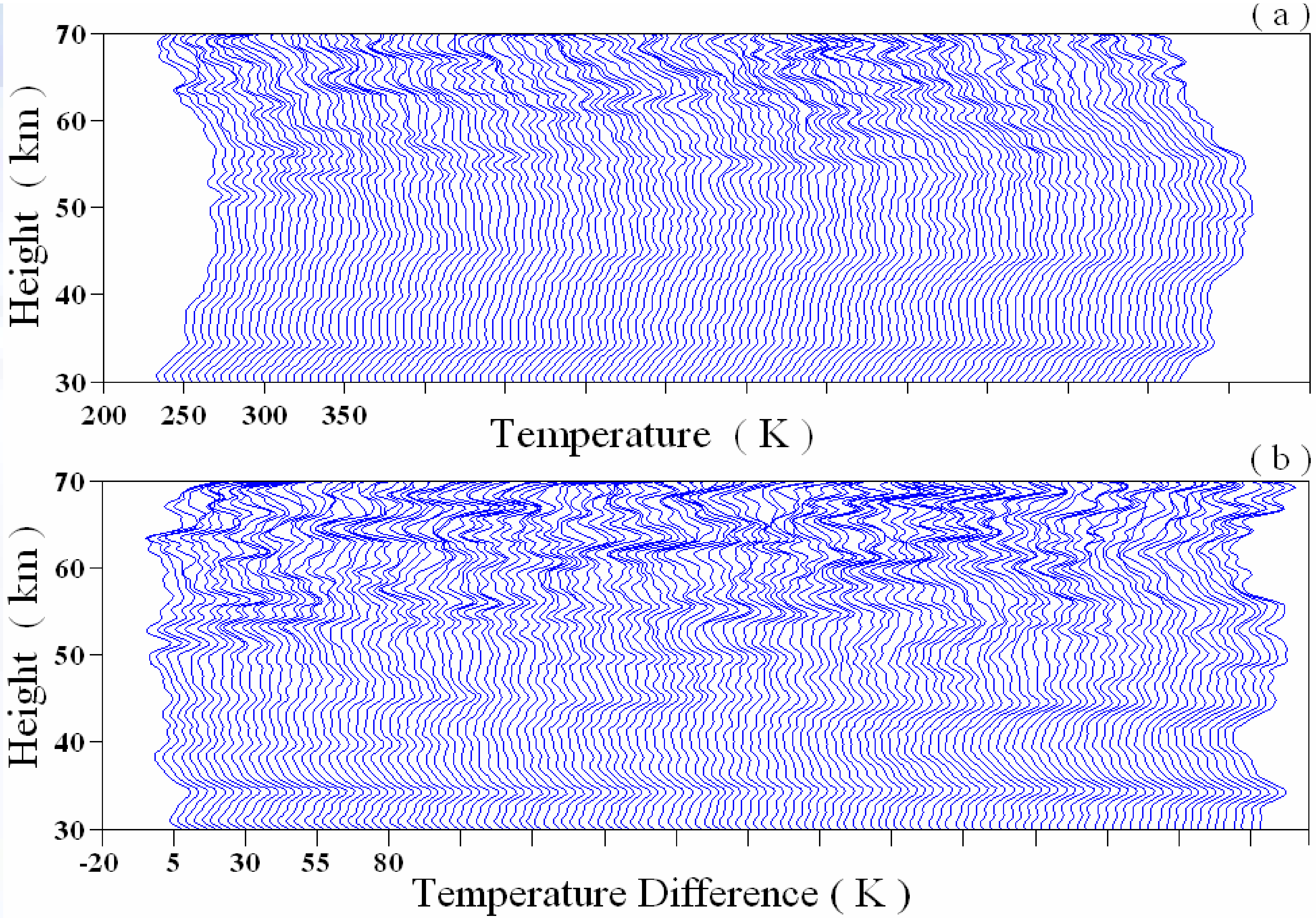
Summer	**: October to March**
Winter	**: April to September**

Temperature profile for a given day

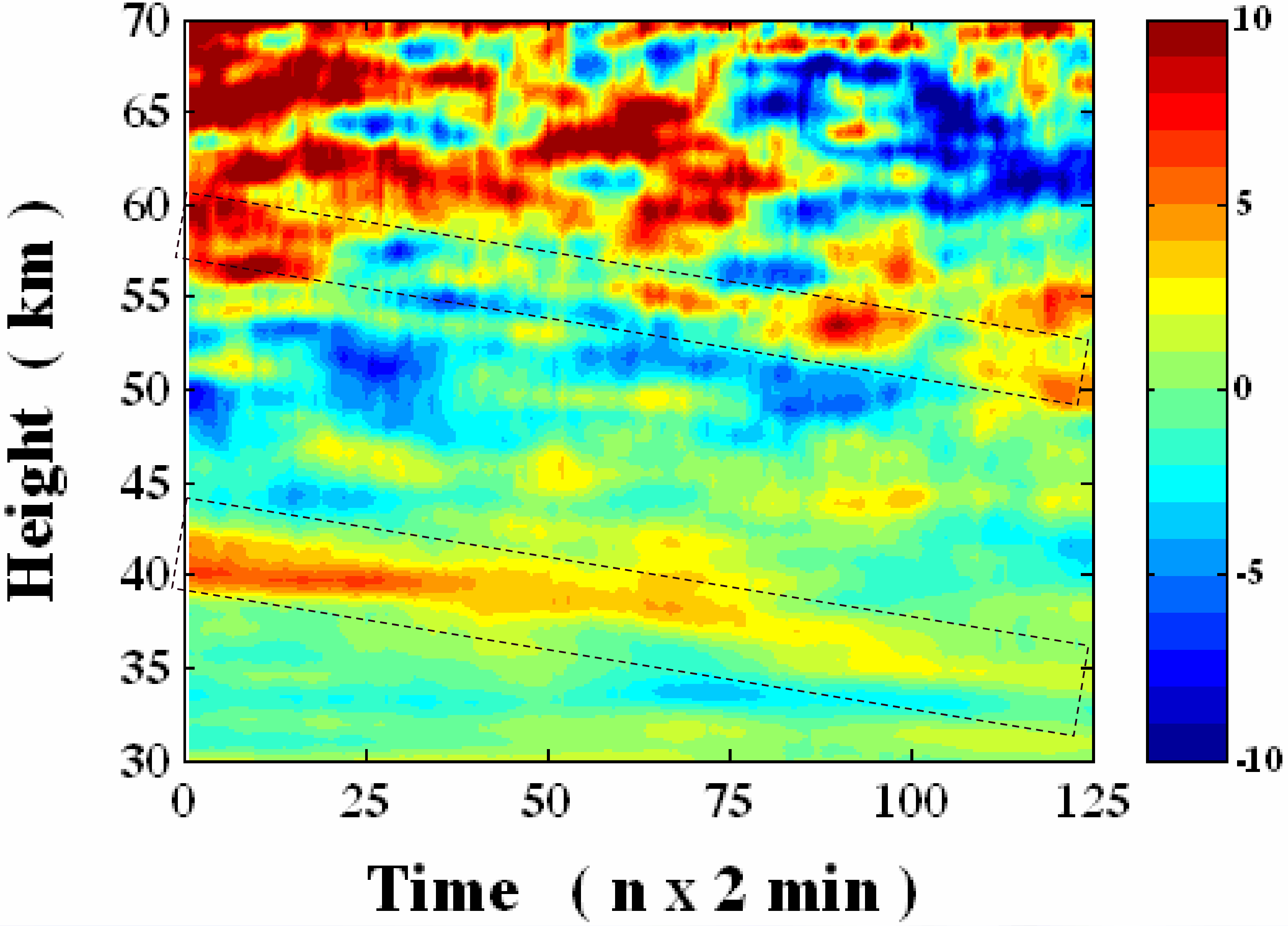


Method : Extraction of GW parameters

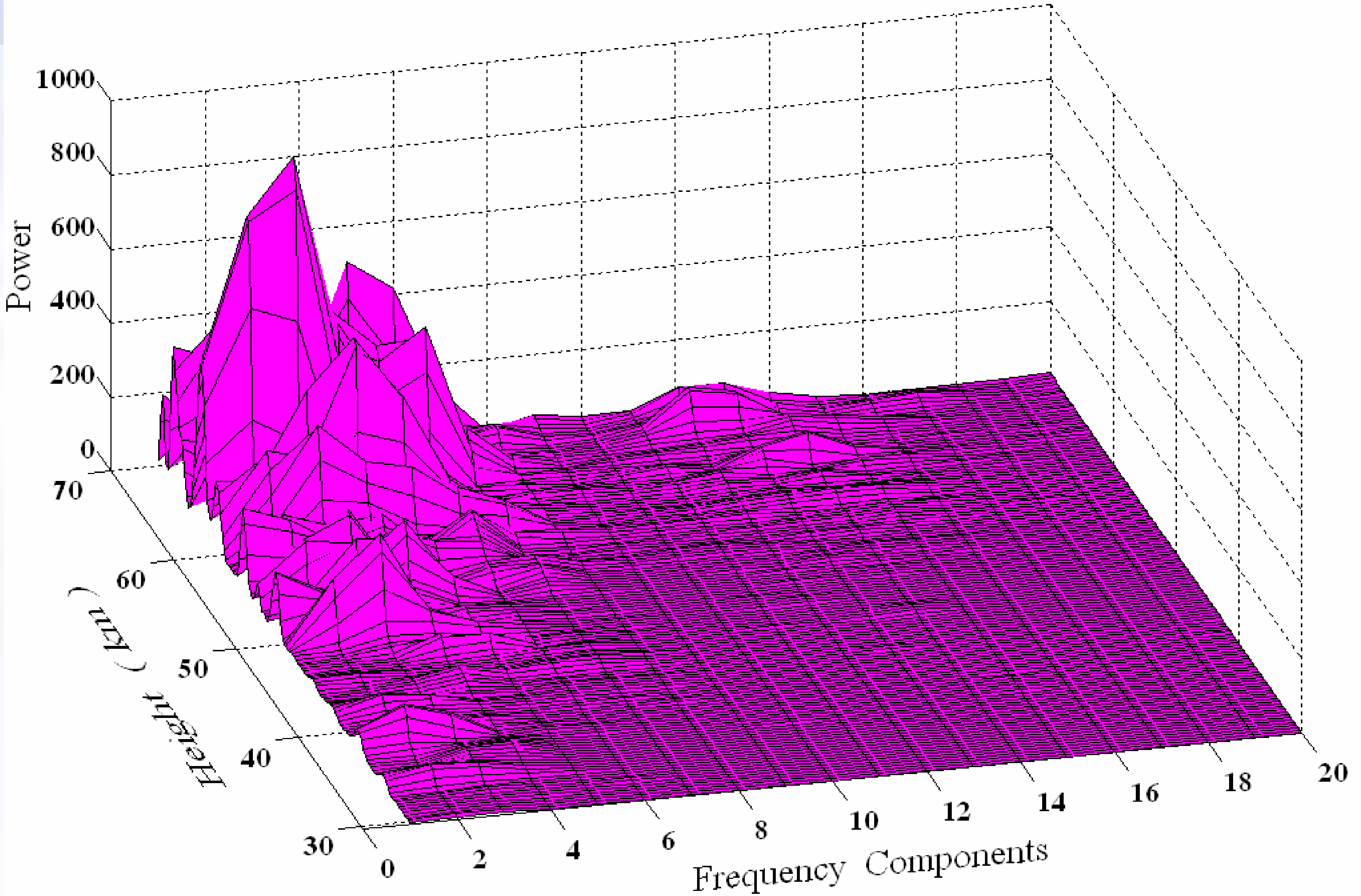




Temperature profiles are corresponds to 2 min and the profile are shifted by 5 K and 3 K for temperature difference profiles



Color map of height-time-temperature difference illustrating GW propagation



Frequency– Power spectra of temperature fluctuation as a function of height

Seasonal Characteristics :

Seasonal characteristics are presented for Summer and Winter

- **Summer : October to March**
- **Winter : April to September**

Height regions : Three different height regions are chosen, such as;

- **35-45 km (Upper Stratosphere - US)**
- **45-55 km (Stratopause Region - SR)**
- **55-65 km (Lower Mesosphere - LM)**

Parameters studied :

- **Dominant Frequency (Time period)**
- **Dominant Wavenumber (Vertical Wavelength)**
- **Potential Energy**

Dominant frequency components

Over all

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Height (km)	62.6 ± 3.5	42.3 ± 3.3	52.5 ± 2.1	63.1 ± 1.9
Time period (min)	134 ± 46	147 ± 57	128 ± 52	118 ± 37
Power (%)		12.9 to 27.9	12.6 to 51.4	94.0 to 98.9

Summer

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Height (km)	62.2 ± 4.6	41.9 ± 4.1	52.5 ± 2.5	63.1 ± 2.1
Time period (min)	138 ± 54	156 ± 58	136 ± 53	160 ± 39
Power (%)		17.4 to 36.5	14.0 to 58.0	89.4 to 97.9

Winter

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Height (km)	63.1 ± 1.8	42.7 ± 2.0	52.6 ± 1.7	63.1 ± 1.8
Time period (min)	107 ± 30	138 ± 54	120 ± 50	107 ± 30
Power (%)		8.2 to 15.0	14.6 to 38.2	100

Dominant wave-number components

Over all

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Wave-length (km)	7.8 to 21.0	1.3 to 8.5	5.0 to 8.3	0.6 to 4.2
Time period (min)	38 to 110	34 to 107	30 to 95	26 to 90

Summer

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Wave-length (km)	7.4 to 19.6	1.3 to 8.1	4.9 to 8.2	0.6 to 5.0
Time period (min)	46 to 129	45 to 132	30 to 95	19 to 71

Winter

Parameter	30-65 km	35-45 km	45-55 km	55-65 km
Wave-length (km)	8.4 to 22.4	1.4 to 9.0	5.1 to 8.4	0.6 to 3.2
Time period (min)	30 to 88	22 to 76	30 to 95	33 to 107

- **The overall dominant time period of GW is found to be longer for US than SR and LM (shorter).**
- **The height of occurrence is found to have much variability for US than SR and LM.**
- **The US and SR is found to have 13 % and 32 % of the observed maximum power and observed in the LM region, as expected with the GW propagation.**
- **The seasonal characteristics between Summer and Winter illustrates that the dominant time-period and their corresponding time and power show high and more variability for Summer than Winter for all the height regions. The longer dominant time-period of GW is found for Summer than Winter for all the height regions. The relative percentage of power for LS, SR and LM is high for summer (almost twice) than winter. It indicates that the stronger GW activity during Summer.**
- **The dominant wavelength component show a shorter wavelength for LM and longer wavelength for SR. The period of occurrence of dominant wavelength is found to be in the later period of observations for Summer than Winter.**
- **The relative power of dominant wavelength has much variabilities for Summer than Winter.**

Gravity wave associated potential energy

The potential energy per unit mass is expressed as

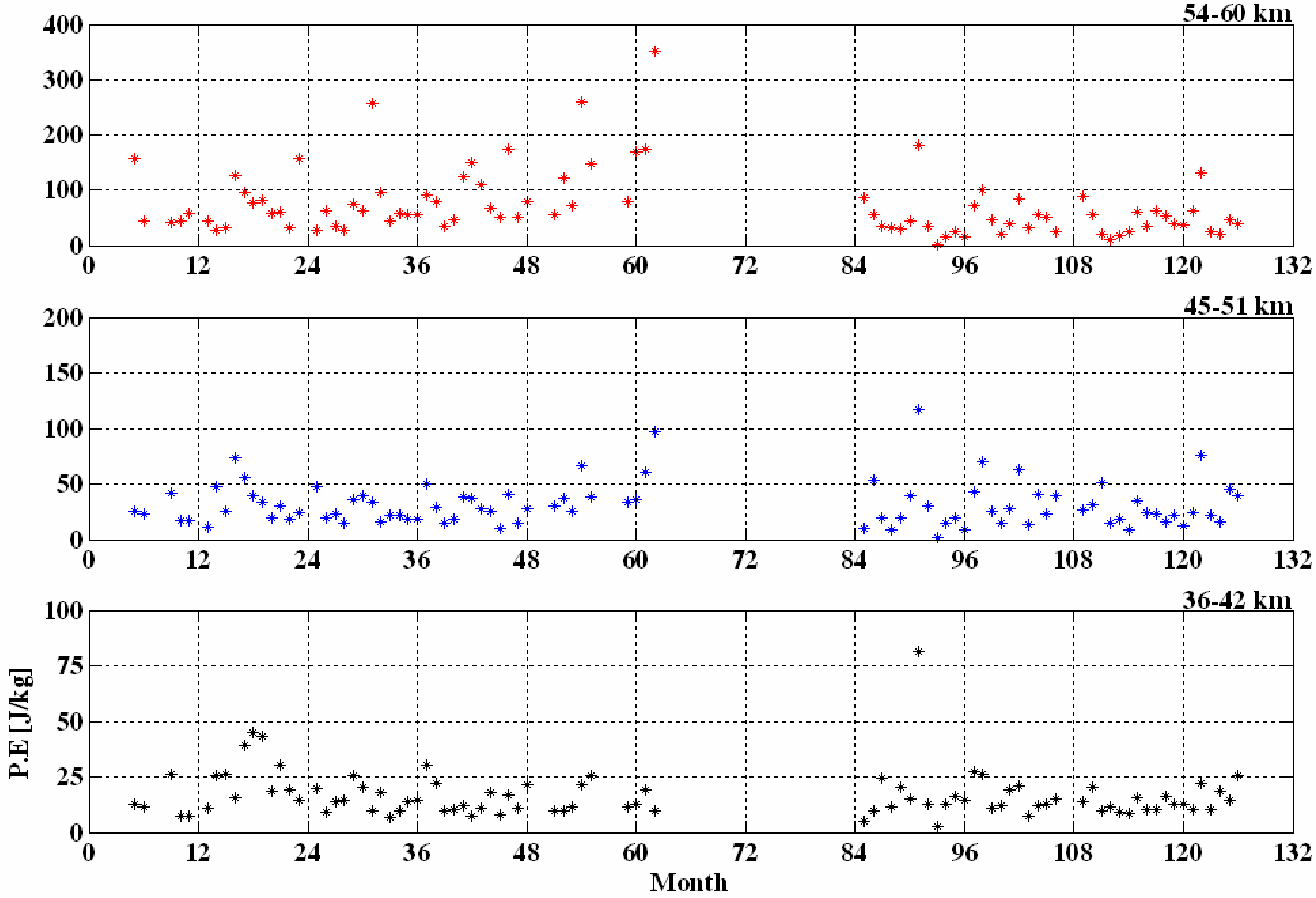
$$E_p = \frac{1}{2}\left(\frac{g}{N}\right)^2 \left\langle\left(\frac{T'}{T_0}\right)\right\rangle^2$$

Where N, the Brunt-Väisälä frequency is given by :

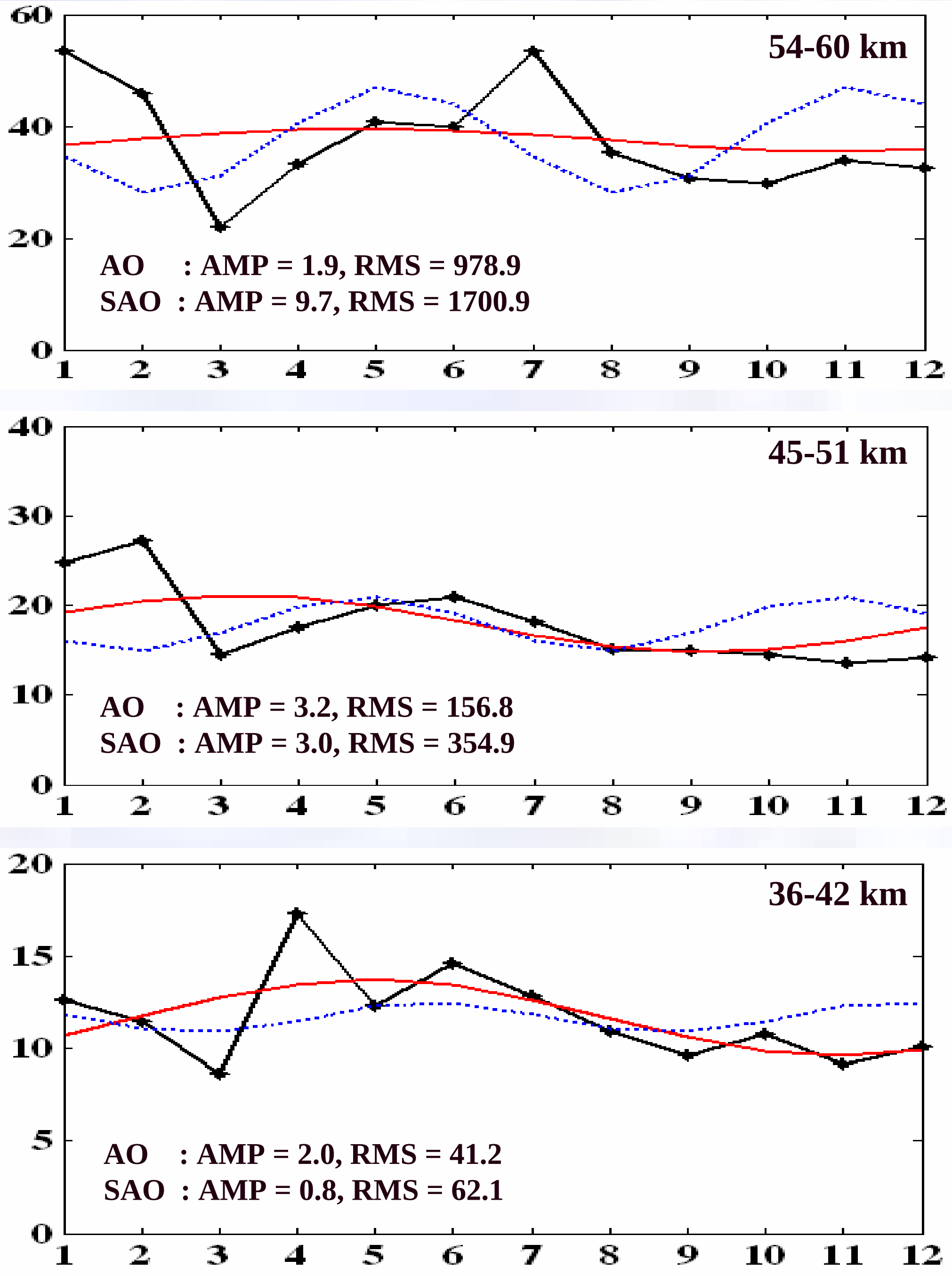
$$N^2 = \frac{g}{\theta}\left[\frac{d\theta}{dz} + \Gamma\right]$$

Γ **is the adiabatic lapse rate (= 9.8 K/km) and**

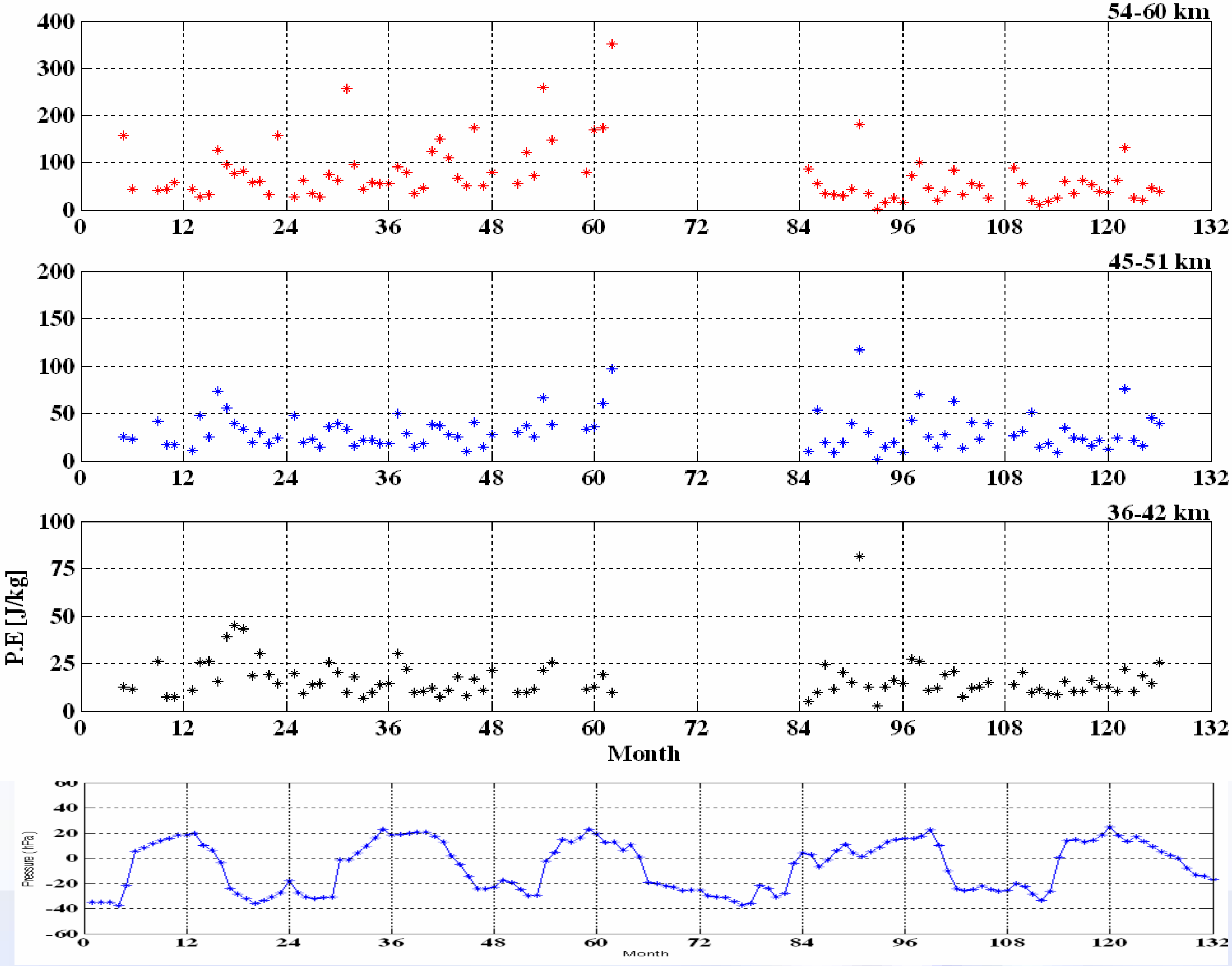
θ **is the potential temperature estimated from the mean temperature.**



The monthly mean potential energy per unit mass associated with the gravity wave perturbations for different height regions.



54-60 km
AO : AMP = 1.9, RMS = 978.9
SAO : AMP = 9.7, RMS = 1700.9
45-51 km
AO : AMP = 3.2, RMS = 156.8
SAO : AMP = 3.0, RMS = 354.9
36-42 km
AO : AMP = 2.0, RMS = 41.2
SAO : AMP = 0.8, RMS = 62.1


54-60 km
45-51 km
36-42 km
P.E [J/kg]
Month
Pressure (hPa)
Month

Mean Characteristics

Potential Energy (J / kg)	35-45 km	45-55 km	55-65 km
Overall	22.1±4.2	54.6±12.6	233.4±79.6
Summer	22.5±4.9	57.3±14.6	255.2±93.7
Winter	21.8±3.4	52.1±9.9	212.1±55.6

Summer : October to March

Winter : April to September

- **The over all P.E is observed to be increasing with height with high value and more variability for LM.**
- **Relatively, the P.E is high during summer and variable than winter.**
- **The monthly temporal variation of P.E for the three different height region illustrate a kind of oscillation with maximum by end of summer. The year 1995 especially, illustrated high values of P.E. than the other years and further indicates a close evidence in relation to QBO.**
- **The least square fit of Annual oscillation (AO) and Semi-Annual Oscillation (SAO) has been applied to the monthly mean P.E. and found that the US and SP follows annual oscillation (AO) with maximum values during March and minimum during September, whereas, the LM found to have SAO with maximum during May and November and minimum during February and August.**

SUMMARY

- Using high resolution temperature profiles and longer data base (~ 11 years), we have studied the GW characteristics for a southern sub- tropical station (Reunion Island; 21^{o} S, 55^{o} E).
- The GW characteristics are presented interms of their time-period, vertical wavelength and the associated potential energy.
- Longer time-period / wavelength is observed for the US and SR in comparison to the shorter time-period/wavelength for LM.
- The wave activity is found to have a maximum during Summer than Winter. Almost, the calculated P.E and the relative power are two times as that observed for winter.
- The GW associated P.E is found to follow AO for US and SR in comparison to LM where it follows SAO.
- During some year, the G.W may have relation with QBO. Further analysis are needed to confirm it.

Thank you for your attention !!!