TIME-FREQUENCY ANALYSIS OF LIDAR SIGNAL TO OBTAIN GRAVITY WAVES CHARACTERISTICS

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ABSTRACT

The Lidar is a laser beam which sent vertically monochromatic pulses in the atmosphere. The analysis of the backscattered light provides information about the vertical temperature evolution versus height. Temperature perturbations are associated with gravity waves phenomenon which play a major role in the middle atmosphere dynamics. The aim of the study is to identify characteristics of these particular waves above Reunion island with an usual parametric time-frequency tool. A comparison is made for two representative periods.

1. INTRODUCTION

Tropical gravity waves are an important contributor of the general stratospheric circulation [1]. To study this phenomenon, Reunion island has a very interesting geographical position (21°S, 55°E).

A perform remote sensing system is efficient to survey middle atmospheric dynamics : the LIDAR (Light Detection and Ranging). It operates as an "optical radar". A typical lidar system employs a laser source to transmit light pulses into the atmosphere. An optical telescope mounted adjacent to the laser is used to intercept backscattered echoes from scatterers in the path of the transmitted pulses. Thus, temperature profile is deduced from recorded density profile assuming that the density is in hydrostatic equilibrium and obeys to the perfect gas law [2]. The profile is limited upwards by the signal to noise ratio at 70-80 km an downward by the aerosols contribution which are superposed to Rayleigh signal. Study of perturbation signals will give gravity waves characteristics.

In a previous work [3] the Smoothed Pseudo Wigner-Ville Distribution (SPWVD) was applied on this kind of signal. At high heights (45-60 km) we have obtained gravity waves characteristics for different nights. In this study we focus on the evolution of wavelengths versus heigth. Magnitude of gravity waves increases with height. An inconvenient of the SPWVD is its difficulty to show on the same representation multicomponent signal with low and high magnitude. For this paper, we prefer parametric time-frequency representations which are less sensitive on the magnitude and more accurate with low number of samples. We represent wavelength evolution with parametric modeling based on an autoregressive model. The aim of the paper is to study gravity waves performances during two periods, austral summer and winter, and also for different atmospheric layers.

2. LIDAR SYSTEM

The use of lidars for atmospheric studies has known a large development in the last two decades. It offers the possibility to probe at a distance and without perturbing the medium several physical parameters as density, temperature, wind, turbulence as well as the concentration of specific atmospheric constituants. This new remote sensing system has opened a whole domain of application for studying the environment. The lidar is a good tool to survey atmosphere due to its possibility to give a continuity of measurements, to its easy handling and to its low cost of operation. Shorter wavelength range gives lidar systems the opportunity for sensing atmospheric constituents and properties to which radar was insensitive.

Our lidar configuration is classical : it is a monostatic system in which the laser beam is projected through the receiving telescope. Backscattered photons collected by the telescope are focused onto a photomultiplier which yields an electronic signal proportional to the received light flux. Then, the signal is sampled, digitized and stored in a microcomputer.

The diagram on Fig.1 shows that lidar system can be divided into three subsystems : emission source, reception device and detection and storage unit. Lidar characteristics of emission and reception are given Table 1.

Table 1 - Lidar characteristics

EMISSION		RECEPTION	
Laser	Nd-YAG	Area	0,67 m^2
Wavelength	532 nm	Resolution	150 m
Pulse energy	300 mJ	Det. mode	Phot. Count
Emission rate	10 Hz	Field of view	3.10^{-4} rad
Beam div.	0,5 10^{-4} rd	Operation	Mai 1994

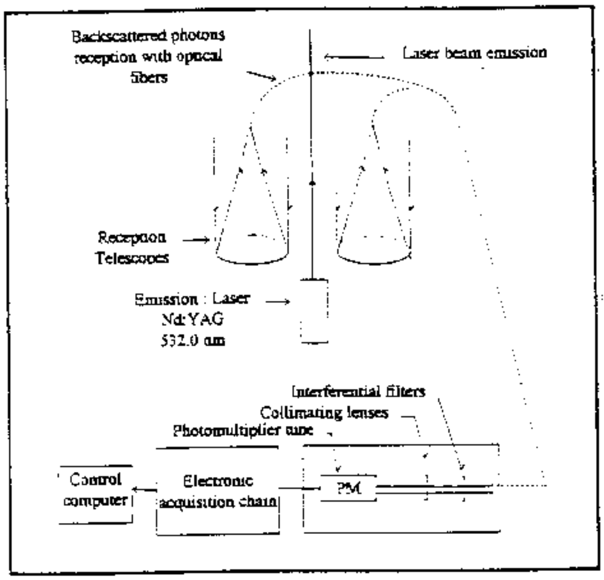

Figure 1 - Lidar system

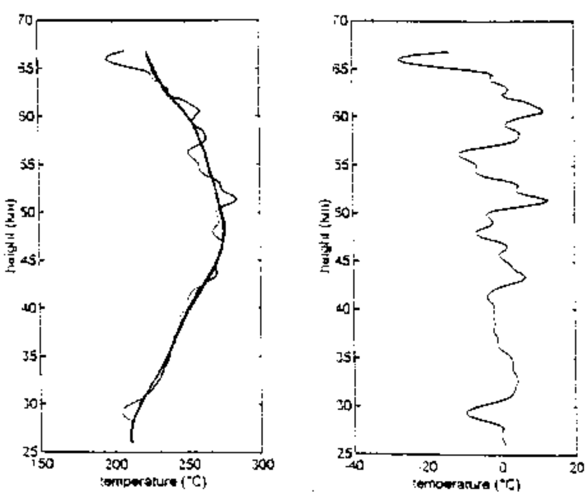

Figure 2 - Left side : initial and mean temperature profile (in Heavy). Right side : Perturbations obtained by substraction of these profiles

3. TEMPERATURE PROFILE

The backscattered photons by atmospheric constituants from layer at a given altitude are proportional to the atmospheric density. These backscattered photons which result in an elastic interaction between emitted laser pulses and the atmosphere are collected by the telescopes and computed after reaching the photomultiplier tubes. Thus, a temporal analysis of the number of backscattered photons reveals the vertical structure of the atmosphere layers crossed by the laser beam. According to the Rayleigh theory, when the atmosphere is typically molecular, the backscattered photons number is right away proportional to the atmospheric density.

Assuming that the atmosphere obeys the perfect gaz law, is in hydrostatic equilibrium, and the molecular air mass M is constant, the temperature profile is then computed from the density profile. Atmospheric parameters : air pressure $P(z)$, density $\rho(z)$ and temperature $T(z)$ can be linked together as below.

The hydrostatic equation

$$dP(z) = -\rho g(z)\Delta(z) \tag{1}$$

can be combined with the ideal gas law

$$P(z) = \frac{\rho(z)RT(z)}{M} \tag{2}$$

and integrated to yield

$$T(z) = \frac{T(z_0)\rho(z_0)}{\rho(z)} + \frac{M}{R}\int_z^{z_0} \frac{g(u)\rho(u)}{\rho(z)}du \tag{3}$$

where R is the universal gaz constant and $g(z)$ the acceleration of gravity. By assuming the acceleration gravity and temperature to be constant in each layer Δz, Hauchecorne and Chanin [4] have showed that, when pressure of the upper layers is fitted with a model, one could deduce, with good accuracy, the temperature profile. This temperature determination is absolute since one can neglect the effect of the pressure fitting at the top of temperature profile, in spite of the fact that density profile is only measured in a relative way. The lidar temperature data obtained since 1978 [4], [5] at the Observatoire de Haute Provence (44°N,6°E) are analysed using this technique.

A mean profile is obtained with a lowpass filter from the initial temperature profile. By subtraction set of these two profiles we obtain the temperature perturbation profile (see fig.2). Study of temperature perturbation signals will give gravity waves characteristics.

4. GRAVITY WAVE

It is now widely recognized that atmospheric gravity waves play a major role in determining the large scale circulation and structure of the middle atmosphere. Gravity waves are generated in the lower atmosphere. Various processes have been proposed to explain the excitation of gravity waves : interaction of surface winds with topography, wind shear associated with jet-streams, geostrophic adjustement, cumulonimbus convection and various meteorological disturbances [1].

5. TIME-FREQUENCY ANALYSIS

5.1 Autoregressive model

For an order p autoregressive (AR) signal modeling, the signal $x(n)$ at time n is modeled as a linear combination of the previous p samples :

$$x(n) = -\sum_{k=1}^{p} a_k x(n-k) + e(n) \qquad (4)$$

$e(n)$ is the model error [6].

5.2 Time-Frequency representation

An advantage of this model is its high frequency resolution for signal with small number of samples. On the opposite, FFT methods depends directly on the signal size. In our case, temperature perturbation signal have around 120-150 samples, it is not enough to obtain accurate time-frequency diagrams with a spectrogram.

To obtain a time-frequency representation, we have computed an AR spectrum on a sliding window. The "instantaneous" spectrum is given by :

$$S_x(f,t) = \sigma_e^2 / \left[1 + \sum_{k=1}^{p} a_k \exp(-j2\pi f k) \right]^2 \qquad (5)$$

t is the center of the sliding window, σ_e^2 is the error power.

5.3 Analysis

Four representative nights are selected for this time-frequency study : two in winter (22 and 23 june) and two in summer (1 and 10 nov.). Perturbation signals are represented in Fig.3. Height resolution is 300 m. We compute an AR model of order 10 on a sliding window of 30 samples (9 km). Four time-frequency representations are shown in Fig.4.

At the austral winter solstice (Fig.4.a,b), the waves are localized in 6-8 km wavelength range in stratosphere and low mesosphere. During this season, the subtropical Jet-Stream has an influence with a maximum strength. Geostrofic adjustement of the Jet-Stream could appear to be a major source of these waves. Different waves appear in austral summer (Fig.4.c,d). Wavelength range is between 1,5 and 8 km and their energy are more important than in june (see fig.3). In the two diagrams appeared two wave components. Wavelengths are more disturbed, but we can notice that they decrease in low mesosphere where components of 2-3 km wavelength appear. In this season convection level is very high, These waves can be associated to convection processes which excite high frequency gravity waves.

6. CONCLUSION

In this study, different temperature perturbation signals coming from a lidar remote sensing system are analysed in term of wavelength versus height. A classical parametric time-frequency method is used to analyse four representative days.

Comparison between time-frequency diagrams indicates that waves are more stable and more localized in term of wavelength in austral winter. In this season, one component is predominant which wavelength belong to the 6-8 km bandwith. We suppose that this kind of wave have geostrophic adjustement origin. On the opposite, in austral summer, wavelengths are more disturbed and have higher amplitude. We explain this phenomenon by the high convection level in this season.

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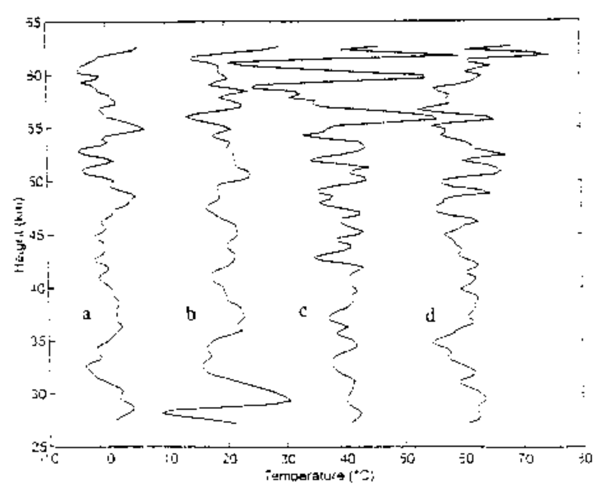

Figure 3 - Temperature perturbation signals
a:22/06/94, b:23/06/94, c:01/11/94, d:10/11/94

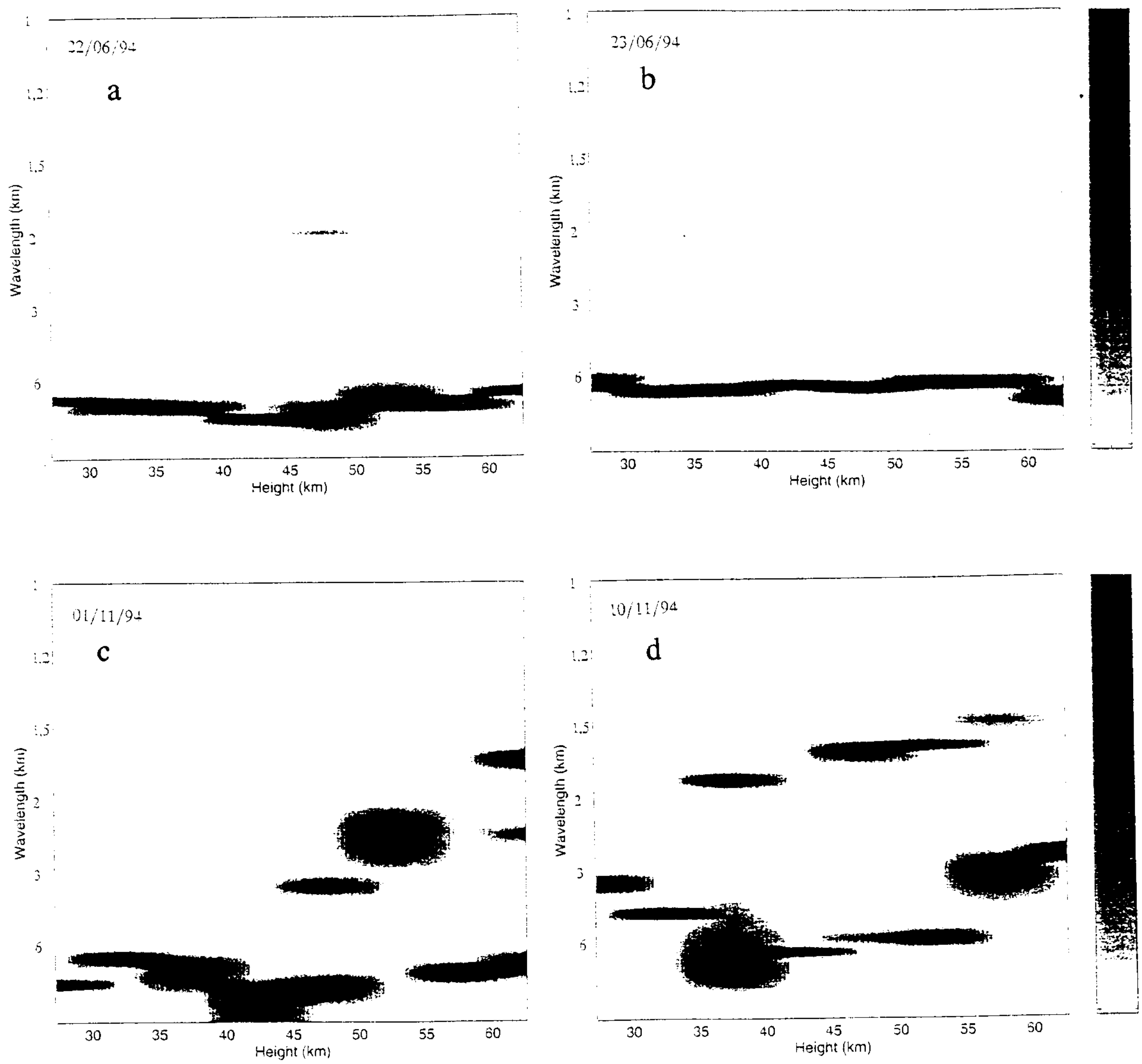

Figure 4 - Time-frequency analysis of temperature perturbations.
Wavelengths versus heights are given for the four days.