The Statistical Characteristics of Gravity Waves over Wuhan

Wei Li, Haoge Ma, Zhiwei Cai,a*

School of Information Science and Engineering Henan University of Technology

Abstract

By analyzing the routine radiosonde data obtained at Wuhan (30.5° N, 114° E) from 2000 to 2004, the characteristics of inertial gravity waves in troposphere and lower stratosphere (TLS) were studied, and a strong correlation between the variation of gravity wave energy and jet intensity was found. Similar result of Wuhan was obtained by analyzing the routine radiosonde data obtained at Haikou (20° N, 114° E) and Beijing (40° N, 116° E). Small scale gravity waves with wavelength less than 1 km were extracted from temperature data to give a further discussion on variation of gravity wave energy at different heights and latitudes.

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1. Introduction

Gravity waves play a more important role in recent observation and theoretical studies about atmosphere circulation and thermal structure. The activities of gravity waves and relative momentum transportation make a significant impact on local troposphere and lower stratosphere[1,2]. It has been delineated by a series of works that gravity waves carry energy and momentum flux from lower atmosphere into middle atmosphere and store them in background atmosphere by breaking of gravity waves, through which the status of background atmosphere is determined[3,4,5] (Lindzen, 1981; Holton, 1982; Tsuda et al., 1990b).

Radiosonde has become one of the most important methods to detect troposphere and lower stratosphere for its wide coverage and steady launching. Making use of observations from 18
meteorological stations, Allen and Vincent[6] investigated gravity wave activity and its variation with position and time and wished to get information of wave sources by wave parameter analysis. Vincent and Alexander[7] carried out a statistical analysis on seasonal and annual variation of gravity waves in the tropical lower stratosphere, and the characteristics of gravity waves were discussed detailedly.

The present study is based on the data of regular Radiosonde observations at Wuhan. The statistical characteristics of gravity wave parameters in TLS are discussed. The results from Haikou and Beijing are compared with Wuhan. In sect. 2 a detailed description of the data processing method is presented. The analysis of results are given in sect. 3. The primary conclusions are drawn in sect. 4.

2. method of data processing

2.1. Extraction of quasi-monochromatic gravity waves

A similar data processing method to that proposed by Allen and Vincent[6] and Vincent et al.[8] is adopted in this paper. To avoid the impact on fitting by the extreme values of jet stream and topopause in height range 10-18 km, it’s separated into two individual height ranges: ground surface to 10 km and 18 to 25 km, to investigate the gravity wave activity in troposphere and lower stratosphere, respectively.

Each vertical profile of temperature and horizontal winds is separated into background and disturbance. We calculate the background \( \bar{T}, \bar{u}, \bar{v} \) by fitting a second-order polynomial, then the fluctuation components \( \tilde{T}, \tilde{u}, \tilde{v} \) can be derived by removing the background. The quasi-monochromatic wave components \( \tilde{U}, \tilde{V}, \tilde{T} \) are extracted by a harmonic fitting to the fluctuation components as following equation:

\[
U = A \sin(\frac{2\pi}{\lambda} z + \phi)
\]  

(1)

Where, \( U = [u, v, T] \) is the fluctuation component, \( A = [A_u, A_v, A_T] \) and \( \phi = \{\phi_u, \phi_v, \phi_T\} \) are the fitted amplitude and phase of the quasi-monochromatic wave components, respectively. We use the maximum entropy spectrum analyzing method to gain the dominant vertical wavelength: the wave length corresponding to the largest amplitude of the maximum entropy spectral is chosen to be dominant vertical wave- length, \( \lambda_z \), for different wave components (temperature, zonal and meridional winds). Considering of the difference of \( \lambda_z \) for each wave components, we choose the mean value of three dominant vertical wavelengths to be the vertical wavelength of a quasi-monochromatic gravity wave, only when the relative standard error of the three dominant wavelengths is less than 20%. Subsequently the specified vertical wavelength is used to determine the wave’s amplitudes and phases for each wave components by harmonic fitting.

The wave energy is computed from

\[
E_x = \frac{1}{2}(u'^2 + v'^2)
\]  

(2)

\[
E_p = \frac{1}{2} \frac{g^2 T'^2}{N^2 T'^2}
\]  

(3)
Where $u'$, $v'$ and $T''$ present the fluctuation amplitude of zonal wind, meridional wind and temperature, respectively; $T_b$ and $N^2$ is background temperature and squared buoyancy frequency; over bar denotes an unweighted average over height.

2.2. Extraction of small scale gravity waves

Limited by the method of data processing, the wave length of gravity waves extracted by above method are more than 2 km. to study the difference of gravity wave energy between low and middle latitude areas, the small scale disturbance of temperature were discussed. Because a extinguish difference of gravity wave appeared in troposphere and lower stratosphere, it's very significant to study the variation of gravity waves with altitude. Relatively, the high resolution in small scale temperature disturbance studying compensate shortcoming of spectral analysis for its limited altitude range.

Smith et al established a saturated gravity wave model on horizontal wind and vertical wave number [9], which was expanded to temperature and potential temperature by Fritts et al [10]. Based on above work, a saturated spectra model on physical scalar was established and applied to potential temperature, temperature and buoyancy frequency [11]. Integrating ranged in saturated wave number, the averaged temperature disturbance can be described as follow

$$T'' = B \int_0^\infty F_T(m) dm$$

$$\bar{T}^2 = CT_b^2 N_b^4$$

where $T''$ denotes temperature disturbance, $T_b$ is background temperature, $N_b$ is background buoyancy frequency, $F_T(m)$ denotes the wave number spectral of $T''$, and $C$ is a constant. $T''$ is calculated by high pass filtering single temperature figure, with a cutoff wavelength of 900 m. As a result, the wavelength of small scale gravity waves ranged from 100 m to 900 m, which in the range of saturated gravity waves.

3. Analysis of results

Figure 1(a) gives out the histogram of $\Omega / f$. The cut-off value of $\Omega / f$ is choose to be 10 because many uncertainties will be caused if $\Omega / f$ is too large [7,13]. As is shown in Figure 1(a), most intrinsic frequencies are less than $4f$, which demonstrate that the gravity waves over Wuhan are mostly inertial gravity waves. The distribution of vertical wavelength is shown in Figure 1(b). Most gravity waves have a vertical wavelength between 4.5 and 5.5 km in troposphere, and 3.5 and 4.5 km in lower stratosphere.

The vertical intrinsic phase velocities can be derived from $\Omega$ and vertical wavelength. In north hemisphere, the anti-rotation of the hodograph of horizontal winds denotes downward propagation of wave energy. Figure 1(c) shows the histogram of vertical intrinsic phase velocities. A symmetric distribution of vertical intrinsic velocities around zero can be observed in troposphere, but in lower
stratosphere 73.1% of the waves have a negative phase speed (upward energy propagation), which is much larger than 46.8% in troposphere. It’s notable that in lower stratosphere the occurrence rate of vertical intrinsic speeds in the range of -0.2-0 m/s^-1 reaches a peak value of 60%. Similar results that most waves propagate upward in lower stratosphere have been observed by Tsuda et al. and Vincent and Alexander[7,12], which indicates that the wave source in lower stratosphere is below 18 km. The results of Haikou and Beijing are analogous to Wuhan, and the concrete parameters are shown in Table 1.

![Fig.1. Histogram of $\Omega/f$, vertical wavelengths (b) and vertical intrinsic phase velocities (c) in Wuhan. The solid and dotted lines denote the occurrence rate of gravity waves in the troposphere and lower stratosphere, respectively.](image)

**Table 1. The statistical results of gravity waves**

| Station | Haikou | Wuhan | Beijing |
|---------|--------|-------|---------|
| $u'$ (m/s) | Trop  | 1.59  | 2.45    | 2.53    |
|          | Stra   | 1.82  | 1.50    | 2.62    |
| $v'$ (m/s) | Trop  | 1.77  | 2.08    | 2.15    |
|          | Stra   | 1.71  | 1.52    | 1.62    |
| $\lambda_z$ (km) | Trop  | 4.78  | 4.88    | 4.79    |
|          | Stra   | 3.83  | 3.84    | 3.34    |
| $\Omega/f$ | Trop  | 3.63  | 3.87    | 3.48    |
|          | Stra   | 3.51  | 3.23    | 3.18    |
| FUP(%) | Trop  | 45.6  | 46.8    | 46.5    |
|          | Stra   | 67.0  | 73.1    | 76.3    |

FUP=Fraction of upward propagation, Trop=Troposphere, Stra=Stratosphere

### 3.2. Analysis of small scale gravity waves

The characteristics of temperature disturbance $T'$ and $\overline{T}^{12}$ with wavelength ranged from 100 m to 900m were discussed to further study on difference of gravity wave energy at different latitudes and seasons. 5 km was chosen to be the starting height to avoid the affection of truncation effect at low height. The observations of small scale gravity wave at Haikou, Wuhan and Beijing were demonstrated in figure 3, summer and winter for each cite. Figure 3(a) show that the temperature reached its minimum value (-75 °C) at 16.5 km according to tropopause, and variate in quasi sinusoidal manner: the amplitude was less than 0.5 K between 5 km and 15 km, then increased gradually untill it reached its maximum value at
24 km; correspondingly, $T'^2$ and $N_b^2$ show relative small value below 15 km and gradually increased beyond that height; the increase of $N_b^2$ between 15 km and 17 km was according to temperature variation at tropopause, which resulted in a violent increase, while remained stable over 17 km. The character of small scale gravity waves in winter was given by Figure 3(b): not as that in summer, the minimum value of temperature appeared around 16 km, and the amplitude of $T'$ show very little variation less than 0.5 K, except 1 K beyond 20 km; As a result, the variation of $T'^2$ and $N_b^2$ kept lenitive that $T'^2$ ranged from $10^{-5}$ to $10^{-4} K^2$, and the abrupt increase at tropopause for $N_b^2$ didn’t appear, instead of slow increase between 13 km and 18 km. Similar results were found in Haikou and Beijing. It’s notable that the minimum temperature of Haikou reached -85°C, which was obviously less that other cites, a more abrupt increase of $N_b^2$ at tropopause in summer can be seen, and the amplitude of small scale gravity waves in troposphere is so small as about 0.2 K; The minimum temperature in Beijing was between -60 and -70°C, but the variation of $N_b^2$ didn’t suggest the exist of tropopause, $T'$ show relative small maximum value, but appeared not only in lower stratosphere, but also around 10 km.

Fig.3 single figure of temperature disturbance in summer and winter at Haikou, Wuhan and Beijing (from left to right the figure is temperature $T$, temperature disturbance $T'$ and $T'^2$, and buoyancy frequency)

Fig.4. monly averaged temperature disturbance in summer and winter at Haikou, Wuhan and Beijing (solid line denote Wuhan, dashed line denote Haikou and chain dotted line denote Beijing)
The monly averaged small scale gravity waves at Haikou, Wuhan and Beijing in summer and winter are shown in Figure 4. with the increase of latitude, the temperature of topopause increased, too. The $T_c$ increased gradually from troposphere to lower stratosphere, and the buoyancy frequency between 5 km and 7 km and beyond 17 km show almost same value, but decreased obviously with latitude increasing between 7 km and 17 km. The wavelength of small scale gravity waves locates in the range of saturated wave, which resulted that it’s very easy to be saturated, and leaded to turbulence and cyclone diffusion, which has great significance to substance transportation in middle atmosphere.

4. Conclusion

By analyzing the routine radiosonde data the statistical characteristics of gravity waves were studied in this paper, and the statistical results from Haikou and Beijing are compared with those from Wuhan. The characteristics of small scale gravity waves were studied, also. The main results are summarized in following:

The vertical wavelength of gravity waves has a dominant scale range 4-6 km in troposphere and 3-5 km in lower stratosphere. The intrinsic frequency of most gravity waves is less than 4 times of inertial frequency. In troposphere the upward and downward propagation of gravity waves have a close proportion, while in lower stratosphere about 70% of the gravity waves propagates upward, indicating that the excitation source of gravity waves in lower stratosphere is in troposphere. The statistical parameters of gravity waves at different latitude have little difference, and there exists a similar seasonal variation for wave energy in both troposphere and lower stratosphere except at Haikou, implying that they have the same wave source.

The energy of small scale gravity waves increased gradually with altitude increasing. In troposphere the amplitude was about 0–0.5 $K$, while it may be 1 $K$ in stratosphere, except that bigger amplitude in troposphere appeared in Beijing.

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