Stratosphere wind and temperature measurements using a Rayleigh Doppler lidar in mid-latitude area of China

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Abstract: Since the 60km mobile Rayleigh Doppler lidar of University of Science and Technology of China had been developed in 2013, more than 100-days valid nighttime wind and temperature data with time resolution of 30 minutes and height resolution of 200m & 1km (below & above 40km, respectively) was obtained during recent 3 years. The observation locations cover the northwest (mid-latitude) of China: Delhi (37.371° N, 97.374° E), Xinzhou (38.425°N, 112.729°E) and Jiuquan (39.741°N, 98.495°E). Recently, we extract the perturbations of the wind and temperature profiles of this database and have found gravity activities of the wind field. Several gravity waves cases of wind field are shown in this paper and typical characteristics of the gravity waves are analyzed in this mid-latitude area of China. This kind of gravity wave observation of stratosphere wind field is rare in the world and is significant for the study of atmospheric dynamics.

Keywords: Rayleigh Doppler lidar, Stratosphere wind, incoherent lidar, Gravity waves

1. Introduction

Rayleigh Doppler wind Lidar is an efficient and important way to detect the wind field in stratosphere and mesosphere with high time-and-spatial resolution. Most of the gravity waves study is based on temperature and density measurements in stratosphere and mesosphere [1, 2]. However, perturbation of zonal and meridional wind will provide more information of gravity waves [3]. Furtherly, simultaneous wind and temperature measurements could provide a full view of a quasi-monochromatic gravity waves. The Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) Rayleigh/Mie/Raman lidar in northern Norway has operated regularly since 1994 to measure temperatures, aerosols and noctilucent clouds in the middle atmosphere [4]. Recently this system was improved and a Doppler wind detection system using a Doppler Rayleigh Iodine Spectrometer was implemented to detect the wind from 30km to 80km. A 3-day-continuous wind and temperature measurement with obvious dominant wave patterns was reported by ALOMAR in Dec. 2015 [5]. The mobile Rayleigh Doppler wind Lidar developed by University of Science and Technology of China (USTC) demonstrated its ability to measure wind and temperature from 15km to 60 km in 2013 [6]. Until now, this system has obtained more than 100 days valid nighttime wind and temperature data during recent 3 years in three different locations of the northwest(mid-latitude) of China: Delhi (37.371° N, 97.374° E), Xinzhou (38.425°N, 112.729°E) and Jiuquan (39.741°N, 98.495°E). Several inertia gravity wave cases observed by this system was reported in March 2016 [7]. The perturbation of the wind field showed prominent wave patterns. Therefore, intrinsic period and propagation direction can be extracted from the perturbations using hodograph method.

2. System and Observations

The mobile Rayleigh Doppler lidar system in USTC uses a triple channel Fabry-Perot interferometer to determine the Doppler frequency shift of the Rayleigh backscatter. Two channels was set at two sides of the emitting laser symmetrically in the spectrum domain, which is called double edge technique [8]. The third channel is used as locking channel to lock the frequency of outgoing laser at the cross-point of the two signal channels. The whole system consists of three subsystems. Two subsystems’ one-meter telescope is
leaned 30 degrees from the zenith to detect the two components of horizontal wind. The third subsystem points to the zenith to detect vertical wind or temperature.

![Wind velocity map](image1)

**Figure 1.** Wind velocity map.

![Wind direction map](image2)

**Figure 2.** Wind direction map.

During the 3-months observation in Xinzhou and the 2-months observation in Jiuquan, observation started from 6:00pm to 7:00 am on clear nights. Radiosonde observations from the local meteorological station were operated twice at the same location on 7:00pm and 7:00 am, realizing a daily comparison between lidar and radiosonde. The comparison result is satisfactory with an acceptable difference which is caused by the radiosonde’s actual flight path and the time delay of the radiosonde measurements [9]. Fig. 1 and Fig. 2 show the wind velocity and direction map, of the entire 2-months observations in 2015, Jiuquan. The upper limit of the data is determined by the Signal-to-Noise-Ratio (SNR). There is obvious seasonal change in height range 15-25km. Before Oct. 15, a quasi-zero wind layer around 20km can be seen from the velocity map in Fig. 1. After Oct. 19, this layer’s wind speed increase and strong wind perturbations appears between 15km and 40km, compared with the situation before Oct. 15. The existing of quasi-zero wind layer is probably a main reason that there are hardly gravity waves above 20km before Oct. 15, but typical inertia gravity waves cases was observed after Oct. 19.[7] This kind of phenomenon was also founded in the data obtained in Xinzhou, 2014. This is a convincing evidence that zero wind layer is a strong shield against upward propagating waves.

3. **Gravity Waves Analysis**

The perturbation of the horizontal wind is extracted from the horizontal wind by subtracting the background wind. The background wind is fourth-order polynomial fit of the whole-night mean wind profile. A bandpass filter will be applied onto the residual of the wind after subtracting the background. The cutoff wavelengths of the bandpass filter will change in different wave patterns. This step is to highlight the
dominant vertical wavelength. Fig. 3 shows the zonal (left) and meridional (right) wind perturbations on Dec. 2nd night, 2014. In the height range of 15-45 km, dominant wave patterns with vertical wavelength of 5km and period longer than 10 hours are visible in the maps. Typical values of the vertical wavelength of the semidiurnal tide is larger than 20km [10] so we attribute this waves to gravity waves. Although the wind perturbation map shows the presence of multiple waves for most conditions, quasi-monochromatic gravity waves can be identified during some periods and altitude ranges. Such as the height range 24-40km from 3:00 am to 6:00 am on Dec. 3rd.

We used hodograph method to extract propagation direction and intrinsic periods. A quasi-monochromatic wave means that the vector of zonal and meridional wind will rotate as an ellipse with increasing height. We selected 7 cases on that night (highlight by the black arrow lines in Fig. 3) and found clockwise rotation of the perturbation vector, which means that it is upward propagating waves. By fitting the ellipse of the rotating vector, we can calculate intrinsic period of the wave from the ratio of the major to minor axes of the ellipse.

Figure 3. Zonal (left) and meridional (right) wind perturbations on Dec. 2nd night, 2014.

Figure 4. Hodoraph (left) and intrinsic frequency (right).

Figure. 4 shows the hodograph of 4:30 am case (left) and the ratio of intrinsic to Coriolis frequency of 7 cases. The red arrows in Fig. 4 shows the propagation direction of the wave and the green line is the fitting ellipse. The altitude and the time of 7 cases is also shown in Fig. 4 (left) by yellow cross. The last three
cases in the height range 24-40km from 3:00 am to 6:00 am is more like quasi-monochromatic with ratio of intrinsic to Coriolis frequency of 1-2, comparing with other cases which have very various intrinsic frequencies. Furtherly, the intrinsic frequency observed by a ground-base lidar is related to the background wind velocity and direction, which will cause Doppler shift to the propagating wave [11]. This gives a reason why lot of our observed gravity wave cases has a larger frequency when altitude increases.

4. Conclusions

In this paper we performed the wind field observed by the Mobile Rayleigh Doppler wind lidar of University of Science and Technology of China. In the 2-months observation in Jiuquan, 2015, we found the quasi-zero wind layer disappears after Oct. 19th and this is probably the cause of increasing of gravity waves activities. Hodograph method is used to calculate the intrinsic frequency and the propagating direction of the waves. In some time period and height range, clear quasi-monochromatic wave patterns can be seen, but most of the conditions the perturbation can be attributed to multiple waves.

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6. References


