Gravity wave parameters and their seasonal variations derived from Na lidar observations at 20°N Haikou, China

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Outline

Background

Content

- 不同纬度地区重力波研究结果的对比 (latitude)
- 北京地区重力波功率谱的观测研究 (GW in Beijing)

Summary
Due to GW saturation, damping, dissipation et al., GW transfers energy and momentum from lower atmosphere to upper atmospheres and lower thermosphere, GW affected the circulation of energy and momentum, constitute and structure obviously in middle atmosphere.
1. GW Source 重力波的波源
   - Topography 地形起伏
   - Convection and wind shear 大气对流、风剪切
   - Wave-wave interaction 波、波相互作用，等

2. GW’s propagation and mechanism 重力波的传播过程、机制
   - Saturation 饱和
   - Damp 衰减
   - Break 破碎
   - Dissipate 能量、动量耗散

3. GW’s Activities （强度、参数等）
   - Seasonal 季节变化
   - Latitude 纬度变化
   - Regional 区域特性

Hot topics of GW study
图一、激光器
Lidar Chain: based on Medirional Project

Hainan
图二、接受望远镜和数据采集系统
图三、激光发射夜景
Sodium Lidar in GW’s observatory research included two facts:

- Measurement of monochromic GW parameters, wavelength, period, amplitude et al [Gardner and Voelz, 1987; Collins et al., 1994, 1996; Yang et al., 2008; …]

- To Calculate the GW activity and their spectrum, due to their random wave perturbations of normally observations. [Senft and Gardner, 1991; Beatty et al., 1992; Yang et al., 2006; …]
Advantages of Sodium Lidar in GW's observatory:

- Shows the GW activities by giving a high spatial and temporal Resolution.
- Due to the large amplitude of GW in the mesosphere, Sodium Lidar is quite helpful in GW observation.
The theory for depriving GW parameters

Fundamental theory developed by C. S. Gardner
the layer density response to a monochromatic gravity wave is written as

$$n_s(r, t) = \frac{n_0(z - \gamma H \ln[1 + \frac{A e^{\beta z}}{(\gamma - 1)} \cos(\omega t - \vec{k} \cdot \vec{r})])}{1 + [A e^{\beta z}/(\gamma - 1)] \cos(\omega t - \vec{k} \cdot \vec{r})}$$

only the linear perturbation is taken into account

$$n_s(r, t) \approx n_0(z) - [n_0(z) + \gamma H \frac{dn_0(z)}{dz}] \cdot \frac{A e^{\beta z}}{\gamma - 1} \cos(\omega t - \vec{k} \cdot \vec{r})$$

The relative sodium density fluctuations (\(r_{\text{Sodium}}\)) can be expressed

$$r_{\text{Sodium}} \approx -\frac{1 + \gamma H \frac{dn_0}{dz}}{n_0 \frac{dz}{\gamma - 1}}$$

$$r_{\text{Atmosphere}} \approx -\frac{1 + \gamma H \frac{dn_0}{dz}}{n_0 \frac{dz}{\gamma - 1}} A e^{\beta z} \cos(\omega t - \vec{k} \cdot \vec{r})$$
(quasi-random GW perturbations and spectrum study)

Relationships between atmosphere and Na density perturbation:

\[ r_s(z,t) = -\frac{1}{\gamma - 1} \left[ 1 - \frac{\gamma H(z - z_0)}{\sigma_0^2} \right] r_a(z,t) \]
Due to the relationships of the atmosphere and Na density perturbation, we use these equations to calculate:

\[
\begin{align*}
rs(z,t) &= \frac{1}{\gamma - 1} \left[ 1 - \frac{\gamma H(z - z_0)}{\sigma_0^2} \right] ra(z,t) \quad (1) \\
ra(z,t) &= \frac{\gamma - 1}{1 - \gamma Hf''(z)} rs(z,t) \quad (2) \\
< ra^2(t) > &= \frac{1}{TL'} \int_{z_0 - \ell/2}^{z_0 + \ell/2} \int_{t - \tau/2}^{t + \tau/2} ra^2(z,t) dt dz \quad (3)
\end{align*}
\]
Seasonal variations of the RMS atmospheric density perturbations.

MMSE: $$y = A_0 + A_1 \cos\left[\frac{2\pi}{365}(d-d_1)\right] + A_2 \cos\left[\frac{4\pi}{365}(d-d_2)\right]$$

- The dots denote nightly average density perturbations, and the lines represent the range of variation during the night. The solid curve is MMSE fit to the atmospheric density perturbation for the mean, annual, and semiannual components.

The mean RMS atmospheric density perturbation over Hainan are 5.63 %, which in summer are obviously larger than that in equinox and the maxima occur near the solstice, while the gravity activity is also intense in winter.
GW–random waves perturbation for Comparison
Middle–latitudes

- The mean RMS atmospheric density perturbation over middle latitude which in summer are obviously larger than that in equinox and the maxima occur near the solstice.

Urbana Illinois USA Senft and Gardner JGR 1991

Beijing, China Our Result 2014
Calculation of GW’s spectra

The vertical wave number spectrum (power spectrum) and The frequency spectrum (temporal spectrum) are important for GW activity characterization.

\[ R_t(m,t) = \int r_t(z,t) e^{imz} dz \]

\[ R_t(\omega,t) = \int r_t(\omega,t) e^{i\omega z} dz \]

\[ F_t(m) = \frac{\left< \left| R_t(m,t) \right|^2 \right>}{L} \]

\[ F_t(\omega) = \frac{\left< \left| R_t(\omega,t) \right|^2 \right>}{L} \]

\( r_t(z,t) \): temperature perturbation
\( F_t(m) \): GW m spectra
Examples of GW’s vertical wave number spectra and their spectrum slopes in Haikou

\[ Fa(m) = \int B_a(s,0) \, ds = \int <ra(z,t) \cdot ra(z-s,t)> e^{ims} \, ds, \quad (4) \]

\[ ra(z,t) : y(z,t) = ra(z,t) - 0.95 ra(z-\Delta z,t) \quad (5) \]

\[ Fa(m) \sim \frac{N^4}{g^2 m^3} ; \]

The relationship between the logarithm of \( Fa(m) \) and logarithm \( m \) is gross linear and the \( m \) slope is -3 due to the basic theory.
GW’s annual mean vertical wave number spectra and the statistical distribution of their spectrum slopes in Haikou

(a) Annual mean of vertical wave number spectra and (b) the distribution of their spectrum slopes
• Examples of GW’s frequency spectra and their spectrum slopes in Haikou

The relationship between logarithm of $F_a(w)$ and logarithm $w$ is also gross linear and the $m$ slope is $-3/5$ due to the basic theory.
GW’s annual mean vertical wave number spectra and the statistical distribution of their spectrum slopes in Haikou

(a) Annual mean of vertical wave number spectra and (b) the distribution of their spectrum slopes
Seasonal distributions of vertical wave number spectral amplitude at $2\pi/(4\text{km})$ (pluses), and $m15=2\pi/(1.5 \text{ km})$ (triangles). The solid curves $ms=2\pi/(8 \text{ km})$ are the MMSE fits for the mean, annual, and semiannual components.

The intensive gravity activity in winter.
Different m spectrum seasonal distribution for comparison in middle latitude
Characterized temporal frequency spectra less than 60min perturbation over Hainan in summer are obviously larger than that in equinox and the maxima occur near the solstice, while the gravity activity is not neglect in winter.
The mean RMS atmospheric density perturbation over middle latitude which in summer are obviously larger than that in equinox and the maxima occur near the solstice.
出现了夏季东风、冬天西风的基本特征；
西风对来自青藏高原的重力波产生滤波作用，使冬天的重力波活动强度降低。
但海南地区冬天重力波活动仍较大，这说明海南地区存在着其它波源。
赤道潜激流(equatorial undercurrent) 是低纬地区的重力波的主要波源之一。

海南上空重力波出现频度减去北京的，其季节变化趋势与南中国海的波源的季节分布一致。
北京、合肥、海南上空的重力波出现频度

- 都出现了夏季最大、冬季较弱的基本特征；
- 北京的季节变化趋势最为明显，海南的最不明显；而且海南的重力波出现频度大于北京，说明低纬地区还有其它可能的重力波波源。
结论：

1、关于重力波出现频度的季节分布：都出现了夏季最大、冬季较弱的基本特征；北京的季节变化趋势最为明显，海南的最不明显；而且海南的重力波出现频度大于北京。

2、以上现象可以通过重力波波源及背景大气对重力波的影响来解释。

3、高分辨激光雷达数据的波动谱首次出现了在涡旋扩散区域的特征。
Thank You!
图三、激光发射夜景
GW observatory can provide the (GW features in spatical and temporal, which is quite helpful for modeling (建模)
北京地区
（Beijing）

小尺度的波比较多
海南地区
(Hainan)
波长、周期、相速度的统计分布图