MESOSPHERIC SODIUM LAYER AND ITS RELATION WITH GRAVITY WAVE PERTURBATIONS OBSERVED BY LIDAR MEASUREMENTS

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ABSTRACT

Lidar observations of the mesospheric sodium layer often reveal wavelike features moving through the layer. In this study we show examples of very special shapes in the height-time evolution of the sodium layers measured by lidar installed at São José dos Campos (23°, 46°w), Brazil. We selected two nights during the period from 1996 to 1999, in order to analyze the morphology of the Na layer and its relation with gravity wave perturbations. In one case the Na layer becomes narrower and then broadens whereas in the other, the sodium layers bifurcate. These data are compared to the layer response predicted by the theory. Both sets of experimental data show a downward progression of wavelike structures that is typical of gravity waves which is moving the Na density peak downward in time. Since the linear layer response is not always adequate to describe gravity wave sodium layer interactions (by linear response, it is meant that the layer density perturbations have the same temporal and spatial frequencies as the gravity wave), nonlinear components of the layer density response must be considered in interpreting sodium lidar data. In this work, these observed morphologies are presented and discussed under linear and nonlinear layer density response.

1. INTRODUCTION

Numerous radio and optical techniques have been developed to monitor gravity waves, tides and planetary waves in the mesosphere region. Structural changes within the nighttime mesospheric layer are often reveled by lidar observations and often reveal wavelike features moving through the layer. Lidar has proven to be a very effective technique for obtaining accurate high-resolution measurements of the spatial and temporal structure of gravity wave induced perturbations in mesospheric sodium layer [1,3,5,8]. Under the assumption that the sodium layer is a passive tracer of the dynamics (a valid assumption except when chemistry is considered important) we can use the structure of the sodium layer to visualize the dynamics. Because of the thickness of the sodium layer and the density gradients, a linear model of the layer response is not always adequate to portrait gravity wave sodium layer interactions. The first-order perturbations response (which is the linear layer response) of an atmospheric layer to gravity waves has been examined by [1,3]. They concluded that the layer density response model is generally of larger amplitude at the bottomside than at the topside, although the amplitude of both depends on the relative sharpness of the layer density gradient in comparison to the gradient of the quiescent background atmosphere. In addition, data indicating the presence of nonlinearities in the sodium layer response, that is, density perturbations at harmonics of the gravity wave temporal and spatial frequencies have been reported by [3,5]. As explained by [1,4], these nonlinearities appear due to the large sodium density gradients and the relatively high amplitudes of gravity wave at mesospheric heights. The layer response model discussed earlier is brief reviewed as following. According to linear gravity wave theory for a gravity wave with period long compared to Brunt-Väisälä period, an expression for a linear density response can be approximately written [1] as

$$\frac{\Delta n}{n_0} \cong -\frac{1}{\gamma - 1}\left(1 + \frac{\gamma H_0}{n_0}\frac{dn_0(z)}{dz}\right)\frac{\Delta N}{N_0} \qquad (1)$$

where
n_0 (z) = sodium density profile in absence of gravity waves,
Δn (z,t) = sodium layer density response,
N_0 (z) = background atmosphere density profile in absence of gravity waves,
ΔN (z,t) = background atmosphere density response,
γ = ratio of specific heats
H_0 = scale height.

The velocity perturbations associated with a gravity wave will induce density perturbations in the sodium. Assuming the diffusion time for sodium is greater than the gravity wave period being considered, the sodium velocity perturbations will be equal to the velocity perturbations in the background atmosphere caused by the passage of this wave. As showed by [1,4], if the wave amplitude is small enough, the term $\Delta N(z)/N_0(z)$ in Eq. 1 can be approximated by $Ae^{z/2H}\cos(\omega t - \mathbf{k.r})$. Also, when the density gradients are large, the sodium layer response will be much larger than atmospheric density response. This is a result of the advection of density gradients. In general, large density gradients will give rise to large “amplification” factors, which imply large perturbations in the density of the minor constituent. In other words, the layer density perturbations and the background atmosphere perturbations are related in Eq.1 by an “amplification” factor that is a function of $1/n_0(z)[dn_0/dz]$. As a result of the sum in the right-hand side of Eq. 1, density perturbations below the layer peak (where $dn_0/dz > 0$) will typically be larger than those above the peak (where $dn_0/dz < 0$). In addition, a phase reversal in the layer response must occurs at the point where $(\gamma H_0/n_0)(dn_0/dz) = -1$. Below this point, atmospheric and sodium density perturbations are 180° out of phase, while above this point these perturbations are in phase. A more accurate representation for layer response, which includes some nonlinear effects, was derived by [4] and is express by

$$\frac{\Delta n}{n_0} = -\frac{1}{\gamma - 1}\left[1 - \frac{(z - z_0)\gamma H_0}{\sigma_0^2}\right]\frac{\Delta N}{N_0} + \frac{1}{(\gamma - 1)^2}\cdot \left[1 - \frac{\gamma^2 H_0^2}{2\sigma_0^2} - \frac{3\gamma H}{2\sigma_0^2}(z - z_0) + \frac{\gamma^2 H_0^2}{2\sigma_0^2}(z - z_0)^2\right]\left(\frac{\Delta N}{N_0}\right)^2 \quad (2)$$

where z_0 and σ_0 are the sodium layer peak and rms width, respectively. The second term in the perturbation series solutions contains the factor $(\Delta N/N_0)^2$ which varies with twice the frequency of the gravity wave. We can observe that the linear layer response is zero whenever $(z - z_0) = \sigma_0^2/\gamma H_0$. This is the point of phase reversal and at this point the layer is completely nonlinear and given by

$$\frac{\Delta n}{n_0} \cong -\frac{1}{2}\left[\frac{\gamma H}{(\gamma - 1)\sigma_0}\frac{\Delta N}{N_0}\right]^2 \quad (3)$$

2. OBSERVATIONS

The lidar installed at São José dos Campos (23°S, 46°W), uses a flashlamp-pumped dye laser tuned to the sodium D2 line by 3 intra-cavity Fabry-Perot interferometers. The transmitted pulse is collimated by a 30 cm parabolic mirror, giving a beam-with of about 0.2 mR. The receiver uses a 76 cm collecting mirror with 3 photon-counting photomultiplier tubes, 2 of which measure the Rayleigh and resonant scattered signals, and the third of which registers the rotational Raman scattering from 15 to 35 km. Figs. 1 and 2 show sodium data collected on July 13-14, 1999, whereas Fig. 3 on August 08-09, 1996 over São José dos Campos, Brazil. These data are compared to the layer response predicted by the theory. Both sets of experimental data show a downward progression of wavelike structures that is typical of gravity waves which is moving the Na density peak downward in time in Figures 1 and 3. Fig. 1 illustrates a special shape in the height-time evolution of the sodium and as can be seen, this plot shows a distinct narrowing followed by a broadening of the layer. The downward velocity was approximately 0.9 m/s. Figure 2 shows the temporal variations in sodium density at selected altitudes through the sodium layer for this night’s data. The mean is subtracted from each curve which is then normalized so that the amplitude of temporal variations appears constant for each altitudes. The diagonal line indicate the apparent phase progression of the wave downward through the layer. The predicted phase reversal is observed to occur in the 92 to 93 km range. The phase reversal near 92-93 km is canceled by the appearance of waves with a temporal period of approximately 50 minutes. Elsewhere in the sodium layer, the wave period is approximately 130 minutes and the vertical wavelength is approximately 9 km. As mentioned earlier, the presence of a second order term in the solution of equation of continuity would explain this double frequency component near the point of phase reversal where the first order term is near zero. In Fig. 3 the height-time evolution of the sodium layer shows a distinct bifurcation that began at 2030 LT and then remain for all period observed.

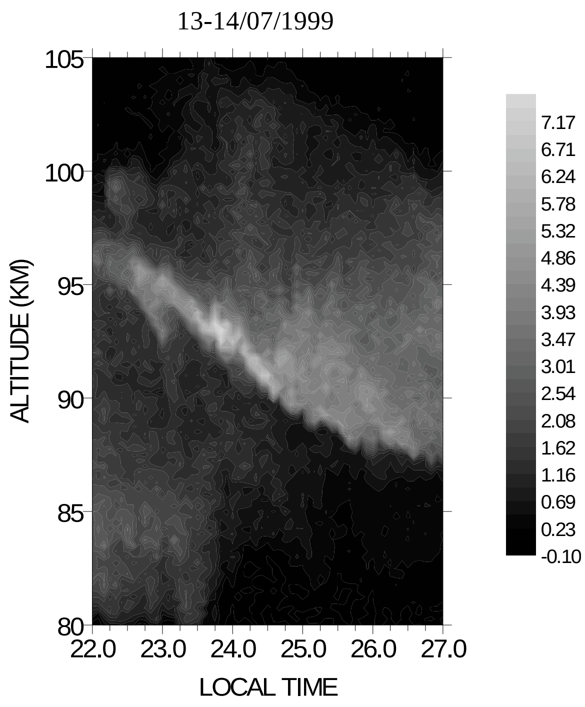

Fig. 1 - Height-time evolution of the sodium layer showing a narrowing followed by a broadening of the layer on July 13-14, 1999. The downward velocity was approximately 0.9 m/s.

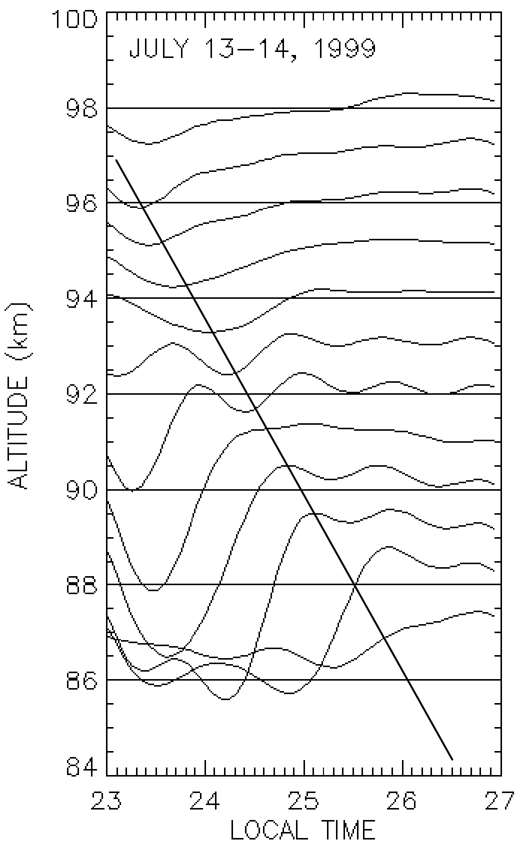

Fig. 2 – Temporal variations in sodium density observed on July 13-14, 1999. Spatial and temporal filter cutofs are at 2.0 km and 40 min, respectively. Diagonal lines indicate the apparent phase progression.

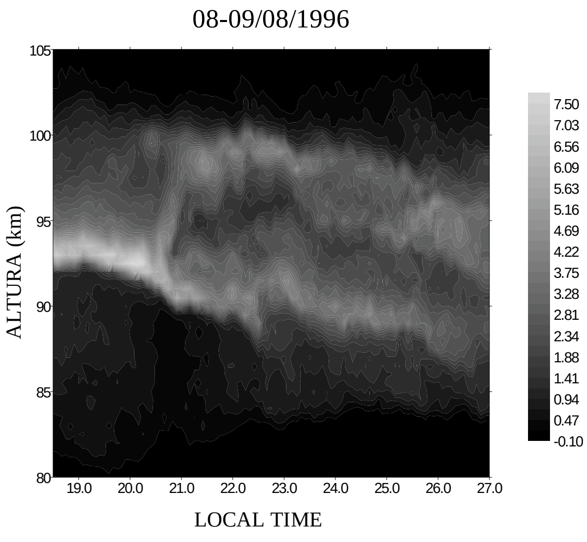

Fig. 3 – Height time evolution of the sodium layer showing an unusual bifurcation in the layer.

3. SUMMARY

In this work we showed some features in the sodium layer as downward progression of wavelike features, periodic changes in thickness and the appearance of bifurcation. In this way, our observations suggest that many of the sodium layer dynamical features are a layer density response to gravity waves. Since the linear layer response is not always adequate to describe gravity wave sodium layer interactions (by linear response, it is meant that the layer density perturbations have the same temporal and spatial frequencies as the gravity wave), nonlinear components of the layer density response must be considered in interpreting sodium lidar data. It is hoped that further examinations of more case studies of sodium morphology will be important to valuable information on the role played by gravity waves on the structures and dynamics of the sodium layer.

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