1. Classification <i>INPE.COM 4(RPE)</i> <i>C.D.U.: 523.4-8</i>		2. Period <i>May 1980</i>	4. Distribution Criterion internal ☐ external ☒
3. Key Words (selected by the author) <i>MESOSPHERE; WINDS; SODIUM,</i>			
5. Report Nº <i>INPE-1811-RPE/179</i>	6. Date <i>June, 1980</i>	7. Revised by <i>Hisao Takahashi</i>	
8. Title and Sub-title <i>MESOSPHERIC WINDS FROM LIDAR OBSERVATIONS OF ATMOSPHERIC SODIUM</i>		9. Authorized by <i>Nelson de Jesus Parada</i> Director	
10. Sector <i>DCE/DGA/GOA</i>	Code <i>30.372</i>	11. Nº of Copies <i>120</i>	
12. Authorship <i>B.R. Clemesha V.W.J.H. Kirchhoff D.M. Simonich P.P. Batista</i>		14. Nº of Pages <i>14</i>	
13. Signature of the responsible <i>R. Clemesha</i>		15. Price	
16. Summary/Notes <i>Laser radar observations of the atmospheric sodium layer, made by various groups of workers during the past decade, have shown that the layer exhibits considerable time-varying structure. In this paper we describe horizontally spaced measurements of this structure, and use the results of these observations to derive horizontal velocities in the height range 82 to 99 km. The measurements were made with a steerable lidar operating at a fixed zenith angle of 20.9° and pointed at each of three azimuths in turn, the complete sequence taking 5 minutes. The azimuths were chosen such that the intersections of the lidar beam with the sodium layer formed a triangle with approximately 60 km sides. We present here analysis of a 10 hour data run taken on the night of July 21, 1979. After low pass filtering to remove rapid uncorrelated fluctuations, a cross-correlation analysis was carried out for each of the height intervals in the range 82 to 99 km. The velocities calculated from the derived time shifts were found to vary with height in an oscillatory manner, with amplitude increasing with height. The E-W component showed a vertical wavelength of approximately 10km, the N-S component a wavelength of 5 km, and the magnitude of the velocity varied between 6 and 146 m s⁻¹.</i>			
17. Remarks <i>This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico (FNDCT)", Brazil, under contract FINEP-537/CT.</i>			

MESOSPHERIC WINDS FROM LIDAR OBSERVATIONS OF ATMOSPHERIC SODIUM

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Abstract. Laser radar observations of the atmospheric sodium layer, made by various groups of workers during the past decade, have shown that the layer exhibits considerable time-varying structure. In this paper we describe horizontally spaced measurements of this structure, and use the results of these observations to derive horizontal velocities in the height range 82 to 99 km. The measurements were made with a steerable lidar operating at a fixed zenith angle of 20.9° and pointed at each of three azimuths in turn, the complete sequence taking 5 minutes. The azimuths were chosen such that the intersections of the lidar beam with the sodium layer formed a triangle with approximately 60 km sides. We present here the analysis of a 10 hour data run taken on the night of July 21, 1979. After low pass filtering to remove rapid uncorrelated fluctuations, a cross-correlation analysis was carried out for each of the height intervals in the range 82 to 99 km. The velocities calculated from the derived time shifts were found to vary with height in an oscillatory manner, with amplitude increasing with height. The E-W component showed a vertical wavelength of approximately 10 km, the N-S component a wavelength of 5 km, and the magnitude of the velocity varied between 6 and 146 m s^{-1} .

Introduction

Optical tracking of sodium and TMA trails has been used by numerous workers to measure the motion of the neutral upper atmosphere. The existence of irregularities in the natural atmospheric sodium layer suggests that lidar observations of this layer could be used to measure upper atmospheric winds. The purpose of this paper is to present a preliminary analysis of some measurements made to this end. The basic idea is to measure the time varying vertical profiles of atmospheric sodium at three different positions, and to measure the time lags between the occurrence of similar variations at the different measuring points. The technique is similar in principle to that first applied to the measurement of ionospheric drifts by Mitra (1949).

Irregular structure in the sodium layer has been reported by a number of workers (Blamont et al., 1972; Kirchhoff and Clemesha, 1973; Thomas et al., 1977; Rowlett et al., 1978), and this structure has been observed to propagate vertically downwards. Thomas et al (1977) have made horizontally spaced observations using a steerable lidar, but although they report horizontal gradients and, in an earlier paper (Thomas et al., 1976), vertical oscillations in the layer, they do not appear to have attempted to measure horizontal motions. In an earlier paper (Clemesha et al., 1980) we reported horizontally spaced observations of a natural sodium cloud of exceptionally high density, and these observations were used to determine its velocity and direction of motion. The observations reported in Clemesha et al. (1980) were part of a series of measurements made in order to determine whether regular observations of winds in the 80 to 100 km region could be made

by this method. In this paper we present a preliminary analysis of a single night's observations. We have restricted this investigation to an analysis of horizontal motions, and have not studied vertical propagation effects.

Results and Discussion

The observations were made with a steerable lidar operated at a zenith angle of 20.9° , and pointed at three azimuths in sequence. The corresponding positions of the three measuring points are shown for a height of 90 km in Figure 1. Each lidar profile took 1.33 min, so that a sequence was completed every 5 min. The signal returns from the sodium layer were recorded in sixteen 2-km range intervals, variations in atmospheric transmission were compensated by monitoring the Rayleigh scattering from the stratosphere, and short term fluctuations in the spectral output of the laser were allowed for by monitoring the output of a sodium scattering cell. Further details of the lidar system are given in Simonich et al (1979). The observations analysed here were made over a 10-hr period on the night of 21-22 July, 1979.

In Figure 2 we show an example of density variations observed at the three measuring positions at a given height, in this case 87.8 km. It is clear that rapid fluctuations in sodium density are not well correlated between the three positions. It should be pointed out that, at least in the case of the larger amplitude variations, the rapid fluctuations represent real density changes, and not just measurement noise. That this is the case is shown by the fact that the rapid variations are significantly correlated between adjacent height intervals for the same measuring position.

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In Figure 2 we show an example of density variations observed at the three measuring positions at a given height, in this case 87.8 km. Note that in Figures 2 and 3 the densities for positions 1 and 2 have been displaced vertically to avoid confusion between the curves. The sample error bars shown in Figure 2 represent the statistical uncertainties in the photon counts registered by the lidar receiver. It is clear that rapid fluctuations in sodium density are not well correlated between the three positions. It should be pointed out that, at least in the case of the larger amplitude variations, the rapid fluctuations represent real density changes, and not just measurement noise. That this is the case is shown by the fact that the rapid variations are significantly correlated between adjacent height intervals for the same measuring position.

In Figure 3 we show the same data as in Figure 2, except that we have removed variations having periods less than about 1 hr by taking a 19 point running mean, and we show the variation for the whole night. A high degree of correlation between the variations at the different measuring positions is now visible, and it is clear that the variations at position 1 lag behind those of positions 0 and 2.

The results of a time-lagged cross-correlation analysis of the variations shown in Figure 3 are given in Figure 4. The time lag between the density variations at position 1 and those at positions 0 and 2 can be seen to be approximately 30 min, and the maximum correlation is 0.95. If we now assume that the time lags are due to the horizontal translation of spatial irregularities in the sodium layer we can determine their velocity and direction of motion. To do this we find the apparent velocities between two pairs of measuring points, simply equal to the separation divided by the time lag, and then determine the velocity vector consistent with these apparent velocities. In doing this we have to assume unchanging isometric irregularities; unfortunately the analysis techniques developed by Briggs et al. (1950) and Phillips and Spencer (1955), to deal with anisometric irregularities which suffer random changes, require longer data samples than we have available.

An analysis of the type described above was applied to the data for ten height intervals between 82.2 and 99.0 km, and the results are shown in Figure 5, where we show the calculated velocities in the form of eastward and northward components as a function of height. As can be seen from Figure 5 the derived velocities generally increase with height in an oscillatory manner, characteristic of tidal or gravity wave oscillations measured by other techniques. The fact that the winds

should represent an average over the ten hour data run suggests that they are tidal in origin. The vertical wavelength of about 10 km visible in the E-W component roughly corresponds to the $\theta_3^{\omega,1}$ component of the solar diurnal tide expected at our latitude, and the 5 km wavelength of the N-S component corresponds to the $\theta_5^{\omega,1}$ oscillation. It should be pointed out that, in view of the fact that our vertical sampling interval is only slightly less than 2 km, there must be some doubt attached to the validity of the 5 km wavelength.

From the analysis presented here it is not clear whether the correlated variations are the result of the horizontal translation of spatial irregularities moving with the wind velocity, or whether we are seeing the propagation of a wave. In a more detailed analysis we hope to determine how the calculated velocity depends upon the period of the correlated oscillation, and its relationship to the velocity with which oscillations propagate vertically, and in this way to obtain some clue as to their nature.

Conclusions

The results of this preliminary analysis appear to show that the method is capable of measuring horizontal motions in the 80 to 100 km region. Data of the sort analysed here is available for 19 nights of the winter of 1979, and a more thorough analysis using more sophisticated numerical filtering techniques is in progress.

Acknowledgements. This work was partly supported by the Fundo Nacional de Desenvolvimento Científico e Tecnológico under contract FINEP-537/CT.

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Figure Captions

- Fig. 1. Locations of measuring positions.
- Fig. 2. Sodium density variations at 87.8 km for the night of 21-22 July, 1979.
- Fig. 3. 19 points running mean of 87.8 km density variations for the night of 21-22 July, 1979.
- Fig. 4. Time lagged cross correlations of data shown in Figure 3.
- Fig. 5. Northward (N) and Eastward (E) velocity components versus height for the night of 21-22 July, 1979.

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Fig. 4. Time lagged cross correlations of data shown in Figure 3.

Fig. 5. Northward (N) and Eastward (E) velocity components versus height for the night of 21-22 July, 1979.