AN INVESTIGATION OF LONG-PERIOD OSCILLATIONS IN BACKSCATTER RANGE AS SEEN BY THE SANAE SUPERDARN RADAR

E. Mravlag[(1)] and A. D. M. Walker[(2)]

[(1)]Space Physics Research Institute, University of KwaZulu-Natal, Durban 4041, South Africa, Email: mravlag@ukzn.ac.za

[(2)]As [(1)] above, but Email: walker@ukzn.ac.za

ABSTRACT

Oscillations in backscatter range with periods of the order of 1 to 2 hours are routinely observed with the SANAE SuperDARN radar in Antarctica. They usually appear in mid-range, 1000 to 1500 km from the radar as a narrow band of backscatter, mostly during the day time. Their amplitude can reach about 1000 km peak to peak and they usually persist for several hours at a time. A one-dimensional simulation of the ray paths through the ionosphere along the magnetic meridian has been carried out. The results indicate that internal gravity waves generate horizontal electron density fluctuations in the E-region which lead to a tilt of the ionosphere at the point of entry of the radar energy.

INTRODUCTION AND OBSERVATIONS

During the last few years the SuperDARN network of HF ionospheric radars has become a major contributor to the ionospheric monitoring effort. SuperDARN is ideal for monitoring the high-latitude ionosphere on a continuous basis, as the radars have a large field of view and are almost all deployed in pairs, overlooking the same area. This allows the derivation of 2-dimensional velocity vectors for the ionospheric convection, thus enabling true convection vectors to be derived. All radars are of identical design, using the frequency band between 8 and 20 Mhz. The antenna array consists of 16 antennae, which are operated as a phased array, producing 16 beams of about 3.3 degrees width, aligned to the magnetic meridian. Under good conditions return signals from a distance larger than 3000 km can be detected. Thus a field of view of about 4 million square kilometres can be monitored continuously. For a detailed description of SuperDARN and the radar operations see references [1]-[3].

In this paper we report on long-periodic oscillations in backscatter range as they are routinely observed by the South African SuperDARN radar at SANAE in Antarctica. Typical examples of these oscillations can be seen in Fig. 1. As is clearly visible, these oscillations usually appear during the daytime as narrow bands of backscatter and persist for several hours more or less coherently, though generally there will be gaps during these hours. They are observed at mid-range, i.e. approximately 1000 – 2000 km from the radar site, with peak-to peak amplitudes of up to 1000 km. Their periods are generally in the range of 1 to 2 hours. On 10 March 1998 (LHS of Fig. 1) we observe these oscillations from about 8:00 UT to about 16:00 UT in the 20 to 40 range bin band, which corresponds to a range from 1100 to 2000 km. As seen on 16 October 2002 (RHS of Fig. 1) there are often two bands of oscillations, which can be either in phase or out of phase. There appears to be a tendency of these oscillations to be seen during the austral summer months,

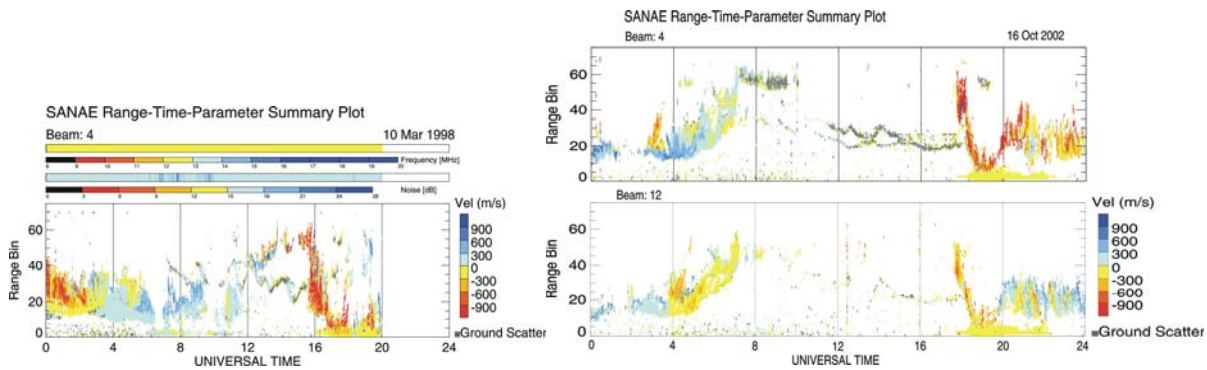

Fig.1: Two typical examples of the long-periodic oscillations in backscatter range as seen by the SuperDARN radar at SANAE. The figure shows the line-of-sight Doppler velocity of the ionospheric irregularities as seen by the indicated beam of the radar. Note the narrow oscillationg backscatter bands of backscatter during the day time.

though examples at other times during the year do exist. Mostly these oscillations show low Doppler velocity and spectral widths and are thus labelled ground scatter by the standard analysis software for radar data.

THEORY AND DISCUSSION

The above observations suggest that these oscillations are indeed ground scatter, with the change in backscatter range due to internal gravity wave activity at the bottom of the ionosphere. These gravity waves are thought to modify the ionopsheric density in such a way that the reflection on the ground of the rays takes place at different backscatter ranges.

Order of magnitude calculations, using the March 8 event with the (wrong) assumption of specular reflection, show that vertical oscillations of the reflection point appear too large to be physically realistic. In a similar way, horizontal oscillations of the point of reflection lead to unphysical amplitudes. However introducing a small tilt of the ionosphere at the point of entry of the ray produces large changes of the backscatter range with very small tilt angles. These can be produced by intorducing a horizontal density gradient, which will tilt the curves of constant density with respect to the undisturbed ionosphere.

In order to verify this contention a simple ray tracing model has been used to check on the ray paths. We used the equations given by K. G. Budden [4] for a collisionless ionosphere to simulate the ray path. We assumed Earth and ionosphere to be flat, a constant magnetic field, a bi-parabolar density distribution in the ionosphere, and we calculate the ray path in the magnetic meridian. In addition, the ionosphere is taken as constant during the time it takes the ray to traverse it to the reflection point and back to the receiver. With these assumptions the relevant equations are

$$\partial x/\partial t = c/\mu^2 \{\mu\sin\theta - \cos\theta\, \partial\mu/\partial\theta\}$$
$$\partial z/\partial t = c/\mu^2 \{\mu\cos\theta + \sin\theta\, \partial\mu/\partial\theta\}$$
$$\partial\theta/\partial t = c/\mu^2 \{\sin\theta\, \partial\mu/\partial z\},$$

where x and z are the horizontal and vertical coordinates, t is the time, μ the refractive index function, θ the angle between the ray and the magnetic field and c the speed of light.

The results for this exercise are shown in Fig. 2. We used the example of Fig. 1 (10 March 1998) to extract the parameters for the ray paths we wish to investigate. These are a backscatter range of 1500 km before the ionosphere is disturbed, and ionospheric densities as determined by model ionospheric profiles for the day, i.e. electron densities of 7×10^{10} m^{-3} at 115 km altitude for the E-region and 3.8×10^{11} m^{-3} at 260 km for the F-region. Entry into the ionosphere is at 90 km. In addition we use a constant magnetic field of 1.1×10^{-4}T, which is 9° inclined to the vertical.

Geometrical considerations immediately determine that the angle of incidence of the ray under these circumstances is very large, thus a very small disturbance of this angle should have a large effect on the backscatter range. This is indeed obvious in Fig. 2. If the ionosphere is tilted by just $\pm3^o$ wrt. to the horizontal the resulting ray paths change their backscatter range rather dramatically. If the ionospheric tilt oscillates with a period of 1 to 2 hours, this would result in exactly the oscillations we see with the radar. From the figure it is also clear that the rays reflect well below the E-region density maximum. This altitude of the reflection region is well within the region disturbed by internal gravity waves, which are thus the likely cause of these oscillations.

There is, however, one small problem to consider. Neither the Earth nor the ionosphere are flat. This introduces a number of problems some of more import than others. The first of these problems and probably the most serious one is the fact that due to the curvature of the Earth (and ionosphere) the angle of incidence must be significantly smaller than before. Otherwise the reflected ray will miss the surface of the Earth and thus not be detectable. This in itself means that the reflection region in the ionosphere will now be at a larger altitude than before. This is clearly demonstrated in Fig. 3, which shows the ray paths for a small ionospheric tilt at the point of entry. This tilt angle decreases linearly with altitude and vanishes for altitudes above the density maximum in the E-region, in Fig. 3 at 115 km altitude.

A second important observation from Fig. 3 is that the maximum altitude reached by the rays is now much larger, which means that the rays are reflected well above the E-region density maximum. At these altitudes internal gravity

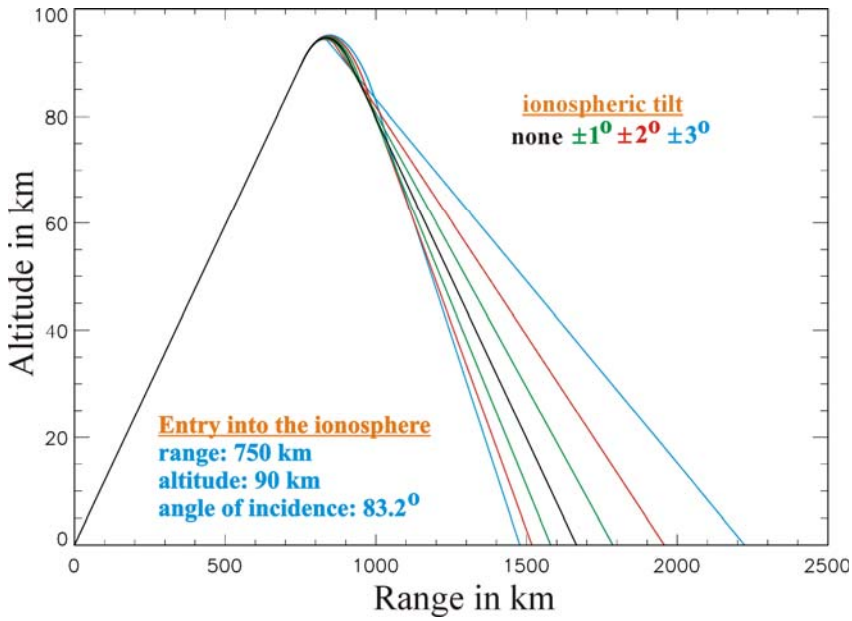

Fig. 2: Change in backscatter range for a small ionosphere tilt as given by the simple ray tracing model used. NOTE: The vertical scale is largely exaggerated for clarity.

waves either do not exist at all or have very small amplitudes. Thus they should not be able to drive these disturbances directly. However, in the results shown in Fig. 3 the ionospheric tilt does not influence the upper layers of the ionosphere as the tilt angle becomes 0 above 115 km. Thus gravity waves disturbing the E-region can still be responsible for the phenomena observed.

A further result of the calculations is shown in Fig. 4, which depicts the ray paths in dependence of the angle of departure of the ray and thus the angle of incidence at the point of entry into the ionosphere. As is clearly demonstrated, only a small range of angles is permitted with rays outside this range either penetrating the ionosphere into space or being reflected from far too large ranges. As can be seen the permitted range yields a spread in backscatter ranges of about 300 to 400 km, which translates into 5 to 10 ranges bins of the radar data. This is exactly what is seen in Fig. 1, where the range oscillations are seen in a narrow band of backscatter, around 5 to 8 range bins wide.

The simplest mechanism providing for an ionospheric tilt would be a fluctuation in density, which tilts the contours of constant density with respect to the undisturbed ionosphere. Such density fluctuations can be generated by various

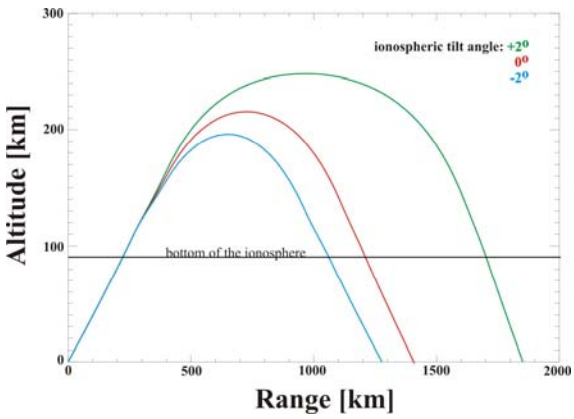

Fig. 3: Ray paths for a small ionospheric tilt at the point of entry which diminishes linearly such that it becomes 0 at the altitude of maximum density in the E-layer. The abscissa is the length of arc from the radar site to the point of reflection at ground level.

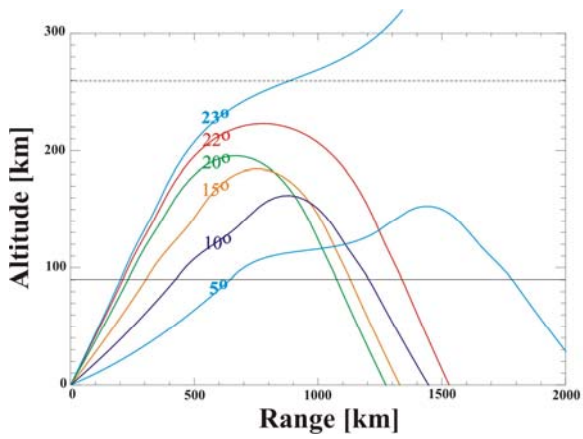

Fig. 4: Ray paths for various angles of departure and thus angles of incidence on the ionosphere. Note that the range of permitted angles is very small. The 2 horizontal lines indiacte the bottom of the ionosphere and the altitude of the F-region density maximum, resp.

processes, amongst them heat input from any dissipating wave activity. Internal gravity waves can generate reversible temperature changes in the E-region (C. O. Hines [5]). In his paper values of up to ±30 K at 120 km altitude are mentioned. Together with a temperature at that altitude of about 350 K this amounts to temperature changes of the order of ± 8.5%. Under the assumption of adiabatic conditions this would lead to a reversable density fluctuation of ±15%. Using geometrical considerations we can argue that this is more than sufficient to produce a 2° tilt of the ionosphere at the point of entry of the ray. Thus we can attribute the oscillations observed to ground scatter being reflected at the ionosphere in regions where the density distribution has been modified by gravity waves with the seen period.

CONCLUSION

Oscillations in backscatter range have been observed by the SANAE SuperDARN radar. These manifest themselves as narrow bands of backscatter, the range of which oscillates with a period of 1 to 2 hours and peak-to-peak amplitudes of up to 1000 km. They appear in midrange (1000 to 2000 km), usually during the daytime.

A simple ray tracing model for a curved Earth and ionosphere was used to show that these oscillations can be reproduced by intorducing a small tilt of the ionosphere at the point of entry and exit of the ray. Due to rather large angles of incidence, only very small tilt angles of the order of 2 to 3° are required to produce the observed changes in the backscatter range of the rays as shown in Fig. 3. At the same time the fact that only a narrow range of angles of departure (incidence) is permitted by the ionosphere clearly demonstrates that we will receive backscattered energy from a narrow band of ranges only, which agrees with the obsergvations.

We contend that the horizontal density fluctuations are produced by gravity waves depositing their energy into the bottom of the ionosphere. These waves will produce temperature fluctuations in the E-layer which in turn will lead to density fluctuations. Using values quoted in the literature [5] and the assumption of adiabatic processes, density fluctuations of up to 15% appear to feasible. From these we can derive tilt angles in the 2 to 3° range depending on the exact ray path geometry.

ACKNOWLEDGEMENTS

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