Indian Journal of Radio & Space Physics
Vol. 15, October & December 1986, pp. 192-196

# The Winter Anomaly of Ionospheric Absorption—A Historical Survey

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Increased non-deviative ionospheric absorption on individual winter days has been observed by different ground-based measurements. Apparently it is caused by increased electron density in the D-region. The aeronomic origin has been confirmed by in situ measurements on board rockets. Although many features of the winter anomaly are known no full theory is available yet. Alternatively the enhanced electron density has been explained by particle precipitation.

## 1. Introduction

Almost 50 years ago Appleton[1] remarked in his paper, Regularities and Irregularities of the Ionosphere, that the diurnal and seasonal variation of the non-deviative absorption of radio waves in the ionosphere cannot be described by a unique law. Theoretically the loss L suffered by radio waves in the D-region should be $L\chi = L_0\cos^2\chi$ where $\chi$ is the solar zenith angle and $L_0$ is the loss at $\chi = o$ (sun in the zenith), assuming a Chapman layer and constant collision frequency. Measurements have shown (Bert & Ratcliffe)[2] that the diurnal variation can be described by $L\chi = L_0 \cos^n\chi$, where n varies between 0.5 and 1.0 with a medium value of 0.75 for middle latitudes. The seasonal variations, however, cannot be described by a linear function of $\cos^n\chi$, regardless of the value of n. Whereas the observed values of $L\chi$ in spring, summer and autumn may correspond to a linear law, the experimental values in winter are considerably higher than the theoretical ones. This was termed: winter anomaly of absorption. For practical purposes (prediction of propagation) formulae with variable factors and exponents have been devised by analysing observed propagation characteristics[3]. Not til 1951 it was shown by Lange-Hesse [4,5] that the high median value of absorption in winter is, to a large extent, caused by days or groups of days with excessive absorption and, using the rigorous methods of Bartels he demonstrated that these effects did not show a correlation to solar or magnetic events. No similar seasonal effects were observed at Singapore in the equatorial belt. These findings were fully confirmed later by Appleton and Piggott[6].

In the meantime Dieminger and Hoffmann-Heyden , using an ionosonde with improved sensitivity, reported about echoes below 100 km predominantly on winter days with excessive absorption. Dieminger[8] showed that during a period of 20 days, low echo heights were correlated with high absorption values. Because of the absence of any correlation with solar and magnetic events, Dieminger [8] conjectured that the structure of the atmosphere itself changes from day to day in a way that the distribution of electron density in the height range below 90 km varies considerably. The stratospheric warmings discovered by Scherhag[9] just before were mentioned in that context.

## 2. Ground-based measurements

A big step forward in the knowledge of electron distribution in the D region was achieved by the partial reflexion method introduced by Gardner and Pawsey[10] in 1953. This method yields electron density profiles by observing the amplitude ratio of the ordinary and the extraordinary components of reflected radio wave. Its accuracy has been increased considerably by Belrose, Bode, Hewitt and Griffin[11]. Its general application on a worldwide basis was hampered, unfortunately, by the great expenditure of the equipment and of the data reduction procedure.

The partial reflection method may be considered a modification of the so-called $A_1$ method, the measurement of the amplitudes of pulses reflected from the ionosphere. This method, however, does not give electron density profiles but the integral value of absorption suffered by the radio wave on the way to the point of reflexion and back, provided the deviative absorption in the reflecting layer is negligible. This method has been devised originally by the group at Slough and used by a number of stations elsewhere. Because fully automatic measurements are somewhat difficult, the number of $A_1$ stations operating on a routine basis was and is much less than the number of ionosondes.

The least expensive method, called $A_3$, is the measurement of the field strength of sky wave signals at short distance and oblique incidence on frequencies suitable for obtaining absorption data. This method was developed to a high degree of perfection at Lindau[12]. The $A_2$ method (measurement of galactic noise), which is very useful in observing big effects especially in the auroral zone, is less appropriate for the less severe effects of the winter anomaly. The least accurate method is the use of $f_{min}$ values from ionograms. They may be affected considerably by interference and by improper function of the equipment. Details of the different methods may be found in the Manual on Ionospheric Absorption Measurements[13].

In contrast to the dense network of vertical incidence ionosondes, n equivalent network of accurate absorption measurements was obtained even in IGY and IQSY periods. Nevertheless many features of the winter anomaly of absorption were revealed by ground-based observations. They may be summarized as follows: 1.) The increase of absorption of radio waves is the result of an increase of the electron density in the height range between 60 and 90 km. 2.) The winter anomaly consists of two components: the absorption in winter is generally higher than derived from the $\cos^n\chi$ law. There are superimposed days or groups of days with excessive absorption. 3.) The winter anomaly is strictly a seasonal effect: it occurs in November - February in the northern hemisphere and in May - August in the southern hemisphere. 4.) It is limited to latitudes between 35° and 60° with a maximum at 55°. It becomes less frequent and less intense towards lower latitudes and merges in auroral effects beyond 60°. 5.) Its longitudinal extent is restricted to a few 100 up to 2000 km. 6.) As to its origin, it was conjectured that it is controlled by "meteorological" changes on the structure of neutral atmosphere[8] or by ionization by precipitated high-energy particles.

## 3. In situ measurements

A test of these hypotheses was possible only by simultaneous in situ measurement of the pertinent aeronomic parameters. Since balloons are restricted to heights up to 40 km and satellites of a reasonable lifetime can move only above 100 km, the only possibility was the use of rockets with an apogee of 90 - 100 km. The first nearly simultaneous rocket measurements of D-region electron densities, neutral temperatures and winds on an anomalous winter day were made by Sechrist, Mechtly, Shirke and Theon[14] at Wallops Island, Virginia. The electron density was measured by an electron current probe at the tip of the payload with a height resolution of 0.1 km. The dc probe current was calibrated by the electron density data obtained by a radio propagation experiment observing Faraday rotation and differential absorption. Neutral temperatures and winds were measured by a grenade experiment and by ARCAS meteorological rockets. The results supported the meteorological hypothesis of the winter anomaly. Measurements of D-region electron density have also been made by the Aberystwyth group (Beynon and Williams[15], Beynon et al.[16], Dickinson et al.[17]). A large number of coordinated experiments have been made during the Western Europe Winter Anomaly Campaign 1975/76. A special issue of Journal of Geophysics-Zeitschrift für Geophysik was devoted to the description of experiments and results[18]. The following measurements were made in situ: Electron density by a guard ring sonde[19] and by retarding potential analyser[20], ion composition and density by cryopumped mass spectrometer[21], ion density, mobility and conductivity by Gerdien condensor[19], neutral gas density by pitot tube[22], ion gauge[22] and falling chaff[19], neutral composition by mass spectrometer[23], NO by filter photometer[24], $O_2(^1\Delta g)$ by infrared radiometer[25], atomic oxygen by 5577 Å filter[26], Ly-α by ionization chamber[27], X-rays by 0.1-60 Å spectrometer[28], temperature by pitot tube[22], ion Gauge[22] and retarding potential analyser[20], winds by falling chaff[29] and lithium trail[30], energetic electrons by solid state detector[27]. The electron density was also derived from radio propagation and Faraday rotation[31].

Wind, pressure and temperature were measured by conventional balloon sondes up to 35 km and by rockets up to 95 km[18]. Simultaneous ground-based measurements such as ionosondes, absorption by the $A_3$ method, meteor wind, incoherent scatter, photometer and magnetometer observations were made on 10 stations in Western Europe[18].

The results, obtained during the period 1974-1978 have been summarized by Offermann[18], screening 159 papers, as follows:

1.) The correlation between enhanced radio wave absorption as measured from ground and electron density determined in situ has been confirmed. Density increases of more than an order of magnitude are found frequently. They occur in the region 75-95 km with maximum enhancement near 80-93 km.

2.) High $NO^+$ densities are found at all winter anomaly events. They are attributed to strong enhancements of neutral NO concentration around the mesopause. $O_2^+$ produced by photoionization of $O_2\,(^1\Delta g)$ seems to contribute up to a factor of 10 more to the ion production rate than expected theoretically. It may be a source as important as $NO^+$ in the ion production on winter anomalous days.

3.) The altitude level of equal density of $NO^+$ and water cluster ions is lowered from 83-85 km on normal days to about 77 km or less on anomalous days.

A number of processes have been brought in order to explain the observed features of the increased absorption such as temperature increase in the D-region, horizontal and vertical transports of minor constituents and turbulence. No clear picture of the importance and interaction of the different processes, explaining satisfactorily all facets of the phenomena, has been established so far.

## 4. Alternative hypothesis

Doubts have been advanced by some authors[32,33,34,35,36,37,38] if the winter anomaly is being produced by aeronomic changes at all, or if precipitation of medium energy particles is responsible. As a matter of fact correlations have been observed between enhanced absorption and magnetic variations accompanying SID's, ionospheric storms, storm after-effects and PCA's. But they differ distinctly from the phenomenon called winter anomaly, characterized by a regular diurnal $\cos^n\chi$ variation and by its occurrence exclusively in the winter hemisphere. Putting together, however, all absorption effects in the analysis, the weight of the particles effects simulates a correlation of the entirety (see also [39]). Moreover, no energetic particles flux of sufficient intensity was discovered during a distinct winter anomaly effect[27].

**Acknowledgement**

The author is very indebted to Dr. H. Schwentek for valuable discussions.

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