An A3 investigation of the effect of geomagnetic activity on radio wave absorption in the equatorial region

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Results from A1 investigations of ionospheric radio wave absorption in the equatorial region do not reveal any relation with absorption and geomagnetic activity. Presently investigation on the influence of geomagnetic activity at 1000 hrs LT has been carried out in the equatorial region using the A3 method. The results obtained do confirm that geomagnetic activity has no significant effect on the equatorial HF radio wave absorption. They also seem to indicate that geomagnetic activity does not influence ionization in the lower F- and E-regions of the equatorial zone.

1 Introduction

The dependence of ionospheric radio wave absorption at auroral latitudes on geomagnetic activity has been clearly established. It is also known that the ionization in the D-region as a result of particle precipitation leads to the increased absorption. According to Ranta and Ranta, the effect of the precipitation is limited only to the D-region with no effect on foE and foF2. For the midlatitude zone, Bourne and Hewitt have shown, from a statistical analysis of medium frequency absorption data, that there is a positive short-term correlation between absorption and magnetic activity. The increase in the radio wave absorption does not occur on the storm day, but 3-5 days after the storm. According to Huang and Cheng during magnetic storms, the auroral ionosphere is heated up. This heating of the auroral latitude spreads to low latitudes through the launching of atmospheric gravity waves which propagate equatorward and produce periodic perturbation in the electron density. Given the results of Piggott and Bourne and Hewitt as well as the periodic perturbation of electron densities in the low latitude during a magnetic storm, it was decided to analyse the absorption data obtained at 4.87, 6.09, and 15.40 MHz at 1000 hrs LT at Lagos (3.40°E, 6.55°N) using the A3 method given by Schwentek.

2 Experimental method

2.1 Field strength measurement

To achieve a reliable programme of field strength measurements, a set of preliminary field strength measurements was carried out using an Eddystone communication receiver model 183011, BBC servogor 200 chart recorder and a horizontal half-wave dipole antenna of span 50.0 m placed 18.0 m above the ground. The dipole antenna is aligned along the magnetic meridian to minimize the effects of wave polarization. The preliminary measurement for this work began in September 1990 and ended in March 1991. During this period the following circuits (Fig. 1) were established:

(i) Accra-Lagos (3.366 MHz; Ghana Broadcasting Corporation)
(ii) Cotonou-Lagos (4.87 MHz; Radio Cotonou)
(iii) Lome-Lagos (5.047 MHz; Radio Diffusion de Lome)
(iv) Enugu-Lagos (6.025 MHz; FRCN, Enugu)
(v) Kaduna-Lagos (6.09 MHz; FRCN, Kaduna)
(vi) Ascension Island-Lagos (15.04 MHz; BBC African Services)

An additional circuit, Libreville-Lagos (9.60 MHz; African No. 1), was added to the number of circuits which were being used after experimental measurements had begun in April 1991. The Accra-Lagos and Enugu-Lagos circuits had to be discontinued because of unfavourable propagation conditions resulting from excessive absorption along the two circuits during the chosen time of measurement. The transmitting stations on the circuits that were retained have consistent broadcast timetables and satisfied the A3 method conditions.
Table 1—Transmission data

<table>
<thead>
<tr>
<th>Transmitter location</th>
<th>Geographical coordinates</th>
<th>Frequency MHz</th>
<th>Hours of transmission hrs LST</th>
<th>Type and orient. of trans. antenna</th>
<th>Output power kW</th>
<th>Ionospheric point coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotonou</td>
<td>2.43°E 6.35°N</td>
<td>4.87</td>
<td>0600-1005 1700-0100</td>
<td>Log periodic Horizontal</td>
<td>50</td>
<td>2.90°E 6.45°N</td>
</tr>
<tr>
<td>Lome</td>
<td>1.20°E 6.27°N</td>
<td>5.047</td>
<td>0600-1005 1700-0100</td>
<td>Log periodic Horizontal</td>
<td>50</td>
<td>2.30°E 6.40°N</td>
</tr>
<tr>
<td>Kaduna</td>
<td>7.50°E 10.50°N</td>
<td>6.09</td>
<td>0530-2305</td>
<td>Half-wave non-directional</td>
<td>100</td>
<td>5.45°E 8.52°N</td>
</tr>
<tr>
<td>Libreville</td>
<td>9.45°E 0.38°N</td>
<td>9.60</td>
<td>0530-2305</td>
<td>Half-wave</td>
<td>200</td>
<td>6.43°E 3.47°N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.92°E 5.01°N</td>
</tr>
<tr>
<td>Ascension</td>
<td>-14.37°E -0.70°N</td>
<td>15.40</td>
<td>0800-0915</td>
<td>Half-wave</td>
<td>200</td>
<td>-5.45°E 2.93°N</td>
</tr>
<tr>
<td>Island</td>
<td>-7.95°N</td>
<td></td>
<td>1000-1230 1600-2400</td>
<td></td>
<td></td>
<td>-1.05°E 2.93°N</td>
</tr>
</tbody>
</table>

Table 1 shows the geographical coordinates of the transmitting stations. The receiving station, Lagos, has geographical coordinates 3.40°E, 6.55°N. The coordinates of the ionospheric point of each circuit is also shown in Table 1. Table 1 shows that the available transmitters lie within a range of latitudes and longitudes with the circuits having different geographical coordinates for their ionospheric points. Now, according to Serafimov et al., radio wave of different frequencies for multi-frequency A3 technique should be transmitted from one and the same site, in which case the geographical coordinates of the ionospheric points of the circuits will be the same. And as such, the ionospheric points will have the same local mean time. But, given the location of the transmitters (Table 1) and that of the receiving station, Lagos, the ionospheric points of all circuits will not be at any reference local mean time simultaneously. This situation necessitated the measuring of field strength on all the circuits within...
ten minutes of a reference time, which is 1000 hrs LMT. This hour was chosen as the reference local mean time, because two of the transmitters, Cotonou and Lome, go off the air at about 1005 hrs LMT.

It must be expected that the inability to measure the signal strength simultaneously on all the circuits would introduce some errors into the data. But observations and analysis show that the time range of measurement did not affect the absorption data much, because it was found that absorption on the two circuits, Libreville-Lagos and Kaduna-Lagos, which require correction, did not quite vary during the time range. The typical percentage correction in the absorption data was about 8.0±3.0%, which was fairly small. The absorptions on these two circuits were nevertheless corrected using correction curves generated from absorption data measured on the said circuits. It must be mentioned that, given that the correction for the circuits is fairly small, its seasonal or other variations may not be important.

2.2 Determination of absorption

The determination of absorption at any particular time for any circuit requires: (i) the determination of the possible modes of propagation, and (ii) the determination of the field strength only of the same for both daytime and nighttime, is given as

\[ L(t) = 20 \log \frac{E(n)}{E(t)} \text{ dB} \quad \ldots (1) \]

When the heights of reflection are different for daytime and nighttime propagation, absorption is deduced from the relationship

\[ L(t) = 20 \log \left[ E(n)S_kk_n - E(t)S_f \right] \text{ dB} \quad \ldots (2) \]

where, \( E(n) \) is the nighttime field strength when there is no absorption, \( E(t) \) the daytime field strength, \( S^\prime \) the half path length of propagation, and \( n \) and \( t \) represent nighttime and daytime, respectively. The factors \( k_n \) and \( k_n \) are calculated from the relative gains of the transmitting and receiving antennas, respectively, in the direction of the dominant mode for daytime and nighttime propagation. The absorption determined using Eqs (1) and (2) is better defined as absorption value relative to the mean nighttime levels. This definition is based on the incidences of low nighttime absorption which has been reported earlier. The low nighttime absorption is due to the absence of direct solar radiation. The small night ionization responsible for low level absorption, especially, in the F-region is possibly maintained by the influx of magnetospheric particles, or geocoronaically scattered He-II 30.4 nm radiation which according to Rishbeth is sometimes regarded as a strong source of F-layer. The value of \( E(n) \), which is used in Eqs (1) and (2) as a reference field strength, is determined as accurately as possible from statistical analysis of individual days’ nighttime signal strength recorded throughout the duration of measurements.

Equation (1) was used to determine absorption for 15.40 MHz, while Eq. (2) was used to determine the absorption for 6.09 and 9.60 MHz for which the application of their respective transmission curves on ionograms showed that, though the radio waves on these circuits are reflected from the F-region, the heights of reflection are different for daytime and nighttime.

3 Data analysis

For the present analysis, absorption data from eighty most magnetically disturbed days (\( \Sigma K_p \geq 30 \)) in the period between October 1991 and December 1992 were selected. The absorption data were for 4.87, 6.09 and 15.40 MHz, respectively.

The analysis was concerned with the variations in absorption, occurring within five days of marked changes in planetary magnetic activity, which is denoted as the storm period. This choice of time frame is according to the results of Piggott, Bourne and Hewitt and the fact that an increase of ionization for a disturbed period compared with quiet day becomes obvious a few hours after the sudden commencement.

The absorption data were divided into six groups, namely, (i) Storm-day, (ii) First-day, (iii) Second-day, (iv) Third-day, (v) Fourth-day and (vi) Fifth-day, after the storm.
In the first part of the analysis, the sum of eight of three-hourly mean planetary $K_p$ indices for each UT day denoted by $\Sigma K_p$ was used as index of magnetic activity. Following Pigott, plots of absorption versus $\Sigma K_p$ are made for each of the above mentioned groups and then sought the correlation between absorption and $\Sigma K_p$.

Figure 2 shows the plots of absorption versus $\Sigma K_p$. They are all scatter diagrams indicating no correlation between absorption and geomagnetic activity.

In the second part of the geomagnetic activity analysis, the fractional change in absorption at 1000 hrs LT for any day of any month which is in the storm period was first computed as reduced absorption ($\Delta L_a$) from the relation

$$\Delta L_a = \frac{(L_a - L_q)}{L_q}$$

where, $L_q$ is the monthly mean absorption for the quietest days ($\Sigma K_p \leq 10$).

Thereafter the reduced absorption $\Delta L_a$ was plotted against $\Sigma K_p$ for each day for each frequency for the various groups of storm days.

The scatter diagrams of Fig. 3 show the plots of $\Delta L_a$ against $\Sigma K_p$. The plots also show no correlation between absorption and magnetic activity in the present study.

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**Fig. 2**—Plots showing the relation between absorption ($L$) and the sum of eight of three-hourly mean planetary magnetic index ($K_p$)
4 Discussion

The absorption data for each frequency and circuit represent the total absorption from (i) the F-region in which the radio waves are reflected; according to Whitehead, a considerable amount of the total absorption occurs near the top of the radio wave trajectory in the deviating region, and from (ii) the E-region where the collisional frequency is relatively high, while the refractive index is still nearly unity.

The results of the analysis of present absorption data are shown in Figs 2 and 3. As can be seen from Figs 2 and 3 that no particular trend is established in the results from Day 0 to Day 5. These results do not indicate that there is any control of HF absorption at 4.87, 6.09 and 15.40 MHz by geomagnetic activity. Gnanalingam had also investigated the influence of geomagnetic activity on equatorial absorption using frequencies from the E-region, and did not find any

Fig. 3—Plots showing the relation between the reduced absorption and the sum of eight of three-hourly mean planetary magnetic index (Kp)
significant magnetic storm effect on absorption, but did not offer any explanation as to the probable cause of this phenomenon. According to the earlier workers, the explanation of the present results must lie on the extent to which geomagnetic activity influences ionization in the F- and E-layers of the equatorial region.

Matsushita investigated equatorial ionospheric variations during geomagnetic storms and found that there is an increase in maximum electron density of the F2-layer, and that the electron density above \( H_{\text{max}} \) over the magnetic equatorial zone seemed to increase at the beginning of the main phase of a geomagnetic storm; the increased density diffused down along the magnetic field lines, whose dip angles at the earth’s surface are 30°-45°, and caused a large concentration of electron density at low latitudes. Given that the HF radio waves used for our investigation are reflected below \( H_{\text{max}} \), absorption may not be affected by the increase in electron density at the altitudes above \( H_{\text{max}} \), which accompanies geomagnetic activity.

Figure 3 shows that, when compared with quietest days’ absorption, disturbed days’ absorption appeared, on some days, to be less in magnitude. This is in spite of the magnetospheric particle precipitation at low altitudes in the equatorial zone [4,10] which is expected to produce ionization and results in increased absorption. This result could be explained by the fact that during geomagnetic storms, strongly enhanced equatorial winds at low latitudes cause the daytime O/N_{2} ratio to decrease, which increases the loss rate/decreases the production rate of ionization [10,12,13]. Hence, from the present results (Fig. 3), it does appear that the changes in chemical composition resulting from equatorward winds that are generated in the auroral zone may be a very dominant factor that influences HF radio wave absorption in the equatorial region during geomagnetic storms.

Furtermore, according to Watermann et al. [14], geomagnetic and substorm activity influence conductivity distributions. But electrical conductivity in the ionosphere is directly proportional to the electron density and also depends on collision [15,16]. Also Rastogi [17] has suggested that integrated conductivity at low latitude is proportional to maximum electron density in the E-region. This implies that geomagnetic activity should affect electron densities in the E-region. However, during disturbed conditions, the changing interplanetary magnetic field component, perpendicular to the ecliptic, produces electric fields which can be communicated to the equatorial latitudes via high latitudes. These changes of electric field produce definite changes in the equatorial electrical conductivities without changing E-region ionizations [18,19].

5 Conclusions

The A3 absorption data have been used to examine the effect of geomagnetic activity on the HF radio wave absorption. The results obtained do confirm that geomagnetic activity has no significant effect on the equatorial HF radio wave absorption. They also seem to indicate that geomagnetic activity does not influence ionization in the lower F- and E-regions of the equatorial zone.

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