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Vertical and oblique ionospheric soundings over a very long multihop HF radio link from polar to midlatitudes: Results and relationships

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[1] A vertical incidence sounder (VIS) was installed at the Spanish Antarctic Base (62.7°S, 299.6°E) during the Antarctic summer survey 2004–2005. In addition, an oblique sounding (OS) system for HF communications between Antarctica and Spain (12,700 km) has been operated during the Antarctic summers since December 2003. OS results are compared to Rec533 model and to VIS data obtained from stations located along the radio path, including VIS stations at the emitter and receiver sites. The results presented in this paper show the potential of this infrastructure for ionospheric monitoring and research purposes at and from polar regions. The results also show that relevant information (e.g., maximum received frequency) of very long range radio links can be obtained from appropriate VIS stations along the path.

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1. Introduction

[2] A vertical incidence ionospheric sounder (VIS) was installed in the Base Antártica Española (BAE, Spanish Antarctic Base), placed at the Livingston Island (62.7°S, 299.6°E; geomagnetic latitude 52.6°S and L value 2.3). The aim of this project was to have an ionospheric research infrastructure in this remote region and to analyze whether it is possible getting useful information for a high frequency (HF) radio link for data transmission developed at the BAE. The HF link has the transmitter at the BAE colocated with the VIS and the receiver is placed at the Observatorio del Ebro (OE, Ebro Observatory, 40.8°N, 0.5°E; geomagnetic latitude 43.2°N and L value 1.5), where another VIS is in operation. The HF radio link is intended to transmit the information delivered by the geomagnetic observatory at the BAE to the OE when the BAE is unattended, from March to November. *Torta et al.* [2009] have already explained the motivation for such radio link, and a description of the radio system can be found in the work of *Vilella et al.* [2006].

[3] At present, one can find many papers related with oblique sounding (OS) results from HF radio links. However, most of them deal with single-hop links [e.g., *Angling et al.*, 1998; *Warrington and Stocker*, 2003] but similar analyses for very long distance links are rarely found. Note that this radio link is over a distance of 12,000 km and it is assumed to have a minimum of four ionospheric hops [*Vilella et al.*, 2008]. The main aim of the radio link is to establish a system for ionospheric data transmission. In addition, the data extracted from the OS records has been analyzed and compared with the data from VIS stations along the link.

[4] Although the results obtained from the OS are complex to interpret in terms of ionospheric physics, they may give some information of the overall ionospheric propagation. Moreover, the results of the VIS may help the HF radio system providing prediction of frequencies for better performance.

[5] The aim of this paper is to present the first results obtained by the VIS installed at the BAE, deepening on the preliminary results presented by *Solé et al.* [2006]. Then, the analyses of the ionospheric data obtained by the VIS at the BAE, and the comparisons between the

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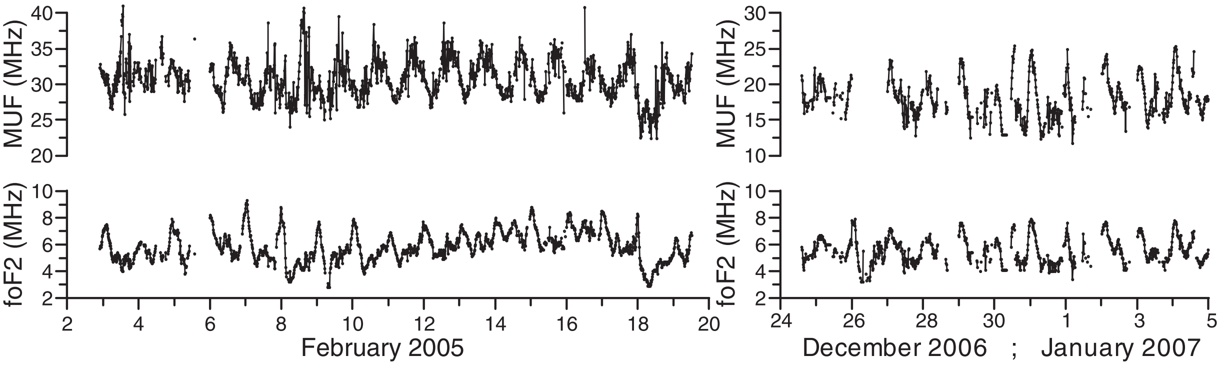

Figure 1. Examples of the day-to-day variation of the (bottom) foF2 and of the (top) MUF(3000) for surveys (left) 2004–2005 and (right) 2006–2007 as recorded at the BAE.

results from OS, HF propagation models and VIS from the available stations located closest to the radio path will be presented and discussed.

2. VIS at the BAE: First Results

[6] The logistic limitations of the BAE resulted in the acquisition of the Advanced Ionospheric Sounder (AIS) developed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) of Rome, Italy. Details of the sounder are available in the work of *Zuccheretti et al.* [2003]. The main reasons for choosing this system were based on the limited time of operation, low-cost and simple infrastructure and transport. The BAE operates only for three to four months per year (during Antarctic summer), and expensive investment was not feasible. The field available for installing research systems was very limited at that moment, being unrealistic to build an array of receiving antennas. The power supply of the BAE was also limited, and a low consumption system was required. AIS accomplished all the above restrictions compared to other ionospheric systems available in the market.

[7] The AIS was installed at the BAE during the Antarctic survey of 2004–2005 and it was sounding from 2 to 19 February 2005 for that survey. *Solé et al.* [2006] had presented some results for that survey and the comparisons of the data obtained with the AIS and the VIS installed at the OE for a testing period June–July 2004, when both systems were running together. The VIS of the OE is a Digisonde model DGS-256 of the University of Massachusetts at Lowell (http://ulcar.uml.edu/digisonde.html). The next surveys have produced data for 17 December 2005 to 21 February 2006, 24 December 2006 to 24 February 2007, and 23 December 2007 to 20 February 2008. The AIS was damaged during the Antarctic winter 2006, when the BAE was unattended, and many problems were detected during the survey of 2006–2007. Some of the electronic cards and the computer were damaged by dampness inside the labs. Ever since then, the AIS has operated irregularly due to communication troubles between the computer and the electronic cards. In addition, the ionograms from the follow on surveys had lower quality than before, especially for frequencies below 3 MHz. The cause of this is uncertain but the degradation of the antenna system and computer may play a role. Nevertheless, the measurements of the ionospheric parameters used in the analyses were convincing for most of the operating time. These parameters are the critical frequency of the F2 layer (foF2), the maximum usable frequency for a single hop transmission at 3000 km reflected at the F2 layer MUF(3000) and the virtual (or group) height of the F2 layer (h'F2). The foF2, MUF(3000) and h'F2 are easily extracted from the ionograms recorded by VIS and we refer the reader to *Davies* [1990] for details. Note that h'F2 gives an estimation of the height at the bottom of the F2 layer and foF2 is related to the electron density at the maximum of the F2 layer (NmF2) by the following well known expression: $NmF2 = 1/80.6 \cdot foF2^2$. As an example, Figure 1 depicts the day-to-day variation of the foF2 and MUF(3000) above the BAE for the survey 2004–2005 and some continuous records for survey 2006–2007. Although the amount of ionospheric data recorded and processed at the BAE to date are not large and an exhaustive study of the morphology of the ionosphere at the latitudes of the BAE is not possible, one can still provide some information of the ionosphere behavior at this station. This section presents some results of the daily pattern of some ionospheric characteristics, their typical variability and one case study of the ionospheric behavior for a geomagnetically disturbed interval.

[8] The daily variation of foF2 (Figure 1) is characterized by clear diurnal and semidiurnal harmonics, this being observed for both survey intervals. The later

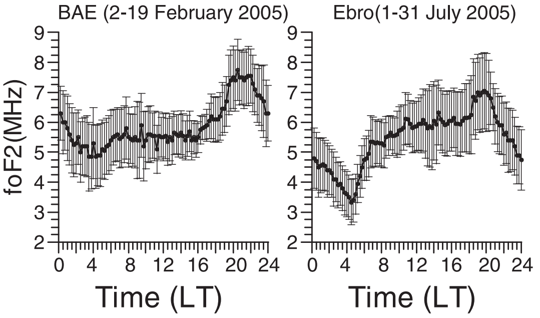

Figure 2. Average summer daily variation of the foF2 as function of the local time for indicated stations and time intervals. The vertical error bars indicate the standard deviations of the measurements at given time.

pattern is typical for summer behavior of the ionospheric F2 parameters at midlatitude stations [e.g., *Altadill et al.*, 2007, 2008]. The largest maximum observed after sunset is characteristic in the summer daily variation of the foF2 also (Figure 2). The daily variation of MUF(3000) is characterized by a clear diurnal harmonic for the 2005 survey, the semidiurnal harmonic being most prominent for survey 2006–2007 measurements. The maximum daily values of foF2 are a bit larger for the survey of 2004–2005 (about 9 MHz) than those foF2 values for the survey 2006–2007 (about 8 MHz). The minimum average daily values of foF2, of about 5 MHz for survey 2004–2005 are also higher than the 4 MHz average for survey 2006–2007. The lower values of the MUF(3000) for survey 2004–2005 compared to those for survey 2006–2007 are even clearer than for foF2. Note the different scale of the axes in Figure 1. These facts may indicate the influence of the solar activity on the ionospheric parameters. Note here that the average of the sunspot number (Rz12) for survey 2004–2005 was of about 34 units, whereas the Rz12 for survey 2006–2007 was of about 12 units.

[9] The average daily variation of the foF2 at the BAE for the survey 2004–2005 has been compared with that variation at the midlatitude site of OE for July 2005 (Figure 2). Both time intervals compared in the Figure 2 correspond to summer intervals with very similar sunspot activity. One can see that the daily average variation is very similar in shape for these distant stations. The differences may be the result of different latitude position, or perhaps less likely related to the different solar activity as Rz12 was 34 units for February 2005 and 29 units for July 2005. In addition, the variability of the measurements within the summer time intervals at both stations is quite similar, of about 1 MHz. Therefore, the typical daily variation and day-to-day variability as recorded at the BAE are quite similar to those obtained for a midlatitude station as OE.

[10] Figure 3 depicts in detail the time evolution of the virtual height of the F2 region (h'F2) and of the foF2 for the time interval 15–19 February 2005 as recorded at the BAE. A significant decrease of the foF2 for 18 February 2005 is shown. This decrease is followed by a strong uplift of the F2 region as observed by the significant increase in the virtual height h'F2. The geophysical conditions for this time interval have been analyzed to explain the 'anomalous' behavior of these parameters on 18 February 2005 compared to the previous days, paying special attention to the geomagnetic activity. We have analyzed the geomagnetic disturbance index Dst which has been downloaded from the Kyoto World Data Center (http://swdcwww.kugi.kyoto-u.ac.jp/). The hourly Dst is a geomagnetic index which monitors the world wide magnetic storm level. Dst measures the strength of the ring current, using magnetic field variations near the dipole equator, averaged over local time [e.g., *Davies*, 1990] and Dst is measured in units of nano-Tesla (nT). Negative Dst values indicate a magnetic storm is in progress, the more negative Dst is the more intense the magnetic storm and it is widely accepted that Dst values lower than −50 nT indicate a geomagnetically disturbed condition. Though not shown here, the records of the Dst index show a quiet interval from 13 to 15 February, with values ranging from −20 to 0 nT approximately. A small activity was noticed on 16 February, when the Dst index reached −40 nT. However, the largest geomagnetic activity was recorded on late 17 February, when Dst index dropped by 70 nT in less than 3 h reaching of about −90 nT the first hours of 18 February. This significant enhancement of the geomagnetic activity fits in time with the noteworthy decrease of the foF2 and with the strong uplifting of the F2 region. The ionosphere reactions to such magnetic perturbations are

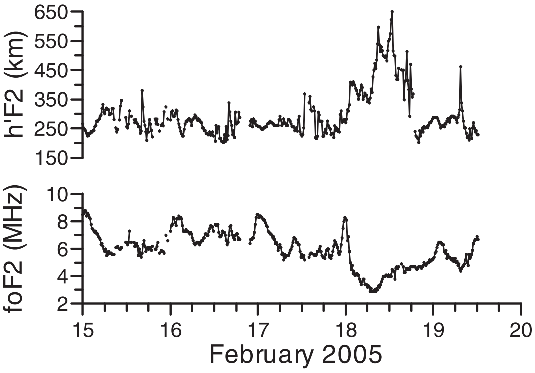

Figure 3. Detail of the time evolution of the ionospheric characteristics (top) h'F2 and (bottom) foF2 for the geomagnetic disturbed interval 17–18 February 2005 as recorded at the BAE.

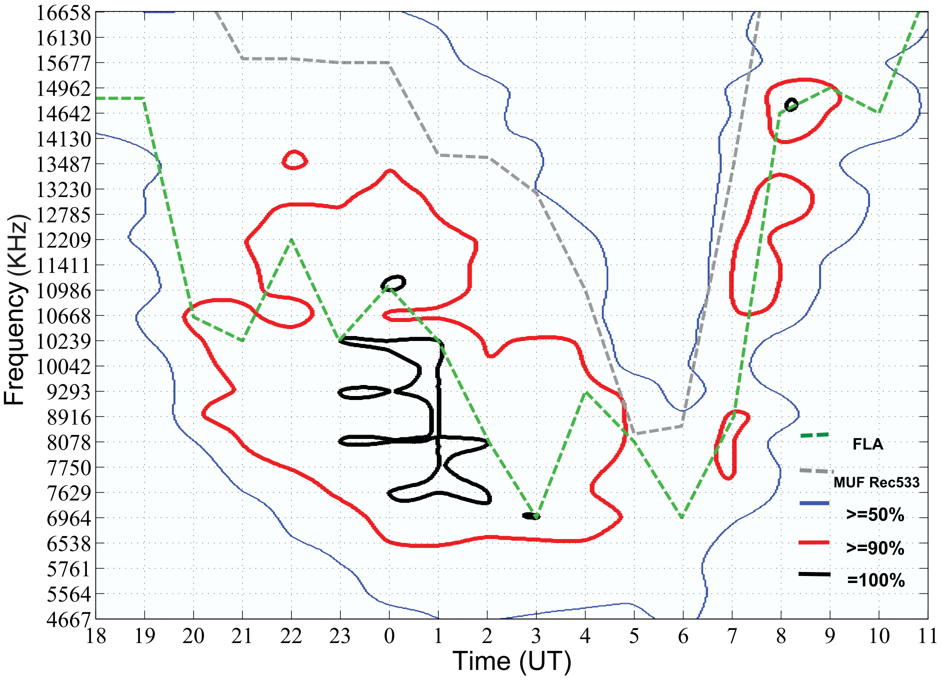

Figure 4. Contours of "availability" of a given frequency at a given time (UT) calculated from transmission data measured from December 2006 to January 2007. MUF are obtained by using Rec 533 model and are displayed for comparison. See text for details.

commonly referred to as ionospheric storms. Typically, they are categorized into two characteristic types according to the ionospheric effects produced by the geomagnetic disturbances: positive storms are those that produce an increase in the maximum electron density of the F2 layer and negative storms are those producing a decrease in the F2 layer electron density maximum. Negative storms are predominantly observed during nighttime, while positive storms are usually associated with daytime periods [*Prölss*, 1993]. A simplified picture of the negative response of the ionosphere to the storm [*Prölss*, 1993; *Fuller-Rowell et al.*, 1994] may be as follows. The energy input in the auroral zone during the initial phase of the geomagnetic storm results in an increase of the Joule heating that drives global neutral wind surges. The divergence of the horizontal winds leads to vertical winds causing a composition change in the upper atmosphere, namely, a change of the O/N_2 ratio. The increase in O/N_2 ratio (corresponding to a higher mean molecular mass) in its turn leads to a faster recombination rate, which reduces overall electron density in the ionosphere. Thus, in the region of the composition change a negative ionospheric storm is observed. Such a region of the increased O/N_2 ratio is often referred to as a "composition bulge." This composition bulge is usually created on the nightside in the region of 0–4 LT and then rotates with the Earth and is also pushed by background neutral winds. The dayside ionosphere typically observes positive storm effects as the horizontal meridional wind surges originating in the auroral oval push the ionosphere upward along the magnetic field lines [*Rishbeth*, 1998] to the region of slower recombination rate thus leading to electron density enhancement after the start of the storm. It is important to note that during the positive storms the increase in the density lags the increase in the layer height by 1–2 h [*Prölss*, 1993]. This time is required to build up an increased ionospheric plasma density in response to the uplifting of the F layer. Therefore, the observations indicate that the geomagnetic disturbance occurred the 18 February 2005 produced a negative ionospheric effect at the latitudes of the BAE. The results are consistent with the idea that the major driver storm at the BAE may be the neutral wind; i.e., the ionosphere over the BAE was located in the nighttime sector and at the region of a composition bulge generated by the geomagnetic disturbance which reduced the electron density. The strong uplifting of the ionosphere observed at the BAE which lags the negative effect on the density may be an evidence for the presence of horizontal neutral winds pushing the ionosphere upward (along the magnetic field line) and/or the result of the bite out in density caused by the composition bulge.

3. Oblique Sounding, Data, and Results

[11] The radio link between the BAE and the OE was first established in December 2003. *Vilella et al.* [2008] have described in detail the radio link, the measurement techniques and the results corresponding to the survey 2006–2007. In summary, the transceivers have been improved for the last five years using multiple techniques and allowing oblique sounding and data transmission in a wide range of bandwidths. At present the emitter and the receiver are mostly based in digital devices, including Field Programmable Logic Devices (FPGA), Digital Up and Down Converters (DUC and DDC) and high speed A/D and D/A converters. The transmission power has been limited to 250 W due to power consumption restrictions in the BAE. The sounding experiments were performed every day during the Antarctic summer, from December to February. The link was probed hourly on 25 preselected frequencies. These frequencies were chosen to uniformly span from 4 to 18 MHz, according to interference measurements in the receiver. The sounding techniques have included narrowband and wideband signals. Narrowband algorithms were used to estimate link availability and signal-to-noise ratio (SNR) while wideband soundings have permitted obtaining multipath and Doppler spreads.

[12] Although the main results of the HF radio link have been already presented by *Vilella et al.* [2008], a short review of them is presented here to quicker understanding of the OS parameters used in this paper. These parameters will be compared with HF propagation model results and with VIS parameters. The discussion is based on results obtained from soundings from December 2006 to January 2007.

[13] The key parameter obtained from the OS to be analyzed here is the 'availability' of the channel. In this paper we call 'availability' to the probability of receiving a tone of a given frequency within a 10 Hz bandwidth with a signal-to-noise ratio (SNR) greater than 6 dB [*Vilella et al.*, 2008]. This OS parameter is obtained as the percentage of successful tone receptions for a given time (UT) throughout the survey. Therefore, the 'availability' is a function of the time and of the sounding frequency, and it is assumed to be strongly related with the ionospheric support for the HF radio link.

[14] Figure 4 depicts the contour lines of the availability with a given percentage for the time interval spanning from 1800 to 1100 UT. From 1200 UT to 1800 UT the system was stopped for configuration and maintenance purposes. The contour lines define the area in the frequency/hour plane with availability larger than a given value. For example, the 100% contour line indicates what frequencies have been successfully received every day of the survey at given UT. Figure 4 shows also the maximum usable frequency obtained by the Rec 533 model (MUF Rec 533). The MUF Rec533 is defined as the highest frequency for which an ionospheric communication path is predicted on 50% of the days of the month [*ITU-R*, 2008]. Finally, the green dashed line in Figure 4 indicates the frequency having the largest availability at a given time (FLA). The FLA is very important for the transmission purposes because it indicates which frequency has the greatest chance reaching the receiver at a given time.

[15] The results presented in Figure 4 show that: (1) The frequencies having largest availability (FLA) decrease progressively from about 16 MHz to about 12 MHz for the time interval from 1800 UT to 2000 UT, believed to be related to the progressive sunset in the places where the ionospheric reflections of the HF radio link occur [*Vilella et al.*, 2008] (see Figure 5). The FLA then oscillates in the 10–12 MHz range from 2000 to 0000 UT. (2) Between 0 UT and 5 UT the reception of radio waves above 9 MHz progressively vanishes. As it will be discussed later, this may be related to the decrease of the MUF(3000) obtained from VIS. (3) The sunrise simultaneously occurs around 0700 UT lengthways the radio path, coinciding with the sudden restart of propagation of radio waves above 9 MHz. In general, the shape of the availability contours is strongly related with the Sun's ionization of the ionosphere along the link and through the survey [*Vilella et al.*, 2008].

[16] As we can see in Figure 4, the comparison of the experimental values of the upper contour line indicating 50% of availability with the predicted values of MUF Rec533 indicates that the model fits well the experimental results for the time interval from 0300 UT to 0700 UT. However, the Rec533 model clearly underestimates the maximum frequencies having 50% of reception for the time interval from 1800 to 0200 UT. Similar results have been obtained with other ionospheric models as ASAPS [*Vilella et al.*, 2008].

4. Comparison Results of OS and VIS Close to the Radio Path

[17] After comparisons between the empirical results of the OS and model results and related discussions, this section presents the comparisons of the OS and of the VIS measurements. The aim of this is to analyze the correlations of the OS and VIS if any and to look for possible relationships between them. To broach the above objective, we have analyzed the MUF(3000) obtained from VIS for the available ionospheric stations

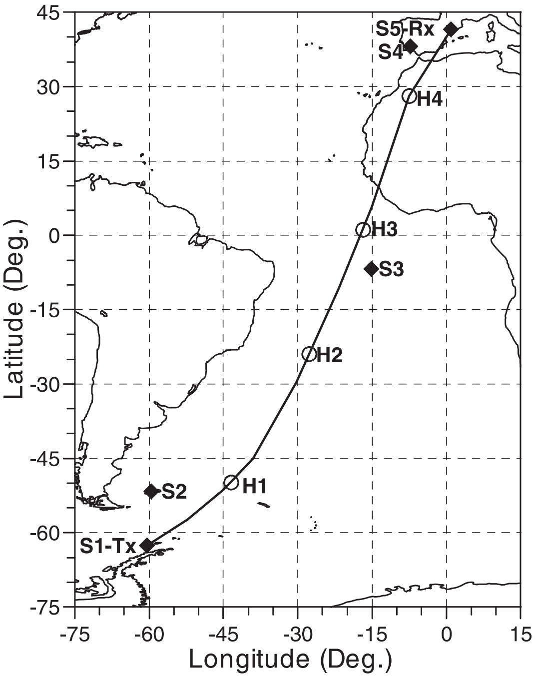

Figure 5. Assumed radio path of the HF link from BAE to OE; Tx indicates the transmitter, and Rx indicates the receiver. The open circles indicate the points where the ionospheric reflections of the HF radio link are assumed to occur. The diamonds indicate the geographical positions of the VIS stations used in this study whose codes S1, S1, S3, S4 and S5 means BAE, Port Stanley, Ascension Island, el Arenosillo and OE, respectively.

closest to the assumed radio path. These stations are located at the BAE (62.7°S, 299.6°E) which is colocated with the transmitter and at the OE (40.8°N, 0.5°E), colocated with the receiver, and whose data are managed by project participants. Data from Port Stanley (51.6°S, 302.1°E), Ascension Island (7.95°S, 345.6°E) and El Arenosillo (37.1°N, 353.3°E) have been used also. The later data have been obtained from the Digisonde Data Base of the University of Massachusetts Lowell (http://umlcar.uml.edu/DIDBase/). All the ionograms have been scaled by the staff of the OE to get the best data quality possible. Figure 5 shows the positions of these stations compared with the assumed radio path and the assumed positions of the ionospheric reflections [*Vilella et al.*, 2008].

[18] The ionospheric characteristic obtained from the VIS to be compared with the parameters recorded with OS is the MUF(3000). This parameter extracted from the ionograms is probably the one obtained from VIS having the most importance to HF radio communications. Figure 6 shows the daily variation of the MUF(3000) recorded at three different latitudes for the survey December 2006 to January 2007 compared with the median diurnal variation. The results presented in the Figure 6 include data from 6 December 2006 to 2 February 2007 for Ascension Island and OE but from 24 December 2006 to 2 February 2007 for BAE. The time interval analyzed for Ascension Island and OE coincides with the interval when the OS were operating. Unfortunately the VIS at the BAE had run for shorter time during the survey 2006–2007. If we assume that the error bars depicted in Figure 6 represent a proxy of the day-to-day variability throughout the survey at a given UT, the results indicate that this variability does not hide the distinct daily pattern of variation of the MUF(3000) for the different stations. Then, we may conclude that these results indicate a quite stable and systematic daily pattern of variation for this parameter. The differences in the obtained daily trends for these stations are the result of the different seasonal conditions, of the different local-time sectors and of the different latitudes, resulting a different amplitude and shape of the diurnal variation and a displacement in the UT of the diurnal maximum and minimum values. Note that the results for these analyzed stations indicate that MUF(3000) rarely drops below 10MHz, the latter happening close to the sunrise sector for Ascension Island and OE (from 0500 to 0700 as indicated by the median pattern). The continuous low values of the MUF(3000) of about 10 MHz during nighttime for the OE (1800–0700 UT) are characteristic for the winter season of the Northern Hemisphere at the latitudes of the OE. As already mentioned in the previous section, there is a distinct average pattern for the OS measurements also. Therefore, the experimental measurement and average measurements of the OS and VIS measurements will be compared.

[19] In single hop transmissions it is well known the relation between the frequencies of the OS and the VIS [*Davies*, 1990]. In multihop path it is not feasible to get this kind of relations because it is not common to have receivers along the path. The only information about the OS is from the receiver installed in the final point of the path. In order to study long path radio links in a global way we propose to compare the maximum received frequency (MRF) of the OS radio link and the MUF(3000) as recorded for the indicated VIS stations.

[20] In Figure 7 we show the daily trends of the above parameters for the considered days. These trends are very similar for VIS and OS. In order to have a quantitative measurement of the possible relation of these parameters we have defined a slope correlation, i.e., two segments with exactly the same slope have correlation +1, and with opposite slope have correlation −1. In Table 1 we indicate these slope correlations at Ascension Island and Ebro station during one week. The stations nearby the

receiver (OE and el Arenosillo) have the best results with an average correlation over 0.7. These correlations suggest that in this link the MRF mainly results from the last of the four hops assumed for the radio link. These results may indicate that searching for empirical relations of the MRF with respect to the MUF(3000) at individual stations would be a successful task for similar ionospheric conditions and may serve for predicting the MRF of the radio link.

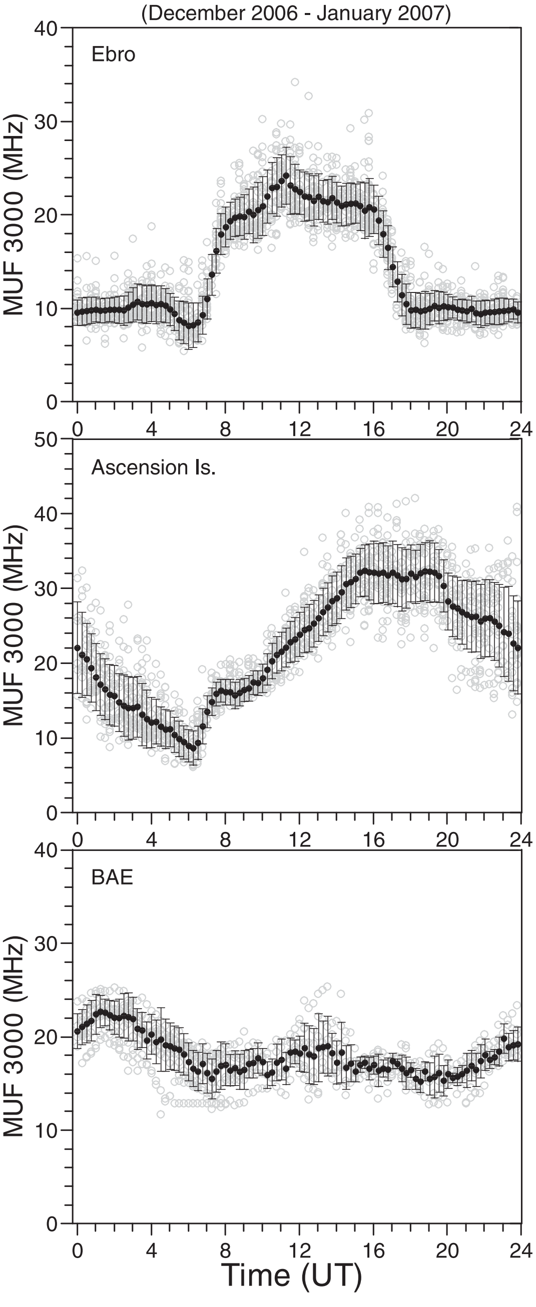

Figure 6. Superposed daily variation of the MUF(3000) (open gray dots) recorded (top) at the midlatitude Northern Hemisphere station Ebro, (middle) at the equatorial station Ascension Island, and (bottom) at the mid high latitude Southern Hemisphere station BAE for December 2006 to January 2007. The solid dots indicate the median values at indicated time, and the error bars have been calculated as the standard deviation of the experimental values at a given time.

[21] The average pattern for the survey of the daily variation of the MUF(3000) at individual stations and the daily variation of the frequency of the radio link having the largest availability (FLA) are compared in Figure 8. These average patterns can be used as a proxy for the expected daily variations of these parameters for similar ionospheric conditions to the ones of the survey 2006–2007. As noticed for the day-to-day variation of the MRF and of the MUF(3000) (Figure 7), it is noteworthy that the time variation of FLA and those of the average MUF(3000) for the stations closest to the receiver (OE and El Arenosillo) are very similar to each other (Figure 8) true for most of the time interval under analysis. These results may indicate that searching for empirical relations of the FLA with respect to the average MUF(3000) at individual stations would be a successful task for similar ionospheric conditions and may serve for predicting the FLA of the radio link. From a detailed inspection of Figure 8, it appears that the average MUF(3000) recorded close to the receiver (OE and el Arenosillo) restricts the FLA of the radio link for the time interval from 2000 to 0800 UT (at night), whereas the average MUF(3000) recorded close to the transmitter (Port Stanley) restricts the FLA of the radio link for the time interval from 0800 to 1100 UT (postsunrise) and from 1800 to 1900 UT (sunset). According to these results we may speculate that having VIS strategically located along the radio path, the lowest of the MUFs recorded at a particular time is the ‘restricting’ value of the FLA.

[22] In addition, we observe a significant dependence of the power delivered at the receiver with the average MUF(3000) recorded at individual stations (Figure 9). The average power delivered at the receiver has been normalized to isotropic by compensating across frequencies for the antennas gains. Therefore, the depicted delivered powers are related with the transmitted power and absorbed power by the propagating medium. As the transmitted power is adjusted to be approximately constant for all frequencies, the variations of the received power are assumed to be mainly related to the propagation losses in the ionosphere. Figure 9 clearly shows a deep drop of about 12 dB in power of the received

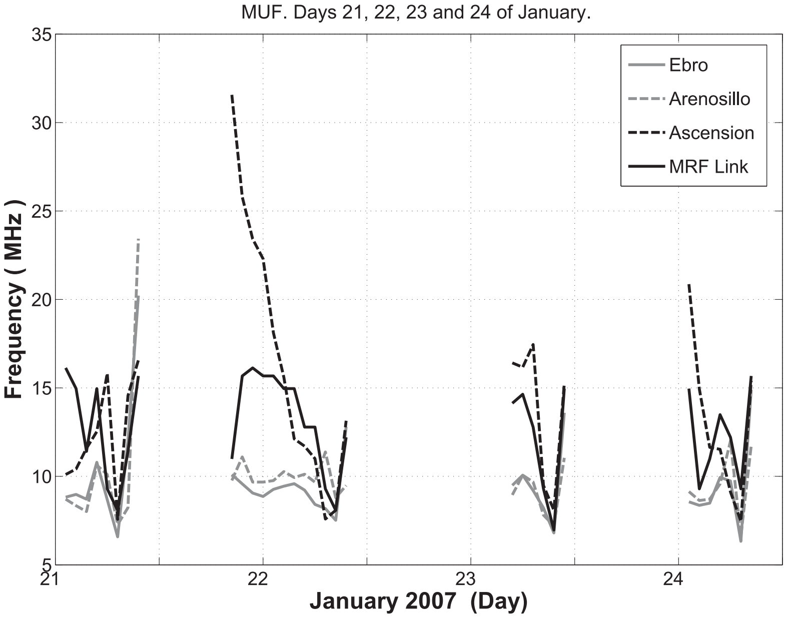

Figure 7. Comparisons of the daily variation of the MUF(3000) for given VIS station with that of the MRF for the OS radio link. The time indicated at the *x* axis is presented in UT.

frequencies above about 10 MHz compared with the power of the received frequencies below about 9 MHz. This drop in power is recorded approximately within the time interval from 2000 to 0700 UT. Maybe it is a happenstance, but the frequencies for the drop in the received power coincide with the average MUF(3000) of the VIS closest to the receiver (OE) for that time interval (Figure 8). The same behavior would have to appear from 1800 to 2000 UT but the signal-to-noise ratio restriction considered for the reception hides the reception of the low frequencies. Moreover, the system starts receiving the low frequencies for this time interval, from 1800 to 2000 UT (Figures 4 and 9), which coincides with the progressive sunset along the channel [*Vilella et al.*, 2008]. Figure 9 shows also that the edge defined by the frequencies received with an average power of about −105 dB decreases from about 16 to about 10 MHz for the time interval from 2100 to 0600 UT. This experimental edge defines the limit for the signal reception and it fits quite well the predicted MUF by Rec533 (Figure 4). Moreover, this behavior correlates well with the MUF(3000) measured in Ascension Island as it can be seen in Figure 8.

5. Summary and Concluding Remarks

[23] The ionospheric data recorded with a VIS installed at the BAE, a recently installed station at mid high latitude (62.7°S, 299.6°E; geomagnetic latitude 52.6°S and L value 2.3) of the Southern Hemisphere, have been analyzed to obtain a daily pattern of the foF2 and MUF(3000) and their typical variability during the Spanish Antarctic surveys when the sounder was in operation. The daily variation of foF2 is characterized by clear diurnal and semidiurnal harmonics, with a largest maximum observed after sunset (Figure 2). Very similar pattern characterizes the daily variation of the MUF(3000) (Figure 6). These patterns are typical for summer behavior of the ionospheric F2 parameters at midlatitude stations. The lower values of the ionospheric parameters recorded for survey 2006–2007 compared to those for survey 2004–2005 indicated the influence of

Table 1. Slope Correlations at Ascension Island and Ebro Station for 21–28 January 2007

	21 January	22 January	23 January	24 January	25 January	26 January	27 January	28 January	Average
Ascension Island correlation	0.4255	0.0922	0.8534	0.8288	0.2158	0.2282	0.5409	0.5385	0.4654
Ebro station correlation	0.7626	0.5146	0.9619	0.7773	0.6046	0.7378	0.7865	0.4715	0.7021

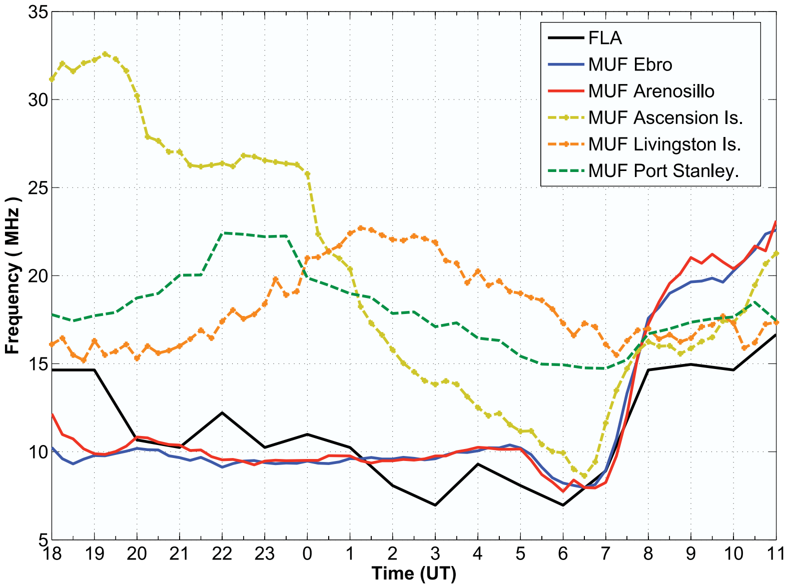

Figure 8. Comparisons of the daily pattern throughout the survey of the MUF(3000) for given VIS station with the frequency with the largest availability for the OS radio link, FLA.

the solar activity also. The analyses for the geomagnetically disturbed interval 17–18 February 2005 made possible detecting ionospheric effects of the stormy conditions. The significant decrease of the foF2 for the night of 17–18 February 2005 is consistent with the idea of a composition surge driven by the neutral wind from auroral activity regions which would explain the recorded decrease of the foF2 and the following strong uplifting of the F2 layer. The results presented in this paper prove the validity of this infrastructure for ionospheric monitoring along multihop HF paths over very long distances, and research purposes at this remote region.

[24] The parameters obtained from the OS HF radio link analyzed here have been the maximum received frequency (MRF), the 'availability' of the channel that

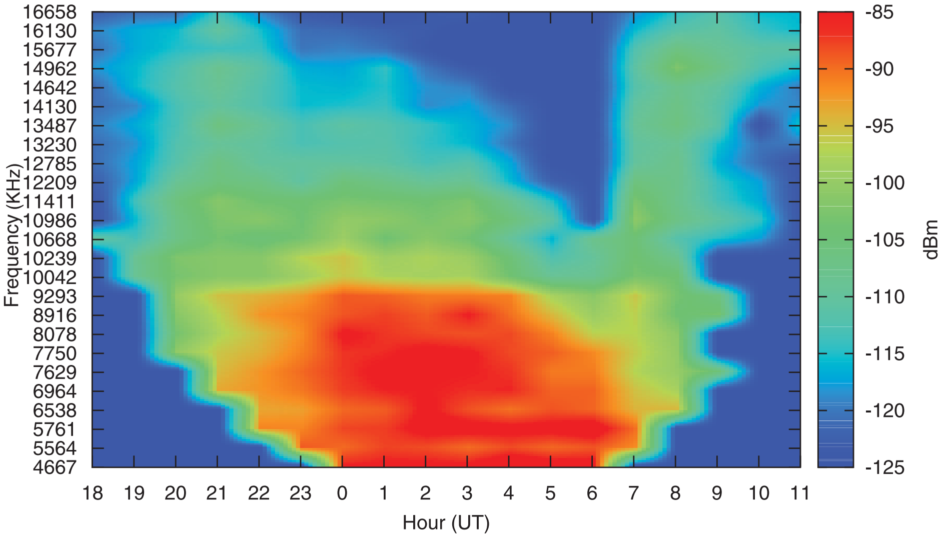

Figure 9. Median power delivered at the receiver for the survey 2006–2007 as function of time and frequency. The gain of the antennas has been compensated.

provided the frequency with the largest availability FLA, and the normalized power delivered at the receiver. These parameters have been investigated for the December 2006 to January 2007 Spanish Antarctic survey and compared with predicted parameters by the HF model Rec533 and with the MUF(3000) recorded at the available VIS stations closest to the radio path. The comparisons of the experimental availability of the HF radio link with the predicted values by the Rec533 model indicate that the model fits well the experimental results for the time interval from 0300 UT to 0700 UT (night) but the model clearly underestimates the maximum frequencies having 50% of reception for the time interval from 1800 to 0200 UT (postsunset). This may be an important output for HF users, informing that available frequency range for transmission is larger than that predicted. The comparisons of OS HF radio link and VIS parameters provided interesting results also. The day-to-day trends of the MRF correlate pretty well with those of the MUF(3000) recorded at stations nearby the receiver, with an average correlation over 0.7. The daily variation of FLA and daily pattern of the MUF(3000) of the stations closest to the receiver are qualitatively and quantitatively very similar to each other for postsunset, night and sunrise (2000–0800 UT), whereas from 0800 to 1100 UT (postsunrise) and from 1800 to 1900 UT (sunset) the MUF(3000) pattern recorded close to the transmitter is the most similar to the FLA. We may speculate that modern assimilation models based on Kalman filter method [e.g., *Maybeck*, 1979] would be successful for obtaining ionospheric information (VIS) from the OS HF radio link and vice versa as well as predicting FLA. Moreover, the FLA values rarely exceed those values of MUF(3000) that are the lowest of the MUFs recorded lengthways the radio path, they being not very different when FLA surpasses the MUF(3000). Therefore, we may conclude that having VIS strategically located along the radio path, the lowest of the MUF(3000) recorded on them at a particular time is the 'restricting' value of the FLA. Finally, a deep drop of about 12 dB is noticed in the average power of the frequencies delivered at the receiver. This drop happens from frequencies below about 9 MHz to frequencies above about 10 MHz. It is noteworthy that the values of the frequencies for which this drop occurs coincide with the average MUF(3000) values of the VIS closest to the receiver, which are the lowest MUF(3000) compared with those recorded lengthways the radio path. This suggest that the lowest MUF(3000) recorded at stations closest to radio path restricts the transmission frequency. The above does not mean that frequencies larger than the above MUF(3000) are not received at the transmitter but they have a strong reduction in power.

[25] The analyses of new data from Spanish Antarctic surveys in the future will provide additional information of the ionospheric behavior at those latitudes. This will make possible the research of similar ionospheric events (ionospheric storms effects) and of the relationships between the measurements from VIS and OS for different levels of solar activity, since the advent of the rising part of the solar cycle 24.

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