Interobl: An interactive software tool for displaying and scaling oblique ionograms[☆]

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Abstract

By analyzing an oblique ionogram several characteristics, such as LOF, MOF, FMUF, FHLOF, FLLOF, and 2FMOF, can be found. These characteristics are important both for ionospheric studies and for terrestrial communication purposes, as they give information about the sky wave communication conditions in the High Frequency (HF) radio spectrum.

A RCS-5B sweeping HF receiver for oblique sounding was installed at Chania (Crete, Greece, 35.7°N, 24.0°E) in April 2005 to perform a radio link with Inskip (UK, 53.5°N, 2.5°W). The receiver, able to record the sounding only as a binary file, was not equipped with a tool to display and scale the recorded trace. This work describes software that is able to do this, consequently increasing the speed of the scaling phase performed by the operator. The usefulness of this software for validating FMUF prediction models is also shown.

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1. Introduction

Ionospheric observations are performed using a high-frequency radar system. The transmitter (T) sends short pulses of radio energy into the ionosphere, which reflects them, and the receiver (R) records the time delay between transmission and reception of pulses. To carry out a vertical sounding, T and R are located in the same place, while to study the structure of oblique echo signals, T and R are separated. By varying the carrier frequency of

pulses, typically from 1 to 20 MHz for vertical sounding and from 1 to 50 MHz for oblique sounding, the time delay at different frequencies is recorded. This record is usually presented in the form of a graph and is called an ionogram.

From the analysis of vertical and oblique ionograms, several important characteristics can be found that play a significant role in the studies concerning ionospheric physics and for terrestrial communication purposes. Pezzopane (2004) dealt with the scaling of a vertical ionogram and developed a software that enables an operator to scale the characteristics fmin, h′E, foE, h′Es, foEs, fbEs, Es Types, h′F, foF1, h′F2, foF2, fxI, MUF(3000)F1, M(3000)F1, MUF(3000)F2, and M(3000)F2. From an oblique ionogram, important characteristics like the LOF, MOF, FMUF,

FHLOF, FLLOF, and 2FMOF can be scaled (see Table 1 for explanations and Fig. 1 for an example of oblique ionogram interpretation). Among these the FMUF, or basic MUF, is the most important, this being the highest frequency at which a radio wave can propagate between given terminals by ionospheric propagation alone. From a vertical

ionogram, the basic MUF is obtained using the transmission curve method (Piggott and Rawer, 1972). In an oblique ionogram the basic MUF corresponds with the frequency at which the high- and low-angle rays join (Davies, 1990), also known as the Junction Frequency (JF). As shown in Fig. 1, the JF can be smaller than the MOF.

In April 2005, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) installed an RCS-5B sweeping High Frequency (HF) receiver (BR Communications, 1989) for oblique sounding in Chania (Crete, Greece, 35.7°N, 24.0°E) to perform a radio link with Inskip (UK, 53.5°N, 2.5°W). This receiver, able to record the sounding only as a binary file, was not equipped with a program to display and scale the recorded trace. This paper describes a software, called *Interobl*, that is able to do this, consequently increasing the speed of the scaling phase. The usefulness of the data obtained using this software to validate basic MUF prediction models is also shown.

Table 1
Oblique sounding characteristics that can be scaled by Interobl and their definition

Characteristic	Definition
LOF	Lowest observed frequency. The lowest frequency observed on the ionogram
MOF	Maximum observed frequency. The highest frequency observed on the ionogram
FMUF	The highest frequency by which a radio wave can propagate between given terminals by ionospheric refraction alone exploiting the one-hop F layer reflection. Also known as basic MUF or Junction Frequency (JF)
FHLOF	The lowest observed frequency of the high-angle signal propagating along the one-hop F path
FLLOF	The lowest observed frequency of the low-angle signal propagating along the one-hop F path
2FMOF	The maximum observed frequency of the two-hop F trace

2. Installation, ionogram files, and output files

The software is written in Visual Basic 6.0; it runs under Win9X / ME / 2000 / XP / Vista. Minimum
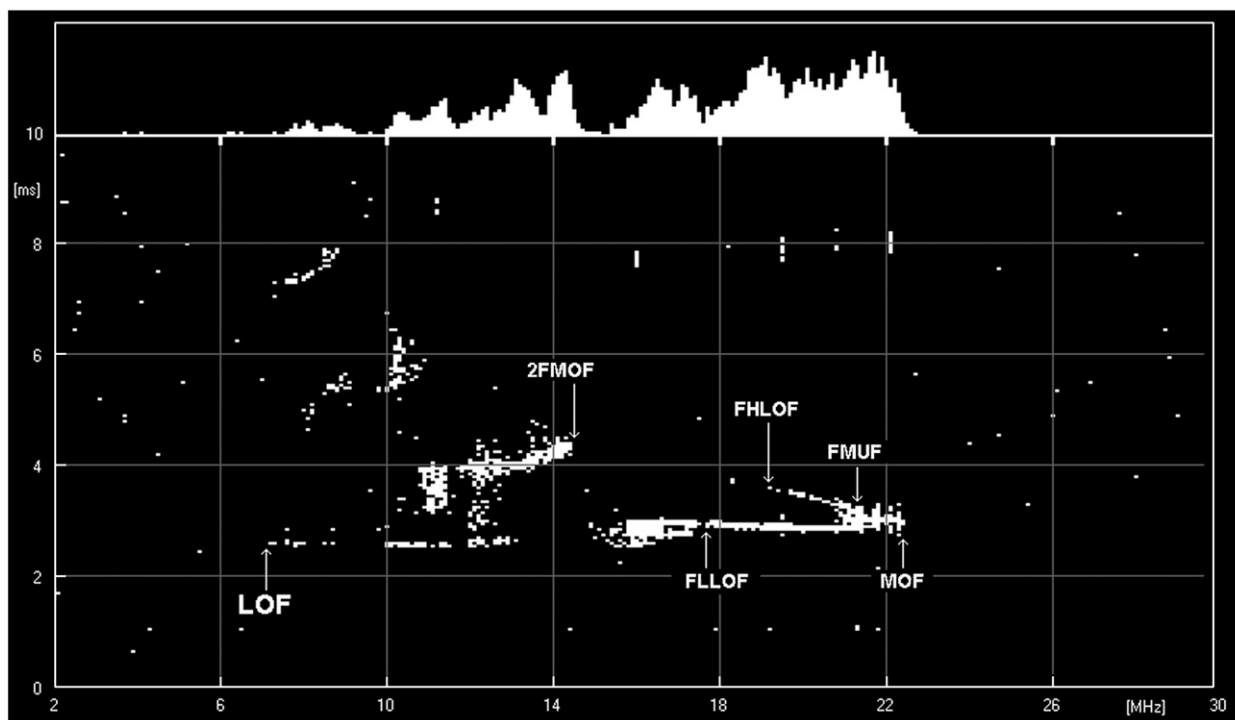

Fig. 1. Oblique ionogram for 2880 km path from Inskip, UK, to Chania, Greece, recorded by RCS-5B sweeping HF receiver, with 1, 2, 3, and 4-hop traces. Characteristics under scaling with *Interobl* are presented.

system requirements: 133 MHz processor, at least 32 MB of RAM, and SVGA graphics 1024×768 pixels. In a directory chosen by the operator, the following files and directories must be present: the file "*interobl.exe*" which is the actual interpretation program, the file "*setting.txt*" that keeps track of the parameters of the on-going interpretation, and the directory "*ionograms*" containing the ionogram files to be scaled.

2.1. Content of file setting.txt

The file "*setting.txt*" is an ASCII file of five records. The first, the second and the third record hold, respectively, the date, the hour, and the minutes of the last ionogram interpreted; the fourth record contains the chosen difference in minutes that has to pass between two consecutive ionograms, and the fifth record memorizes the number of the line of the output file where the program writes the values obtained from the interpretation of the ionogram.

2.2. Ionogram file format

All ionogram files have extension .OS1. The name of the ionogram file is *yygggllmm.os1*, where *yy* are the last two digits of the year, *ggg* are three digits identifying the day of the year, *l* is the letter identifying the hour (A≡00, B≡01, C≡02, D≡03, E≡04, F≡05, G≡06, H≡07, I≡08, J≡09, K≡10, L≡11, M≡12, N≡13, O≡14, P≡15, Q≡16, R≡17, S≡18, T≡19, U≡20, V≡21, W≡22, and X≡23), and *mm* represent the minutes. This file, consisting of 59 279 bytes, has this form because the data stream to the PC is equivalent to a serial printer input. This explains why the 59 279 bytes are distributed as follows:

- 8 header bytes (0_{hex}–7_{hex});
- 58 926 bytes for the graph (8_{hex}–$E635_{hex}$);
- 345 bytes for ASCII elements ($E636_{hex}$–$E78E_{hex}$) giving information on the time of the sounding, the initial and final frequency of the sounding, the name of the receiving station, the corresponding offset and receiving channel, and the video modality of the receiver;
- the central body of 58 926 bytes is a result of 61 rows of 966 elements each. Each row starts with 4 bytes ($1B_{hex}$ $4C_{hex}$ $C0_{hex}$ 03_{hex}) then 960 bytes of graph, concluded with 2 bytes ($0D_{hex}$ $0A_{hex}$);
- each of the 960 bytes constituting the graphical body of the file should be considered as the

writing head of a printer, hence as a column of 1 (pixel present) and 0 (pixel absent).

The real ionogram body is constituted by 834 bits along the frequency axis and 396 bits along the time delay axis. Taking into account that the frequency of the sounding varies from 2 to 30 MHz, the passage between two successive bits is equal to ∼0.034 MHz for the frequency axis, and ∼0.025 ms for the time delay axis.

2.3. Output file format

The output file is an ASCII file named *ddmoyymm.txt*, where *dd*, *mo*, and *yy* represent the day, the month and the last two digits of the year, respectively. *mm* is the chosen difference in minutes between the ionograms under scaling. It is created and updated in the directory "*ionograms*" once the interpretation goes on. The standard record of the output consists of 190 bytes. The first 5 bytes identify the time of the sounding, byte number 6 is a "blank". From byte 7 to byte 84 the record structure is 13 (8A," = ", 3I, "blank"), where 8A identifies the name of the ionospheric characteristic and 3I the corresponding numeric value. From byte 85 to byte 188 the sounding parameters included in the ionogram file are stored; the last 2 bytes of the record are those of carriage and return.

The number of records of these files depends on the chosen difference in minutes in the initial graphic interface (Fig. 2) of the program.

3. Interobl: start up and features

To run the software, double click the "*interobl.exe*" icon. The graphic interface shown in Fig. 2 appears, and the operator can select the date of the day for which he wants to scale the ionograms, and the time difference between the ionograms, which can be 5, 15, 30, or 60 min.

Choosing 60 the program will look for ionogram files that have 00 in place of *mm*; choosing 30 the program will look for ionogram files that have 00 or 30 in place of *mm*; choosing 15 the program will look for ionogram files that have 00, 15, 30, or 45 in place of *mm*; choosing 5 the program will look for ionogram files that have 00, 05, 10, 15, 20, 25, 30, 35, 40, 45, 50, or 55 in place of *mm*.
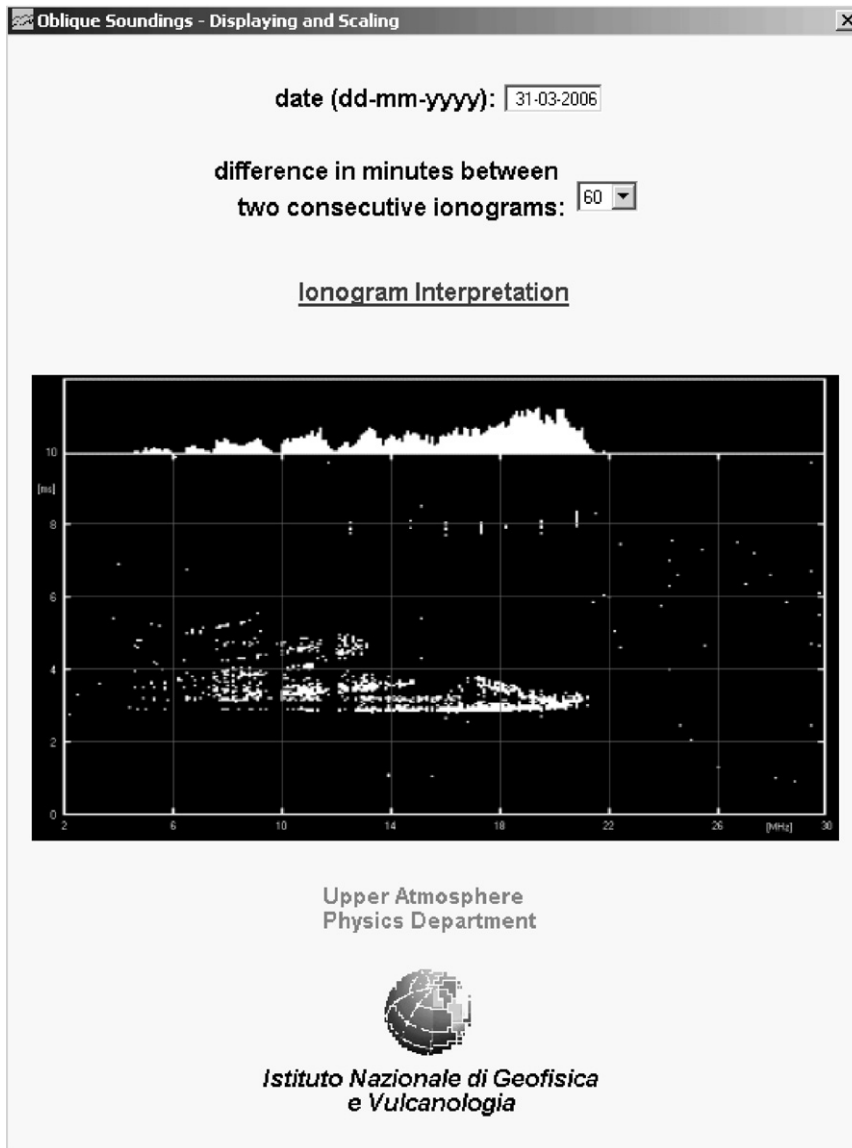
Fig. 2. Initial interface of *Interobl*.

Once the required parameters to identify the ionogram files are set, the operator can click on "Ionogram Interpretation" to load the graphic interface used for the interpretation of the ionograms (Fig. 3). When the cursor is inside the ionogram, it becomes a green cross and in the upper side of the interface the corresponding values of frequency and time delay are displayed.

To scale one of the ionospheric characteristics listed in Table 1 the corresponding label must be clicked. In response, the label becomes red and after clicking the ionogram point considered the most suitable for the chosen characteristic, the value field is filled following the International Union of Radio Science standard (Piggott and Rawer, 1972). To pass from one characteristic to another, instead of clicking on the corresponding labels, the operator can press the keys F1 or F2.

Once the interpretation of the ionogram is complete, the operator can move on to the next or previous ionogram by clicking on the corresponding labels or simply pressing the keys F3 or F4. The Previous Val fields on the left side of the characteristics labels illustrate the values of the previously
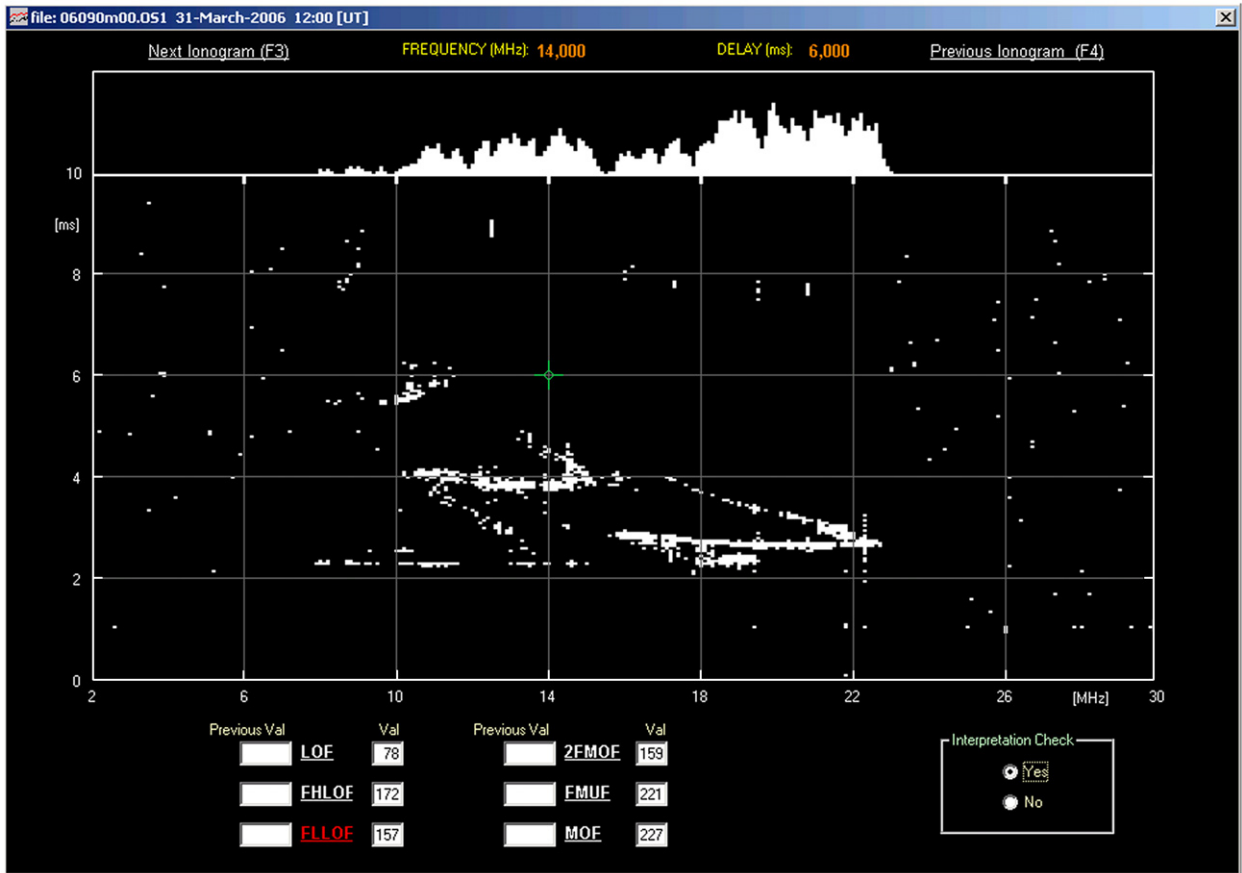
Fig. 3. Interface loaded by *Interobl* to display ionogram to be scaled in which the green cross representing cursor is positioned over ionogram pixel with coordinates 14 MHz and 6 ms.

scaled ionogram. In the passage between iono-grams, if the property "Interpretation Check" is set to YES, the absence of LOF, FMUF, and MOF values is checked and if this is the case the operator is warned, otherwise this check is not carried out. It is only possible to transit between ionograms of the same day. To scale ionograms of different days the operator must go back to the graphic interface in Fig. 2, by pressing the key ESC, and insert the correct date. The user can of course insert a date for which the ionograms have already been scaled, for instance to check the quality of the scaling. In this case the ionograms are displayed together with the scaled ionospheric characteristics, which are edited in the corresponding fields.

If when moving from one ionogram to another, the next ionogram is unavailable, then the space where the ionogram is normally displayed is totally black and the cursor will not become a green cross, avoiding the recording of any values.

4. Checks during the interpretation phase

When scaling an ionogram, if one of the following cases arises:

- MOF < FMUF
- MOF < LOF
- MOF < 2FMOF
- MOF < FHLOF
- MOF < FLLOF
- FMUF < LOF
- FMUF < 2FMOF
- FMUF < FHLOF
- FMUF < FLLOF
- FHLOF < LOF
- FLLOF < LOF
- 2FMOF < LOF

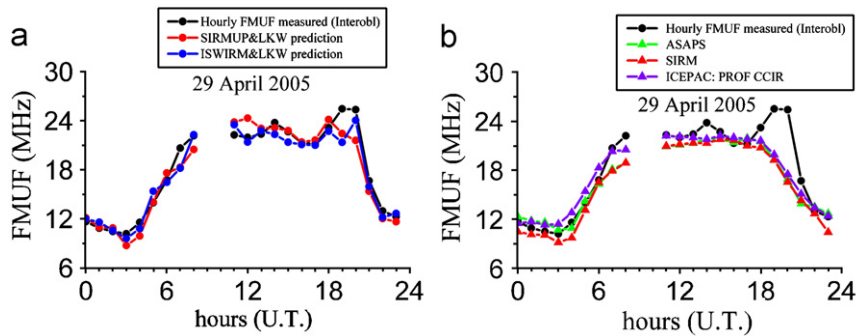The operator is warned with the message "A cannot be greater than B. Do you want to save the

Fig. 4. Comparisons between MUF measured values obtained using *Interobl* and MUF predicted values calculated (a) by SIRMUP&LKW and ISWIRM&LKW, and (b) by ASAPS, SIRM, and ICEPAC for radio link Inskip-Chania on 29 April 2005.

value in any case?'', where, considering for example the case MOF < LOF, A = LOF, and B = MOF. These simple checks are very useful in helping the operator to give output values that are as reliable as possible. For instance, from a physical point of view (see Fig. 1) it would be very strange to have an output value of FHLOF greater than FMUF. These checks prevent such errors from happening.

5. *Interobl*: an application

The oblique-incidence ionospheric soundings are very useful for the specification of the ionospheric propagation conditions in real time and for ionospheric research purposes. Unfortunately, the availability of the ionospheric characteristics obtained from oblique soundings is very limited because of the difficulties in maintaining the experimental equipment for a given radio link. Although Real-Time Channel Evaluation devices are increasingly being used in modern management of HF communication systems and are obviously the most effective for any short-term or nowcasting predictions on a given radio link, they cannot provide information over all the potential radio links. This means that the actual observations of ionospheric characteristics, carried out by means of *Interobl*, have great importance for testing the predictions of the frequencies that need to be chosen to successfully ensure HF radio links, and for validating different long-term ionospheric models and nowcasting techniques in different regions.

As an example application of the proposed software, the FMUF measurements obtained from the oblique soundings recorded at Chania using *Interobl* were considered to test the performance of the nowcasting models SIRMUP&LKW and

ISWIRM&LKW. In order to compute FMUF predicted hourly values, these models utilize the nowcasting SIRMUP (Tsagouri et al., 2005) and ISWIRM (Pietrella and Perrone, 2005) prediction models in conjunction with the Lockwood (1983) formula.

In Figs. 4a and 5a the FMUF hourly measured values for the radio link Inskip-Chania are drawn in comparison with the FMUF predicted values calculated by the SIRMUP&LKW and IS-WIRM&LKW models for two geomagnetically quiet days, 29 April 2005 and 25 January 2006.

For a further analysis, in Figs. 4b and 5b, the FMUF hourly values are compared with the FMUF predicted values produced by the long-term prediction models such as ASAPS,[1] SIRM (Zolesi et al., 1996), and ICEPAC.[2] The results show how the values obtained using *Interobl* immediately make it clear to the viewer that the long-term prediction models cannot follow the day-to-day or hour-to-hour ionospheric variability, while the nowcasting models more effectively describe the day-to-day F region ionospheric variability and therefore the propagation channel characteristics.

6. Conclusions

This work presents a user-friendly software that facilitates the scaling analysis of the oblique soundings recorded at Chania by the RCS-5B sweeping HF receiver. Besides speeding up the scaling phase and increasing the reliability of the

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[1]IPS Radio and Space Services. ASAPS Introductory Booklet (http://www.ips.gov.au/Products_and_Services/1/1/2).

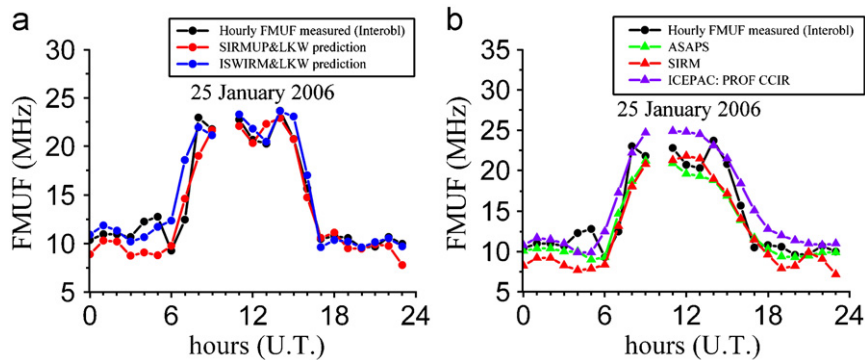[2]Stewart, F., G. ICEPAC Technical Manual (http://www.greg-hand.com/manuals/icepac_tech_manual.pdf).

Fig. 5. Comparisons between MUF measured values obtained using *Interobl*, and MUF predicted values calculated (a) by SIRMUP&LKW and ISWIRM&LKW, and (b) by ASAPS, SIRM, and ICEPAC for radio link Inskip-Chania on 25 January 2006.

data given as output, this program is also useful to build up a database of basic MUF validated data, which is essential to assess the reliability of forecasting and nowcasting models over a certain area or for point-to-point connections. This will hopefully lead to refinement of model prediction and perhaps incorporation of real-time oblique soundings into regional ionospheric predictions. The basic MUF validated database recorded at Chania will soon be included in the electronic Space Weather upper atmosphere (eSWua) database (Romano et al., 2008), which the INGV has been developing since June 2005 and is accessible through the site http://www.eSWua.ingv.it/.

On request the authors can provide additional code lines to read different ionogram file formats or to change the output file format.

Acknowledgments

Appendix A. Supporting Information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.cageo.2007.09.018.

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