

## **Autoscala: an Aid for Different Ionosondes**

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### **A b s t r a c t**

Autoscala is a software to automatically scale ionospheric characteristics from an ionogram. Initially it was only applied to the ionograms recorded by the AIS-INGV ionosondes installed at Rome and Gibilmanna (Italy), and Tucumán (Argentina), that are not able to record the polarization of the received echo.

Recently, Autoscala was also applied to the ionograms recorded by the AIS-Parus ionosonde installed at Moscow (Russia), that is not able to tag the received echo in terms of polarization, and by the VISRC2 ionosonde installed at Warsaw (Poland) that is instead able to perform the polarization tagging of the ordinary and extraordinary echoes.

This work shows different examples of processing performed on ionograms recorded by all these three different types of ionosondes.

**Key words:** ionograms, ionosonde, Autoscala program, automatic scaling, ionospheric monitoring.

### **1. INTRODUCTION**

In the last years, due to the growing interest in real time mapping and short term previsions, the necessity of immediate availability of well scaled data became more and more important (Belehaki *et al.* 2005, Materassi and Mitchell 2005, McNamara *et al.* 2007). For this reasons, together with the iono-

sonde AIS (Advanced Ionospheric Sounder), the Istituto Nazionale di Geofisica e Vulcanologia (INGV) developed a computer program, called Autoscala (Pezzopane and Scotto 2005, 2007), for the automatic scaling of critical frequency  $f_oF2$  and  $MUF(3000)F2$  from ionograms. Autoscala was later completed with a routine for the automatic interpretation of F1 layer, a routine for E sporadic (Es) layer and an Adaptive Ionospheric Profiler (AIP) for the real time estimation of the electron density profile (Pezzopane and Scotto 2008, Scotto and Pezzopane 2007, Scotto 2009).

From the early stage of its development, Autoscala was designed to be applied to any kind of ionosonde. In fact its main characteristics are that it is based on image recognition technique, allowing the algorithm not to be strictly related to the hardware features of a particular ionosonde, and that it can scale ionograms even without having information on polarization tagging, actually giving the algorithm the peculiarity to be applied to any kind of ionosonde.

In order to highlight the versatility of the algorithm, this work shows some examples of Autoscala processing on ionograms recorded by three different ionosondes: the AIS-INGV (Zuccheretti *et al.* 2003) and the AIS-Parus (Gajdanskij *et al.* 1996), that are not able to record the polarization of the received echo, and the VISRC2 that is instead able to perform the polarization tagging of the ordinary and extraordinary echoes (Pezzopane *et al.* 2008).

The application of Autoscala to these three different equipments may turn out to be very helpful for ionosonde network, like DIAS (Belehaki *et al.* 2007), collecting real-time ionospheric data on a European scale. The DIAS system uses this real-time data to prepare ionospheric specifications and forecasts for communications, surveillance and navigation systems. At the moment, the DIAS ionosonde network is equipped throughout with the same type of ionosonde, the DPS4 digisonde, produced by the University of Lowell, Massachusetts, United States, on which the ARTIST system, an automatic scaling program widely used and tested (Reinisch and Huang 1983, Gilbert and Smith 1988, Jacobs *et al.* 2004, McNamara 2006), is installed. The ARTIST system is a very clever algorithm characterized by high percentages of reliable autoscaled values given as output, but it can be applied only on ionograms whose polarization is differently tagged in terms of ordinary and extraordinary ray.

On the contrary, Autoscala, as it will be illustrated in the next paragraphs, works equally well whether having information on the polarization tagging of the trace or not. This might give DIAS system the possibility to include in its network additional ionosondes otherwise not able to perform a real time monitoring of the ionospheric plasma, with a corresponding improvement of the nowcasting and forecasting products.

## 2. DATA INPUT

Autoscala processes ionograms recorded as a binary file. This file has a header of 197 bytes, with the bytes between 1 and 6 representing the initial frequency of the sounding (which cannot be smaller than 1 MHz), the bytes between 8 and 13 representing the final frequency of the sounding, the bytes between 15 and 19 representing the frequency step, and the remaining bytes concerning the receiver settings, the signal processing algorithm, the date, the time, the calendar day of the sounding, the URSI code of the station, and the geophysical parameters depending on the specific installation site. The mandatory geophysical parameters that have to be present in the header are the geographical latitude and longitude, the magnetic latitude, longitude and inclination, and the gyrofrequency. The bytes between 120 and 121 form the “polarization information field” (hereinafter PIF) that can be equal to “OX”, “X”, “O”, or empty.

Following the header, these files are structured in a certain number (depending on the monitoring frequency range) of records of 150 bytes, each record representing the sounding in height for a specific value of the frequency; the value of the first byte is associated to the energy reflected back towards the ground from a height of 90 km, byte 150 is associated to the energy reflected back towards the ground from a height of 760.5 km, so that the passage between two successive bytes of the record corresponds to a movement in height of 4.5 km.

PIF = “OX” means that both the O and the X mode were recorded and differently tagged in terms of polarization; in this case for each frequency there are two consecutive records of 150 bytes, the first one for the O mode and the other one for the X mode. PIF = “O” means that only the O mode was recorded and for each frequency only one record of 150 bytes is present. PIF empty means that both modes were recorded but without being tagged differently in terms of polarization; in this case, only one record of 150 bytes is present for each frequency.

For the AIS-INGV ionosonde this kind of ionogram file format is native while in order to apply Autoscala to the ionograms recorded by the AIS-Parus and the VISRC2 ionosondes, a change of file format was necessary.

## 3. AUTOSCALA ALGORITHM: A BRIEF DESCRIPTION

Depending on the value of PIF, initially the ionogram is memorized by Autoscala as a single matrix  $A_{\text{ord}}$  (PIF = “O”) or  $A$  (PIF empty), or as a couple of matrixes  $A_{\text{ord}}$  and  $A_{\text{ext}}$  (PIF = “OX”). The number of rows and columns of these matrixes depends on the final frequency, the final virtual height, the initial frequency, the initial virtual height, the frequency step, and the virtual height resolution of the sounding as described in Pezzopane and Scotto

(2007). The matrix element is an integer associated to the echo amplitude received by the ionosonde.

Two empirical curves,  $T_{\text{ord}}$  and  $T_{\text{ext}}$ , that are able to fit the typical shape of the F2 trace, are then defined for the detection of the ordinary ray and of the extraordinary ray respectively. If PIF = "O" only the  $T_{\text{ord}}$  curve is considered, if PIF is empty or PIF = "OX" both curves,  $T_{\text{ord}}$  and  $T_{\text{ext}}$ , are considered.

The local contrast  $C$  between  $T_{\text{ord}}$  and  $A_{\text{ord}}$  (PIF = "O"), or between  $T_{\text{ord}}$  and  $T_{\text{ext}}$  and  $A$  (PIF empty), or between  $T_{\text{ord}}$  and  $T_{\text{ext}}$  and  $A_{\text{ord}}$  and  $A_{\text{ext}}$  (PIF = "OX") is then calculated making allowance for both the number of matched points and their amplitude.

The curve  $T_{\text{ord}}$  (PIF = "O") or the curves  $T_{\text{ord}}$  and  $T_{\text{ext}}$  (PIF empty or PIF = "OX") having the maximum value of  $C$  are then selected. If this value of  $C$  is greater than a fixed threshold  $C_t$ , the selected curves are considered as representative of the F2 trace.

If the F2 trace was identified, the F1 routine is run. Unlike the F2 layer autoscaling procedure, which is based on the identification of both ordinary and extraordinary rays, this procedure tries to identify only the F1 ordinary from the F1 cusp to the lowest virtual height of the F2 layer ordinary trace using a branch of parabola (Pezzopane and Scotto 2008).

The local contrast  $C$  between the branch of parabola and the matrix  $A_{\text{ord}}$  (PIF = "OX" or PIF = "O") or  $A$  (PIF empty) is then calculated making allowance for both the number of matched points and their amplitude. The parabola having the maximum value of  $C$  is then selected. If this value of  $C$  is greater than a fixed threshold  $C_t$ , the selected parabola is considered as representative of the F1 ordinary trace.

The Es routine is independent of the F2 and F1 routines and relies on a set of curves having the typical shape of the Es layer (Scotto and Pezzopane 2007). The local contrast  $C$  between the curve and the matrix  $A_{\text{ord}}$  (PIF = "OX" or PIF = "O") or  $A$  (PIF empty) is calculated making allowance for both the number of matched points and their amplitude. The curve having the maximum value of  $C$  is then selected. If this value of  $C$  is greater than a fixed threshold  $C_t$ , the selected curve is considered as representative of the Es trace. If PIF = "OX" or PIF = "O", then the output corresponds to  $f\phi\text{Es}$ , while if PIF is empty, then the output corresponds to the top frequency of the Es layer  $f\text{Es}$ .

Once different parts of the ionogram trace have been automatically identified, the electron density profile is estimated using a model with free parameters. In order to obtain the best fit with the recorded ionogram, these free parameters are varied using an iterative technique (Scotto 2009).

#### 4. EXAMPLES OF AUTOSCALA PROCESSING ON IONOGRAMS RECORDED BY THE AIS-INGV, THE AIS-PARUS, AND THE VISRC2 IONOSONDES

This section is devoted to illustrate some examples of processing performed by Autoscala on ionograms recorded by the three different ionosondes: AIS-INGV, AIS-Parus, and VISRC2.

##### AIS-INGV ionosonde

The AIS-INGV ionosonde has been designed to accomplish some physical characteristics such as the power reduction (about 200 W against several kW of traditional systems) and consequently weight, size, power consumption and hardware complexity. It exploits the resources of a PC to manage the sounding, the real time signal processing, data storing and sharing; it has also the capability to be remotely programmable.

This ionosonde, designed and developed at the INGV, is installed at Rome (41.8°N, 12.5°E), Gibilmanna (37.9°N, 14.0°E), Italy, and Tucumán (26.9°S, 294.6°E), Argentina, and it is not able to record the polarization of the received echo. Figures 1-3 show three examples of processing performed by Autoscala on ionograms recorded at Gibilmanna.

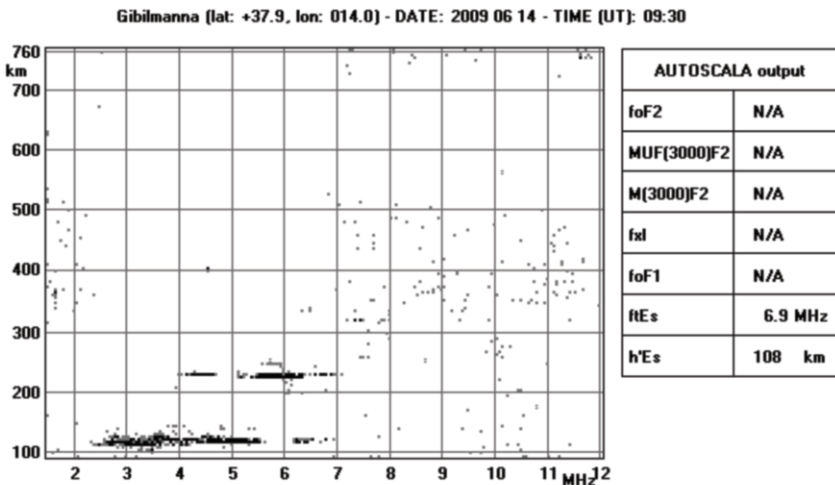


Fig. 1. Example of processing performed by Autoscala on a daytime ionogram recorded by the AIS-INGV installed at Gibilmanna. In this case, a strong Es layer blankets the ionogram trace and Autoscala gives as output only the ionospheric characteristics referring to the Es layer. The AIS-INGV cannot distinguish between ordinary and extraordinary ray and hence Autoscala gives as output  $fEs$  instead of  $f\hat{o}Es$ .

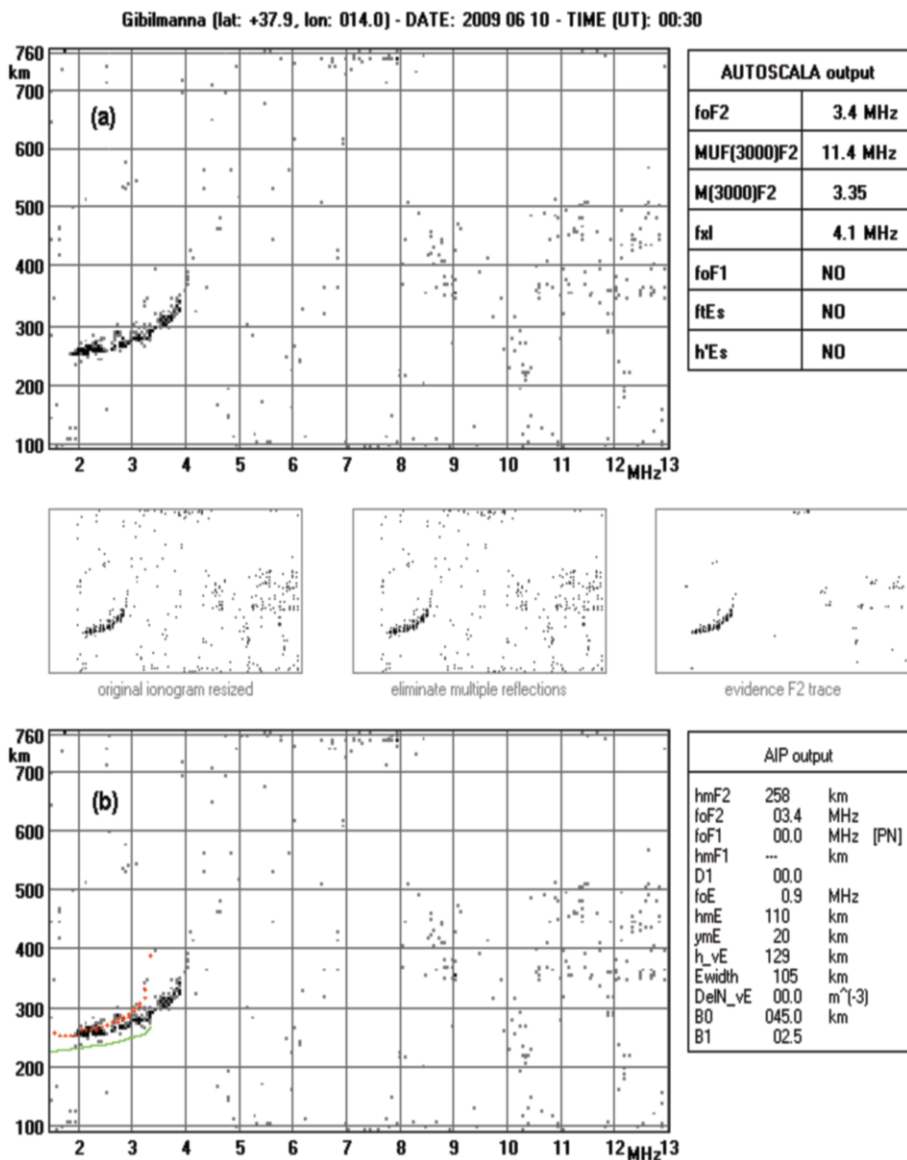


Fig. 2. Example of processing performed by Autoscala on a nighttime ionogram recorded by the AIS-INGV installed at Gibilmanna. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in red) and the corresponding vertical electron density profile (in green) were drawn. In the table “AIP output” the parameters used by Autoscala to estimate the vertical electron density profile associated with the reconstructed ordinary trace.

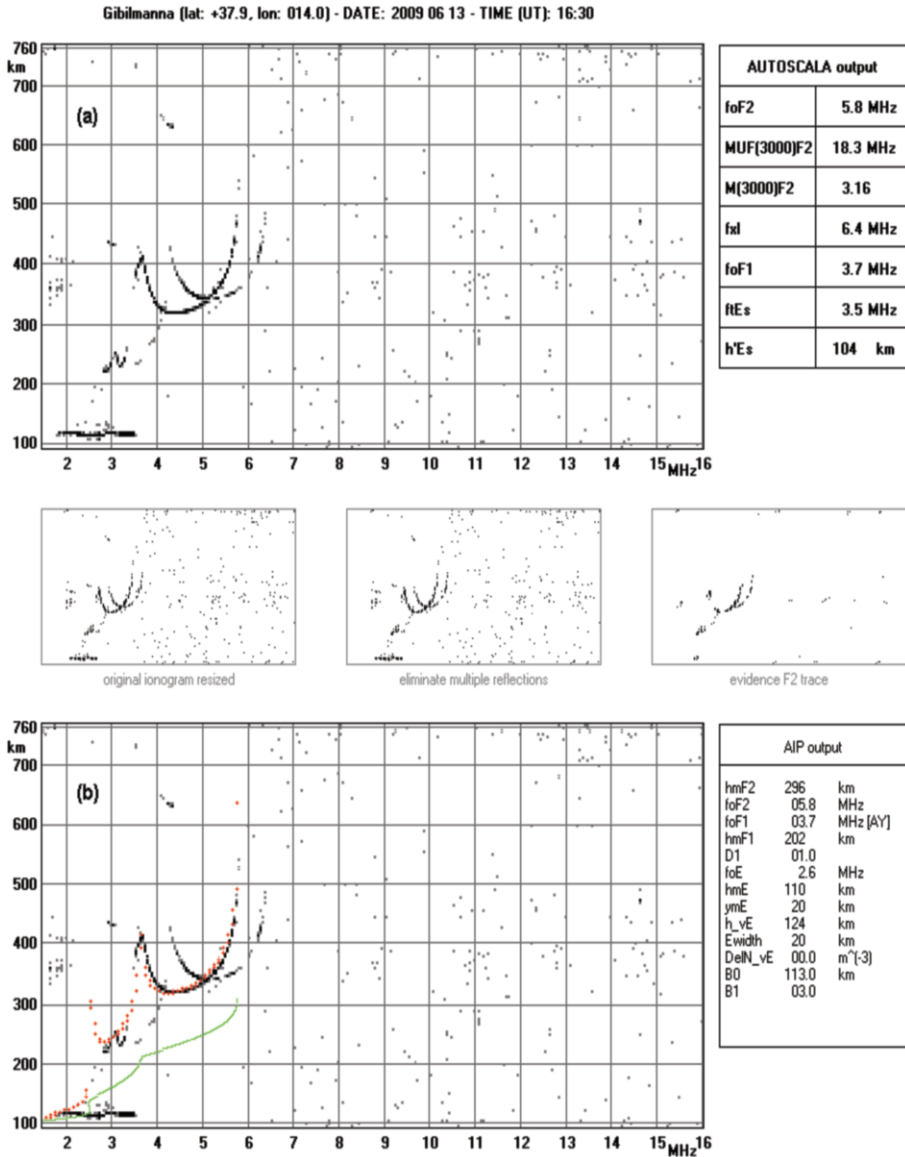


Fig. 3. Example of processing performed by Autoscala on a daytime ionogram recorded by the AIS-INGV installed at Gibilmanna. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in red) and the corresponding vertical electron density profile (in green) were drawn. Explanation to Table “AIP output” same as in Fig. 2.

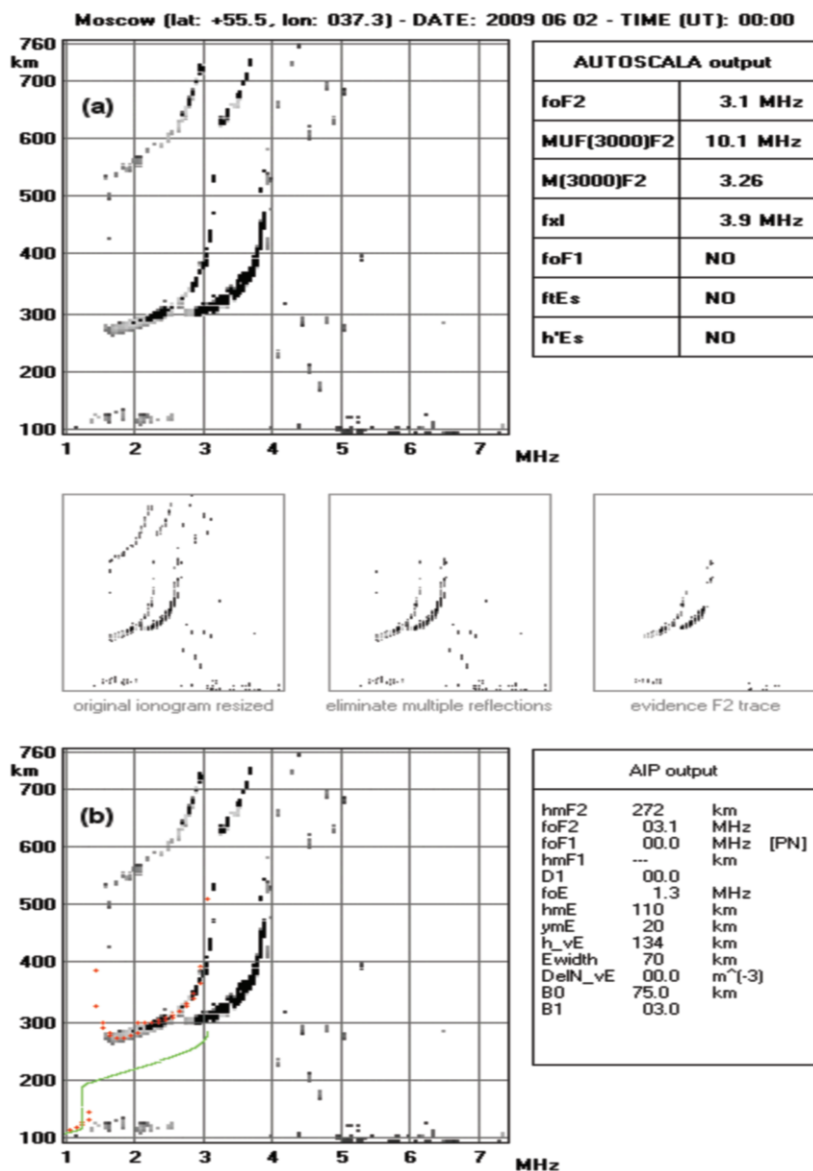


Fig. 4. Example of processing performed by Autoscala on a nighttime ionogram recorded by the AIS-Parus installed at Moscow. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in red) and the corresponding vertical electron density profile (in green) were drawn. Explanation to Table “AIP output” same as in Fig. 2.



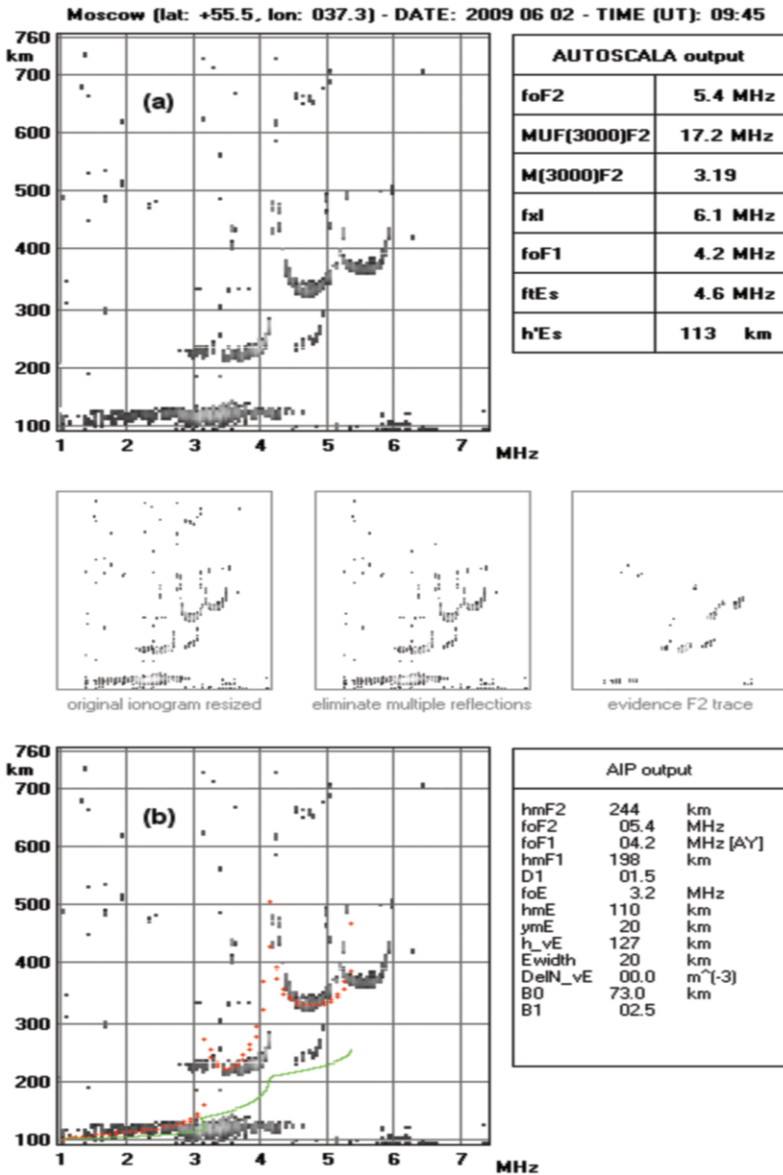


Fig. 5. Example of processing performed by Autoscala on a daytime ionogram, characterized also by an Es layer, recorded by the AIS-Parus installed at Moscow. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in red) and the corresponding vertical electron density profile (in green) were drawn. Concerning the Es layer the AIS-Parus cannot distinguish between ordinary and extraordinary ray and hence Autoscala gives as output  $ftEs$  instead of  $foEs$ . Explanation to Table “AIP output” same as in Fig. 2.

### AIS-Parus ionosonde

The AIS-Parus ionosonde, built at the Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russia, and installed in Moscow (55.5°N, 37.5°E), was designed on the classical scheme, using a simple pulsed signal. High power emission (~12 kW) and large-sized antenna enable reception of ionospheric echo from 1 MHz. It is not able to record the polarization of the received echo and before the adaptation of Autoscala to its ionograms it was not equipped with a tool to perform an automatic scaling of the recorded trace in real-time operation.

Figures 4-5 show two examples of processing performed by Autoscala on ionograms recorded at Moscow.

### VISRC2 ionosonde

The VISRC2 ionosonde, built at the Space Research Center in Warsaw, Poland, is installed at Warsaw (52.2°N, 21.1°E). The main characteristics of this ionosonde are: transmitted power 10 kW, pulse duration 100  $\mu$ s, sampling period 5  $\mu$ s, frequency resolution 25 kHz, and capability to distinguish ordinary and extraordinary reflections. Before the adaptation of Autoscala to its ionograms, VISRC2 was not equipped with a tool to perform an automatic scaling of the recorded trace in real-time operation.

Figures 6-8 show three examples of processing performed by Autoscala on ionograms recorded at Warsaw.

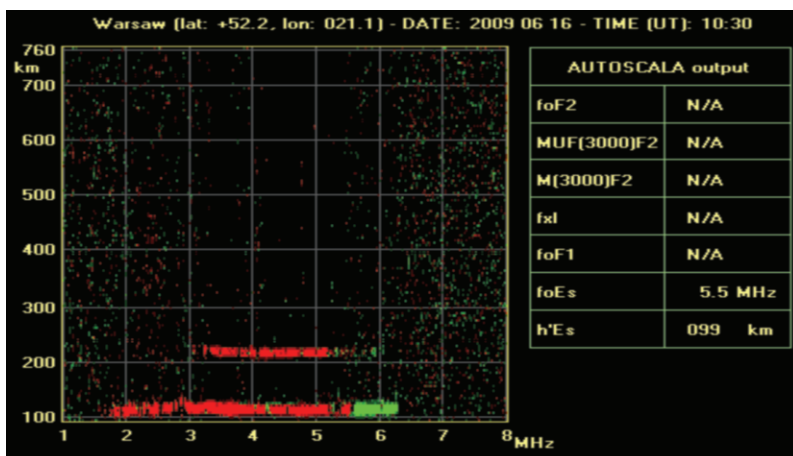


Fig. 6. Example of processing performed by Autoscala on a daytime ionogram recorded by the VISRC2 installed at Warsaw. In this case, a strong Es layer blankets the ionogram trace and Autoscala gives as output only the ionospheric characteristics referring to the Es layer. The VISRC2 can tag differently the ordinary and extraordinary ray and hence Autoscala gives as output  $f_oE_s$ .

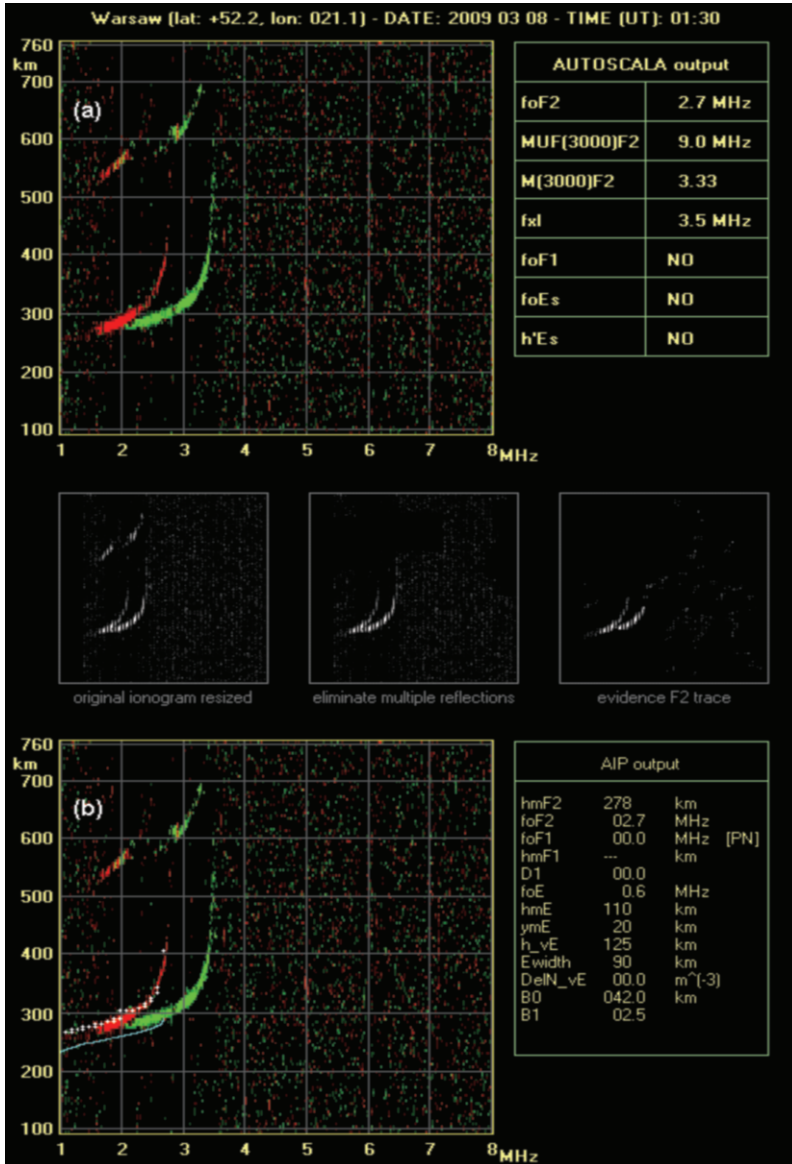


Fig. 7. Example of processing performed by Autoscala on a nighttime ionogram recorded by the VISRC2 installed at Warsaw. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in white) and the corresponding vertical electron density profile (in light blue) were drawn. Explanation to Table “AIP output” same as in Fig. 2.

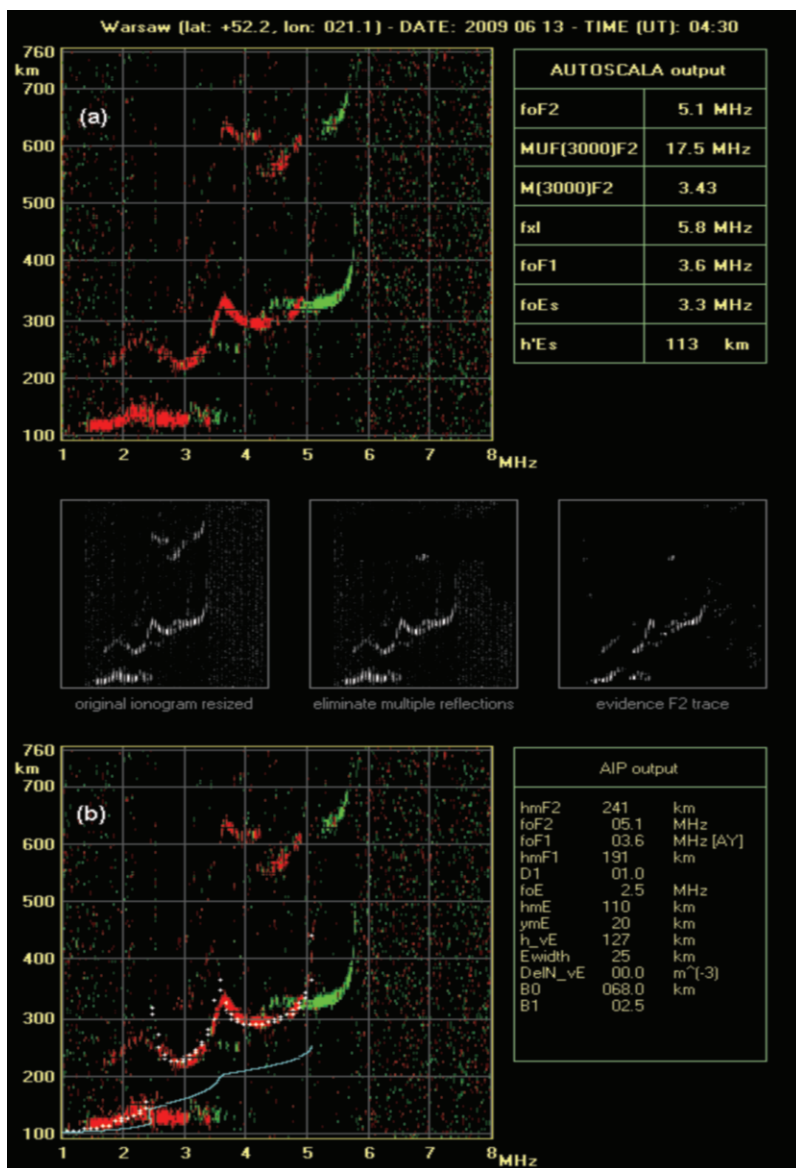


Fig. 8. Example of processing performed by Autoscala on a daytime ionogram recorded by the VISRC2 installed at Warsaw. In the top panel (a) the original recorded ionogram and the main ionospheric characteristics given as output by Autoscala. In the bottom panel (b) the same ionogram on which the reconstructed ordinary ray (in white) and the corresponding vertical electron density profile (in light blue) were drawn. Explanation to Table “AIP output” same as in Fig. 2.

## 5. CONCLUSIONS

This work has highlighted the versatility of Autoscala by showing some examples of processing performed on ionograms recorded by three different types of ionosondes. It has been shown how Autoscala can face in the same way ionograms that are with or without polarization tagging. This represents a result of some significance, because the ionosonde-Autoscala systems turn out to be a further resource for existing ionosondes networks like DIAS, by increasing their potentiality and reliability in terms of ionospheric nowcasting and forecasting, relying on automatically scaled data.

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