A method for automatic scaling of sporadic *E* layers from ionograms

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[1] A method for automatic scaling of the maximum frequency and virtual height of a sporadic *E* layer is presented. A set of ionograms recorded at the ionospheric observatory of Gibilmanna was used to test the performance of the algorithm. The test was performed by comparing the data obtained automatically with the values scaled by an operator.

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1. Introduction

[2] Recently, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) developed a low-power (less than 200 W) advanced ionospheric sounder called AIS-INGV [*Zuccheretti et al.*, 2003; *Bianchi et al.*, 2003]. This ionosonde was installed at the ionospheric stations of Gibilmanna, Rome and Terra Nova Bay, in Antarctica. Together with the ionosonde, Autoscala, a computer program for the automatic scaling of critical frequency f_oF_2 and $MUF(3000)F_2$ from ionograms was developed [*Scotto and Pezzopane*, 2002; *Pezzopane and Scotto*, 2004, 2005].

[3] The aim of this work is to present a procedure to identify the presence of a sporadic *E* (E_s) layer in the ionogram estimating its maximum frequency f_tE_s and the associated virtual height $h'E_s$. This procedure is designed for application as an extension of the current version of Autoscala.

[4] The E_s layers are thin structures (usually about 1 km thick) in the *E* region having enhanced electron density. Sporadic *E* layers may be very flat and uniform or may form clouds of electrons 2–100 km in size and moving horizontally at 20–130 m s^{-1}. From a fixed observation point on the Earth's surface, E_s layers can last from a few minutes to several hours. Unlike other ionospheric parameters such as the critical frequency of the F_2 region, f_oE_s values do not cluster round a mean; sporadic *E* is often not present at all and at other times f_oE_s reaches values many times greater than its mean [*Whitehead*, 1989]. For this reason the word "sporadic" must be considered in the sense that the E_s events are unpredictable but they are statistically very common at midlatitude in late spring and early summer.

[5] An E_s event sensibly affects radio communication systems. In the HF range it can cause the maximum usable frequency (MUF) for reflection in the *E* layer to be higher than the corresponding MUF for the *F* layer. Therefore the reliable automatic real time monitoring of f_tE_s is desirable for space weather applications. In addition $h'E_s$ can be a useful parameter to distinguish different E_s layers formed by the downward propagation of wind shear convergent nodes associated with tide [*Haldoupis et al.*, 2006].

[6] On ionograms the E_s layer appears as a strong reflection that can occur over a range of heights from about 90 to 120 km or more. The maximum frequency reflected can be greater than the critical frequency of any of the normal layers. An E_s layer is classified according to the URSI standard in 11 morphological types [*Piggot and Rawer*, 1972]. The routine described in this work is designed to scale f_tE_s and $h'E_s$ for all these E_s types except for the retardation type (identified by the letter *r*) typical of the auroral zone. In the case of multiple E_s layers the routine was thought unable to scale the layer having the maximum frequency by type as suggested by the URSI standard [*Piggot and Rawer*, 1972]. However, with regard to this issue no conclusion can be reached because in the data set considered there are few ionograms showing multiple E_s layers.

2. Automatic Scaling Method for Sporadic *E* Maximum Frequency and Virtual Height

[7] The routine for automatic scaling of the E_s layer was developed along similar lines to the routine currently used for f_oF_2 and $MUF(3000)F_2$ [*Scotto and Pezzopane*, 2002, *Pezzopane and Scotto*, 2004, 2005]. This routine is based on image recognition techniques giving as output f_tE_s whose meaning depends on the antenna system of the ionosonde. If only the ordinary component is recorded the output corresponds to f_oE_s, while if only

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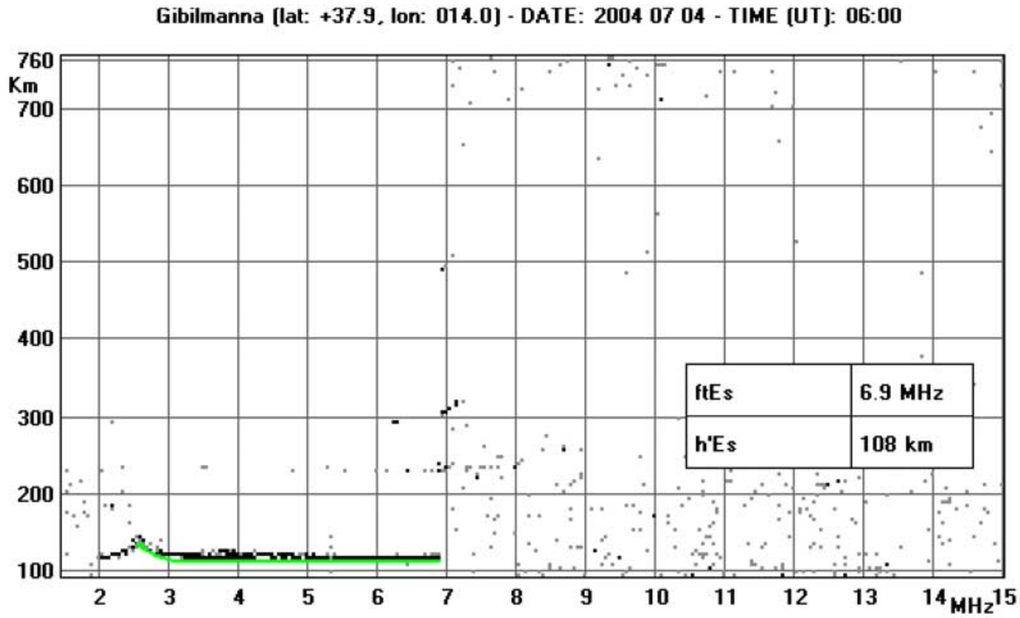

Figure 1. Ionogram having a clear E_s trace. In this case the routine properly scaled f_tE_s as 6.9 MHz (in green, the trace identified by the software) in close agreement with the value given by an experienced operator.

the extraordinary component is recorded the output corresponds to f_xE_s. For the ionograms considered in this study both components were recorded. For such ionograms the routine described in this paper limits itself to give as output f_tE_s but is unable to specify this value as f_oE_s or f_xE_s.

[8] The technique relies on a set of curves having the typical shape of the E_s layer. The mentioned set is defined setting appropriate bounds for the height and the frequency. In particular curves having maximum frequency that does not exceed the modeled critical frequency f_oE of the normal E region are not considered. The shape of each curve is defined by several parameters p_1, p_2,. . .p_n. For each curve the local contrast $C(p_1, p_2, \ldots p_n)$ with the recorded ionogram is calculated with allowance made 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 E_s trace. The value f_tE_s is thus obtained as the maximum frequency of the curve together with the associated height $h'E_s$. On the contrary if C_t is not exceeded then the routine assumes the E_s trace is not present on the ionogram.

3. Comparison With the Manual Method

[9] The test was performed using a set of 1421 ionograms recorded in July 2004 and January 2005 by the ionosonde AIS-INGV installed at the ionospheric station of Gibilmanna. This data set was divided into two subsets. The subset *Y*, containing the ionograms for which the operator observed an E_s trace, and subset *N* containing the ionograms for which the operator did not observe any E_s trace.

[10] For each subset we considered (1) the number of ionograms for which the routine detected the E_s trace scaling the maximum frequency and virtual height and (2) the number of ionograms for which the routine did not detect the E_s trace.

[11] Figure 1 shows an ionogram for which the operator observed the E_s layer and scaled f_tE_s: in this case the routine detected the E_s and scaled f_tE_s correctly. Figure 2 is an ionogram for which the E_s trace presents some discontinuities. In this case the operator scaled f_tE_s (5.1 MHz), and this value was also correctly scaled by the routine.

[12] The main cause of error is related to the presence of noise in the recorded ionogram. Figure 3, a case of an ionogram for which both the operator and the routine detected the E_s layer, but the automatically scaled value is not acceptable. In this case the signal at 8.8 MHz was incorrectly recognized by the routine as the last part of the E_s trace. At the same time the operator considered such an echo as noise giving a value of 6.9 MHz for f_tE_s. Figure 4 shows an ionogram for which the software failed by not detecting an E_s layer that is actually present. This ionogram belongs to the 33 cases reported on

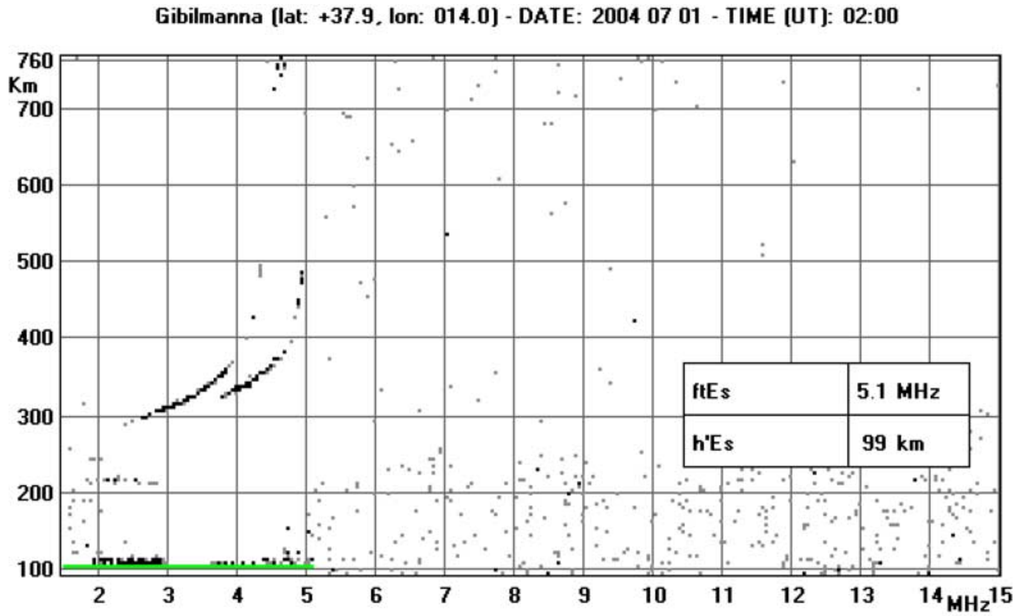

Figure 2. Ionogram for which the E_s trace has some discontinuities. In this case the routine scaled f_tE_s as 5.1 MHz (in green, the trace identified by the software) in close agreement with the value given by an experienced operator.

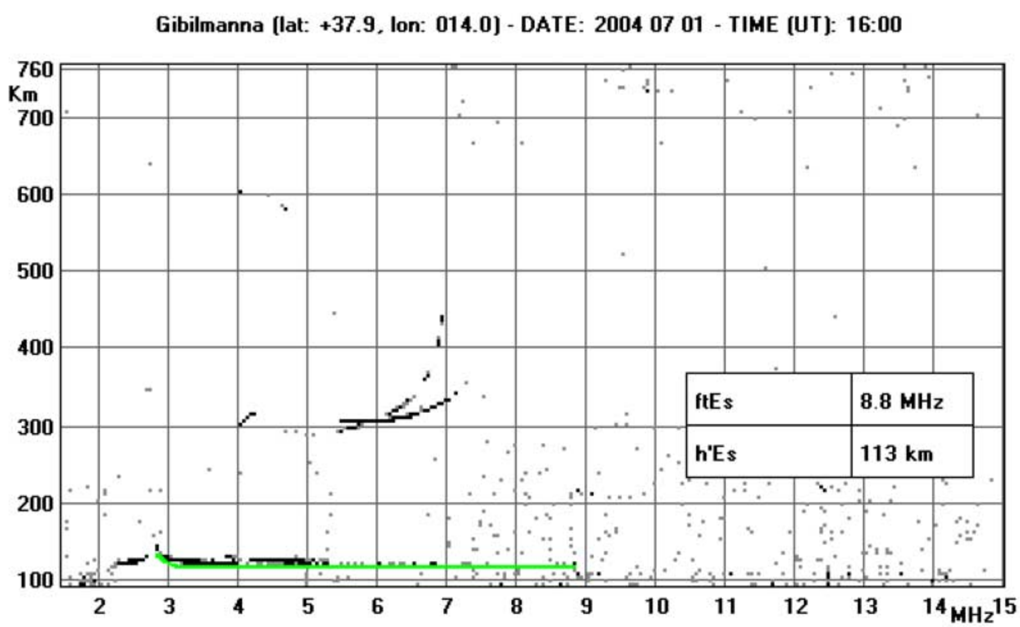

Figure 3. Ionogram for which the routine failed, giving an unacceptable automatically scaled value. In this case the signal at 8.8 MHz was incorrectly recognized by the routine as the last part of the E_s trace (in green, the trace identified by the software), while the operator considered such an echo as noise and gave a value of 6.9 MHz for f_tE_s.

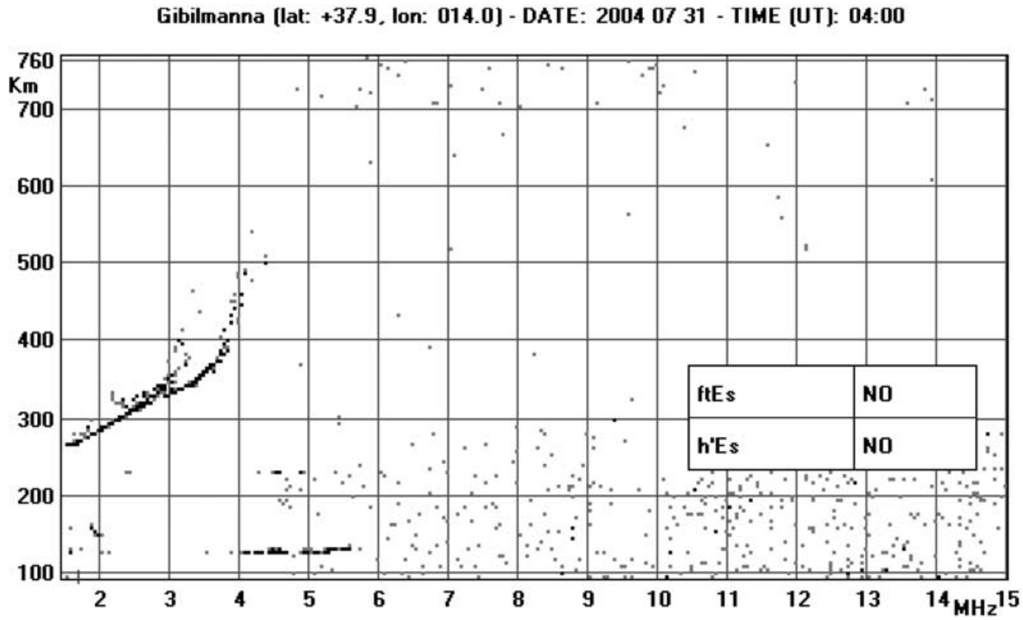

Figure 4. Ionogram for which the software failed by not detecting an E_s layer that is actually present.

Tables 1a and 1b for which the above mentioned threshold C_t was not exceeded, although an E_s trace was observable.

[13] The results of the data analysis for f_tE_s are reported in Table 1a and can be summarized as follows.

[14] 1. Among the 609 ionograms for which the operator observed an E_s layer the routine correctly identified 576 cases and failed in 33 cases.

[15] 2. With reference to the ionograms in which the presence of an E_s layer was assumed both by Autoscala and by the operator, f_tE_s was acceptably scaled in a high percentage of cases (540 out of 576, equal to 93.8%) (in this work a value is considered acceptable if within ±0.5 MHz of the value obtained by the operator); in this case the results are also presented in the form of a histogram in Figure 5.

[16] 3. When the E_s layer is not observed in the ionograms, the routine never wrongly detected the presence of an E_s layer.

[17] Analogous results for $h'E_s$ are shown in Table 1b. These results highlight the good reliability of the autoscaled values of $h'E_s$ once the routine correctly detected the presence of an E_s layer. In this case a value is considered acceptable if within ±5 km of the value obtained by the operator.

4. Conclusions

[18] The results reported in Tables 1a and 1b show that the routine for automatic scaling of E_s layers can reliably identify the cases in which there is an E_s layer. The results reported in Table 1a indicate that acceptable values of f_tE_s are obtained in 540 out of 576 cases, or 93.8% of cases, for the ionograms for which both the software and the operator observed an E_s layer.

[19] For the same ionograms, the results reported in Table 1b indicate that acceptable values of $h'E_s$ are

Table 1a. Behavior of the E_s Scaling Routine for f_tE_s[a]

	Autoscala	
Operator	E_s Detected	E_s Not Detected
E_s observed	540 acceptable, 36 not acceptable	33
E_s not observed	-	812

[a]The test was carried out on the ionograms recorded at Gibilmanna in July 2004 and January 2005.

Table 1b. Behavior of the E_s Scaling Routine for $h'E_s$[a]

	Autoscala	
Operator	E_s Detected	E_s Not Detected
E_s observed	572 acceptable, 4 not acceptable	33
E_s not observed	-	812

[a]The test was carried out on the ionograms recorded at Gibilmanna in July 2004 and January 2005.

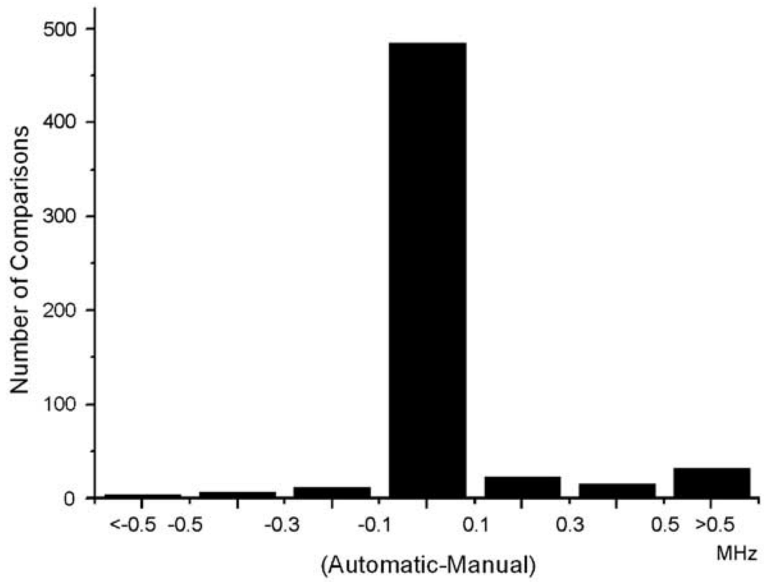

Figure 5. Differences (δ = automatic-manual) between the values of f_tE_s for ionograms for which both the INGV software and the operator identified an E_s layer. Out of 576 cases the results were: for 484 cases, -0.1 MHz $\leq \delta \leq$ 0.1 MHz; for 23 cases, 0.1 MHz $< \delta \leq$ 0.3 MHz; for 12 cases, -0.3 MHz $\leq \delta < -0.1$ MHz; for 15 cases, 0.3 MHz $< \delta \leq$ 0.5 MHz; for 6 cases, -0.5 MHz $\leq \delta < -0.3$ MHz; for 32 cases, $\delta >$ 0.5 MHz; for 4 cases, $\delta < -0.5$ MHz.

obtained in 572 out of 576 cases, equal to 99.3% of cases.

[20] For these reasons we can conclude that the INGV routine for automatic scaling of E_s layers performs well and can be added to Autoscala. It is possible to see on the Internet the real time ionograms recorded and autoscaled by the AIS-INGV/Autoscala system installed in the station of Gibilmanna by connecting to the Web site http://ionos.ingv.it/Gibilmanna/latest.html.

References

Bianchi, C., U. Sciacca, A. Zirizzotti, E. Zuccheretti, and B. J. Arokiasamy (2003), Signal processing techniques for phase-coded HF-VHF radars, *Ann. Geophys. Italy*, *46*(4), 697–705.

Haldoupis, C., C. Meek, N. Christakis, D. Pancheva, and A. Bourdillon (2006), Ionogram height-time-intensity observations of descending E layers at mid-latitude, *J. Atmos. Sol. Terr. Phys.*, *68*, 1063–1073.

Pezzopane, M., and C. Scotto (2004), Software for the automatic scaling of critical frequency f_oF_2 and $MUF(3000)F_2$ from ionograms applied for the ionospheric observatory of Gibilmanna, *Ann. Geophys. Italy*, *47*(6), 1783–1790.

Pezzopane, M., and C. Scotto (2005), The INGV software for the automatic scaling of f_oF_2 and $MUF(3000)F_2$ from ionograms: A performance comparison with ARTIST 4.01 from Rome data, *J. Atmos. Sol. Terr. Phys.*, *67*, 1063–1073.

Piggot, W. R., and K. Rawer (1972), *URSI Handbook of Ionogram Interpretation and Reduction*, 2nd ed., 325 pp., Elsevier, New York.

Scotto, C., and M. Pezzopane (2002), A software for automatic scaling of f_oF_2 and $MUF(3000)F_2$ from ionograms, paper presented at 2002 URSI General Assembly, Union Radio Sci. Int., Maastricht, Netherlands, 17–24 Aug.

Whitehead, J. D. (1989), Recent work on mid-latitude and equatorial sporadic-E, *J. Atmos. Terr. Phys.*, *5*, 401–424.

Zuccheretti, E., G. Tutone, U. Sciacca, C. Bianchi, and B. J. Arokiasamy (2003), The new AIS-INGV digital ionosonde, *Ann. Geophys. Italy*, *46*(4), 647–659.

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