Comparison between manual scaling and Autoscala automatic scaling applied to Sodankylä Geophysical Observatory ionograms

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Abstract

This paper presents a comparison between standard ionospheric parameters manually and automatically scaled from ionograms recorded at the high-latitude Sodankylä Geophysical Observatory (SGO, ionosonde SO166, 64.1° geomagnetic latitude), located in the vicinity of the auroral oval. The study is based on 2610 ionograms recorded during the period June–December 2013. The automatic scaling was made by means of the Autoscala software. A few typical examples are shown to outline the method, and statistics are presented of the differences between manually and automatically scaled values of F2, F1, E and sporadic E (E_s) layer parameters.

We draw the conclusions that:

1. The F2 parameters scaled by Autoscala, foF2 and M(3000)F2, are reliable.

2. F1 is identified by Autoscala in significantly fewer cases (about 50 %) than in the manual routine, but if identified the values of foF1 are reliable.

3. Autoscala E layer parameters are close to those manually scaled when identified; however, Autoscala detects an E layer in many cases when none is identified by the manual scaler.

4. E_s and parameters of E_s identified by Autoscala are in many cases different from those of the manual scaling. Scaling of E_s at auroral latitudes is often a difficult task.

1 Introduction

Ionosondes for studying the ionosphere were invented in the late 1920s, and their worldwide implementation started in the 1940s as military shortwave communication became important. An ionosonde is a radio echo instrument transmitting radio waves of alternating frequency, receiving reflections from the ionosphere, and measuring the
travel times of the waves at different frequencies. The return power vs. frequency and travel time is presented as graphs called ionograms, from which information on the structure of the ionosphere can be derived. The travel times $\Delta t$ are presented as virtual heights $h' = \frac{c \Delta t}{2}$; the true reflection heights are different due to the significant radio wave refraction close to the critical ionospheric plasma frequencies. Up to four distinct layers, called the D, E, F1 and F2 regions respectively in increasing altitude order, can be identified in ionograms, depending on location, season and time of day.

Historically, the shapes of ionograms are described by a number of standard parameters (Piggott and Rawer, 1978). This is useful in order to characterise the main features of the ionosphere, such as what frequencies are usable for long distance communication. These parameters have been read out manually at several observatories since the 1950s, a procedure referred to as ionogram scaling. Thus, time series of continuous ionospheric observations span several solar cycles, and in order to monitor long-term environmental changes these observations must be continued in a consistent way without significant methodological changes. However, manual scaling of ionograms requires substantial work efforts and the results are subjective, so development of automatic scaling routines has started and progressed together with recent developments in computer performance.

One such routine is Autoscala (Pezzopane and Scotto, 2005), which has been developed at the Italian National Institute of Geophysics and Volcanology (INGV). Autoscala is a program able to perform an automatic scaling of vertical soundings, giving as output the main ionospheric characteristics (Pezzopane and Scotto, 2007, 2008, 2010; Scotto and Pezzopane, 2007, 2008; Scotto et al., 2012) and an estimation of the electron density profile (Scotto, 2009). It is based on an image recognition technique and can run without polarisation information, which allows the algorithm to be applied to any kind of ionosonde (Pezzopane et al., 2010).

Autoscala works by defining a set $S$ of $N$ pairs of empirical curves $S \equiv \{T_{i[0]}, T_{i[x]}\}$, $i = 1, 2, \ldots, N$, fitting the typical shape of the F2 ordinary and extraordinary traces. For each pair of curves $T_{i[0]}$, $T_{i[x]}$ the local contrast $C$ with the recorded ionogram is calculated,
making allowance for both the number of matched points and their amplitude. The pair of curves \( T_{i[0]} \), \( T_{i[x]} \) having the maximum value of \( C \) is then selected. If this value of \( C \) is greater than a fixed threshold \( C_t \), the selected curves are considered as representative of the traces. The values of the critical frequencies are thus obtained from the selected curves. If \( C \) does not exceed \( C_t \), the routine assumes that the F2 trace is not present on the ionogram. With a similar procedure the F1 and E\(_s\) traces are also detected.

The accuracy of the Autoscala output has been tested against manually validated data at low and middle latitudes (Pezzopane and Scotto, 2005, 2007, 2008; Pezzopane et al., 2007; Scotto and Pezzopane, 2007; Bullett et al., 2010; Krasheninnikov et al., 2010) and also compared with that of the Automatic Real-Time Ionogram Scaling with True-height (ARTIST) system (Reinisch et al., 2009; Galkin and Reinisch, 2008; Pezzopane and Scotto, 2005, 2007).

Experience from high latitude stations including the two different automatically scaling ionosondes at the EISCAT transmitter site at Ramfjordmoen, Norway (69° northern latitude), a Dynasonde (Rietveld et al., 2008) and a Digisonde (see e.g. Reinisch et al., 2009), shows that in the auroral zone the scaled parameters may differ significantly depending on the radio pulse scheme and scaling method. The present comparison is based on hourly ionograms from the high latitude CW chirp ionosonde at Sodankylä Geophysical Observatory (SGO, 67° N, 26° E, 64.1° CGMLAT).

2 The Sodankylä ionosonde

Ionosondes have been running at SGO, URSI station SO166, since the International Geophysical Year 1957. The present ionosonde, called Alpha Wolf, is the third instrument in order and was installed in 2005. Details of the instrument have also been described in Kozlovsky et al. (2013). The Alpha Wolf is an FM chirp CW sounder developed at SGO. The CW chirp technique implies that transmission and reception must be simultaneous, so the transmitting and receiving antennas are separated by approximately 1 km. The transmitter antenna is a rhombic wide-band loop. At the
receiver site an array of crossed magnetic loop antennas is installed in order to provide imaging capabilities. However, during these tests the signals from all antennas were combined into two channels, one per linear polarisation. The transmitter and receiver are completely separate systems, starting on the same full second by GPS synchronisation. The exciter of the transmitter and the local oscillator of the receiver are basically identical, producing identical CW frequency sweeps (chirps). The name Alpha Wolf derives from the distinct “howling” sound produced when the down-converted received signal is fed to a loudspeaker. After mixing and filtering, the base-band converted signal is digitised into data streams of in-phase and quadrature channels, in total 4 real vectors or one complex signal per polarisation. The conversion from complex sampled data to ionograms is simple: because of the continuous, constant rate frequency sweep, the frequency spread around the centre frequency at each instant in time corresponds to a range (virtual height) interval. The ionograms are thus obtained by applying a windowed Fourier transform (FFT) to the digital signal after combining the linearly polarised data into the O or X mode circular polarisation. The centre time of the FFT window gives the centre frequency and the length of the window determines the range resolution, both determined by the sweep rate. The selection of length and overlap of the FFT windows thus implies a tradeoff between frequency and range resolution. Interference from known shortwave transmitters may be filtered out in the process.

Figure 1 shows a simplified block diagram of the whole system including data processing. The receiver computer reads the digital signals from the A/D converter of the receiver and stores the data temporarily as binary files. These data are then made available to the processing computers through the local network. Most important of those computers is the operational real time processing computer. Its analysis software, a single Matlab script, produces O mode ionograms, which are archived and also available online in real time.
3 Manual scaling of ionograms

The Sodankylä ionosonde station is unique in that its ionograms have been interpreted manually in a consistent way since the start in 1957. Until the deployment of the present system in 2005, the ionograms were recorded and scaled on photographic film. The present system is designed to present the ionograms to the scaler in a similar manner. Real-time ionograms are copied through the local network and backed up on a dedicated ionogram server, from which they are read and interpreted on the desktop workstation of the scaler. Matlab software running on this workstation displays the O mode ionograms (see an example in Fig. 2, top panel) and aids the scaler to read out the parameters and save their values. The 11 parameters listed below are routinely scaled once per hour according to Piggott and Rawer (1978); Wakai et al. (1987). Additionally ionograms at half hours (full hours + 30 min) are scaled for critical frequencies (i.e. excluding the virtual heights).

3.1 Scaled parameters

\[ f_{\text{min}} \] the lowest frequency of reflected waves recorded in the ionogram

\[ f_{\text{oE}} \] the ordinary polarisation mode critical frequency of the lowest thick stratification in the E region

\[ h'_{E} \] the minimum virtual height of the normal E layer

Type\(E_{s}\) classification of sporadic E layers (\(E_{s}\)), i.e., thin layers showing rapid changes observed in the height range 100–170 km (more details are given in Sect. 5.2).

\[ f_{\text{OE}_{s}} \] the top frequency of the ordinary wave component of continuous \(E_{s}\) traces

\[ h'_{E_{s}} \] the lowest virtual height of the trace from which \(f_{\text{OE}_{s}}\) is scaled

\[ f_{\text{bE}_{s}} \] the blanketing frequency of the \(E_{s}\) layer, i.e., the lowest frequency at which the \(E_{s}\) layer allows reflections from higher layers
the virtual height of the F layer, i.e., the lowest virtual height of the F layer ordinary mode trace

foF1 the ordinary mode critical frequency of the F1 layer (which is formed during the daytime mainly in summer at heights above 150 km)

foF2 the ordinary mode critical frequency of the highest stratification in the F region

M(3000)F2 the M factor (maximum usable frequency factor), which is a conversion factor for obtaining the maximum usable frequency for oblique propagation with reflection from the F2 layer for the standard distance of 3000 km.

The six parameters indicated in **bold face** in the above list are those automatically scaled by Autoscala. Their values are compared in the following.

### 4 Automatic scaling

Autoscala works using input ionograms in a specific binary format called RDF (Pezzopane and Scotto, 2005), in which O and X mode traces are saved separately. Hence, in order to apply Autoscala to the ionograms recorded by the SGO ionosonde, a change of file format was required. During the Autoscala test phase presented here, a parallel real time ionogram processing instance was therefore installed on a separate computer in order to produce the required O and X mode traces. A modified and improved version of the real time analysis software was used, running under the open source Matlab-compatible language Octave (Eaton et al., 2015). In order to improve the contrast of the O and X mode traces, an improved filtering to mask out weak echoes was applied when converting the data to ionograms. This filtering may be necessary in order for the automatic scaling to find the normal E and F layer ionogram traces, but as will be seen it may also mask out real features such as spread F and sporadic E layers. The filtered O and X mode traces were interpolated to matrices of fixed frequency and height resolution as required by Autoscala. Subsequently the data were saved as RDF.
files and automatically copied to INGV for processing. Matlab scripts for writing RDF files are available on request from the corresponding author.

Figure 2 shows an example that makes the difference between the standard O mode real time ionograms and the filtered RDF ionograms clear. The standard ionogram in the upper panel does show some X mode leakage, which is disregarded in the manual scaling process. The panel below is the output from Autoscala, showing both the filtered traces and retrieved parameters.

5 Results of comparison

The Autoscala scaling was applied to SGO ionograms from the period June–December 2013: 1 June–1 July, 29 July–13 October and 1–19 December 2013; in total 117 days. Out of the data from these days, 2610 ionograms were analysed both manually and automatically.

5.1 Comparison of scaled parameters

Figure 3 presents a comparison of manually and automatically scaled parameters for one day, 4 June 2013. The five panels in the plot represent (from top to bottom):

1. M(3000)F2, shown by red asterisks (manual) and black circles (Autoscala).
2. F layer O mode critical frequencies: foF2 (red asterisks for manual and black circles for Autoscala), and foF1 (blue stars for manual and black squares for Autoscala).
3. E layer O mode critical frequency, foE (red asterisks for manual and black circles for Autoscala).
4. Critical frequency of sporadic E layers, foEs (red asterisks for manual and black circles for Autoscala).
5. Virtual height of sporadic E layers, $h'_E_s$ (red asterisks for manual and black circles for Autoscala), manually scaled virtual height of E layer, $h'_E$ (blue diamonds), lower edge of E layer, always set to 90 km in Autoscala (dashed line).

Figure 3 shows a good agreement between automatically and manually scaled foF2 and foF1. However, scaling of sporadic layers appears to be more problematic. Similar daily summaries were made for all 117 days when at least one of the 24 ionograms was scaled by Autoscala. The results are presented in Tables 1, 2 and 3 and shown as histograms in Figs. 4 and 5.

Table 1 presents the relative number (%) of ionograms in which a certain parameter was identified manually, automatically, by both methods, and by one method only. The F2 layer is in general well identified by Autoscala, whereas for the other layers (F1, E, and $E_s$) the coincidence of visual and automatic identifications is rather low. In particular, the automatic routine identifies an E layer in many cases when the manual scaler does not. On the other hand, F1 and especially $E_s$ layers are frequently not identified at all by Autoscala. Possible reasons for that will be discussed in Sect. 5.3.

Table 2 presents statistics of the differences between the manually and automatically scaled values of all parameters. In the bottom row we present only manually scaled $h'_E$, since Autoscala always assumes the height to be 90 km. These results are also illustrated by histograms in Figs. 4 and 5, where Fig. 4 shows the distributions of the differences between manually and automatically scaled parameter values with medians and quartiles, and Fig. 5 shows the distribution of manually scaled $h'_E$ values and the fixed height of 90 km assumed by Autoscala. The distribution of manually scaled values has its most probable value close to 90 km as well, so the assumption is reasonable, but there is a long tail of $h'_E$ observations well above 100 km. It will be seen that the occurrence such E layers presents a problem.

The results can be summarised as follows:

**F2** Generally, there is a very good agreement between the manually and automatically scaled F2 parameters, foF2 and M(3000)F2.
The F1 layer was detected by Autoscala in only about half of those cases when it was identified manually. In the cases of detection however, foF1 was identified with satisfactory accuracy.

Values of Autoscala foE are close to those obtained manually, but Autoscala identifies foE in many cases (30% of all ionograms) when no E layer was identified manually. See also an example in Sect. 5.3 below.

Sporadic E layers were identified by Autoscala in relatively few cases (about 1/3 of the manual detections). The difference between manually and automatically scaled parameters may be significant.

It thus appears that sporadic E layers are the most difficult to scale automatically. In the next section this is considered in more detail.

5.2 Scaling of sporadic layers

Scaling of sporadic E layers at the auroral latitudes is often a difficult task (e.g. Turunen and Rao, 1976). In addition to those Es caused by metallic ions, typical at mid latitudes, there are specific high-latitude sporadic layers caused by auroral precipitation. Sporadic E layers are usually classified in the following way:

5.2.1 Mid-latitude types

C (cusp), an Es trace showing a relatively symmetrical cusp at or below the critical frequency of the normal E or particle E layer.

H (high), an Es trace showing a discontinuity in height with the normal E or particle E layer trace at or above the critical frequency. The cusp is not symmetrical.

L (low), a flat Es trace below the normal E or particle E minimum virtual height.

F (flat), a clean Es trace which shows no appreciable increase of height with frequency, observed at night only.
5.2.2 High-latitude types

R (retardation), an \( E_s \) trace showing an increase in virtual height at the high frequency end but which becomes partially transparent below \( f_0E_s \).

K (particle), denotes the presence of a particle \( E \) layer, similar in appearance to normal \( E \), which obscures higher layers up to its critical frequency.

A (auroral), denotes all types of very spread \( E_s \) traces. The typical pattern shows a well-defined flat or gradually rising lower edge with stratified or diffuse traces present above it.

5.2.3 Indicated but not scaled

S (slant), a diffuse \( E_s \) trace whose virtual height rises steadily with frequency.

D (D-layer), a weak diffuse trace at or below 95 km associated with high absorption and consequently high \( f_{\text{min}} \).

In Table 3 we present a comparison of manual and Autoscala parameters separately for each type of \( E_s \). The first three columns in the left present types of \( E_s \), numbers of manual identifications, and percentage of Autoscala identifications. Then, averaged differences between manually and automatically scaled values are presented as mean values with standard deviations and median values with upper and lower quartiles.

From Table 3 it is evident that K, R, and F types were better recognised by Autoscala, whereas the H type was seldom identified. Autoscala typically underestimates \( f_0E_s \) by about 0.5 MHz, and the virtual height is typically overestimated, especially for the high-latitude type \( E_s \) (up to the order of 10 km).

5.3 Examples of problems

Scaling of high latitude ionograms is often difficult even for an experienced scaler, due to phenomena such as particle precipitation and oblique reflections. A comprehensive
consideration of particular cases is beyond the scope of the present paper, but to illustrate possible problems we present a few examples in Figs. 6, 7, 8 and 9 that point out differences between manual and Autoscala scaling. In these ionograms black lines show manually scaled parameters, and red colour (lines and/or letters) indicates Autoscala results.

In Fig. 6, foE\textsubscript{s} (scaled manually at 3.5 MHz) was identified as foE. The foE\textsubscript{s} value was automatically detected at 4.8 MHz and \( h'\)E\textsubscript{s} was detected near 126 km. The slant E\textsubscript{s} (type S) was identified as an F layer with foF\textsubscript{2} = 9.9 MHz. In Fig. 7, the manually scaled foE\textsubscript{s} is 4.9 MHz, whereas Autoscala finds foE\textsubscript{s} = 13.7 MHz. One more example of foE\textsubscript{s} difficulties is given in Fig. 8 where the Autoscala value is 3.0 MHz whereas the manually scaled value is 7.0 MHz. Figure 9 shows an example of \( h'\)E\textsubscript{s}, identified manually at 91 km and by Autoscala at 117 km.

However, with regard to this issue it is worth underlining the two following points:

1. The Autoscala routine for autoscaling the E\textsubscript{s} layer is designed mostly for mid-latitude ionograms (Scotto and Pezzopane, 2007).

2. The filtering process applied when generating RDF ionograms from raw SGO Alpha Wolf ionosonde data often causes a deletion of significant parts of the ionogram trace, especially those related to spread F and E\textsubscript{s} features. Although improving the contrast of normal E and F traces, this clearly affects the ability of the Autoscala E\textsubscript{s} routine.

### 6 Conclusions

In summary, this comparison between manual and Autoscala scaling of ionograms at the high-latitude Sodankylä Geophysical Observatory site has shown that:

1. F2 parameters (foF\textsubscript{2} and M(3000)F\textsubscript{2}) are reliably identified by Autoscala.
2. F1 is identified by Autoscala in significantly fewer cases (about 50%) than by the manual scaler, but when identified the values of foF1 are reliable.

3. E layer parameters found by Autoscala are close to the manually scaled ones. However, Autoscala detects E layers in many cases when none is identified by the manual scaler.

4. The identification and classification of sporadic E layers are in many cases very different from those of the manual scaling.

Scaling of ionograms at auroral latitudes is in many cases a demanding task. Oblique echoes will show up as spread traces, and a special difficulty is presented by the frequent sporadic E layers caused by particle precipitation. This makes automatic scaling less straightforward as compared to scaling of ionograms from mid latitudes. More studies, including scaling of ionograms processed from the raw recorded data with different FFT and filter parameters, will be required in order to find optimal settings for the contrast of normal E and F traces, which is a tradeoff with the detectability of sporadic E and spread F.

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References


Table 1. Number of identifications of F and E layer parameters, % out of the total 2610 ionograms.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Manual</th>
<th>Auto</th>
<th>Man and Auto</th>
<th>Man only</th>
<th>Auto only</th>
</tr>
</thead>
<tbody>
<tr>
<td>foF2 and M(3000)F2</td>
<td>90.4</td>
<td>87.4</td>
<td>85.9</td>
<td>4.5</td>
<td>1.4</td>
</tr>
<tr>
<td>foF1</td>
<td>35.6</td>
<td>17.6</td>
<td>16.3</td>
<td>19.3</td>
<td>1.3</td>
</tr>
<tr>
<td>foE</td>
<td>58.9</td>
<td>84.9</td>
<td>54.9</td>
<td>4.0</td>
<td>29.9</td>
</tr>
<tr>
<td>foEs and h'Es</td>
<td>63.0</td>
<td>20.0</td>
<td>19.4</td>
<td>43.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>
**Table 2.** Differences between manually scaled and Autoscala values (manual – auto).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Q1</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔM(3000)F2</td>
<td>−0.02 ± 0.16</td>
<td>−0.04</td>
<td>−0.11</td>
<td>0.06</td>
</tr>
<tr>
<td>ΔfoF2 (MHz)</td>
<td>−0.0 ± 0.4</td>
<td>0.1</td>
<td>−0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>ΔfoF1 (MHz)</td>
<td>0.1 ± 0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>ΔfoE (MHz)</td>
<td>−0.0 ± 0.4</td>
<td>−0.0</td>
<td>−0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>ΔfoEs (MHz)</td>
<td>0.5 ± 1.2</td>
<td>0.6</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Δh′Es (km)</td>
<td>−6.0 ± 8.3</td>
<td>−3.7</td>
<td>−9.3</td>
<td>−0.1</td>
</tr>
<tr>
<td>Manual h′E (km)</td>
<td>96 ± 11</td>
<td>92</td>
<td>89</td>
<td>98</td>
</tr>
</tbody>
</table>

SD = standard deviation, Q1 = first quartile, Q3 = third quartile.
Table 3. Scaled parameters of sporadic E layers.

<table>
<thead>
<tr>
<th>Type E&lt;sub&gt;s&lt;/sub&gt;</th>
<th>N man</th>
<th>% auto</th>
<th>Δf&lt;sub&gt;oE&lt;sub&gt;s&lt;/sub&gt;&lt;/sub&gt; (MHz), man – auto</th>
<th>Δh&lt;sub&gt;E&lt;sub&gt;s&lt;/sub&gt;&lt;/sub&gt; (MHz), man – auto</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Median</td>
</tr>
<tr>
<td>C</td>
<td>328</td>
<td>35</td>
<td>0.7 ± 1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>H</td>
<td>244</td>
<td>7</td>
<td>0.6 ± 0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>L</td>
<td>373</td>
<td>25</td>
<td>0.4 ± 1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>F</td>
<td>128</td>
<td>41</td>
<td>0.5 ± 1.3</td>
<td>0.5</td>
</tr>
<tr>
<td>A</td>
<td>105</td>
<td>19</td>
<td>0.2 ± 1.4</td>
<td>0.5</td>
</tr>
<tr>
<td>R</td>
<td>389</td>
<td>43</td>
<td>0.6 ± 1.3</td>
<td>0.7</td>
</tr>
</tbody>
</table>

SD = standard deviation, Q1 = first quartile, Q3 = third quartile.
Figure 1. Simplified schematic diagram of the SGO ionosonde system and data flow. Note that the transmitter and receiver station are separated by almost 1 km and have no physical connection. Transmission and reception of the FM CW chirp soundings start by GPS synchronisation. Left column: schematics of transmitter station with exciter (direct digital synthesizer) and power amplifier. Filters are not shown. The transmitter feeds a wide-band rhombic antenna. Centre: schematics of one receiver channel. Signals from all receiver antennas are combined into two channels, one per polarisation. The local oscillator is identical to the exciter. Raw data are saved in binary files containing 4 real (or 2 complex) vectors: 2 linear polarisations, samples of in-phase and quadrature-mixed filtered signals. Right upper: the real time processing computer reads the raw data, combines the polarisations into O mode circular polarisation (applying phase corrections), and produces ionograms. O mode ionograms are stored and those from each full hour are interpreted manually. Right lower: during the described test phase, O and X mode ionograms were uploaded in the INGV RDF format required by Autoscala.
**Figure 2.** Example of SGO ionogram scaling. Upper: manual scaling interface with a typical Alpha Wolf O mode ionogram (5 June 2013, 11:00 UT). Lower: graphical output of Autoscala, input based on the same raw data but with separated, filtered O (red) and X (green) mode traces.
Figure 3. Comparison of manually and automatically scaled parameters for 4 June 2013. Panel 1: M(3000)F2, panel 2: F layer O mode critical frequencies, panel 3: foE, panel 4: foEs, and 5: E layer virtual heights. Autoscala always assumes the lower edge of the E layer at 90 km (dashed line). The yellow dot on the time axis indicates a time (18:00 UT) when the ionosonde was not operating.
Figure 4. Distributions (histograms) of the differences between manually and automatically scaled parameters. Numbers (\(N\)) on top of the panels indicate the numbers of ionograms for which both manual and Autoscala parameter values were obtained, and, hence, the differences were calculated. Vertical lines show medians and quartiles.
Figure 5. Distribution of $h^\prime E$ scaled manually. The red line at 90 km indicates the fixed height assumed in Autoscala. The mode of the manually scaled $h^\prime E$ distribution is close to 90 km as well.
**Figure 6.** Examples of differences between manual and Autoscala scaling arising from high latitude sporadic E phenomena. Black lines show manually scaled parameters, and red colour (lines or/and letter) indicates Autoscala results: 1. $f_{o}E_s$ identified as $f_{o}E$, and the slant $E_s$ (type S) identified as an F layer.
Figure 7. Examples of differences between manual and Autoscala scaling arising from high latitude sporadic E phenomena. Black lines show manually scaled parameters, and red colour (lines or/and letter) indicates Autoscala results: 1. overestimated foE (13.7 MHz vs. manual 4.9 MHz).
Figure 8. Examples of differences between manual and Autoscala scaling arising from high latitude sporadic E phenomena. Black lines show manually scaled parameters, and red colour (lines or/and letter) indicates Autoscala results. 3. Underestimated $f_{0}E_s$ (3.0 MHz vs. manual 7.0 MHz)
Figure 9. Examples of differences between manual and Autoscala scaling arising from high latitude sporadic E phenomena. Black lines show manually scaled parameters, and red colour (lines or/and letter) indicates Autoscala results: 4. Error in $h'_{E_s}$ scaling (117 km vs. manual 91 km).