JASS *Journal of Astronomy and Space Sciences*

Manual Scaling of Ionograms Measured at Jeju (33.4°N, 126.3°E) Throughout 2012

Se-Heon Jeong, Yong Ha Kim[†], Ki-nam Kim

Department of Astronomy, Space Science and Geology, Chungnam National University, Daejeon 34134, Korea

The ionosphere has been monitored by ionosondes for over five decades since the 1960s in Korea. An ionosonde typically produces an ionogram that displays radio echoes in the frequency-range plane. The trace of echoes in the plane can be read either manually or automatically to derive useful ionospheric parameters such as foF2 (peak frequency of the F2 layer) and hmF2 (peak height of the F2 layer). Monitoring of the ionosphere should be routinely performed in a given time cadence, and thus, automatic scaling of an ionogram is generally executed to obtain ionospheric parameters. However, an auto-scaling program can generate undesirable results that significantly misrepresent the ionosphere. In order to verify the degree of mis-representation by an auto-scaling program, we performed manual scaling of all 35,136 ionograms measured at Jeju (33.43˚N, 126.30˚E) throughout 2012. We compared our manually scaled parameters (foF2 and hmF2) with auto-scaled parameters that were obtained via the ARTIST5002 program. We classified five cases in terms of the erroneous scaling performed by the program. The results of the comparison indicate that the average differences with respect to foF2 and hmF2 between the two methods approximately correspond to 0.03 MHz and 4.1 km, respectively with corresponding standard deviations of 0.12 MHz and 9.58 km. Overall, 36 % of the auto-scaled results differ from the manually scaled results by the first decimal number. Therefore, future studies should be aware of the quality of auto-scaled parameters obtained via ARTIST5002. Hence, the results of the study recommend the use of manually scaled parameters (if available) for any serious applications.

Keywords: ionosonde, ionogram, auto-scaling, manual-scaling

1. INTRODUCTION

Following its discovery (Appleton 1932; Marconi 1967), the ionosphere is observed and monitored by numerous instruments including various radio sounders such as ionosondes, ground based receivers of global navigation satellite system (GNSS) and satellite-based radio occultation experiments, and other devices (e.g., Kim et al. 2011; Choi et al. 2013; Park et al. 2015; Hong et al. 2017). Among these, ionosondes have been used world-wide for a long time as vertical sounding radars with sweeping frequencies. Ionosondes are considered as one of the most common tools for monitoring the ionosphere, and ionosonde stations are networked by international organizations (Galkin et al. 2006).

An ionosonde typically produces an ionogram that displays radio echoes in the frequency-range plane. The trajectory of radio echoes is projected on an ionogram, and this is either manually or automatically scaled to extract the parameters of the ionosphere such as foF2 (peak frequency of the F2 layer), hmF2 (peak height of the F2 layer), and other parameters.

With respect to automatically scaling ionograms that involves automatic extraction of ionospheric parameters via software, several software programs have been developed since 1960s. A widely used program is automatic real-time ionogram scaler with true height (ARTIST), which was developed by the University of Massachusetts, Lowell, USA. This is continuously updated (Reinisch & Huang 1983; Gilbert & Smith 1988; Galkin et al. 1996; Reinisch et al. 2005; Galkin et al. 2008). Another widely used program is Autoscala that was recorded in the advanced ionospheric sounder-istituto nazionale di geofisica vulcanologia (AIS-INGV) and developed by istituto nazionale di geofisica vulcanologia

(INGV). Other programs are used and are in the process of development or upgrading.

Despite the advances in the aforementioned scaling programs, automatic scaling occasionally yields unreasonable results that misrepresent the ionosphere. Specifically, Gilbert & Smith (1988) argued that when the ARTIST software is used to extract the ionospheric parameters, an average of 7 % of the results are not reliable. More recently, Bamford et al. (2008) compared the eight ionospheric parameters obtained from automatic and manual scaling as follows: foE (E layer critical frequency), foF2, foF1 (F1 layer critical frequency), fmin (minimum frequency of ionogram echoes), MUF(3000) F2 (maximum usable frequency for ground distance of 3,000 km in F2 region), M(3000)F2 (=MUF(3000)/foF2), h'E (minimum virtual height of E trace), and h'F2 (Minimum virtual height of F2 trace). The results indicated that an average of 10 % of foF2, h'E, MUF(3,000), and M(3000) F2 and 20 % of the remaining parameters are not reliable. The percentage of erroneous results appears to vary with software versions and ionosonde stations.

Therefore, it is necessary to verify or evaluate the quality of the ionosonde data acquired from Jeju station, which was recently established with an auto-scaling program, ARTIST 5002. Section 2 explains the data used and how automatic and manual scaling procedures are executed. A comparison of the ionospheric parameters obtained by the two methods is given in Section 3, and finally conclusions are detailed in Section 4.

2. DATA AND METHOD

2.1 Data

The data used in the study corresponds to ionograms measured by Jeju ionosonde (33.43˚N, 126.30˚E) and auto-scaled ionospheric parameters that were provided by the Korea Space Weather Center (KSWC) of National Research Agency (NRA). Jeju ionosonde produces ionograms every 15 min, and we analyzed the ionograms that were produced throughout 2012.

2.2 Automatic Scaling

The ionograms are automatically scaled to acquire ionospheric parameters such as foF2 (peak frequency of the F2 layer) and hmF2 (peak height of the F2 layer). Jeju ionograms are routinely scaled by an auto-scaling software termed as the Automatic Real-Time Ionogram Scaler with True Height (ARTIST) 5002 program developed by Lowell
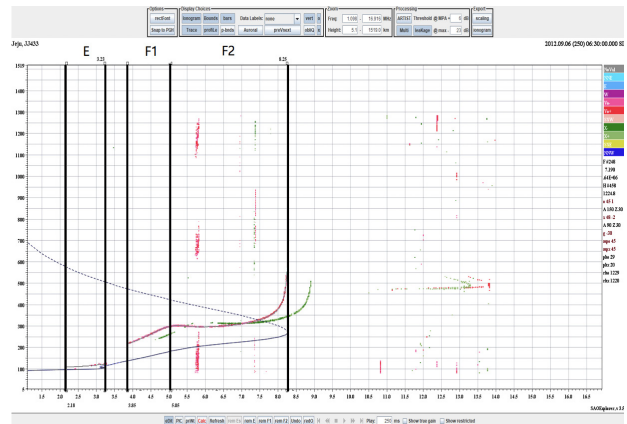

Fig. 1. Normal ionogram measured at 0630UT on September 6, 2012 (DOY 250). The red dots and green dots represent ordinary and extraordinary traces, respectively. The curve is calculated from the ordinary trace by the scaling program, and the dashed part of the curve above the F2 peak is computed by assuming the α-Chapman shape. The regions of E, F1, and F2 layers are indicated by vertical solid lines.

University. The program is built into the Standard Archiving Output (SAO) explorer, and this allows users to visualize and edit ionograms. The ionospheric parameters are computed by the auto-scaling program when an ionogram is fed into the SAO explorer. Fig. 1 shows an example of a normal ionogram that results in auto-scaled parameters that are perfectly matched with manually scaled values. The auto-scaled parameters are stored in the form of an SAO file.

2.3 Manual Scaling

When noisy or disturbed ionograms are fed into the auto-scaling program, the resulting parameters are unreasonable or occasionally significantly incorrect (Reinisch & Huang 1983). We independently trained ourselves through 160 examples of the ionograms via the standard method described in the handbook detailed by Wakai et al. (1987), and we manually scaled all the 35,136 ionograms measured in 2012. The handbook shows ionograms in specific conditions, such as spread F and sporadic E, and explains how to extract ionospheric parameters. It is used by numerous researchers in the field (e.g., Pezzopane & Scotto 2010). In the manual scaling process, there are five cases in which the auto-scaling program yields incorrect results when compared with manually scaled values. A brief description of the five cases is provided in Table 1. Figs. 2–6 show the aforementioned five cases as follows: left figures include a curve that represents the ionospheric profile and vertical lines that denote foF2, fminF(the minimum frequency of F layer), and F1/F2 peaks derived by the auto-scaling program, and right figures contain the corresponding curve and lines from manual scaling. Figure 2 illustrates the

Table 1. Brief description of the five cases for incorrect auto-scaling

| Case	Error	Description
1	Errors in determining foF2	foF2 (the critical frequency of the F2 layer) is not properly determined.
2	Tracing error	Trace is not properly fitted.
3	Errors in determining fminF	fminF (the minimum frequency of F layer) is misrecognized.
4	Errors in distinguishing the F1/F2	F1 layer and the F2 layer are not correctly distinguished.
5	Errors in two or more	Two or more above cases occur simultaneously.
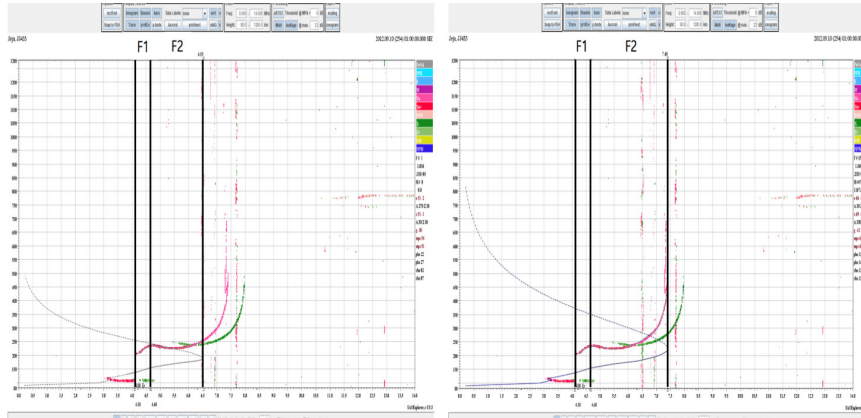
Fig. 2. (left) Ionogram with auto-scaling results that exhibit error in determining the foF2 (Case 1). (right) Ionogram with manual scaling results. It should be noted that the region of F2 layer is extended to the end point of the O-mode trace.
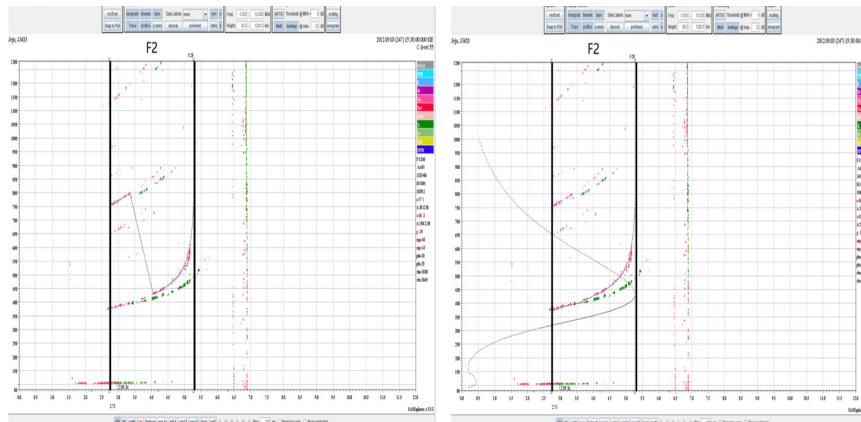

Fig. 3. (left) ionogram with auto-scaling results that exhibit tracing error (Case 2). (right) ionogram with manual scaling results. It should be noted that the curve is inaccurately calculated (left), and it is properly fitted to the O-mode trace (right).

first case in which foF2 is incorrectly determined. In the left plot in Fig. 2, the end point of the O-mode trace (red dots) should correspond to the foF2 value although the midpoint of the trace is mistakenly selected as the foF2 value. Fig. 3 shows the second case in which the tracing of echoes is not properly fitted. In the right plot of Fig. 3, the O-mode trace is properly fitted, thereby resulting in a well-fitted profile with accurate foF2 and F2 peaks. The third case corresponds to when the fminF is misrecognized as shown in Fig. 4. In the left plot of Fig. 4, the minimum frequency of F-layer echoes

is set incorrectly due to the sporadic E (Es) layer echoes. The fourth case corresponds to when the F1 layer and the F2 layer are not correctly distinguished (Fig. 5). In a normal O-mode trace, a cusp is observed at the critical frequency of F1 layer and F2 layer. However, the ARTIST program does not recognize the cusp, and thus that it fails to distinguish the F1 layer from the F2 layer. Conversely, this is correctly performed by manual scaling as shown in the right plot of Fig. 5. The final case corresponds to when the two and more of the aforementioned cases occur simultaneously.
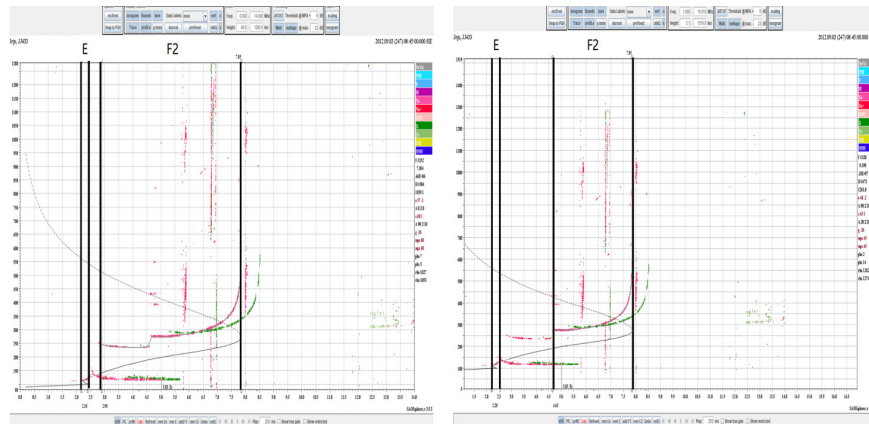
145

Fig. 4. (left) Ionogram with auto-scaling results that exhibit error in determining the fminF (Case 3). (right) Ionogram with manual scaling results. It should be noted that the starting point of F layer (fminF) should be located at the cusp point of the O-mode trace as shown in the right plot.
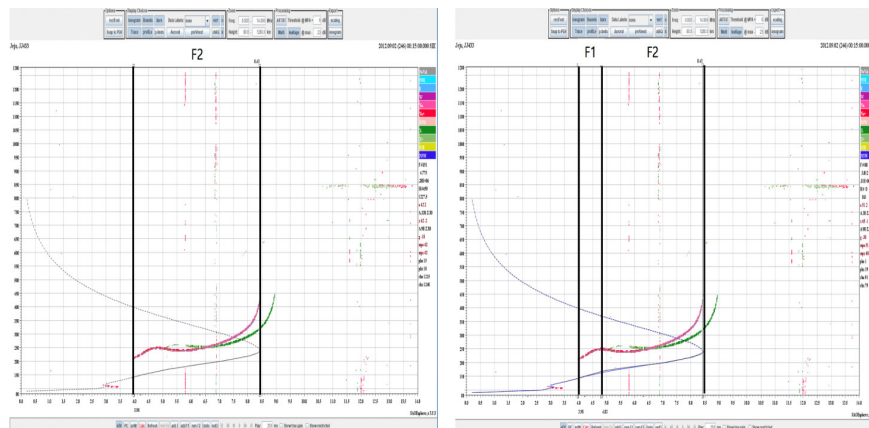

Fig. 5. (left) Ionogram with auto-scaling results that exhibit error in distinguishing the F1/F2 (Case 4). (right) Ionogram with manual scaling results. It should be noted that the erroneously distinguished F1/F2 layer (left) should be divided into F1 and F2 layers based on the cusp of the O-mode trace as shown in the right plot.
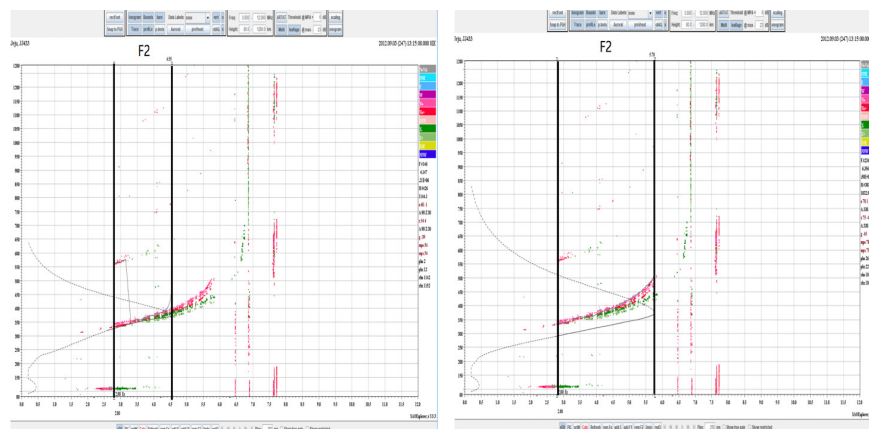

Fig. 6. (left) Ionogram with auto-scaling results that exhibit errors in two or more of the above cases (Case 5). It should be noted that the auto-scaling leads to error in collectively determining the foF2 (case 1) and tracing error (case 2) in the left, which are corrected in the right panel.

Fig. 6 shows an example of this case in which incorrect determination of the foF2 (case 1) and incorrect tracing of the profile (case 2) occur simultaneously.
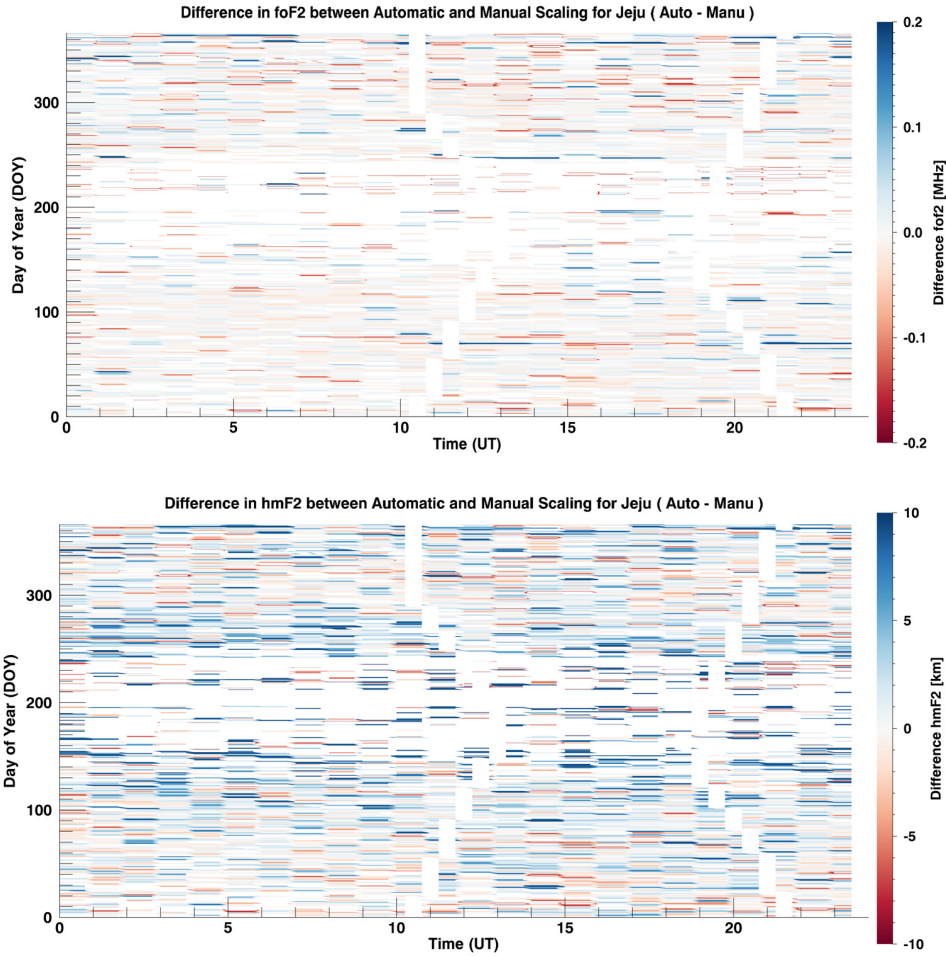
146

Difference in foF2 between Automatic and Manual Scaling for Jeju (Auto - Manu)

Difference in hmF2 between Automatic and Manual Scaling for Jeju (Auto - Manu)

Fig. 7. Contour plots of foF2 and hmF2 differences between auto-scaled and manually scaled values throughout 2012.

Histogram foF2 difference (Auto - Manu)

Total count : 25247 (35136)

Mean : 0.03

Standard deviation : 0.12

Histogram HmF2 difference (Auto - Manu)

Total count : 25195 (35136)

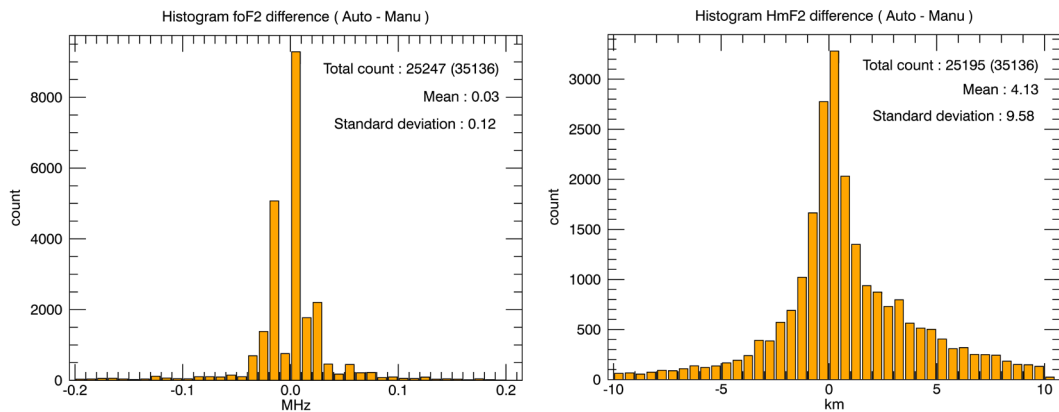Mean : 4.13

Standard deviation : 9.58

Fig. 8. Histograms of foF2 and hmF2 differences between auto-scaled and manually scaled values.

3. RESULTS

Among the parameters of the ionosphere, we compared manually scaled foF2 and hmF2 values (the peak height of F2 layer) with the corresponding auto-scaled values. Fig. 7

shows differences in foF2 and hmF2 between auto-scaled and manually scaled values in the form of contours on the time versus day of year plane. When a contour is closer to blue, then the auto-scaled values are higher. Conversely, when a contour is closer to red, then the manually scaled
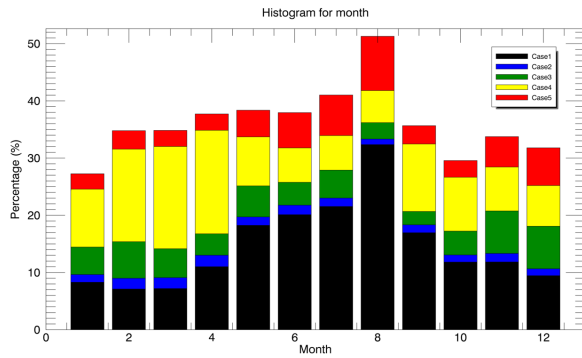
147

Fig. 9. Percentages of the five cases for incorrect auto-scaling in each month.
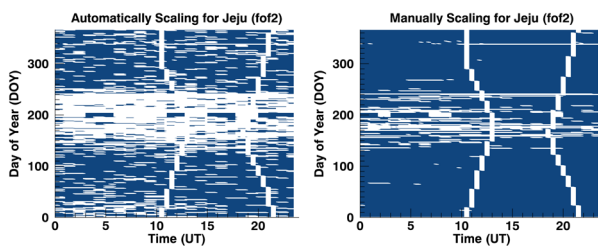

Fig. 10. Distributions of foF2 results from auto-scaling and manual scaling based on time and DOY.

values are higher. Fig. 7 illustrates that hmF2 differences are more evident when compared with F2 differences.

Histograms of the differences in auto-scaled and manually scaled foF2 and hmF2 values are shown in Fig. 8. A total of 25,247 foF2 values are included in the histogram for 35,136 ionograms with the exception of those that cannot be used to extract the parameters. The average foF2 difference value between the auto-scaled and manually scaled methods is 0.03±0.12 MHz. Additionally, 25,195 data points are used on the right side (hmF2). The average difference of hmF2 values is 4.13 km (auto-scaled values are positively biased) and its standard deviation is 9.58 km, and this is significantly high.

Fig. 9 shows the percentages of the five cases that were designated during the manual scaling process. The results indicate that more than half of the ionograms in August should be manually scaled because the ionograms contained abnormal echoes especially during a period from July 22 to August 27. With respect to the other months, approximately 30–35 % of the ionograms should be manually scaled. In the five cases, we observe that case 1 (errors in determining foF2) and case 4 (errors in distinguishing F1/F2) occur more frequently when compared with the other cases. We observe that 36 % of the ionograms (9,245) by auto-scaling result in values that differ from those obtained via manual scaling.

Fig. 10 shows the distributions of auto-scaled foF2s and manually scaled foF2s on the plane of time versus day of year. Evidently, the deficiency of auto-scaling during summer is highlighted by the significantly high number of manual scaling values. Specifically, from a total of 35,136 ionograms recorded in 2012, we manually extracted parameters from 32,065 ionograms, and this exceeds the auto-scaled ionograms by 6,384.

4. CONCLUSION

In this study, we manually scaled 35,136 ionograms recorded by Jeju ionosonde throughout 2012 and compared the resulting foF2 and hmF2 values to those obtained via the auto scaling program, ARTIST 5002. We identified five cases in which the auto-scaling program leads to incorrect results when compared with manual scaling results. The results indicated that 36 % of the auto-scaled parameters in 2012 differed from the manually scaled parameters by the first decimal number. The auto-scaled hmF2 values differ more significantly from manually scaled values when compared with the foF2 values. Hence, future studies should note the uncertainty of auto-scaled parameters, and manually scaled values should be used for any serious applications to the maximum possible extent.

ACKNOWLEDGMENTS

REFERENCES

Appleton EV, Wireless studies of the ionosphere, Inst. Electr. Eng. Proc. Wirel. Sect. Inst. 7, 257-265 (1932). https://doi.org/10.1049/pws.1932.0027

Bamford RA, Stamper R, Cander LR, A comparison between the hourly autoscaled and manually scaled characteristics from the Chilton ionosonde from 1996 to 2004, Radio Sci. 43, RS1001 (2008). https://doi.org/10.1029/2005RS003401

Choi BK, Yoo SM, Roh KM, Lee SJ, Real-time GPS ionospheric TEC estimation over South Korea, J. Astron. Space Sci. 30, 207-212 (2013). https://doi.org/10.5140/JASS.2013.30.3.207

Galkin IA, Reinisch BW, Ososkov GA, Zaznobina EG, Neshyba SP, Feedback neural networks for ARTIST ionogram

processing, Radio Sci. 31, 1119-1128 (1996). https://doi.org/10.1029/96RS01513

Galkin IA, Khmyrov GM, Kozlov A, Reinisch BW, Huang X, et al., Ionosonde networking, databasing, and web serving, Radio Sci. 41, RS5S33 (2006). https://doi.org/10.1029/2005RS003384

Galkin IA, Reinisch BW, The new ARTIST 5 for all digisondes [Internet], cited 2008 Apr 7, available from: http://www.ursi.org/files/CommissionWebsites/INAG/web-69/2008/artist5-inag.pdf

Gilbert JD, Smith RW, A comparison between the automatic ionogram scaling system ARTIST and the standard manual method, Radio Sci. 23, 968-974 (1988). https://doi.org/10.1029/RS023i006p00968

Hong J, Kim YH, Chung JK, Ssessanga N, Kwak, YS, Tomography reconstruction of ionospheric electron density with empirical orthonormal functions using Korea GNSS network, J. Astron. Space Sci. 34, 7-17 (2017). https://doi.org/10.5140/JASS.2017.34.1.7

Kim E, Chung JK, Kim YH, Jee G, Hong S, et al., A climatology study on ionospheric F2 peak over Anyang, Korea, Earth Planet. Space 63, 335-349 (2011). https://doi.org/10.5047/eps.2011.03.011

Marconi G, Wireless telegraphic communication, Nobel Lectures Physics 1901-1921, ed. Novel Prize Foundation (Elsevier, Amsterdam, 1967), 196-222.

Park J, Kwak YS, Mun JC, Min KW, Vertical scale height of the topside ionosphere around the Korean Peninsula: estimates from ionosondes and the Swarm Constellation, J. Astron. Space Sci. 32, 311-315 (2015). https://doi.org/10.5140/JASS.2015.32.4.311

Pezzopane M, Scotto C, Highlighting the F2 trace on an ionogram to improve Autoscala performance. Comput. Geosci. 36, 1168-1177 (2010). https://doi.org/10.1016/j.cageo.2010.01.010

Reinisch BW, Huang X, Automatic calculation of electron density profiles from digital ionograms: 3. processing of bottomside ionograms, Radio Sci. 18, 477-492 (1983). https://doi.org/10.1029/RS018i003p00477

Reinisch BW, Huang X, Galkin IA, Paznukhov V, Kozlov A, Recent advances in real-time analysis of ionograms and ionospheric drift measurements with digisondes, J. Atmos. Sol.-Terr. Phys. 67, 1054-1062 (2005). https://doi.org/10.1016/j.jastp.2005.01.009

Wakai N, Ohyama H, Koizumi T, Manual of ionogram scaling (Ministry of Posts and Telecommunication, Japan, 1987).