Using two-dimensional autocorrelation method to improve the performance of automatic algorithm on ionogram

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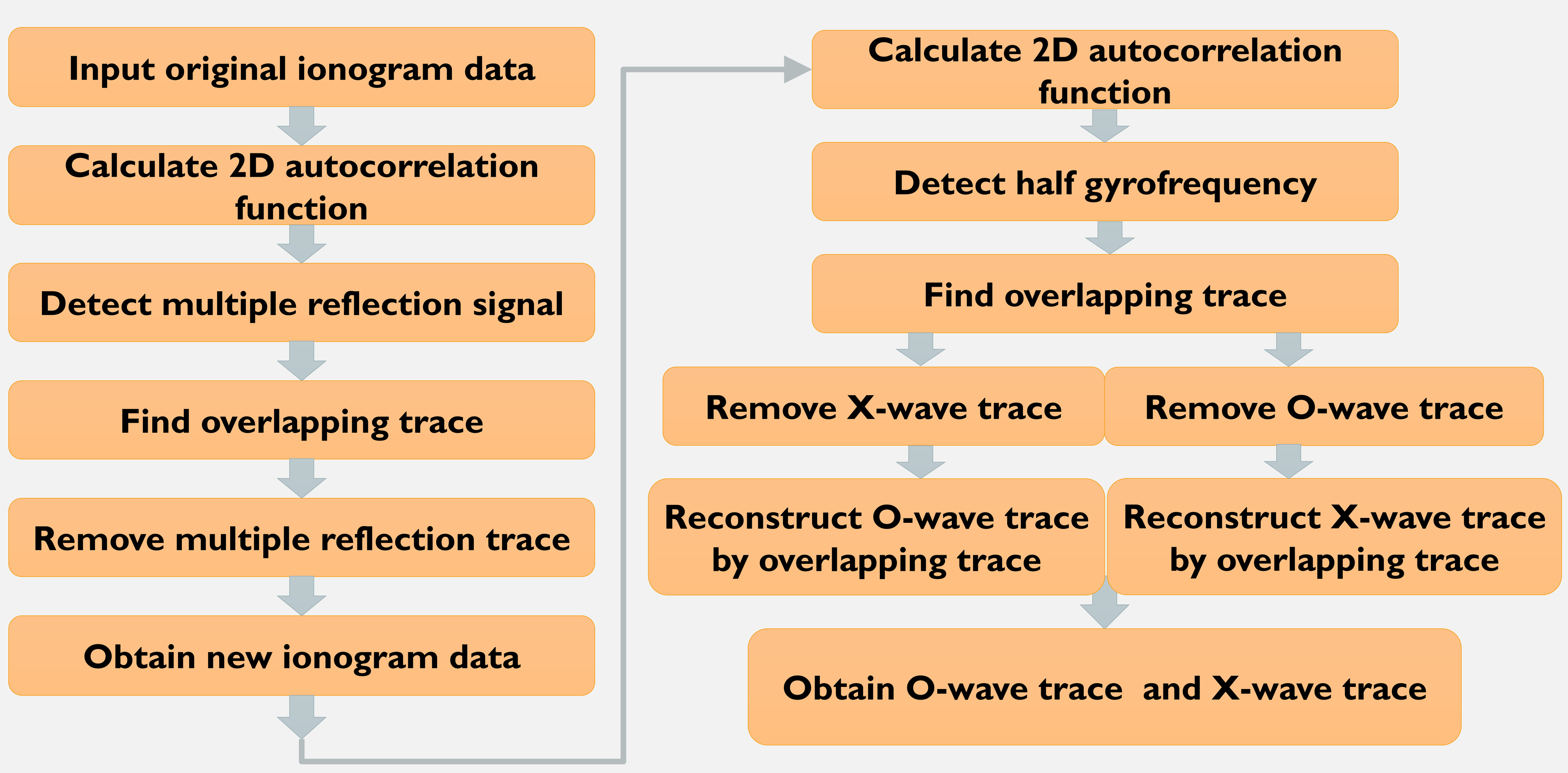
Abstract

A new ionosonde is under construction at Chung-Li VHF radar station on the campus of National Central University in Taiwan. We develop our own data processing algorithm to automatically retrieve ionospheric parameters of different sublayers from observed ionogram traces in nearly real time. In addition to the conventional image analysis technique, we use two-dimensional autocorrelation function to identify and separate the ordinary (O-) wave from extraordinary (X-) wave traces for further analysis. A comparison between ionospheric parameters retrieved from the automatic processing algorithm developed in this study and those obtained from manually scaling ionograms shows that the use of two-dimensional autocorrelation function combined with image analysis can achieve reliable and accurate ionospheric parameters.

Introduction

Ionogram scaling can obtain the ionospheric parameters for retrieving the electron density profile on bottom side of ionosphere. Image technique is extensively used in ionogram scaling. However, we notice that the scaled ionospheric parameters are unreliable when either O wave or X wave traces is ambiguous. In order to improve the scaling results, we develop a method that can unambiguously identify the O- and X-wave traces based on two dimensional autocorrelation of the traces. In order to validate the scaled parameters of this method, we manually scale 8494 ionograms that are observed by Chung-Li ionosonde on September 2013 to compare with the automatic scaling results from the two dimensional autocorrelation method. The results show that this method can effectively scale the ionogram with high accuracy.

2D Autocorrelation Method Procedure



Automatic scaling analysis

In this study, the automatic scaling algorithm that is based on 2D autocorrelation method is proposed. For automatic scaling, we use existing image technique to obtain the initial parameters in the beginning. We then carry out the true height analysis based on the initial parameters Each one of parameter sets do the true height analysis to measure the correlation coefficient and root mean square error. At the end of the algorithm, it provides the best parameters and corresponding electron density profile. Figure 2 shows that the progress of ionogram scaling algorithm is from initial parameters to final parameters.

- **Initial ionospheric parameters**

In order to further analysis, we use international reference ionospheric (IRI) model to obtain the initial guesses of ionospheric model parameters. Because IRI model provides numerical values, we suggest that the initial parameters should be fine-tuned approximately for true height analysis, i.e., ± 0.3MHz for critical frequency, ± 50km for peak height, and ± 50km for semi-thickness. The model parameters are foE, hmE, ymE, foF1, hmF1, ymF1, foF2, hmF2, and ymF2.

- **True height analysis**

After we obtain the parameters of each sublayer, we can derive the electron density profile by quasi-parabolic segment (QPS) mode [Norman, 2003]. Furthermore, the ionogram synthesized trace will be calculated by the true height analysis [Scotto et al. 2012].

Automatic / Manual Scaling Results

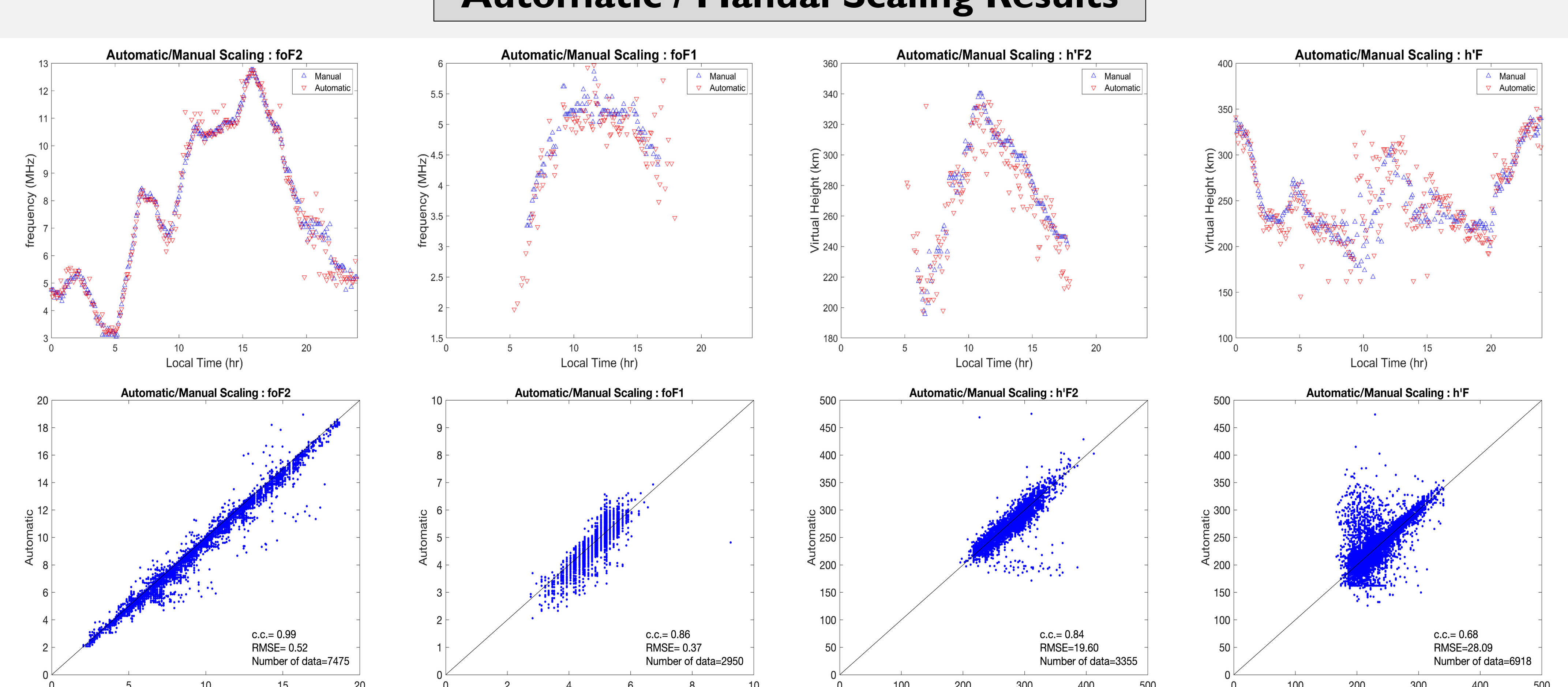


Figure 3

Figure 3 shows that the automatic scaling algorithm including 2D autocorrelation method is very consistent with the manual results. The foF2 is one of significant parameters to provide peak density of F region. The correlation coefficient of foF2 is close to 1.; the foF1 is the peak density of F1 region on daytime. The correlation coefficient of foF1 is 0.86; the h'F is the virtual height of F region. The correlation coefficient of h'F is close to 0.68; the h'F2 is the virtual height of F2 region which is usually presented on daytime. The correlation coefficient of h'F2 is close to 0.84. Due to the high correlation coefficient, we can validate the capability of ionogram scaling algorithm with 2D autocorrelation method.

Two-Dimensional Autocorrelation Method

Two-dimensional autocorrelation function is a mathematical technique that is used to study changes in measured signals. The 2D autocorrelation equation can be written as follow:

$$\mathrm{AC}(\tau_x, \tau_y) = \sum_{i=-m, j=-n}^{m,n} F(i,j)\, F(i+\tau_x, j+\tau_y)$$

τ_x, τ_y is the movement in x and y direction. The ionogram traces usually perform two wave mode which can be derived by the Appleton equation. The phenomenon is caused by the difference of the refractive index considered with magnetic field in the ionosphere. In this study, we assume that the O-wave trace are approximately the same as X-wave trace. According to the Appleton equation, the difference frequency between O-wave and X-wave is known to correspond to the half electron gyrofrequency. Two-dimension autocorrelation method procedure shows that the 2D autocorrelation method has capability to remove the multiple reflection signals and obtain two wave mode trace.

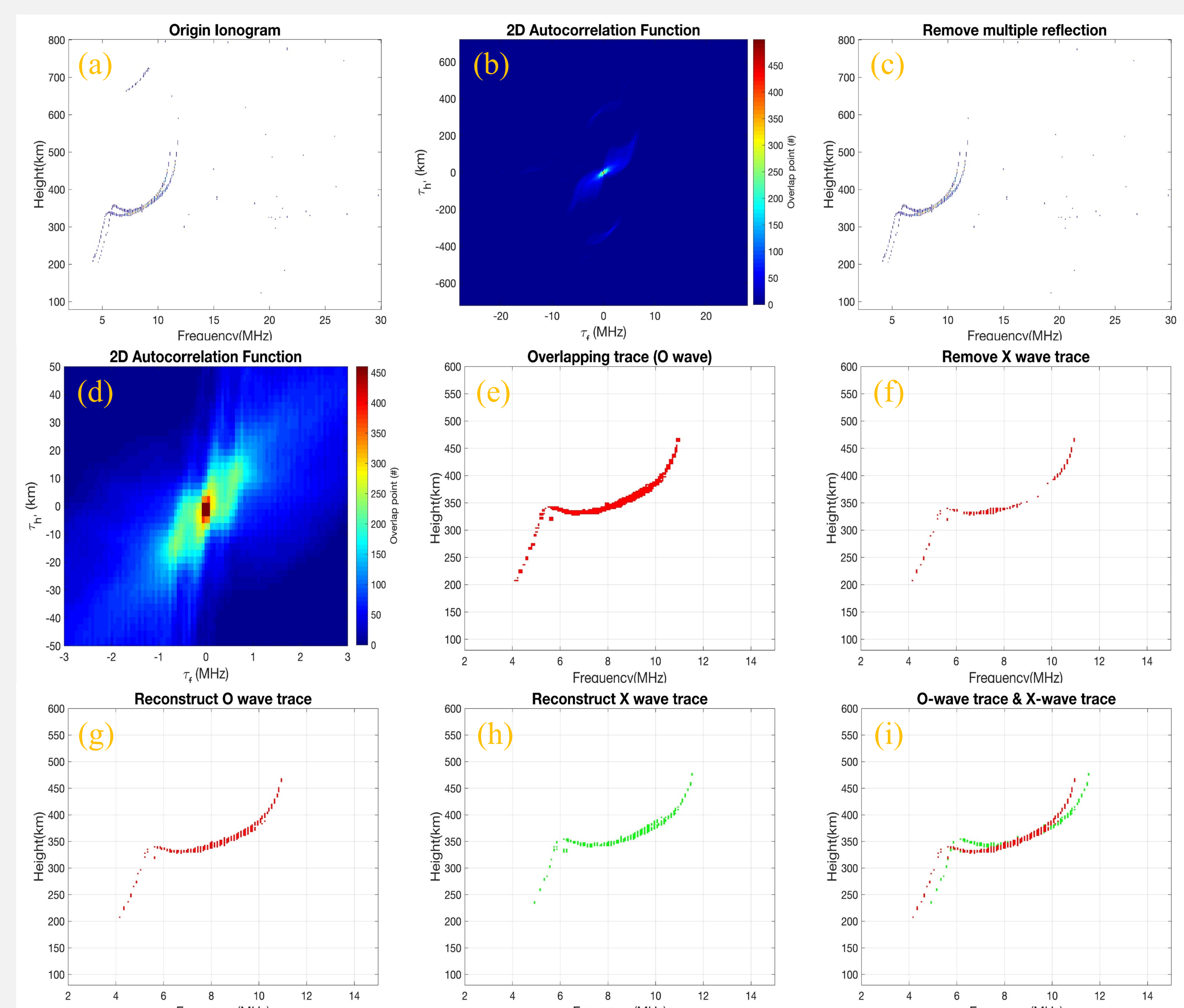
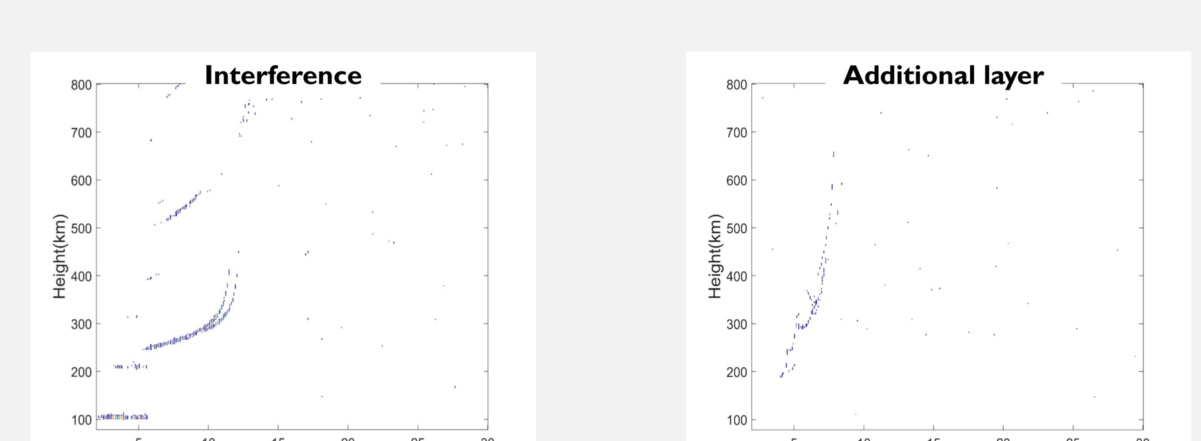


Figure 1

Figure 1 illustrates the total procedure of this method. (a) input the original ionogram with the multiple reflection signal. (b) calculate 2D autocorrelation function to detect the multiple reflection signal. (c) move ionogram (τ_x, τ_y) to remove multiple reflection signal. (d) calculate the ionogram without the multiple reflection to detect the gyrofrequency. (e) move ionogram (τ_x', τ_y') to measure the overlapping trace and dilate the trace. (f) remove the X-wave trace by the overlapping trace. (g) & (h) reconstruct the absent trace by the overlapping trace. (i) obtain the two wave mode trace.

Discussion and Conclusion

1. **Missing points:** For 2D autocorrelation method, we can't identify the O-wave trace and X-wave trace completely. The overlapping trace is depending on the form of two wave trace. Some cases may contain noises or lose the points on the critical frequency. As a result, the traces that we reconstruct may be unreliable and lead to incorrect interpretation.
2. **Additional layer:** the present algorithm is not designed to identify the additional layers (such as E2 layer, F0.5 layer or F1.5 layer). Therefore, we cannot provide the additional ionospheric parameters using current algorithm.
3. **Interference / Absorption :** According to the handbook of ionogram scaling, some of ionospheric parameters are difficult to determine by manual scaling. For example, in the presence of interference, F traces blanked by lower intense Es layer, extraordinary absorption of HF waves will make manual scaling difficult. This is the reason why the ionogram trace may be too ambiguous to interpret and the unwanted fluctuations are present, as shown on figure 3.



Due to the results of comparison, our ionogram scaling algorithm can be considered to stable and reasonable. For 2D autocorrelation method, it is a useful method to identify O-wave trace and X-wave trace and improves ionogram scaling algorithm. However the additional layer, interference ,or ionospheric absorption should be considered, we'll improve our algorithm for much reliable and accurate parameters in the future.