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Histogram-based ionogram displays and their application to autoscaling

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Abstract

A simple method is described for displaying and auto scaling the basic ionogram parameters foF2 and h'F2 as well as some additional layer parameters from digital ionograms. The technique employed is based on forming frequency and height histograms in each ionogram. This technique has now been applied specifically to ionograms produced by the IPS5D ionosonde developed and operated by the Australian Space Weather Service (SWS). The SWS ionograms are archived in a cleaned format and readily available from the SWS internet site. However, the method is applicable to any ionosonde which produces ionograms in a digital format at a useful signal-to-noise level. The most novel feature of the technique for autoscaling is its simplicity and the avoidance of the mathematical imaging and line fitting techniques often used. The program arose from the necessity to display many days of ionogram output to allow the location of specific types of ionospheric event such as ionospheric storms, travelling ionospheric disturbances and repetitive ionospheric height changes for further investigation and measurement. Examples and applications of the method are given including the removal of sporadic E and spread F.

Keywords: Ionogram; Auto-scaling; Histogram; Sporadic E; Spread F

1. Introduction

A standard set of ionospheric parameters to be measured from ionograms was developed to allow the inter-comparison of ionospheric characteristics from the world-wide network of ionosondes established in many countries. Such parameters are available from many internet sites and are archived in the World Data Centre. Even in the digital age, the relevant parameters continued to be measured manually, typically limited to one-hour intervals because of the huge amount of work involved. Until recent years, most of what is known about the general climatology of the ionosphere has been derived from such scaled ionogram measurements. The manual scaling measurement of the traditional ionospheric parameters severely limited the results which could be obtained. Consequently, much effort over many years has gone into the development of auto-scaling techniques which can unlock the full potential of the modern, fast, digital ionosonde by removing entirely the blockage created by a need for manual measurements while still maintaining adequate accuracy. Since the presence of the earth's magnetic field makes the ionosphere a birefringent medium, an upgoing radio transmission comes back separated into two traces called the o-ray trace and the x-trace. The main difficulty in auto-scaling ionograms has often been seen in terms of the requirement to recognize and separate out the lower frequency ionogram o-ray trace for measurement.

Current methods of auto scaling ionograms include ARTIST (Automatic Real Time Ionogram Scaling with True Height Analysis) which has undergone development over many years (Galkin and Reinisch, 1996, 2008). Fox and Blundell (1989) developed a successful program for autoscaling based on trace recognition and trace- following.

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Tsai and Berkey (2000) used fuzzy segmentation and connectedness techniques. Autoscala (Pezzopane and Scotto, 2008, 2010) used formula fitting techniques. Further improvements to Austoscala have been given by Scotto and Pezzopane (2007, 2008). Ding et al. (2007) have developed a technique based on empirical orthogonal functions (EOFs). Uemoto et al. (2009) examined ways of tagging the o and x rays in ionograms. Su et al. (2012) used a mix of algorithms combined with Kalman filtering. Chen et al. (2013) have presented automatic scaling of the F2 layer based on mathematical morphology. Zheng et al. (2013) have used image processing. Jiang et al. (2013) have used template matching as well as annealing (2015). Kalita et al. (2015) have used adaptive windowing and curve fitting.

A related problem is the auto scaling of oblique ionograms (e.g. Redding, 1996; Ippolito et al., 2015; Hu et al., 2015). The Australian Defence Science and Technology Group (DST Group) maintains both autoscaling and a three-parabolic layer fitting to both vertical and oblique ionograms in support of the operational Australian Over-the-Horizon radar (Barnes et al., 1998; Gardiner-Garden et al., 2011; Turley et al., 2013; Harris et al., 2016), but full details of current methods have yet to be published.

The essential point in the present paper is to recognize that for most practical and scientific studies of the F2 layer, the parameters most often sought are foF2 (the maximum critical o-ray frequency of the F2 layer) which is related to the peak electron density of the ionosphere (e.g. Davies, 1990) and h'F2, the base virtual height of the F2 layer and the corresponding values for other layers. As described here, these parameters can be measured without the necessity to separate the o and x traces and without the application of complex mathematical techniques. The process is based on a histogram technique, independently developed but apparently similar to that outlined by Igi et al. (1992) and Igi (1993). The autoscaling technique described here applied to the histograms has not previously been used. Although specifically developed to auto scale ionograms produced by the Australian Space Weather Service (SWS) IPS5D ionosonde, the technique described can be applied to digital ionograms from any source.

2. IPS5D ionogram characteristics

The o and x-rays returned from the ionosphere have approximately circular polarization but in the opposite sense. In the IPS5D, crossed receive antennas are combined with phase switching to record both polarizations separately. In the IPD5D ionosonde, the o and x ray ionograms are output separately after a preliminary cleaning and then made available at the World Data Center. With the imperfect separation achieved, it was preferable here to use the x-ray ionograms as having the strongest x mode trace. The histogram technique produces stronger histograms if there is no o-x ray separation and best of all when directly finding foF2 and h'F2 when perfect o ray separation can be achieved, a more difficult task (see examples by Harris et al., 2016). SWS provide hourly raw ionograms of large size at hourly rates and partially de-noised ionograms of reduced size, described as clean, are archived at the sampling rate. The cleaned SWS ionograms are the ones used in this paper.

3. Initial signal level adjustment

Signal amplitude is recorded with the IPS5D ionosonde. The first stage of noise removal is done by finding the maximum and minimum signal strength values in the ionogram and then choosing a related percentage level to determine an amplitude threshold of points to be displayed. The amplitude threshold must be chosen to provide a suitable compromise between cutting out low-level noise while not destroying vital ionogram trace information. The approach to removing noise used here is to do so incrementally since each stage of the processing allows for noise removal as will be described.

4. Finding foF2

The o-ray trace in an ionogram is overlaid by the x-ray trace and is thus apparently difficult to separate. The point to note here is that fxF2 varies in the same manner as foF2 and bears a fixed frequency relationship to foF2 in terms of ultimate o and x critical frequencies. An average separation between the o and x rays at their critical frequencies is easily measured at each site using standard ionogram scaling software. Once measured, the o-x separation measurements do not need to be repeated as they are constant for a given site. The problem of finding foF2 when both o and x traces are present can now be shifted to the much simpler problem of finding fxF2, the highest F2 layer frequency return in the ionogram

5. Forming raw frequency and height histograms

The basis of the display and autoscaling technique lies in the production of separate histograms of ionogram pixel numbers as a function of virtual height and of frequency. This technique has a long history (Igi et al., 1992; Igi, 1993). For simple displays, the frequency histogram is formed by summing pixels at all heights including noise at each frequency in the ionosonde sweep. For the height histogram, all pixels including noise are summed at each height for all frequencies during the frequency sweep. A raw ionogram showing the preliminary histograms are shown in Fig. 1(a). If signal amplitude is available, as here, then each pixel is weighted with this value so that the histograms becomes a measure of total received signal strength as a function of height and frequency.

A frequency-time display is obtained by converting the frequency histogram into a single vertical line whose color or intensity is based on the histogram strength (number of pixels, weighted with signal strength if available) and plot-

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