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Ionsonde monitoring and related studies in China with International Meridian Circle Program

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Abstract

Based on the Chinese Meridian Project (CMP), the International Meridian Circle Program (IMCP) organizes a comprehensive ground-based monitoring network along the 120°E – 60°W Great Meridian Circle to track the propagation and evolution of space weather events. IMCP has more than ten ionosonde along the Meridian Circle at different latitudes to monitor the ionosphere, supporting Chinese researchers in studies on ionospheric statistical characteristic and events. The DPS-4D Ionosonde at Hainan Fuke station (19.5°N, 109.1°E) has been observing the ionosphere for 20 years, with this data we manually classified the SF as 4 types and studied the variation features. Furthermore, with deep learning method, we made a detection (accuracy≥95%) & classification (average accuracy=95%) model and a short-impending prediction model for the SF in the ionogram over this station. The models are based on image characteristics, no matter what the ionogram data formats or the auto-models in ionosonde.

1 Introduction

Our terrestrial environment is coupled to the Earth's magnetosphere and its boundaries with the Solar Wind and interplanetary space via a critical layer: its Ionosphere, Upper and Middle Atmosphere (IMUA). The space plasma processes are strongly affected by the Earth's magnetic field, the formation and development always shows latitude dependence.

Therefore, the science and human activities require the coordinated scientific operation of a global network of ground-based instruments to continuously measure the key parameters of our ionosphere, middle and upper atmosphere. This is the overarching goal of the International Meridian Circle Program (IMCP). The North America, Europe, Southeast Asia and Oceania has built several regional network, but only IMCP contains so many instruments along a large Great Meridian Circle.

For the ionosphere, the ionosonde is one of the major instruments for 24-h monitoring. Its frequency-virtual height figure (ionogram) contains ionospheric electron density profile and structures/disturbances, shown as Spread F (SF), Sporadic E (Es), discontinuity blank region for "valley", and so on. Since 1970s, URSI published handbook for ionogram [1].

Ionosondes have had a remarkable comeback in the 2010s due to strong technological and scientific interests that require ionosondes to provide accurate and prompt imaging of ionospheric dynamics during disturbed conditions. Digisonde ionospheric sounders installed at nearly 100 sites all over the world to form the ionosonde network of Global Ionospheric Radio Observatory (GIRO) portal. The IMCP has joint Digisondes with GIRO such as Hainan Fuke station.

The SF phenomenon, i.e., the spread characteristics on F trace in ionogram, is considered to be caused by ionospheric disturbances. This diffusion is normally resulted from different frequencies are reflected at the same height or the same frequency is reflected at multiple heights. Obviously, the SF shows HF signal interference by ionospheric plasma density disturbances and irregularities, and the image features are associated with ionospheric features, corresponding to different physical mechanism.

Although the SF types in ionograms could show many processes and their mechanisms in the ionosphere, benefiting science and space weather application, one still have to identify the figure characteristic by eyes. Nowadays, the machine learning method states to be used in the auto-process of ionograms.

2 CMP/IMCP and its ionosondes

The Chinese Meridian Project (CMP) is the Space Environment Ground Based Comprehensive Monitoring Network of China. The CMP now plays a major part in the IMCP system. It was funded by the National Development and Reform Commission of China with 1.5 billion yuan, and its construction started in 2008. In 2012, the first phase of the Chinese Meridian project started operation. By 2021, more than 8 TB of monitoring data with 64 kinds of space environment parameters have been collected. After the completion of CMP-II in 2024, it will form a two-cross enhanced and more powerful space weather monitoring network over China.

Based on the CMP, the International Meridian Circle Program (IMCP) aims to coordinate the deployment of a comprehensive ground-based monitoring network along the 120°E – 60°W Great Meridian Circle to track the propagation and evolution of space weather events from the Sun to the Earth, monitoring the major natural and anthropic hazards on the ionosphere, the middle and upper atmosphere [2, 3]. The IMCP network of instruments could monitor the average state and disturbances thereof of the IMUA. For the Primary 120°E – 60°W meridian circle, 1000+ instruments deployed along it, once integrated into a coherent network, could provide a comprehensive cross-sectional scan of space from ground to nearly 3000 km altitude. We can simultaneous obtained distributions of ionospheric density, electric and magnetic fields, wind fields, temperature, waves, and so on.

A strong interplay between production of observational data and use of advanced numerical models is required. Advanced data assimilation techniques derived from numerical weather prediction (NWP) has been adapted to IMCP data, building on the works of Chinese researchers who have successfully applied them to ionospheric short-term prediction. We believe the large amount of IMCP data could deepen our understanding to space science.

IMCP has more than ten ionosonde along the Great Meridian Circle at different latitudes to monitor the ionosphere, while more sites are added into the project. In China, ionograms from ionosondes at Hainan (Fuke), Mohe, Wuhan, Beijing, Zhongshan (south pole) et al. have long been used by not only Chinese scientists, but also foreigner researchers. Papers are published on statistical study and case analysis, while the data also serve applications in many fields. With CMP-II, ten more ionosondes in China will be added into the project.

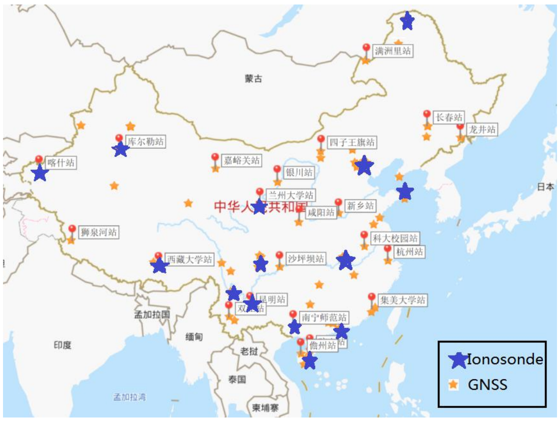

Figure 1. Locations of CMP ionosondes (blue stars) all over China.

3 The Hainan Fuke Station with DPS-4D ionosonde

Digisonde (DPS Ionosonde) at Hainan Fuke Station (19.5°N, 109.1°E) has been observing the ionosphere since 2002. Before 2010 it was DPS-4 and then it was updated to DPS-4D. With the data of this Ionosonde, we studied low latitude ionospheric structures, disturbances and irregularities for decades.

Each year the ionosonde could obtain about 50,000 ionograms (some year could be more than 75,000). The SAO-Explorer could auto process the ionogram figures, while we have also manually processed all the figures, obtaining not only the parameters (i.e., foF2, hmF2, h'F, et al.) of the electron density profile, but also the SF/Es records.

URSI's ionogram handbook suggestedthe SF all over the world could be divided into 4 types: range spread F (RSF), branch spread F (BSF), frequency spread F (FSF), and mixed spread F (MSF). FSF is which the intensity of spread increases with frequency and foF2 is not definable; RSF is which diffuse echoes at lower frequency with clear foF2; MSF is which mixed by FSF and RSF; BSF is which multiply traces of similar strength occur giving two or more foF2 and the individual frequencies are well defined.

We proposed a Spread F (SF) type as Strong Range SF (SSF), which is draw from Range SF (RSF), and found only the SSF is highly consistent with ionospehric scintillation mainly produced by Equatorial Plasma Bubbles (EPB) [4]. We found at latitude in Asia, Oceania, South America and Africa, SF only has types of FSF, MSF, RSF and SSF, but no BSF. We found the occurrences of different types of SF varied with local time, seasons, solar/magnetic activities. We also used SF as indicator to study the relationship of different ionospheric irregularities (such as bubbles and blobs) with in-situ measurement from satellite. Therefore, the studies on the different SF types are of great help to Ionosphere plasma research.

4 SF models with deep learning method on data from Hainan

As we mentioed, there is no model auto classifying FSF/RSF/MSF/SSF, and no quantitative parameter describing SFs. Researchers still manually identify the SF and make qualitative research.

Since we have recorded the SF types by eyes, intelligent SF detection and classification models were developed based on our ionogram data set by using deep learning (DL) methods. We use data from 2002 to 2015 to train the models, and use data from other years to verification.

Redundant information on each ionogram image was cropped out and then the cropped images were unified to the same size. To balance the number of different types, some simulated noises were added to these images in the type with a small sample set. On the basis of the balanced image set, a lot of experiments have been done to train VGG, ResNet, EfficientNet, ViT, MobileNet and other models.

The verification shows that the detection models have accuracy higher than 95%. For the SF classification, the evaluate accuracy of four best models are all over 92%.

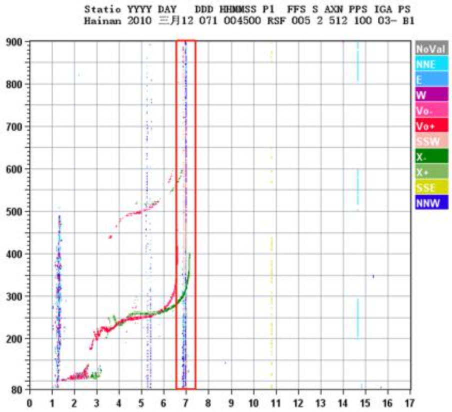

Figure 2. Ionograms with common noise, which makes auto SF classification difficult.

Since the ionosphere has regional differences at different latitudes and in different continents, SF types have been proved to be different in different regions. To make the models applying to wider areas, we added ionograms with SF type records from Russia, Brazil, Australia and Ascension IS in the Atlantic Ocean.

We also made a short-impending prediction model for the SF in the ionogram, it could predict ionograms in the next 1 hour based on the ionograms in the past 3 hours. Different from the existing models predicting the parameters (i.e., foF2, hmF2, h'F, et al.) of the electron density profile, our model provide full F region trace with possible SF echoes. Therefore, it could make a forecast of ionospheric disturbances caused by different mechanisms. By now the SF predict accuracy is higher than 80%, and we state to experiment several new models.

5 Summary

IMCP is a great project allowing scientists study processes and mechanism of space weather events along the Meridian chain. Inside China, there have been more than 30 sites with hundreds of ground-based instruments to monitor the space. For the Great Meridian Circle, multinational power could really make things different. Not only the ionosonde network mentioned in this article, but also optical/radio instrument networks with IMCP are coordinated to study the ionosphere, middle and upper atmosphere.

For the ionosonde, although our models with deep learning method are based on ionograms only from Hainan Fuke station, our goal is promoting the model to GIRO digisondes and ionosondes from other networks all over the world. We believe our models based on image characteristics have great advantages, and Chinese scientists' experience could be transferred into AI tools to share with all the researchers on the ionosphere.

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The data used are from International Meridian Circle Program, mainly from CMP (http://www.meridianproject.ac.cn/data-download.html) and others could be asked through the site.

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