INSTANTANEOUS GLOBAL MAPS OF IONOSPHERIC CRITICAL FREQUENCY GIM-foF2 FOR EVALUATION OF THE IONOSPHERIC WEATHER

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Abstract

Global instantaneous ionospheric maps of foF2 critical frequency GIM-foF2 and the ionospheric weather W(foF2) maps are produced with PRIME Kriging technique with a resolution of 1 h, 5° and 2.5° in time, longitude and latitude respectively for 1998-2017. The results are obtained for the first time for the global super-storm on March, 1989, demonstrating a new opportunity for the ionosphere investigations in the past since the 19th solar cycle when ionosonde network has been active while none navigational satellite data existed.

1. Introduction

The monthly median maps of the ionospheric characteristics provide reference values of various parameters at the selected locations but differ from the actual value. More information can be obtained by using different instantaneous maps of ionospheric parameters [1-3]. Instantaneous mapping is defined as the technique that is applied when simultaneously measured or forecast values of ionospheric characteristics at limited number of locations are used for map generation at a single moment of time. These randomly spaced data can be of different origin: vertical incidence, radar, navigational satellite signals or in situmeasurements from satellites and rockets, as well as predicted of forecast values.

During recent years Global Navigation Satellite System, GNSS, has become one of the most powerful tools for sensing the earths ionosphere. A global permanent network of dual-frequency GNSS receivers makes it possible to monitor the temporal and spatial variation of ionosphere continuously and cost-effectively with different methods. One typical example is that, since June 1998, international GNSS service (IGS) Ionosphere Working Group has been established to provide global ionospheric total electron content (TEC) maps (GIMs) with a resolution of 1 h, 5° and 2.5° in time, longitude and latitude respectively. The primary objective of GIMs is to monitor the variation of ionosphere continuously and apply this information to other radio signal propagation. The potential users can be those with single-frequency receivers who demand up-to-date ionosphere correction or scientists who are interested in highly accurate ionosphere models.

2. Data analysis

In the present study a set of hourly Global Ionospheric Maps, GIM-foF2, is obtained using PRIME-251 Krigingmapping technique (PRIME-foF2) [1]. These maps are produced by assimilation of the ionosonde foF2 data into IRI model adjusted to the ITU-R (CCIR) median foF2 map. The incorporation of the ionosonde foF2 data into updated PRIME251 software is applied and the global hourly PRIME-foF2 maps in IONEX format are produced for evaluation of the ionospheric weather W(foF2) index [2, 4]. GIM-foF2 maps and W(foF2) maps are produced for the total period from January, 1998 to January, 2017. In a case of missing ionosonde foF2 observation, the missing value is filled by prediction according to the method described in [4]. To demonstrate a potential for producing GIM-foF2 and W(foF2) maps with the ionosonde observations back in the past when none GIM-TEC could be produceddue to lack of relevant GNSS observations, the analysis of the super-storm in March, 1989, is carried out for the first time in literature using GIM-foF2 and W(foF2 maps.

Figure 1 presentsthe examples of foF2 maps produced by (a) PRIME-foF2 mapping technique and (b) IRI-CCIR real-time mapping (IRTAM) adjusted to GIRO data [4] on 26.01.2017 at 16:00 h UT.The ionosonde locations for foF2 data are indicated by circles at the both maps.

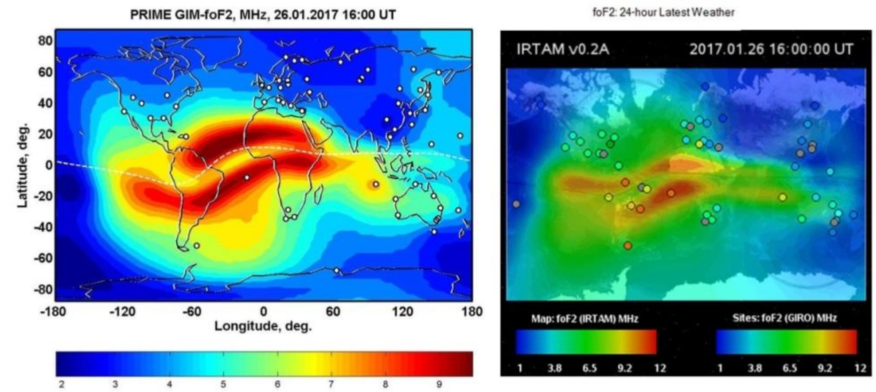

Figure 1. Instantaneous PRIME and IRTAM foF2 maps 26.01.2017 at 16:00 UT.

Real-time extension of the empirical International Reference Ionosphere IRI-ITU-R model, IRTAM, is used for the instantaneous update of climatological ionospheric features using Global Ionosphere Radio Observatory, GIRO [4] input from more than 50 ionosondes, which provide instantaneous global assimilative maps of foF2 and hmF2. Animated real-time maps of foF2 and hmF2 are published with a few minutes latency at http://giro.uml.edu/IRTAM/ that reproduce available data at the sensor sites and smoothly return to the climatological specifications when and where the data are missing. Computation of theupdated coefficient set for a given point in time includes analysis of the latest 24-hour historyof observations, which allows the morphing technique to sense evolving ionospheric dynamicseven with a sparse sensor network.

The space weather super-storm on March 13-14, 1989, has had an unprecedented impact on electric power systems. It has plunged the entire Hydro Quebec system, which serves more than 6 million customers, into a geomagnetically induced currents (GIC) triggered blackout. Most of Hydro Quebec's neighboring systems in the United States came close to experiencing the same sort of outage [6]. GIC interactions with new technological devices such as large electric power controllers affected voltage regulation and caused undesired relay operations in the system equipment. The severe space weather storm signatures are evident from Figure 2a [6] where GOES-7 monitors the space weather conditions during the Great Geomagnetic storm of March 1989, the Moscow neutron monitor recorded the passage of a CME as a drop in levels known as a Forbush decrease.

3. Evaluation of ionospheric weather on March, 1989, severe storm

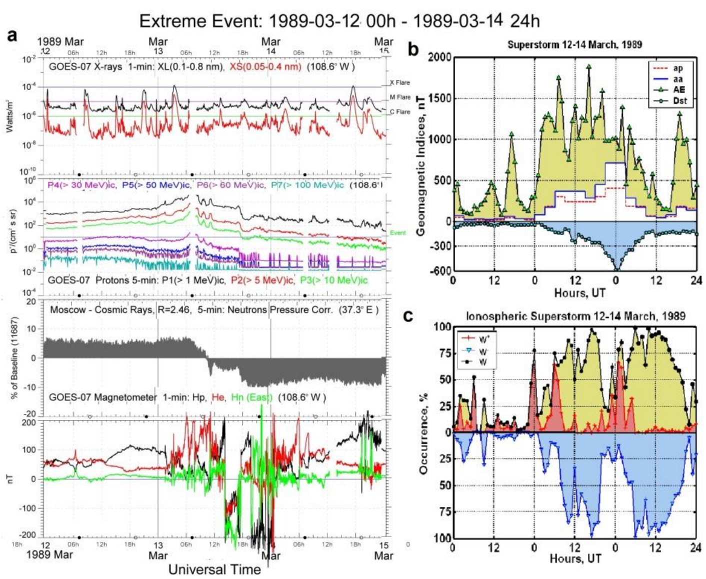

Figure 2. The space super-storm on 12-14 March, 1989: (a) GOES-7 monitor and the Moscow neutron monitor records; (b) geomagnetic indices aa, ap, AE and Dst; (c) percentage occurrence of positive pW and negative nW and total W(foF2) stormy cells on hourly W(foF2) maps.

In [4] a segmented logarithmic scale of the ionospheric weather Windex is introduced for the different thresholds of change in peak plasma density NmF2 (proportional to foF2 square) for quantifying the ionosphere variability. The thresholds of the logarithmic ratios for NmF2 and TEC are selected by equal increments in absolute values for the positive and negative logarithm magnitudes varying from W=-4 (extreme negative storm) in step of 1 to W=+4 (extreme positive ionosphere storm).The ionosonde observations in the past allow mapping ionospheric characteristics for more than 70 recent years. We define an intensity of global ionospheric storm by percentage occurrence pW, %, of positive ionosphere storm index (W = 3, 4) and negative ionosphere storm index nW, %, relative to the global cell number. The results in Figure 2 show maximum negative storm occurrence (which is plotted in the bottom subsection for the convenience but with positive percentage occurrence scale) which can reach 90% of the global sphere. As a result total occurrence of the both type of W(foF2) stormy cells could amount to 100% of the map.

The individual ITU-R (CCIR) predicted median foF2 map (left panel), PRIME-foF2 instant map (middle panel) and W(foF2) index map are plotted in Figure 3 for the peak of the Dst super-storm (Dst = -589 nT) on 14 March, 1989, at 01:00 h UT. The dominant positive storm on March 14, 1989, at 01:00 h UT is observed (pW=66%) in W(foF2) map (Figure 3) as compared to the negative storm (nW=12%) at this particular instant.

4. Conclusion

The proposed technique for foF2 map adjustment to the climatological ITU-R predictions appears to be very promising for investigation of the ionosphere weather in the past for few decades of ionosonde observations when none GNSS monitoring of the ionosphere existed. Application of the PRIME-foF2 mapping and W(foF2) mapping to the severe March, 1989, storm demonstrates that W index captures the increases and decreases in the peak electron density which could amount to 100% global occurrence during the severe space weather storm. A potential of application of the proposed approach appears to be promising for a significant improvements in modeling and forecasting the ionospheric weather.

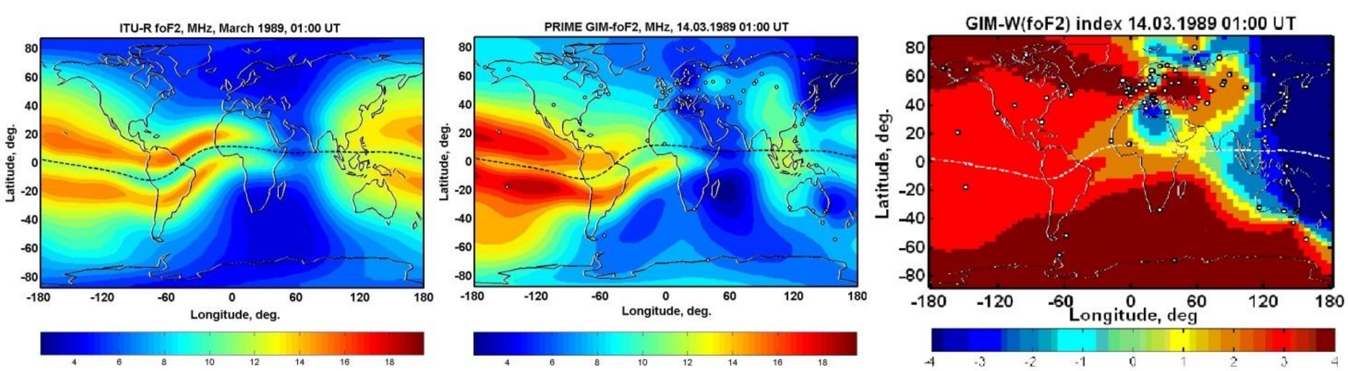

Figure 3.ITU-R (CCIR) prediction of reference quiet monthly foF2 map (left), instant PRIME GIM-foF2 map (middle) and W(foF2) map (right) at the peak of super-storm 14.03.1989 at 01 h UT.

5. Acknowledgements

The PRIME251 foF2 instantaneous maping software and Prime foF2 map for 1999-2006 are provided by SRC at http://rwc.cbk.waw.pl/. The ionosonde foF2 data are provided by UK Solar System Data Centre (http://www.ukssdc.ac.uk/wdcc1/data_menu.html), Australian Space Weather Data Service (http://www.sws.bom.gov.au/World_Data_Centre/1/3), NICT, Japan (http://wdc.nict.go.jp/IONO/HP2009/ISDJ/index-E.html), NOAA SPIDR Server, USA (http://spidr.ionosonde.net/spidr/logoff.do), IZMIRAN Ionospheric Weather service, RF (http://www.izmiran.ru/ionosphere/weather/).

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