Mid-Latitude irregularities observed through morning during the magnetic storm on 19 March 2001

Jinghua Li, Guanyi Ma

National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100012 China, jhli@bao.ac.cn, guanyima@bao.ac.cn

Abstract

Ionospheric irregularities extending into morning were detected by GPS Earth Observation Network (GEONET) of Japan during the recovery phase of a magnetic storm started on 19 March 2001. Meanwhile spread F was observed from post-midnight through morning with the meridional ionosonde chain. They were seen as plasma bubbles by the Defense Meteorological Satellite Program (DMSP). The plasma bubble reached 45°N in latitude (magnetic latitude 40.2°N) and sustained until ~1000 LT in the morning. Mid-latitude irregularities extending into daytime were reported for the first time.

1. Introduction

Related with ionospheric irregularities, spread F or scintillation is basically a nighttime phenomenon. However, it has been occasionally reported that VHF scintillation events extending into daytime were observed at the equatorial anomaly or near the equatorial region [1-3]. L-band scintillation beyond sunrise was once reported by Aarons and DasGupta [1]. This paper reports for the first time mid-latitude irregularities extending into morning hours during 19 March 2001 magnetic storm. The observations for the irregularities and spread F are described first, then shown the geomagnetic conditions at the time. The results of various observations are presented in detail to show the spatial range and the duration of the irregularities. Discussion is concentrated on the morphology and the possible source of the mid-latitude irregularities.

2. Data used

327 dual frequency GEONET GPS receivers distributed uniformly in Japan, are used to survey the irregularities. Each station provides the carrier phase and pseudo range at 30s intervals. First relative slant TEC (sTEC) based on pseudorange-leveled carrier phases is calculated [4], and then the rate of change of the TEC (ROT) is obtained from the difference of sTEC sequence. 5-min resolution ROTI ($ROTI = \sqrt{<ROT^2> - <ROT>^2}$) is computed [5]. To reduce the effects of multi-path, the data from satellite whose elevation is small than 30° are removed.

The ionograms in 15-min interval from three ionosondes at Wakkanai (45.4°N,141.7°E; magnetic latitude 40.5°N), Kokubunji (35.7°N, 139.5°E; magnetic latitude 30.0°N) and Okinawa (26.3°N, 127.8°E; magnetic latitude 20.7°N) in Japan are used to examine spread F occurrences.

The ion density (Ni) with 4-seconds temporal resolution by DMSP in-situ measurement is used to analyze the plasma bubbles. DMSP is in a sun-synchronous orbit at an altitude of ~840 km above the ground.

The geomagnetic index Dst and interplanetary magnetic field (IMF) B_z component measured by ACE spacecrafts located at L1 point are used to describe the geomagnetic conditions on 19-21 March 2001.

3. Geomagnetic conditions

Fig. 1 shows the IMF Bz and Dst variations during the storm. Magnetic storm sudden commencement was recorded at 1114 UT on 19 March 2001. The 4-min resolution IMF B_z is plotted with a time delay of 63 minutes, corresponding to the estimated convection delay from ACE to the magnetosphere at the measured solar wind speed of ~400km/s. Dst reached maximum excursion at ~1530 UT on 20 March 2001, and then the geomagnetic field entered the recovery phase.

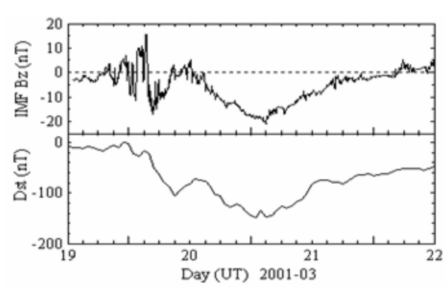

Figure 1 IMF Bz and Dst during 19-21 March 2001

4. Results and discussion

4.1 Irregularities observed by GEONET GPS receivers

ROTI maps at 9 different times are present in Fig. 2. Except the map at 2250 UT, which is presented to show the distinct 'y'-like structure, the interval between two sequential maps is 1 hour. The irregularities first appear near (144°E, 33°N) at ~1920 UT (~0455 LT), and disappear near (127.8°E, 26.3°N) at ~0220 UT (~1051 LT). They survived as long as ~7 hours. At ~2020 UT, three patches with different scales were observed, and then at ~2120 UT another patch appeared near (143°E, 39°N). From the following maps at 2220 UT and 2250 UT, we can conclude that the new patch is one branch of bifurcated irregularities. And the irregularities were observed to drift westward. The extension from lower latitude to higher latitude was not observed.

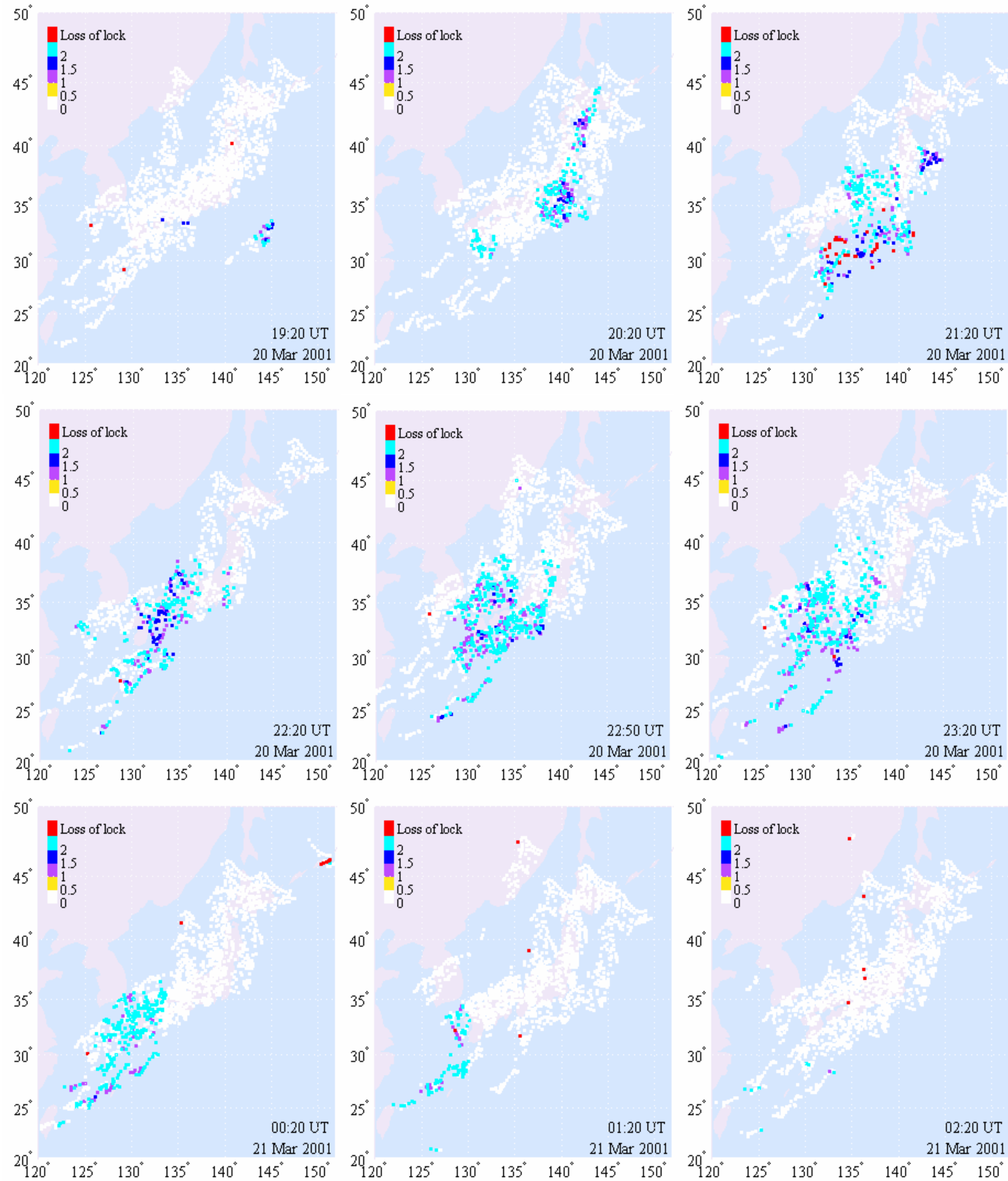

Figure 2 ROTI maps showing the temporal and spatial evolution of the irregularities.
Longitude (°E) and latitude (°N) are labeled at horizontal and vertical axis respectively.

To confirm the irregularities' movement and estimate the drift velocity, sTEC from GPS sites along east-west direction are used. Results for satellite PRN3 are shown in the left column in Fig. 3. TEC depletions reached ~25 TECU. The corresponding traces of the ionospheric piercing points are shown in the top panel in the right column, and the black circles show the beginning of plasma bubbles. From the time delay among these similar bubbles, the drift velocity can be estimated. The westward velocity is ~150m/s.

The middle column in Fig. 3 shows sTEC from meridian GPS sites. We can find that the depth of TEC depletion caused by plasma bubble decreasing with the increase of latitude. Another fact is that no distinct time delay with the increase of latitude, implying that the extension of plasma bubbles from low latitude to high latitude can not be found. This is consistent with the observations by GEONET GPS receivers.

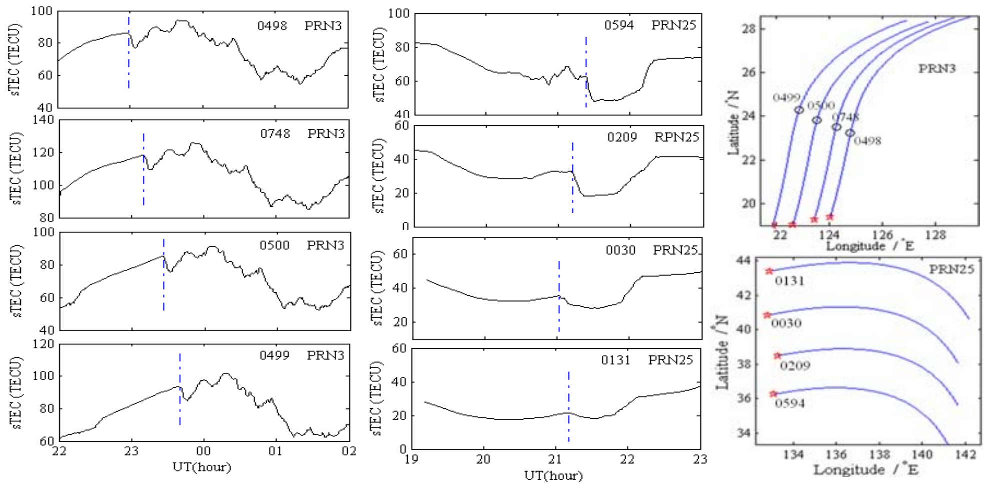

Figure 3 Irregularities observed by east-west (left) and north-south (middle) GPS sites, and the traces of PRN3 and PRN25. The red pentacles show the beginning positions of GPS satellites at the observations sites.

4.2 Spread F

Spread F was detected by three ionosondes at Okinawa (OKI), Kokubunji (KOK) and Wakkanai (WAK) through morning of 21 March 2001. Table 1 gives the ionsondes' positions, and the start and end time when the spread F was observed. It shows that the spread F appeared before dawn, at continued through morning hours. At OKI the irregularities appeared later and kept up longer than the other two sites.

Table 1 Period of spread F

Station	latitude	longitude	magnetic latitude	period of spread F (LT)	period of spread F (UT)
WAK	45.4°N	141.7°E	40.5°E	5:13~7:42	19:45~22:15
KOK	35.7°N	139.5°E	30.0°E	5:03~7:48	19:45~22:30
OKI	26.3°N	127.8°E	20.7°E	5:00~10:15	20:30~01:45

4.3 Plasma bubbles detected by DMSP

Plasma bubbles were also detected by DMSP, as shown in Fig. 4. Fig. 5 is presented here as an example. Out of the area in Fig. 4, no plasma bubbles were detected. DMSP flied southward. According to the traces, we separated the data into three groups, A, B and C, as shown in Fig. 4. Table 2 listed observations by DMSP. The sign of "\" means that no bubble was observed. Comparing the observations from DMSP and GPS, we find that most of the time the bubbles seen by DMSP and GPS are different parts, it confirmed that irregularities exist in large spatial range consist of several patches with different spatial scales as mentioned above.

Fig. 4 shows the irregularities are asymmetric to the magnetic equator. At 2008 UT the bubble was first detected by F13 at around (152°E, 20°N). But F12 which pass ~170°E at 2029~2142 UT did not observe bubbles. It was supposed that the east edge of bubble was near 160°E. In group C, only F14 detected bubble. F12 and F14 flew over the area simultaneously, but F12 didn't detect bubble. F13, which passed the area two hours earlier, did not observe bubble, either. This demonstrated that the west edge of the bubbles was near 100°E.

4.4 Discussion

It has been shown that the post-midnight occurrence of the irregularities often follows the reversal of the ionospheric vertical drift [6]. Scintillation events started at post-midnight and extended into daytime were observed occasionally at equatorial anomaly or near equatorial region [1-3]. It is reported here for the first time that mid-latitude irregularities sustained to the morning hours. From the ROTI maps and spread F observations, the irregularities were not observed coming from the lower latitude. Westward drift was shown by GPS observations.

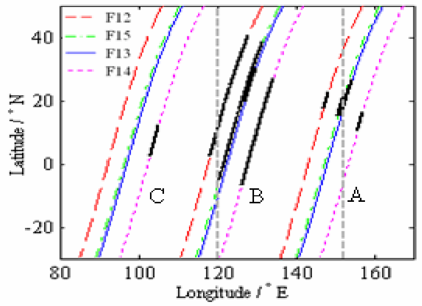

Figure 4 Plasma bubbles detected by DMSP.
The thin lines distinguished by different line styles and colors are the traces of DMSP, and the thick black lines show the positions of bubbles. Gray lines show the longitude range in figure 2.

Table 2 Bubbles detected by DMSP

	Satellite	Bubbles detected by DMSP		Time of DMSP flying over (UT)
		UT	Spatial range	
A	F13	20:08~20:10	~153°E, 15~17°N	20:00~20:23
	F14	22:21~22:22	~156°E, 10~16°N	22:11~22:34
	F12	22:19~22:20	~148°E, 17~23°N	22:11~22:34
	F15	23:34~23:35	~151°E, 15~22°N	23:26~23:49
B	F13	21:48~21:51	~128°E, 19~30°N	21:42~22:05
	F14	23:59~00:09	~130°E, -7~27°N	23:53~00:16
	F12	23:55~00:07	~123°E, 2~14°N	23:53~00:16
	F15	01:11~01:24	~125°E, -5~39°N	01:08~01:31
C	F13	\	\	23:24~23:47
	F14	01:46~01:48	~104°E, 2~12°N	01:35~01:58
	F12	\	\	01:35~01:58
	F15	\	\	02:50~03:13

Accompanying the irregularities on 21 Mar. 2001, intense negative ionospheric storm occurred on the same day and expanded to the southest of Japan [7]. The storm started at about 0~3 hours after sunrise, and continued for the whole day. It was explained that the equatorward neutral wind transported the composition-changed atmosphere from high latitude to lower latitude, which lead to the decrease of the electron density and hence the negative storm. The density or TEC level for the storm was similar to that at usual night. It is most likely that such a background was favorable for the survival of the irregularities after sunrise.

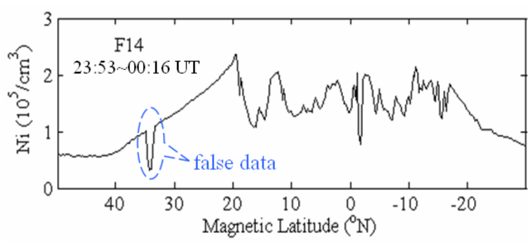

Figure 5 Plasma bubbles detected by DMSP

5. Summaries

Mid-latitude irregularities extending into morning hours were observed by muti-equipments during the recovery phase of the storm on 19 March 2001. The total time the irregularities sustained was ~7 hours. The irregularities were first seen by GEONET GPS receivers at ~1920 UT. They appeared to be several small patches at their early period. Then bifurcated structure was observed. The irregularities disappeared at ~0220 UT. The local time of irregularities observed is from ~0500 LT to ~1030 LT. The highest latitude the irregularities reached is ~45°N (40.2°N magnetic latitude), with an apex height of ~4500km in altitude. And shown by DMSP observation, they are asymmetric to the magnetic equator at western pacific longitudes. During their evolution, the irregularities drifted westward at a speed of ~150 m/s. The intense ionospheric negative storm occurred on the same day was probably a favorable condition for the survival of the irregularities after sunrise.

References

1. Aarons, J., DasGupta, A., "Equatorial scintillations during the major magnetic storm of April 1981," *Radio Science*, Vol.19, 1984, pp.731-739
2. Chandra H., G. D. Vyas, B. M. Pathan and D. R. K. Rao, "Spectral characteristics of magnetic storm-induced F-region scintillations extending into daytime," *J. Atmos.Terr. Phys.*, Vol.57, 1995, pp.1273-1285
3. DasGupta, A., Maitra, A., Das, S.K., "Post-midnight scintillation activity in relation to geomagnetic disturbances," *J. Atmos.Terr. Phys.*, Vol.47, 1985, pp.911-916
4. Ma, G., and T. Maruyama, "Derivation of TEC and estimation of instrumental biases from GEONET in Japan," *Ann. Geophys.*, Vol.21, 2003, pp.2083-2093
5. Ma, G., and T. Maruyama, A super bubble detected by dense GPS network at east Asian longitudes, *Geophys. Res. Lett.*, Vol.33, 2006, L21103, doi:10.1029/2006GL027512
6. Fejer B.G., Scherliess L., de Paula E. R., Effect of the vertical plasma drift velocity on the generation and evolution of equatorial spread F, *J. Geophys. Res.*, Vol.104(A9), 1999, pp.19859-19869
7. Maruyama T., M. Nakamura, Conditions for intense ionospheric storms expanding to lower midlatitudes, *J. Geophys. Res.*, Vol.112, 2007, A05310, doi:10.1029/2006JA012226