Plasma bubble monitoring by HF trans-equatorial arrival angle and propagation distance measurements

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Abstract

Demand for plasma bubble monitoring for global navigation satellite system users is increasing. Large-scale ionospheric structures associated with plasma bubbles are studied by measuring trans-equatorial propagation of HF radio waves from Australia to Japan. Propagation distance of the radio waves are simultaneously measured with two digital radio receiver, one near the radio transmitting site in Australia and the other at receiver site in Japan. The study shows that off-great circle trans-equatorial propagation of HF radio wave corresponds to plasma bubble and useful for wide-area plasma bubble monitoring. Propagation distance measurement helps improving the monitoring performance.

1 Introduction

Trans-equatorial propagation of HF radio waves have been used to study large-scale structures of the equatorial ionosphere[1]. By using a latest direction finding system of HF radio waves, it has been found that nighttime off-great circle propagation (OGCP) of HF radio waves corresponds to a plasma bubble. Directions-of-arrival (azimuth and elevation angles, DOA) measurements of trans-equator propagating HF radio waves enables us to monitor the existence of plasma bubbles as well as to estimate their drift velocity[2,3]. However, measured DOAs have largely scattered, and the accuracy of the estimation of the position and velocity of plasma bubbles was not satisfactory. The scattering could probably be due to multiple propagation paths. Distinguishing different propagation paths in the DOA measurement by propagation distance measurements would be helpful.

In this study, DOAs and propagation distances of trans-equator propagating HF radio waves are simultaneously measured to estimate the position and velocity of plasma bubbles with better accuracy. The propagation distance is measured by a passive radar technique with a set of two digital radio receiver. The final goal of this study is to examine the performance of HF trans-equatorial propagation (HF-TEP) measurement as a wide-area plasma bubble monitoring system to respond to an increasing demand by global navigation satellite system (GNSS) users, especially for those who use GNSS in highly advanced ways.

2 Method

DOA of HF radio waves are measured with an HF direction finder which consists of seven crossed-loop antennas with 2 m diameter. The MUSIC algorithm is used to determine the DOA to determine three different DOAs simultaneously with an angular resolution of 1° and a time resolution of 0.5 s[2]. Propagation distance of HF radio waves are measured with a set of two digital radio receivers. One is located at the same location as the direction finder, and the other is located near a radio wave source. Comparing two waveforms recorded by the two receivers, delay time which corresponds to the propagation time is measured. Configuration of observation is shown in Figure 1.

The digital receiver is developed based on an open-source software development toolkit for software radios

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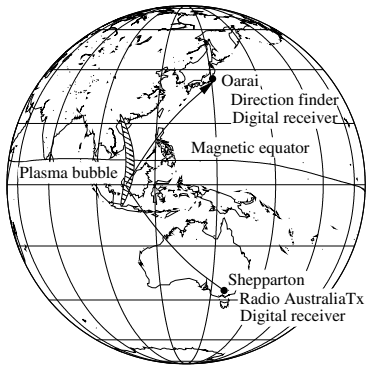

Figure 1: Configuration of the experiment of this study.

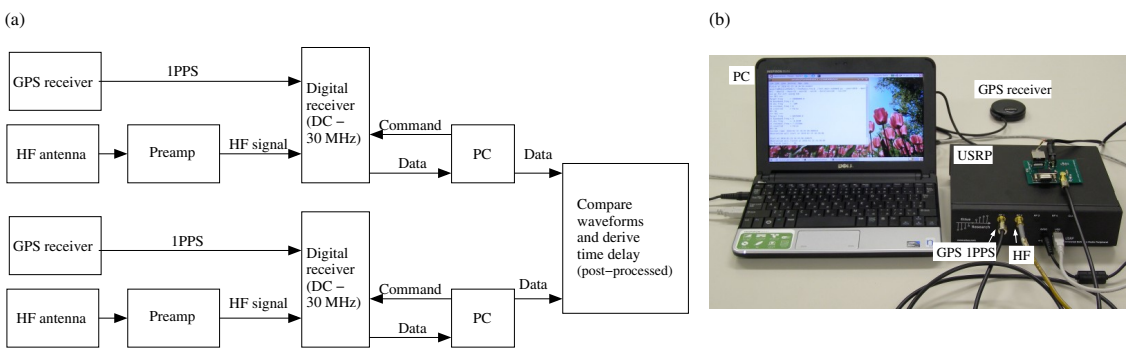

Figure 2: (a) Block diagram of the propagation distance measurement system and (b) an image of one of the digital receivers.

called GNU Radio (http://gnuradio.org) and a hardware called Universal Software Radio Peripheral (USRP, http://www.ettus.com). Two sets of receivers are time-synchronized by recording pulses per second (1PPS) generated by GPS receivers. Both the HF radio and 1PPS signals are simultaneously sampled at 32 kHz . Figures 2a and 2b show a block diagram of the propagation distance measurement system and a image of one of the digital receiver, respectively.

3 Propagation distance measurement test

To check the capability of the digital receiver system to measure propagation distance, broadcasting signals from Japanese domestic HF radio station is observed. The radio source is Radio Nikkei transmitted from Nagara (35.46°N, 140.21°E), Japan at 3.945 MHz. Two digital receivers are located at Chofu (35.68°N, 139.56°E), Japan and Uji (34.91°N, 135.80°E), Japan. The distances from the transmitter site to Chofu and Uji are 64 and 405 km, respectively.

Figure 3a shows the dynamic spectrum of correlation coefficient between two signals received at Chofu and Uji at 10 UT on 21 March 2010 for 3 min. Vertical axis shows the difference of propagation distance between Uji and Chofu calculated from the lag . They are calculated every 1 s. Positive distance difference means that the propagation distance to Uji is longer than that to Chofu. Strong peaks of correlations around 140 km are seen. Fading of signals are also seen.

To estimate the distance the first-order moment of the distance spectrum is taken using ±8 points around the peak of the correlation. Figure 3b shows the estimated distance difference at 10 UT on 21 March 2010

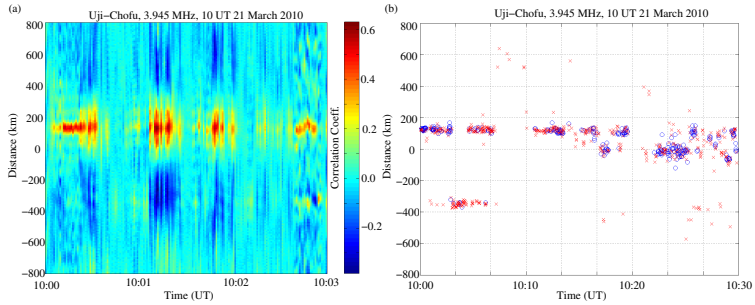

Figure 3: (a) Dynamic spectrum of correlation coefficient between two signals received at Chofu and Uji at 10 UT on 21 March 2010 and (b) estimated distance difference. Blue circles indicate data with high correlation ($c > 0.4$), and red crosses indicate relatively low maximum correlation ($0.2 < c \leq 0.4$).

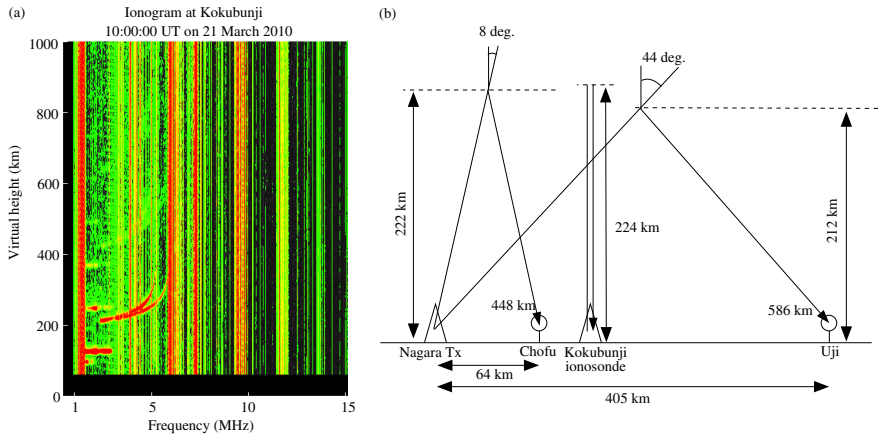

Figure 4: (a) Ionogram obtained at Kokubunji, Japan at 1000 UT on 21 March 2010 and (b) illustration of refection heights with different incident angles.

for 30 min. Here n is taken to be 8. Standard deviation of the estimated distance differences in the first two minutes (10:00 to 10:02 UT) is 5 km. The distance difference is constantly about 140 km with intermittent fading and interference by other radio sources. The estimated distance difference, 140 km, is much smaller than the horizontal distance between Chofu and Uji. This is considered to be because both the signals propagate through the ionosphere.

To validate this results, propagation distance difference is estimated by using ionosonde data obtained at Kokubunji, Japan very close to Chofu. Estimated distance difference from the ionosonde measurement is 138 km (see Figure 4b) which is in extremely good agreement with the estimation by our digital receiver system, 140±5 km. This result proves that our system is well capable of measuring the HF-TEP distances.

4 HF-TEP experiment

HF broadcasting signals from Radio Australia transmitted from Shepparton (36.2°S, 145.3°E), Australia are received to measure HF-TEP. An HF direction finder is located at Oarai (ODF, 36.3°N, 140.6°E), Japan. One of the digital receivers are located at Oarai, and the other is located at Shepparton. These receivers are operated simultaneously.

The first experiment campaign was conducted from 13 to 17 October 2010. The ODF and digital receivers

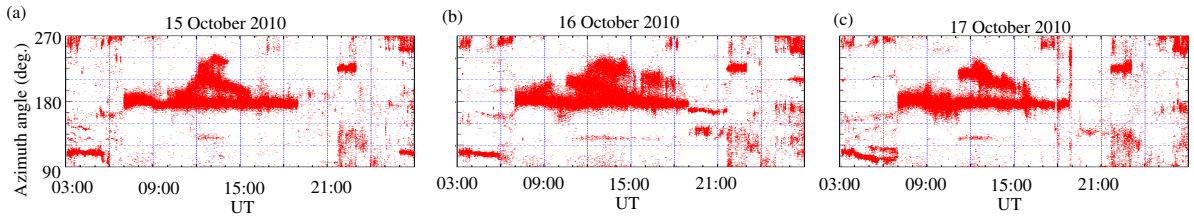

Figure 5: Azimuth angles of arrival of 9.475 MHz radio waves observed by ODF on (a) 15 October 2010, (b) 16 October 2010, and (c) 17 October 2010. Azimuth angle is measured clockwise from the geographic north.

were tuned at 9.475 MHz. Figure 5 shows an example of ODF measurements on 15 October 2010. Radio Australia transmits at 9.475 Hz from 07 to 19 UT everyday. Signals in the other time period are due to interference from other radio sources. Clear OGCF traces were observed showing that multiple plasma bubbles occurred during the night. OGCF were observed very frequently on other days indicating that plasma bubble activity is increasing as the solar activity increases. Unfortunately, however, system trouble occurred to one of the digital receivers, and the propagation distance were not obtained. The trouble is now fixed, and the second experiment campaign is planned in March 2011.

5 Conclusion

An HF-TEP distance measurement system with a set of two digital radio receivers are developed. Test experiment shows that it has a very good accuracy in measuring the propagation distance. DOA and propagation distance measurements of HF-TEP of Radio Australia broadcast waves were conducted from 14 to 17 October 2010. DOA measurements showed frequent occurrence of the plasma bubble. Although propagation distance measurement data were not obtained during the campaign, the system is now working well, and the second campaign planned in March 2011 will certainly give a good data set with the increasing solar activity. The results of the second campaign will be reported at the conference.

6 Acknowledgments

This study is supported by Grant-in-Aid for Young Scientist (B) by Japan Society for the Promotion of Science (JSPS) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

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