Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

PEM27-P01 Room:Convention Hall Time:May 26 18:15-19:30

Water vapor estimation using digital terrestrial broadcasting wave

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We, National Institute of Information and Communications Technology (NICT), are developing a water vapor measurement system using digital terrestrial broadcasting wave. Radio waves are delayed due to water vapor through propagation. Water vapor can be retrieved by measuring this time delay. If the humidity increases by 1 %, radio waves delay by about 17 ps during propagating 5 km distance. Very precise measurements (at least several tens of pico-second order) are needed for the effective observations. Radio waves used for digital terrestrial broadcasting are modulated with OFDM, and known signals (SP signals) are embedded. Complex delay profiles are calculated using these known signals. Using the phase of delay profile, we can measure propagation delay with precise accuracy (pico-second order). When we consider the accuracy with order of sub-nano seconds, phase fluctuations of local oscillators at radio tower and receivers are essential error factors. So we measure the propagation delay at two receiving points on the same line including the radio tower. Each result includes phase fluctuations of local oscillators at radio tower and receivers. Phase fluctuation of local oscillator at radio tower will be canceled out by taking the difference. We can estimate water vapor between two receiving points by synchronization between their local oscillators.

We are developing a real-time delay (phase of delay profiles) measurement system with software-defined radio technique. We have improved this system and maximum number of channels which can be processed in real-time has expanded to 5. Measurement accuracy of this system is evaluated, and the time resolution of measured delay time is found to about 50 ps. We plan to use CATV to synchronize the local oscillators at different sites. Signals pass-through in the CATV network are the same RF signals as that transmitted from the radio tower, and they can be also processed with the system mentioned above. Phase fluctuations of local oscillators at both sites are canceled out using the signals pass-through in CATV as references. Each signal pass-through in CATV has its own delay due to the difference of network path. We have developed the method to correct it. The precision of synchronization is less than 100 ps, and in-house test is going on to improve it. We are planning demonstration experiments to estimate water vapor using two receiving stations in next summer. We will use optical fiber synchronization method, which is already established by NICT, to evaluate CATV synchronization. We investigate miniaturization of measurement system using DSP board for the multi-point measurement in the future.

Keywords: water vapor, radio wave, propagation delay, digital terrestrial broadcasting

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Dual frequency observation of subionospheric perturbations associated with Hokuriku winter lightning

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Intense electromagnetic pulses (EMP) radiated from lightning discharge could cause heating and ionization and alter the conductivity in the ionospheric D-region. The purpose of this study is to reveal influence of the lightning on the lower ionosphere and its dependence on properties of lighting discharges. For this purpose, two LF radio observation systems were installed in Takine (Fukushima) and Sasaguri (Fukuoka). Radio signals from two JJY transmitters at Haganeyama (Fukuoka, 60kHz) and Otakadoyayama (Fukushima, 40kHz) are simultaneously measured at Takine and Sasaguri, respectively. Radio propagation paths of both transmitter ? receiver pairs are almost overlapped and the midpoints of both paths are located over the coast of Hokuriku area. These enable us to investigate the lightning effect on the lower ionosphere at different height because it is expected that reflection height of radio wave depends on radio frequency.

The LF signature of subionospheric perturbations associated with winter lightning in the Sea of Japan (around Hokuriku) has been observed from December 13, 2014. Signatures of subionospheric perturbation (early event) which occur immediately after the causative lightning were detected. While modeling studies (E. D. Schmitter. 2014) show that change of ionization state in the lower ionosphere depends on intensity of EMP, there is no clear observation evidence that shows quantitative relationship between them. We analyze the data derived from these observations using peak current of causative lightning and difference in frequency of two JJY.

Acknowledgement: We would like to thank A. Yoshikawa, T. Uozumi and S. Abe, Kyushu University, Fukuoka and T. Ohno, Hoshinomura astronomical observatory, Fukushima, for cooperating LF radio observation.

Keywords: lightning discharge, subionospheric perturbation, dual frequency observation

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PEM27-P03 Room:Convention Hall Time:May 26 18:15-19:30

Spectral analysis of ionospheric and atmospheric perturbations associated with typhoons using HFD and microbarometer

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It is reported that ionospheric perturbations are observed by extreme weather conditions such as tornadoes and typhoons, and they cause ionospheric disturbances. However, the features and propagation characteristics of atmospheric waves is still unclear. We examined atmospheric waves caused by typhoons, using HF doppler (HFD), which is maintained by The University of Electro-Communications, and microbarometer located at Mineyama, Kyoto prefecture. In this study, HFD receiver data for 5006 kHz observed at Sugadaira is used. Because of unstable ionosphere in the nighttime, we examined HFD data from 7:00 to 18:00. Details of typhoons, path, barometric pressure, and wind speed, are provided by Digital Typhoon, managed by National Institute of Informatics. Here, we give a brief description of Typhoon No.26 in 2013. This typhoon passed Japan in 2013/10/15 ˜10/17. It was closest to the Sugadaira observation point on 10/16. From dynamic spectrum of HFD data, it is found that perturbations of spectral intensity at the frequency under 5 mHz were observed in these 3 days even though Typhoon No.26 didn't get closed to Japan. On the other hand, spectral intensity of perturbations were enhanced at the frequency from 5 mHz up to 40mHz when Typhoon No.26 got closed to Japan. Simultaneously, a perturbation of doppler shift was observed whose amplitude is 0.2 Hz. Spectral intensity on microbarometer data also tended to be strong at the frequency from 5 mHz up to 50 mHz. Then we also examined temporal variations of spectral intensity at 4 mHz and 30 mHz, comparing them with the distance between Sugadaira observation point and the center of Typhoon No.26, and with wind velocity at Chichibu, which is the nearest observatory to the reflection point. Data of wind velocity was provided by AMeDAS, maintained by Japan Meteorological Agency. As a result, when Typhoon No.26 was approaching Japan, the spectral intensity of the perturbations at 30 mHz was clearly enhanced, but not at 4mHz. Therefore, it is clear that typhoons seem to affect spectral intensity at frequency higher than 5mHz. The spectral intensity reaches its maximum when the distance between Sugadaira and the center of Typhoon No.26 became the shortest. At this moment the wind velocity at Chichibu became the strongest.

Keywords: Typhoons, ionosphere, atmosphere, microbarometer, HFD

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PEM27-P04 Room:Convention Hall Time:May 26 18:15-19:30

Origin of small-scale field-aligned currents as observed by SWARM above the ionosphere in middle and low latitudes

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We analyzed magnetic field data obtained by the Swarm satellites launched on 22 November 2013, and confirmed that the short-period(10˜40 s) and small-amplitude scaled(0.1˜5 nT) magnetic fluctuations observed in middle and low latitudes are the manifestation of small-scale field-aligned current structure (Iyemori et al., GRL, 2015). Because of the characteristics of geographical and seasonal dependence of their amplitude obtained by analysis of the CHAMP satellite magnetic field data (Nakanishi et al., EPS, 2014), we interpret these results as the indication of field-aligned currents generated by dynamo action in the ionospheric E-layer. We assume that the dynamos are caused by the acoustic waves generated by the lower atmospheric disturbances. In this presentation, we show the evidence of the above interpretation by comparing the meteorological data with the magnetic fluctuations, and estimate in which hemisphere, i.e., in north or south hemisphere, the origin of the dynamo exists from a comparison of spectral indices of the small magnetic fluctuations above typhoons in 2014.

Keywords: field-aligned current, ionospheric dynamo, atmospheric gravity wave, acoustic gravity wave, swarm satellite, typhoon

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The verification of the small spatial structure of field aligned currents over the Brazilian Anomaly

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Nakanishi et al. (2014), using the magnetic data observed by the CHAMP satellite through high-pass filter with cutoff period around 40 seconds, show the ubiquitous existence of small scale (1-5 nT) magnetic fluctuations with period around a few tens seconds along the satellite orbit in middle and low latitudes. The results of analysis show the difference in the dependence of the amplitude and period on latitude between the magnetic fluctuations over the Brazilian Anomaly and the other region. That is, as the satellite approaches the dip equator, the period and amplitude get longer and smaller, respectively over the other region; on the other hand, over the Brazilian Anomaly, the period doesn't get longer and the amplitude doesn't get smaller or rather gets larger respectively. Another characteristics of the magnetic fluctuations over the Brazilian Anomaly are similar to those over other regions. That is, the magnetic fluctuations are perpendicular to the geomagnetic field; the amplitude on the dayside is much larger than that on the nightside, which shows high correlation between the amplitude and the ionospheric conductivities in E-layer with respect to local time; the amplitude has the geomagnetic conjugacy in general; almost no dependence on both geomagnetic activity and the solar wind parameters is found; the global distribution of the amplitude has clear seasonal dependence with the geographical characteristics.

They, putting importance on the dependence of the amplitude and period on latitude seen over the other region, suggest that the above characteristics can be interpreted as the spatial structure of small scale (200 ? 300 km) field-aligned currents generated by the ionospheric dynamo driven by atmospheric gravity waves (acoustic mode or inertial mode) propagating from the lower atmosphere. The dependence of the amplitude and period on latitude can be explained in the following way. With use of dipole model, the spatial scale of the field aligned current is traced to the satellite altitude along the main magnetic field. The scale at the satellite altitude gets larger as latitude decreases to the dip equator. Over the dip equator, the scale gets larger than a scale corresponding to the cutoff period and the amplitude gets attenuated.

This time we verify that the magnetic fluctuations over the Brazilian Anomaly have the same generation mechanism with those over the different region and especially show the possibility that the different characteristic can be explained by the above model. That is, as the geomagnetic field leans to the East-West direction over the Brazilian Anomaly, by trace along the magnetic field, the latitudinal scale doesn't get larger than the scale corresponding to the cutoff period comparatively even over dip equator, therefore, the amplitude doesn't get smaller comparatively.

The possibility shows that we can study the objective magnetic fluctuations over all the regions in middle and low latitudes including the Brazilian Anomaly.

Keywords: spatial structure of field aligned currents, middle and low latitudes, the CHAMP satellite, the SWARM satellite, atmospheric gravity wave, the Brazilian Anomaly

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PEM27-P06 Room:Convention Hall Time:May 26 18:15-19:30

The relationship between ionospheric disturbances detected by HFD and ground perturbations associated with earthquakes

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Many studies have reported that ionospheric disturbances occur after giant earthquakes. One of the causes is the acoustic wave excited by surface waves propagated on the ground from the epicenter. In this study, we compared the ionospheric vertical drift velocity calculated from HF Doppler (HFD) observation and vertical ground motions recorded at seismometer directly beneath the reflection point of the HFD radiowave in order to elucidate relationships between them. The HF Doppler observation is enable to detect ionospheric disturbances since this can observe ionospheric vertical drift from Doppler shift of HF radiowaves transmitted from the Chofu campus of The Univercity of Electro-Communications. In this study, using Doppler shift data for 5006 kHz, ionospheric disturbances associated with earthquakes are detected. To obtain accurate vertical drifts, we determined reflection altitudes of radiowave from ionogram data (Kokubunji) using POLAN (ionospheric density profile calculation software) . For seismometer data, we used 2 types of seismic networks installed by NIED, Storong-motion Seismograph Networks (K-NET,KiK-net) and Broadband Seismograph Network (F-net) .

We examined the correlation of the maximum values of ionospheric vertical drift velocity and vertical velocity of ground motion for 30 events (M≥6, 2003˜2013) . HFD observatories are Sugadaira, Oarai, and Iitate. The closest seismomete from each reflection points were selected.

As for Sugadaira observatory (20 events) , ionospheric velocity tends to increase in proportion to the square root of the ground velocity regardless of types of seismometers. In the other two observatories (Oarai, Iitate), ionospheric velocities are not proportional to square root of the ground perturbations. This is because sufficient events are not supplied (6˜12 events) in these observatories. However, the ionospheric vertical velocity increases with the ground velocity. If the numbers of the events are larger, the correlations of these observatories would be the same as the result of Sugadaira.

Keywords: ionosphere, HFD, earthquake, acoustic wave, seismometer, ground perturbations

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PEM27-P07 Room:Convention Hall Time:May 26 18:15-19:30

Simulation Results for the Ionospheric Density Disturbances Triggered by Earthquake Rayleigh Waves

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During the great earthquake event of M9.0 Tohoku earthquake on 11 March 2011 in Japan, previous studies detected the horizontal wave structure of ionospheric total electron content (TEC) disturbances by a dense ground-based GPS receiver network. These results suggested that the ionospheric TEC disturbances could be caused by the earthquake-triggered seismic surface, acoustic-gravity, and tsunami waves, which are distinguished by the different propagation velocities, durations, and periods. In order to further investigate the vertical coupling effect for the ionospheric plasma density disturbances, this study employed a three-dimensional, non-linear, compressible numerical model. This model simulated the disturbances of neutral mass densities from the surface to lower, upper atmosphere and the ionosphere, by specifying the surface displacement triggered by the earthquake, such as the rayleigh waves, at the model lower boundary. The results show that the TEC disturbances have two types of the propagation waves, first horizontal waves and slow co-centric waves. These might be caused by the neutral wind dynamo effect and the ion-neutral collision along the magnetic field.

Keywords: Earthquake, Rayleigh wave, Ionosphere, Plasma density disturbance

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Comparison between the ionospheric holes between inland earthquakes and subduction earthquakes with tsunami.

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We investigate the ionospheric holes generated by two inland earthquake and two subduction earthquakes with tsunami of which magnitudes are similar, using data of GPS total electron content. For the comparison, the ionospheric hole clearly appeared only in the subduction earthquakes. From our interpretation, this is due to the difference of the initial conditions to excite the acoustic waves.

Keywords: Ionospheric hole, Inland earthquake, Tsunami

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OBSERVATION OF METEOR SHOWERS IN 2014 - 2015 BY 5CH HRO-IF AND EVALUATION OF SYSTEMS AT KOCHI UNIVERSITY OF TECHNOLOGY

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Introduction: Ham-band Radio meteor Observation (HRO) has an advantage of 24-hour continuous data-detection. In Kochi University of Technology (KUT), 5 channel HRO-interferometer (HRO-IF) was developed in 2009 and has been observing the meteor appearance position of every meteor echo. We operated an automatic meteor observation system that automatically shows observational results on Web in quasi-real time for about two years until 2011 (Noguchi, 2009). In addition, we have developed a system of meteor trajectory measurement by multiple-sites observation with GPS time keeping and the 5ch HRO-IF (Yamasaki, 2012). In 2012, an HRO observation with a calibrating system which could regularly observe the absolute strength of the meteor echo was developed, thus the plasma density of each meteor echo was precisely determined (Yamato, 2013). We will report observation facilities, equipments, the future prospects and latest observation result.

Meteor observation by 5ch HRO-IF: In KUT, we started 6 direction HRO in 2003. We performed the basic development of the 3ch HRO-IF from 2005 to three years (Horiuchi, 2005; Okamoto, 2005) and obtained an arrival angle of each meteor echo from the phase difference of three antennas, calculating the approximate meteor appearance position (Hamaguchi, 2006; Noguchi, 2007). The 3ch HRO-IF is limited in positional accuracy for the angle of arrival obtained from the phase difference. In order to solve this problem, we developed the 5ch HRO-IF as the improved version in 2009, realizing the automatic meteor observation for two years in KUT (Noguchi, 2009). Since high time resolution is needed for interferometer, we calculate phase difference at every 0.1 s, synchronizing the 5 channel input signal to an AD board with 1 PPS (Pulse Per Second) signal provided by a GPS receiver every 1 s. We observed Camelopardalis meteor shower (May, 2014) and Daytime Arietids meteor shower (June, 2014) by using these equipments.

Meteor shower observation result in 2014 - 2015: We observed meteor showers of Camelopardalis, Daytime Arietids and Leonids 2014 by the KUT 5ch HRO-IF. We tried calculate trajectory vector of each meteor echo by a multisite observation of Geminids 2014 and Quadrantids 2015 meteor showers. The multisite observation system was developed with the other two HRO sits in addition to the KUT 5ch-IF. Preliminary result of the multisite observation was obtained and the system performance was evaluated with trouble shooting process.

Summary: We performed the KUT 5ch HRO-IF as a forward scattering meteor radar system continuously with some verifications of accuracy that is important to reveal meteor showers structures (e.g. Geminids). However, it is necessary to realize calculation of meteor trajectory information by the multiple-sites observation to obtain precise parameters of the meteor showers such as the suddenly observed Camelopardalid 2014 meteor shower. Therefore, we will have to develop an improved version of the HRO-IF observation system as a permanent automatic data transmission with acquiring observation data from multiple sites. We tried multisite observation of Geminids 2014 and Quadrantids 2015 meteor showers with evaluating the system performance and trouble shooting process. In this paper, we will report the current status of the KUT 5ch HRO-IF system with recent observational results in 2014 - 2015 and outlook for the future.

Keywords: Meteor radio observations, Radio interferometer, Multisite observations

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Large-scale structure and continuation of intense Es around the Kyusyu-Okinawa by VHF long-distance propagation

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We have been observing VHF long-distance propagations reflected by intense sporadic-E (Es) both at Kure and at Chofu [1]. It has shown that intense Es may have a very long and thin structure [2]. In this report, we describe the large structure and the moving characteristic of three intense Es observed around the Kyushu-Okinawa area on May 11, 2014 and September 14, 2013 and July 1, 2014. Since these three events were observed in the same area, it's suitable to compare the structure and characteristics.

(1) The speed of Es by VOR around 17:00 JST on September 14, 2013 was about 40 m/s and the length of the intense Es observed was about 300 km moving in southeast. The width of the Es was 7˜20 km which was much smaller than the length, but the west-portion became expand to 120 km, and the moving speed and the direction were different from the east-portion. Therefore, the whole structures were presumed to be during the observation period bending around the center. Additional the west-portion became thick with progress, but the east-portion did not showing change. Moreover, the duration times of the Es were more than 2 hours.

(2) The Es observed at around 19˜21:00 JST May 11, 2014, had two frontal structures moving in the same northwestward direction. But the two fronts had the moving speed of 50˜60 m/s, the length fronts of 300˜400 km, and the variable width of 5˜80 km, the duration time were about 1 hour.

(3) The Es observed at around 10˜11:00 JST July 1, 2014, had two frontal structures moving in the same northwestward direction. While moving 2 structures with speed different in about 50 m/s and about 150 m/s big as a point different from (2), and it intersected. The length of the structure was same as about 380 km and about 300 km mostly but different from 7˜35km and 55˜180 km in the width of the structure big like (2). Both of 2 were about 1 hour in duration.

These three intense Es observed in the same area had the structure length of 300˜400km equally, but the Es structure and moving speed were different. (1) was the southeast for the movement direction, but (2) and (3) were the reverse northwestward. Moreover (1) could continue high electronic density structure for about 2 hours, but only half of about 1 hour of (1) could continue (2) and (3). As these results, intense Es can be presumed that can move maintain the slender structure for about 1-2 hours.

In poster session, we will describe the comparative results, such as the moving characteristic of Es, the feature and structure, are reported in detail.

[1]Takuya Yamahata, Ichirou Tomizawa, Atsushi Yamamoto: Broader-based Es structure observation system development by VHF belt long distance propagation reception, SGEPSS, B005-P038, 2012.

[2]Ichirou Tomizawa, Koutarou Hujii : HF wave reflection propagation model by the shape of a wave face Es, JPGU, P-EM29-01, 2013.

Keywords: Ionosphere, Sporadic E layer, Large-scale structure

Japan Geoscience Union Meeting 2015
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Derivation of shape of cross-section of frontal sporadic E by the HF Doppler spectral analysis

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As for shape of cross-section of frontal sporadic E(Es), it has been revealed that had a shape of thin cylindrical structure by a past study [1]. However, there are no observation data about the shape of cross-section along Es front concerning we have developed a new method of analysis HF Doppler spectrum multi-state network in Kanto with high resolution.

At first I observe shape of cross-section of frontal Es passing HFD middle reflection point of Kanto and demand three dimensions of details data of the electric field strength every Doppler shift frequency at the near midway point passage time. We are able to consider the change to be the incidence angle dependence of the equivalence of value dispersion cross section when an radio wave was incident on a slim Es shape of cross-section from the lower part in time for field strength that cut and brought down these data every constant frequency. Because the baseline halfway point between each transmission and reception points are different, We can estimate cross-section of frontal Es reflection surface finely. I find a movement direction and the speed of frontal Es by performing this analysis at the many observation point and derive the sectional structure of the reflection whole shape of cross-section of frontal Es in detail.

A change really demands an average change from the electric field strength graph which cut and brought down observation data in the frequency direction by a quadratic equation fitting by the least-squares method because it is difficult to greatly analyze it directly. We found width based on this average change at the biggest strength every the Doppler shift frequency and the time, 3 dB time width. We found the width of cross-section of frontal Es from the product of 3 dB time width and the horizontal mobility speed, and the irregularity of shape of cross-section from the biggest strength and the time.

I applied the above mentioned method of analysis and checked the frontal Es which occurred at 23:00 JST on July 23, 2009 in detail. Shape of cross-section of frontal Es which advanced in 102 m/s, the southwestern direction, and the width of shape of cross-section was found with approximately 12 km. This shape of cross-section of frontal Es knew that structure and the asymmetry structure that there were not only one simple mountain-formed sectional structure but also two mountains existed when I looked at the shape of cross-section of the Es in resolving power of Fresnel zone approximately 4 km.

From the above results, I knew that I could derive shape of cross-section of frontal Es on the scale of the Fresnel zone by checking HF Doppler spectrum in detail at each observation point. I derive a regularity of the structure of shape of cross-section of frontal Es by performing this analysis for more frontal Es and can expect that I understand deeply to an atmosphere change to be concerned with Es generation.

[1]Ichiro Tomizawa and Kotaro Fujii: HF propagation model reflected by frontal Es, JPGU 2013, PEM29-01, 2013.5.

Keywords: ionosphere, HF Doppler, Sporadic E

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Examination of the Es propagation model of ITU-R based on VOR long distance propagation and the observation of ionosonde

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The University of Electro-Communications observe Very High Frequency Electric wave Reflected in Sporadic E layer in Chofu and Kure. It is necessary to check electron density structure in a wide area to examine it whether a long-distance propagation wave by a strong Es reflection pro-VHF propagation (GBAS-VDB) is not beyond interference permissible level. In the Es propagation model of ITU-R based on the observation until

the 1970s, expression of relations of the Es reflection ionosphere reflection decrement quantity is guaranteed only to Electric wave Reflected in Sporadic E layer to 80MHz. In this lecture, I express the result about whether it is possible to apply data of the ionosphere reflection decrement quantity observed from VOR observation of frequency around 110MHz and NICT verticality critical point frequency foEs data of the middle reflection point neighborhood to Es propagation model type of ITU-R.

In from May 1, 2014 to September 30, I observed an electric wave of the VOR transmission station of Yoron Island (27.044N, 128.398) and Yonagunijima (24.457N, 122.998E) which the distance with Yamagawa (31.20N, 130.62E) and the VOR middle reflection point was close in Kure (34.246N, 132.528E). I demanded Yamagawa perpendicular critical frequency foEs and ionosphere reflection decrement quantity for the use frequency and, from data of provided VOR reception electricity, performed the comparison with the Es propagation model type of ITU-R. As a result, which is obtained from Kure VOR reception electricity is smaller than the Es propagation model of ITU-R and gives weaker value than real reception electricity. This goes down assuming the Es reflection model that is bigger than Fresnel zone in the Es propagation model of ITU-R, and it is thought that this is because it observes the Es in Fresnel zone domains by the VOR long distance propagation observation. The ionosphere reflection decrement quantity between Kure and Yoron Island interval of surface of the earth propagation distance 893km has a bigger bigger difference with the predicted value than Kure and Yonagunijima Island interval of surface of the earth propagation distance 1427km. In addition, it becomes the slow degree of leaning in the VOR when I pay attention to a degree of leaning of ionosphere reflection decrement quantity for foEs and shows that an index to express the frequency dependence of the Es propagation model of ITU-R is too big. As a result, it is necessary for the propagation model type of ITU-R in frequency around 110MHz to perform a review. I increase the number of the examination lines and am going to examine an Es propagation model type of ITU-R at around 110MHz in detail in future.

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Keywords: ionosphere

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Estimation of spatial structure of sporadic E layer observed by S-310-40 rocket with 2-dimentional FDTD simulations

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We developed a 2-dimensional FDTD simulation code
which can treat wave propagations in magnetized plasma.
According to sounding rocket experiments,
we can only obtain altitude profile of wave intensity,
usually magnetic field intensity.
In this study, therefore, we are going to estimate spatial structure of sporadic E layer
in the lower ionosphere by analyzing the altitude profile of the magnetic field intensities.

We compared simulation results and observation results obtained by S-310-40 sounding rocket,
but were not able to identify spatial structure of the sporadic E layer.
This is because the scale of the spatial structure of the sporadic E layer
assumed in the simulation was inappropriate.
We are going to perform 2-dimensional FDTD simulations with different spatial scales of the sporadic E layer,
and investigate the influence that a scale of the space structure gives electric wave propagation.
Then, we will identify spatial structure of the sporadic E layer observed by S-310-40 sounding rocket
from the altitude profile of the magnetic field.

Keywords: Sporadic E layer, spatial structure, 2D FDTD simulation

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PEM27-P14 Room:Convention Hall Time:May 26 18:15-19:30

Improvement of an estimation method of the electron density profile in the lower ionosphere with time domain Full wave

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We are going to simulate the observation process of the present MF radar system
with the time domain Full wave method,
and investigate the observation method with which
we can obtain the precise electron density profile in the lower ionosphere.
One of the general methods to estimate the electron density in the present MF radar system
is the differential absorption experiment (DAE) method.
The DAE method is a technique to estimate the electron density from
the differential amount between the left and the right polarized waves
reflected from the lower ionosphere.
We simulated the MF radar with time domain Full wave analysis and examined the DAE method.
We improved the DAE method by using appropriate parameters automatically,
and succeeded to estimate more accurate electron density profiles in the lower ionosphere.
In the present improved DAE method, however,
we can only find appropriate parameters in the case that
the electron density increases with increase of the altitude.
Therefore, we are going to improve the DAE method, which is available in any case.

Keywords: Ionospheric D region, MF Radar, Full-wave method, DAE method

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Analysis of Propagation Characteristics of Radio Wave by S-520-29 Sounding Rocket

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S-520-29 sounding rocket experiments was carried out in Uchinoura Space Center on August 17, 2014. The purpose of this sounding rocket experiments is observation of sporadic E layer that appears in the lower ionosphere at near 100km. Therefore, the experiments was carried out using three methods. The first method is an optical method that observe light of metal ion emitted by the resonance scattering in sporadic E layer using the imager. The second is a method of using radio waves that receive the LF/MF band radio waves transmitted from the ground to rocket. The third is a method that measuring the electron density in the vicinity of sounding rocket using the fast Langmuir probe and the impedance probe. In this presentation, we explain the preliminary report of radio waves observations and radio waves propagation characteristics using frequency analysis of S-520-29 sounding rocket experiment. This rocket was equipped with LF/MF band radio receiver for observation of characteristics of LF/MF band radio waves propagation, and observe the LF/MF band radio waves in rocket flight. Antenna of LF/MF band radio receiver is composed of three axis loop antenna. LF/MF band radio receiver receives three radio waves of 873kHz (JOGB), 666kHz (JOBK), 60kHz (JJY) from the ground. 873kHz and 60kHz radio waves are coming from north side of the rocket, 666kHz radio waves are coming from the east side to the trajectory of the rocket. It is possible to estimates the position and size of the high electron density region in the sporadic E layer by analysis radio waves propagation characteristics using radio waves come from different directions. In the sounding rocket experiment, LMR was working properly. We have completed the observation of radio wave intensity. We analyze the observation results using a Doppler shift calculations by frequency analysis. Radio waves received by the sounding rocket undergoes a Doppler shift by polarization and direction of rocket spin and magnetic field of the earth. Radio waves received by the sounding rocket was separated into characteristics waves using frequency analysis. Then we calculate the Doppler shift from the separated data. Finally, this study estimate the electron density by using Doppler shift and the equation of booker. As a result, 873kHz, 666kHz radio waves are reflected by the ionosphere. 60kHz radio wave was propagated to maximum altitude of sounding rocket after it converted into whistler mode. Then, this study was able to estimate the altitude distribution of electron density by using the Doppler shift. In this study, we explain the reports of LMR observations and characteristics of radio waves propagation by frequency analysis by S-520-29 sounding rocket experiment.

Keywords: sounding rocket, radio wave propagations, Doppler shift, sporadic E layer

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Velocity distribution of electrons generating plasma waves around the wake of an ionospheric sounding rocket

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When a body moves in plasma at supersonic velocities, a rarefied plasma region called 'plasma wake' is formed behind the body. Wakes can develop behind a solar system body immersed in solar-wind plasma as well as behind spacecraft such as satellites and ionospheric sounding rockets.

Plasma waves around the rocket wake have been suggested by the observational results from previous rocket experiments, while there are also several studies which reported plasma waves around the wakes of a satellite and of the moon. In the S-520-26 rocket experiment (apex: 298 km), carried out in Japan at dawn of January 12, 2012, three kinds of plasma waves were identified (hereafter denoted Group-A,B, and C). We concluded that they are electrostatic electron cyclotron harmonic (ESCH) waves or upper hybrid resonance (UHR) mode waves (Group-A waves), and whistler mode waves (Group-B and Group-C waves). They have spin-phase dependence in characteristic manners.

Meanwhile, it was found that Group-A waves were also observed in the S-520-23 rocket experiment (apex: 279 km), which was performed in Japan at dusk of September 2, 2007, and that their spin-phase dependence is nearly the same with that of the Group-A waves observed in the S-520-26 rocket experiment.

We performed numerical calculations of plasma dispersion relations by assuming anisotropic velocity distribution functions such as electron beam and temperature anisotropy. As a result, positive linear growth rates have been obtained in the wave number and frequency ranges of UHR mode waves and ESCH waves in addition to electrostatic whistler mode waves. Accordingly, there have to be electrons with some anisotropic velocity distribution functions which are equivalent to those we assumed in the calculations. However, we have to clarify what kind of velocity distribution can be generated around the actual wake through the interaction between a sounding rocket and ionopsheric plasma.

Singh et al. (1987) performed a one-dimensional simulation of plasma entering a void region from the two sides using a Vlasov-Poisson code. They found counterstreaming electron beams in the very near wake. However, their study concentrates on electrons on the wake axis and does not indicate distribution functions in other areas. Besides, temperature anisotropy could not be treated in their simulation because it was performed in one dimension in velocity space.

In order to investigate inhomogeneity of electron distribution functions around the rocket wake, we are developing a Vlasov-Poisson code with one-dimensional space and two-dimensional velocity space, which is redesigned from the simulation code used in Singh et al. (1987). In this simulation, we deal with cases that electrons and ions are filling in a void space. The time evolution can be understood as spatial distribution along the wake axis. The direction of one-dimensional space is along the geomagnetic fields, along which electrons and ions can move easily. The size of space is 10 m, which is divided into 1024 grids in the calculation.

In this presentation, we clarify the frequency range and spatial distribution of the plasma waves around the wake based on the analyses of S-520-26 and S-520-23 rocket experiment data. We also discuss the velocity distribution of the electrons which can generate the plasma waves as observed. In addition, we report the results of our simulation for investigating the velocity distribution of electrons around the wake.

Keywords: wake, plasma wave, sounding rocket, ionosphere

Japan Geoscience Union Meeting 2015
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Characteristic feature of plasma irregularity obtained in ICI sounding rocket campaign

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ICI-3 (Investigation of Cusp Irregularities) campaign was conducted in December 2011, to study a better description of plasma instabilities and wave phenomena related to Reversed Flow Events (RFEs) in the cusp ionosphere. In this campaign, sounding rocket was launched at Ny-Alesund in Svalbard, and intercepted the dayside cusp aurora region as expected. Among science instruments onboard, a purpose of Fixed Bias Probe (FBP) is to measure electron current incident to its spherical probe with high time resolution for investigating plasma irregularity with a spatial scale from 1 m to 100 m. The FBP successively identified existence of the small-scale electron density irregularity during the flight.

Power spectrum analysis was applied to the incident electron current, which is basically proportional to the electron density, with an interest in understanding characteristic feature of the spatial scale in the irregularity. In fact, the data obtained in this campaign are appropriate to investigate altitudinal variation of the frequency characteristics because the rocket was staying almost in the irregularity region through its flight.

As a result of spectrum analysis of the electron density variation, it is clearly found that spectral power with 10 meter scale increases with altitude. However, it should be noted that spectral power tends to increase with the background density if the irregularity is contained at a constant rate in the background density. Therefore, spectral amplitude normalized by the background density was used to investigate the altitudinal dependence. Our analysis indicates that normalized amplitude of the density irregularity with 1-10 m scale is most significant at altitudes between 100 and 150 km, while the one with 100 m scale is almost constant independently of altitude. In particular, it is noticeable that the amplitude of electron density irregularity has a small local maximum in the frequency of 100-200 Hz (corresponds to decameter spatial scale) at 100 km altitude. Such feature is not found at other altitudes. The electron density irregularity with such a scale can be a target of HF backscatter radar echoes.

We will discuss altitudinal variation of the density irregularity in more detail.

Keywords: Sounding rocket, plasma irregularity, ionosphere, Cusp, electron density

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PEM27-P18 Room:Convention Hall Time:May 26 18:15-19:30

Space structure of Es layer observed by Langmuir probe and a new analysis method

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The sporadic E layer has been studied for a long time, and wind-shear theory is generally accepted about its generation mechanism. The theory explains an accumulation process of the electron density, but hardly gives information on thermal energy budget inside the layer. A great number of observations have been reported about the electron density structure in the sporadic E layer, but few information on the electron temperature are available, and therefore the accurate measurement is expected to conduct on the sounding rocket. In general, since a velocity of the sounding rocket is very high, it is difficult to get high special resolution data on the density structure of the sporadic E layer in the vertical direction. Therefore, it is necessary to find a new idea to estimate electron temperature and electron density in high-time resolution to understand the small scale structure of the sporadic E layer.

The sounding rocket ”S-520-29” was launched from Uchinoura Space Center at 19:10 on August 17, 2014. The purpose of this experiment is to elucidate spatial structure of sporadic E layer in the lower ionosphere. Langmuir probe was installed as one of the probes for direct measurements. In some current-voltage characteristics obtained by the Langmuir probe during this experiment, it was noted that the current variation with the bias voltage showed unusual behavior which suggests significant gradient in the electron density inside the sporadic E layer. In such a case, it is not possible to estimate electron density and electron temperature by using the conventional method.

In this study, we suggest a new analysis method to enable accurate estimation of the electron temperature and density, even when electron density is rapidly changed. It becomes possible to estimate the temperature and density in a time interval shorter than a period of the voltage sweep, because the probe current are interpolated by using adjacent data.

In this presentation, we report the small scale density structure and vertical thickness of the sporadic E layer estimated by adopting the new method, and validity of the current interpolation.

Keywords: E layer, Langmuir probe, sounding rocket

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Analysis of DC electric field in ionosphere by S-520-26 sounding rocket

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S-520-26 sounding rocket experiment was carried out at Uchinoura Space Center (USC) in Japan at 5:51 JST on 12 January, 2012. The purpose of this experiment is the investigation of the bonding process between the atmospheres and the plasma in the thermosphere. S-520-26 sounding rocket reached to an altitude of 298 km 278 seconds after a launch. The S-520-26 payload was equipped with Electric Field Detector (EFD) with a two set of orthogonal double probes to measure both DC and AC less than 200 Hz electric fields in the spin plane of the payload by using the double probe method. One of the probes is the inflatable tube structure antenna, called the ITA, with a length of 5 m (tip-to-tip). And ITA is very lightweight (12.5g per one boom). The ITA extended and worked without any problems. It was the first successful use of an inflatable structure as a flight antenna. Another one is the ribbon antenna with a length of 2 m (tip-to-tip). The electrodes of two double probe antennas were used to gather the potentials which were detected with high impedance pre-amplifier using the floating (unbiased) double probe technique. The potential differences on the two main orthogonal axes were digitized using 16-bit analog-digital converter, sampled at 800 samples/sec with low pass filter at cut-off frequency of 200 Hz.

Results of measurements of DC electric fields by the EFD have the large sine waves that result from the payload rotation at the spin period. The largest contribution to the electric field measurements by double probes moving through the ionosphere at mid-latitudes is that due to the v X B fields created by their motion across the ambient magnetic field, where v is the rocket velocity in the Earth-fixed reference frame and B is the ambient magnetic field. The sum of the squares of the two components represents the magnitude of the DC electric field in the spin plane of the payload. These data reveal abrupt, large-scale variations which can immediately be attributed to changes in the geophysical electric field since the v X B fields are slowly varying. The sum of the squares data also reveals contributions at the spin frequency and its harmonics. These contributions result primarily from distortions of the waveforms in the raw data. Then we obtained three components of natural DC electric fields by subtracting the v X B fields from raw data. As a result, the magnitude of DC electric field on a rocket orbit during the ascent was about 1mV/m, and the direction was for north-east.

Keywords: DC electric field, ionosphere, rocket experiment

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Inter-annual variations of Nitric Oxide in the polar mesosphere observed by a millimeter-wave radiometer at Syowa

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Recent observations revealed that the nitrogen oxides (NO,NO2) are increased in the lower thermosphere and the mesosphere and the upper stratosphere, when energetic particle precipitations associated with solar proton events or magnetic storms occurred (e.g. Lopez-Puertas et al. 2005),. To detect such the enhancement, we installed a millimeter-wave spectroscopic radiometer at Syowa Station in Antarctica, and observation of the NO spectrum has been conducted since January 2012. The NO column density derived from this observation shows a seasonal variation that the NO column density increases in winter. In winter, the observed NO column density of 2014 is lower than 2012 and 2013.

To study reliability of millimeter wave spectral radiometer, we compared the NO column amount with the SOFIE sensor on board AIM satellite. We picked observed data in the same magnetic latitude zone as the Syowa Station, and calculate an NO column density. The NO column density observed at Syowa Station and SOFIE shows a same tendency. Further, we compared month averaged NO column density, and found a good correlation. From this, the millimeter-wave spectral radiometer do uniform observations, and decreasing of the NO column density in 2014 winter season is reliably phenomenon.

Next, we study about impact of variations of relativistic electron flux to NO column density in winter. We used the electron flux data observed from POES satellites and calculated monthly integrated amount of the electron flux. The electron flux in the 2014 is less than those of 2012 and 2013. In particular, this tendency is significant in a period between April and August in 2014. From this, a lower amount of NO column density of 2014 winter may be caused by a low amount of relativistic electron flux.

Keywords: microwave spectroscopy, Nitric Oxide, MLT region, Energetic Particle Precipitation

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An observation of sodium twilight airglow using a Fabry-Perot imager

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The mesosphere and lower thermosphere (MLT) region is thought as a key region to solve a mechanism of the global change in the Earth's atmospheric system. Atomic metal layers which are maintained by ablation of meteors in the MLT region are known as a precious tracer to investigate chemistry and dynamics of the upper atmosphere [Williams, 2002]. For example, resonance scatter lidars tuned for wavelengths of various metal species are widely used to infer the winds and temperature in the MLT region [Plane, 2003]. However, there are still many ambiguities in knowledge about a horizontal structure and a seasonal variability of the metal layers. Therefore, a twilight airglow is focused on as a tracer to investigate horizontal structures of the metal layers in the MLT region in this study. The twilight airglow is luminous phenomenon which is caused by a resonance scattering of the metallic atoms in the MLT region illuminated by solar irradiance. This emission is effectively detectable in twilight time under a suitable geometric condition among the Sun, the metal layers, and a ground-based observer [e.g. Chamberlein, 1961]. Unlike a resonance scattering lidar, an emission from a metallic atom layer occurs simultaneously in a horizontally spread area, because a light source of the emission is solar irradiance in a case of twilight airglow. Thus, it is possible to deduce a horizontal distribution of metallic atoms from twilight airglow observations by using a sensitive and narrow band imaging device with a wide field of view. The Fabry-Perot interferometric imager (FPI) of the National Institute of Polar Research (NIPR) is one of instruments which satisfy these requirements. In this study results of a test observation of sodium twilight airglow, which is one of the strongest emissions in twilight, using the FPI at NIPR are presented, and future possibilities for study of a horizontal structure of metallic atom distribution in the MLT region using the FPI are discussed.

Keywords: twilight airglow, mesosphere, thermosphere, metallic layer, Fabry-Perot

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An estimation of three-dimensional structures of airglow emission discontinuities using images taken from ISS

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Three-dimensional structures of airglow emission discontinuities were revealed using images taken by astronauts from International Space Station (ISS). Airglow layers over the Earth's rim were captured by astronauts with a digital camera at night. Because these images were for the visible-light range, Na 589nm and OI 557.7nm emissions 90km altitude were expected to be dominant on these images. Two discontinuities on the airglow layers were observed on 16 October 2011 and 26 August 2014. They were observed from various viewing-angles during observing time 4m24s and 8m15s. Thus the three-dimensional structures of the discontinuities were estimated from these series of images. It was found that the structures would be caused by splitting of two emission layers, Na and OI. It is also found that they extended over 700km in the east-west direction. We estimated the altitude distributions of these emission layers' intensity and their RGB ratio by using Abel function. From the ground-based optical observation, mesospheric bore has been observed as an airglow discontinuity by terrestrial observation of airglow. The observed discontinuities and the bores have similarities and differences. In the presentation, the three-dimensional structures of the discontinuities will be reported, and their generation mechanism will be discussed in the comparison with the bore.

Keywords: airglow, mesospheric bore

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New analysis of gravity wave in middle atmosphere by Rayleigh/Raman lidar at Syowa station in Antarctica

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The gravity waves are generated in lower atmosphere, propagate upward and transfer momentum to the middle atmosphere. It has been found that the gravity waves induce large scale meridional circulation and drive the middle atmosphere away from radiative equilibrium [Lindzen, 1981; Holton, 1982; Matsuno, 1982]. However, we has not completely known the quantification of gravity wave roles in the middle atmospheric circulation. In particular, it has not been found that the quantification of gravity waves generated from convection (e.g. polar night jet). A Rayleigh/Raman lidar was installed in January 2011 at Syowa station, Antarctica (69S, 40E). It has measured temperature profiled between approximately 8 and 70 km for more than 850 nights (before the end of October in 2014).

We have analyzed the lidar data based on Duck et al. (2001) and Alexander et al. (2011). However, their analysis has a problem. They estimated gravity waves' temperature amplitude to be the value (T') that is difference between background temperature and atmospheric temperature. Their analysis may underestimate the potential energy (Ep) due to not consider the phase. To solve the above problem, we calculated the value (T_h') delaying 90 degree from T' phase to perform Hilbert transformation on T′ weighted by the square root of density, and defined gravity waves' temperature amplitude as $((T')^2+(T_h')^2)^{1/2}$. In this presentation, our analysis will be explained in detail.

Keywords: Stratsphere, Mesosphere, Middle atmosphere, gravity wave, Antarctica, Lidar

Japan Geoscience Union Meeting 2015
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Measurements of Fe and Ca+ temperatures using by a frequency-tunable lidar

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We are developing a new resonance scattering lidar system to be installed at Syowa Station (69S, 39E) in Antarctica. For the new lidar system, we have employed a tunable alexandrite laser covering the resonance scattering lines of two neutral species, which are atomic potassium (K, 770 nm) and atomic iron (Fe, 386 nm), and two ion species, which are calcium ion (Ca^+, 393 nm) and aurorally excited nitrogen ion ($N2^+$, 390 nm, 391 nm). Thus the new lidar system will provide information on the mesosphere and lower thermosphere as well as the ionosphere. Using the new resonance scattering lidar together with colocated other instruments, we will conduct a comprehensive ground-based observation of the low, middle, and upper atmosphere above Syowa Station. This unique observation is expected to make important contribution to studies on the atmospheric vertical coupling process and the neutral and charged particle interaction.

In this presentation, we will report current status on test observations of the iron atom layer at National Institute of Polar Research (NIPR) at Tachikawa, Japan (36N, 139E). In order to obtain the iron resonance line at 386 nm, we operate the fundamental laser (i.e. the tuneable alexandrite laser) at 772 nm, which is shifted by 2 nm from the potassium resonance line at 770 nm, and then obtain the pulsed 386 nm laser using nonlinear crystal based on the second harmonic generation (SHG) technique. On 14 August 2013, we successfully detected first signals from the iron atom layer, with one-frequency mode for Fe number density measurement. The observed iron number density would be fairly comparable to that from the previous observations at Illinois (40N, 88W). After that, we have prepared three-frequency mode for Doppler temperature measurements. Based on a theoretical calculation, we have determined good combination of the three laser frequencies to minimize the temperature error, and then performed operations of the three-frequency mode on 5 and 18 Augsut 2014. The obtained temperature data will be compared with those from NRLMSISE-00 model and satellite observations. Furthermore, we will show a challenge of observing Ca^+ temperature.

Keywords: Resonance scattering lidar, Mesosphere/Lower thermosphere, Ionospheric D/E region, Neutral temperature, Ion temperature

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Report of the STEL optical observation at the Tromsoe EISCAT radar site by March 2015

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Solar-Terrestrial Environment Laboratory (STEL) has been operating various kinds of optical instruments for more than 10 years at the Tromsϕ EISCAT (European Incoherent Scatter) radar site in Norway (69.6^{o}N, 19.2^{o}E), which is one of the state-of-art observatories at high latitudes. Five instruments are now in automatic operation regularly from October to March: (1) three-wavelength photometer (427.8 nm, 630.0 nm, and 557.7 nm), which is fixed to look along the magnetic field line, (2) digital camera for monitoring weather and aurora, (3) proton all-sky camera (486.1 nm), (4) multi-wavelength all-sky camera (557.7 nm, 630.0 nm, OH band, 589.3 nm, 572.5 nm, and 732.0 nm), and (5) Fabry-Perot interferometer (557.7 nm, 630.0 nm, and 732.0 nm). The quick looks are available on the web at www.stelab.nagoya-u.ac.jp/~eiscat/data/EISCAT.html. These instruments are programmatically operated, and they have contributed to many campaign observations with the EISCAT radars, rockets, satellites, and other ground-based instruments by adjusting the observation mode.

Keywords: aurora, air glow, optical instrument, ionosphere, thermosphere, polar region

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Observation of GNSS scintillation in Tromso

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Ionospheric scintillation is a phenomenon that received radio wave fluctuates in phase and amplitude. It has been known that amplitude scintillation frequently occurs at equatorial regions, and that phase scintillation frequently occurs at high latitudes. We have been operating dual-frequency GNSS (Global Navigation Satellite System) receivers at Tromsoe, Norway. The receivers are controlled by PC and record carrier phase and signal-to-noise ratio of the received signal from GPS satellites. We have calculated S4 and $\sigma\phi$ indices. S4 is defined as a ratio of standard deviation of the signal intensity to the average signal intensity in each 1 minute. $\sigma\phi$is defined as the standard deviation of the phase of the received signal. During November and December 2013, in 12 days, we observed amplitude scintillation events in which S4 exceeds 0.3.In 7 days out of 5 days, magnetic activity was high. In this study, we will compare the amplitude scintillation with phase scintillation and total electron content (TEC) obtained from the GNSS receivers to discuss generation mechanisms of ionospheric irregularities causing the amplitude scintillations.

Keywords: scintillation, ionosphere, GPS, GNSS, geomagnetic disturbance, TEC

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Statistical analysis of Medium-Scale Traveling Ionospheric Disturbances using a GPS network at high-latitudes

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In our previous study, using global positioning system (GPS) data taken from more than 100 GPS receivers in Alaska in 2012, we investigated two-dimensional maps of total electron content (TEC) perturbations with a time resolution of 30s and a spatial resolution of 0.15○×0.15○ in longitude and latitude to examine statistical characteristics of Medium-Scale Traveling Ionospheric Disturbances (MSTIDs) for the first time. From the statistical analysis of the TEC maps obtained in 2012, we have revealed some of the characteristics of MSTIDs in Alaska. MSTIDs over Alaska frequently occur in winter from 8 to 20 LT. Maximum occurrence rate of the MSTIDs in monthly and hourly bins exceeds 50%. Propagation direction of MSTIDs is dominantly southward or southeastward from 8 to 14 LT and southwestward from 14 to 20 LT.

In this study, we focus on the statistical result of propagation direction. Southward or southeastward propagating MSTIDs is consistent with that of MSTIDs at mid-latitudes and could be caused by atmospheric gravity waves (AGW) in the thermosphere. The southwestward propagating MSTIDs have been observed with all-sky airglow imager in Alaska, and are considered to be attributed to AGW generated by auroral activity. The present study shows that the southwestward propagating MSTIDs appear before sunset when the airglow observations can be carried out.

In this presentation, we show that statistical characteristics of parameters of MSTIDs, such as period, horizontal wave length, and propagation velocity, and discuss possibility of TEC perturbation caused by AGW propagation excited by auroral activity. Also, we investigate propagation direction of MSTIDs more detail using GPS data taken from GPS receiver networks in northern Europe in 2008 and discuss whether southwestward propagating MSTID is common phenomenon at high-latitudes.

Keywords: Medium-Scale Traveling Ionospheric Disturbances, GPS, auroral activity

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Statistical study of longitude dependencies of MSTIDs observed with GPS networks

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We revealed statistical characteristics of medium-scale traveling ionospheric disturbance (MSTID) by using global positioning system (GPS) networks in North America and compared them with previous studies.

TEC (Total Electron Content) is obtained from delays of radio wave transmitted GPS satellites to the receivers. Using two-dimensional maps of TEC perturbations, for the first time, we statistically analyzed MSTID above North America in 2013. The observed characteristics can be summarized as follows:

1. The occurrence rate of MSTID above North America during daytime (0800LT-2000LT) is high in winter (November-March) and its propagation direction is predominantly south-eastward. This seasonal variation of daytime MSTID occurrence rate is consistent with that reported by earlier publications. The daytime MSTID could be caused by gravity waves.

2. The occurrence rate of MSTID during nighttime (2200LT-0600LT) is high in summer (May-August) and its propagation direction is predominantly south-westward. This feature is consistent with that reported in earlier studies. Perkins instability could play an important role in generating the nighttime MSTID.

3. The occurrence rate of morning MSTID is high throughout the year. Its propagation direction is predominantly eastward and the gravity waves generated by terminator could account for this type of MSTID.

4. The occurrence rate of MSTID above the west part of North America is 20 percent higher than that above the east part in summer (May-June).The pervious paper shows that occurrence rate of ES layer in west part of North America is higher than that in east part, on the basis of occultation observations using low orbit satellite. Our statistical result suggests that the coupling process between E and F regions could play an important role for generating MSTIDs.

Keywords: MSTID, GPS, sporadic E layer, longitude dependencies