

## Meridional movement of northern and southern EIA in the East-Asia sector during 2002-2003 SSW

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This presentation investigates the asymmetrical variability of the location of the north and the south equatorial ionization anomaly (EIA) crests in the East-Asian sector, along with their association with simultaneous observations of equatorial electrojet (EEJ) strength, geomagnetic activity index, and solar flux index during the 2002–2003 sudden stratospheric warming (SSW) event. Analysis of these observations indicates the existence of a large-scale quasi 16-day periodic meridional movement in both EIA crests, and also reveals a strong correlation between the quasi 16-day oscillation in geomagnetic latitudes of the EIA crest and EEJ strength. The latitude of the northern/southern EIA crest and the EEJ strength indicate that obvious synchronous periodic oscillations were in-phase in the northern and southern hemisphere when the SSW occurred. In addition, it is also found that both the EIA crest location and amplitude of the periodic movement of the EIA locations exhibit hemispheric asymmetry. The amplitude of the periodic movement of the EIA location in the southern hemisphere is larger than that of the northern hemisphere, and the southern EIA crest is further off from the equator than the north one. Understanding these asymmetries requires a combination of mechanisms that involve at least trans-equator meridional winds and the position of a sub-solar point; however, potential disturbances in neutral winds associated with the SSW may additionally complicate the equatorial ionospheric dynamics.

Keywords: equatorial ionization anomaly, sudden stratospheric warming, ionosphere

## Vertical structures of stratospheric and mesospheric temperature changes during sudden stratospheric warming in northern high latitude

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We analyze the temperatures obtained from Fourier Transform Spectrometer (FTS) and Micro Limb Sounder (MLS) onboard Aura satellite for two major SSW occurred in Jan. 2006 and Jan. 2009 in order to investigate the vertical structures of the stratospheric and mesospheric temperature changes with SSW phase. For our purpose, we divide wintertime into three periods and compute the height profiles of the correlation coefficients between daily MLS temperature anomalies of 45 height levels and about 33 km height, which can be thought to represent the stratospheric variability, using the mean value averaged over 65°N latitude. Our results showed that there seem to be a relatively weak and broad negative correlation between temperature anomaly at about 33 km height and temperature anomalies in mesosphere during pre-SSW, while this pattern seems to become stronger negative correlation during main phase. In addition, during the recovery phase, it seems to be shallower within the altitude range between about 40 and 80 km with strong positive correlation in the altitude range above about 80 km. We compare the results from observation with those from WACCM simulation and also investigate ozone variability in stratosphere during the recovery phase of major SSW. Preliminary results and some discussions will be presented.

Keywords: Stratospheric and mesospheric temperatures, Vertical profiles of correlation btw. stratosphere and mesosphere, Mesospheric cooling during SSW

# Ionospheric E-region Plasma Irregularities Measured by Space Plasma Sensor Package Onboard Sounding Rocket IX

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Space Plasma Sensor Package (SPSP) onboard Sounding Rocket IX was successfully launched from the south of Taiwan at 21:34 National Standard Time on 26 March 2014. It consists of a plasma impedance probe to measure electron density, a retarding potential analyzer (RPA) to measure ion temperature, an ion trap/ion drift meter/ion trap (IT/IDM) to measure ion currents and arrival angles, and a planar Langmuir probe to measure electron temperature. The RPA and IT/IDM are fabricated with high optical transparent electro-formed bonded gold meshes (100 LPI mesh density and 0.5 mil mesh thickness) in grid construction to minimize quasi-hysteresis effect. The two ion sensors are used as a pre-flight test of Advanced Ionospheric Probe for FORMOSAT-5 satellite scheduled to launch in 2017Q2. In the laboratory test, the current-voltage (I-V) curves measured by the SPSP indicate that PLP and RPA are almost free from contamination. In the flight test, all the sensors work well and meet design goals. During the up-leg path, nighttime E region is detected around 91-109 km altitude by IT/IDM and confirmed by the other sensors, RPA and PLP. An Es-layer is also found between 100 and 103 km altitude with peak at 101.6 km altitude. During the down-leg path, IT/IDM also detects the E region structure but cannot verify if the Es-layer exists due to weak current readings. It is noted that the preliminary geophysical parameters are derived without attitude calibration. The  $N_i$ ,  $V_i$ ,  $T_i$ , and  $T_e$  will be further calibrated according to attitude information from an onboard 3-axial fiber optical gyroscope and normalization on the I-V curves.

Keywords: Space Plasma Sensor Package, Sounding Rocket IX, Advanced Ionospheric Probe

## Vertical velocity of acoustic wave detected with GNSS total electron content

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Acoustic waves are generated by the ground and sea surface motion after large earthquakes. The acoustic waves reach upper atmosphere and disturb plasma in the ionosphere through collision with neutral atmosphere. The ionospheric disturbance are observed ionospheric observation such as ionosonde and GNSS total electron content (TEC). Using dense GNSS network, the ionospheric disturbance associated with the earthquakes (co-seismic ionospheric disturbance, CID) has been investigated. Several type of traveling ionospheric disturbances are often observed. The one is associated with acoustic wave generated at the epicenter/tsunami source area. The velocity of the disturbance around 1 km/s. The other is associated with Ryle wave whose velocity is around 3 km/s. Further, localized ionospheric depletion (ionospheric hall) is observed after the earthquakes accompanied with tsunami. Since the center location of the ionospheric hall are located at the place of maximum vertical displacement, namely tsunami source area, it is concluded that the ionospheric hall is created by acoustic wave generated at the tsunami source area. Therefore, it is a quite plausible conclusion that the source of CID is generated at the maximum vertical displacement. Similar result is also obtained in the CIDs after Nepal earthquake occurred on 25 April 2015. The CIDs are mainly observed over the maximum vertical displacement located at east side of the epicenter. The result indicates that the conclusion is valid for not only submarine earthquake inducing tsunami but also inland earthquake. However, ambiguity of the location of the CID still exists because sub-ionospheric point is located at away from (close to) the sensor when the ionospheric layer is assumed at higher (lower) altitude. Therefore, the location of generation of acoustic wave has not been confirmed enough.

The CIDs are also observed after the foreshock of Tohoku earthquake occurred on 9 March 2011. In this case, initial point of CID were observed by using the signal of 3 GPS satellites. When estimation of the center of the CID is performed with triangulation using 3 satellites data, it is possible that accurate location of the center of the CID is estimated. Further, we found altitude difference of the estimated altitude of the disturbance from the results. From the result, vertical velocity of the acoustic wave is estimated at 1.03 km/s. These results suggest that using GNSS TEC is effective tool to estimate the location of maximum vertical displacement and vertical velocity of the acoustic wave.

キーワード：全電子数、音波、東北地震、地震後の電離圏擾乱、熱圏

Keywords: Total electron content, acoustic wave, Tohoku earthquake, co-seismic ionospheric disturbance, thermosphere

## Evidence for Dynamical Coupling of Stratosphere-Mesosphere and Lower thermosphere (MLT) during 2010 minor Stratospheric Warming in Southern Hemisphere

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The coupling between stratosphere and mesosphere-lower thermosphere (MLT) was studied in the southern hemisphere (SH) during 2010 minor sudden stratospheric warmings (SSW). Three episodic SSWs were noticed from early August to late October in ECMWF data and the specified dynamics-Whole Atmosphere Community Climate Model (SD-WACCM) simulations. Utilizing wind data measured by a meteor radar at King Sejong Station (62.22°S, 58.78°W), we find that the mesospheric zonal winds at 82 km significantly differ from those of normal years due to enhanced planetary wave (PW) activity before the SSWs and secondary PWs in the mesosphere afterwards. The zonal winds in the mesosphere reversed approximately a week before the SSW occurrence in the stratosphere as has been observed in 2002 major SSW. The Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy (GAIA) simulates similar zonal wind reversal that occurred in the lower thermosphere at 100-140 km two or three days before the associated SSW event. Since the periods of minor SSWs are characterized by low solar and geomagnetic activity, the observed and simulated variability in the MLT region is mainly due to SSW. We also find signatures of mesospheric cooling in association with SSWs using the Microwave Limb Sounder (MLS) measurements. However, according to the GAIA simulations, warming instead of cooling took place in the lower thermosphere around 120- 140 km after few days of SSW event. Thus, the observation and model simulation indicate for the first time that the minor SSW also affects dynamics of the MLT region over SH in the same way as the major SSW.

Keywords: Sudden Stratospheric Warming (SSW), Mesosphere and Lower Thermosphere, Meteor Radar, Stratosphere-MLT Coupling, GAIA simulations, MLT dynamics

## 北海道陸別観測所の大気光画像を用いた中間圏・電離圏波動の水平速度分布の長期統計解析

### Long-term statistical analysis of horizontal phase velocity distribution of mesosphere and ionosphere waves in airglow images at Rikubetsu and Shigaraki, Japan

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Atmospheric gravity waves (AGWs) transport momentum from the troposphere into the mesosphere and the thermosphere. The momentum deposit through wave breaking causes the large-scale pole-to-pole circulation. The vertical propagation of AGWs depends on the horizontal phase velocity. Thus, investigation of the horizontal phase-velocity characteristics of AGWs helps us to understand the dynamical variation of middle and upper atmosphere. On the other hand, the propagation direction of medium-scale traveling ionospheric disturbances (MSTIDs) seems to be different at different latitudes. However, the cause which determines their propagation direction has not been understood.

A new spectral analysis method has been developed to obtain power spectra in the horizontal phase velocity by using the 3-D FFT technique [Matsuda et al., JGR, 2014]. Takeo et al. (submitted to JGR, 2017) studied horizontal parameters of AGWs and MSTIDs over 16 years by using airglow images at wavelengths of 557.7 nm (emission altitude: 90-100 km) and 630.0-nm (200-300 km) obtained at Shigaraki, Japan (34.8N, 136.1E) which is located at the middle part of Japan.

In this study, we have applied the same spectral analysis technique to the 557.7-nm and 630.0-nm airglow images obtained at Rikubetsu, Japan (43.5N, 143.8E), which is at the northern edge of Japan, for 16 years from 1999 to 2014. We examined similarities and differences of horizontal wave spectra between Shigaraki and Rikubetsu over 16 years to see their dependence on locations.

The propagation direction of AGWs is northeastward in summer and southwestward in winter at both Shigaraki and Rikubetsu, but yearly variation of power spectral density is different between these two stations. In summer, the propagation direction of AGWs is northeastward irrespective of the phase velocity, probably due to wind filtering of these waves by the mesospheric jet. However, in winter, low phase-velocity waves (20-100 m/s) propagate to southwest, but high phase-velocity waves (100-150 m/s) propagate to southeast at both Shigaraki and Rikubetsu, suggesting reflection of westward high-velocity waves at both stations by the mesospheric jet. For MSTIDs, there is a negative correlation between yearly variation of powers spectral density and F10.7 flux at both sites. Propagation direction is southwestward in all season at both Shigaraki and Rikubetsu. The sub-peak at northeastward MSTIDs is larger in Rikubetsu than in Shigaraki. This may suggest latitudinal dependence of northeastward-moving MSTIDs, though further analysis will be needed for data at different stations.

キーワード：大気重力波、中規模伝搬性電離圏擾乱、スペクトル解析  
Keywords: AGWs, MSTIDs, spectral analysis

## Study of interannual gravity wave in the middle atmosphere over Syowa using Rayleigh/Raman lidar

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Gravity waves have important roles in transporting energy and momentum between the lower and upper atmosphere [Lindzen, 1981; Holton, 1982; Matsuno, 1982]. Their momentum deposition induces a meridional circulation from the summer pole to the winter pole, and the circulation makes the stratospheric temperature distribution in summer and winter away from radiative equilibrium. However, we have not completely known the quantification of gravity wave roles in the middle atmospheric circulation, especially Antarctic. A Rayleigh/Raman (RR) lidar was installed in January 2011 at Syowa Station, Antarctica (69°S, 40°E). The lidar has measured temperature profiles between 10 and 80 km since February 2011.

In this study, we investigated monthly mean gravity wave potential energy ( $Ep$ ) in the height range of 15-70 km from May 2011 to October 2015 except for November, December and January. The number of nights used for this analysis is 360 nights in five years. Above 30km altitude,  $Ep$  was maximized during winter in the each year. The seasonal dependence of  $Ep$  over Syowa was similar to  $Ep$  over Davis (69°S, 79°E) [Alexander et al., 2011; Kaifler et al., 2014] and McMurdo (78°S, 167°E) [Lu et al., 2015]. We also investigated the interannual variation of  $Ep$  in each year, and the variation was  $\pm 40\%$ . However, the  $Ep$  in August of 2014 was 3 times larger than that in August of the other years above 40 km altitude. We also compared the  $Ep$  with the location of the polar night jet according to Nash et al. [1996]. The comparison shows that the polar night jet existed over Syowa in August of 2014 and suggests that GWs from the polar vortex could contribute to  $Ep$  in August of 2014.

In this presentation, we will discuss the interannual variation of  $Ep$  and the contribution of the polar night jet.

キーワード：中層大気、ライダー、重力波、南極域

Keywords: middle atmosphere, lidar, gravity wave, Antarctic



## Daytime ionospheric longitudinal gradients seen in the observations from a regional BeiDou GEO receiver network

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Many studies have devoted to the longitudinal variations of the ionosphere globally. However, the ionospheric longitudinal variations in a small region are rarely reported. In this paper, we use the TEC data from a BeiDou geostationary orbit (GEO) receiver network to investigate ionospheric longitudinal variations within the zonal scale of 1000 km in China. The BeiDou GEO TECs provide a good dataset to study longitudinal variations, compared with non-GEO TEC, without contaminating the spatial variations and elevation change due to satellite motion. Pronounced daytime longitudinal gradients within the distance of 1000 km are present in BeiDou GEO TEC observations. It was found that the TEC is larger in the west than in the east. In some cases, the TEC gradient magnitudes are larger than 20 TECU. For most events, the obvious daytime longitudinal gradients occurred under the weak and moderate geomagnetic activity conditions. In addition, daytime longitudinal gradients are mostly accompanied by TEC enhancement. We suggest that the observed daytime longitudinal gradients are probably associated with the electric field disturbances.

Keywords: ionospheric longitudinal gradients, BeiDou GEO TEC, small region, small region

## Seasonal and spatial variation of He<sup>+</sup> column density in the evening topside ionosphere observed by ISS-IMAP/EUVI

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The seasonal, longitudinal and latitudinal variations of He<sup>+</sup> distribution in the evening topside ionosphere in 2013 - 2015 are elucidated with data of He<sup>+</sup> resonant scattering obtained by Extreme Ultra Violet Imager (EUVI) onboard the International Space Station (ISS). EUVI provides a data set of the column density of He<sup>+</sup> in the topside ionosphere. The data set provides a unique opportunity to study He<sup>+</sup> distribution in the topside ionosphere from a different perspective of past studies using in-situ measurement data. During the solstice seasons, an enhancement of He<sup>+</sup> column density in the winter hemisphere is observed. The magnitude of this hemispheric asymmetry shows a longitudinal variability. Around the June solstice, the hemispheric asymmetry was greater in the longitude sector where the geomagnetic declination angle is negative and smaller in the longitude sector where the geomagnetic declination angle is positive. Around the December solstice, on the other hand, this longitudinal variation of the asymmetry magnitude had opposite tendency. The hemispheric asymmetry of the effective neutral wind well explains this behavior of He<sup>+</sup>. The field-aligned component of neutral wind in the F-region is varied in longitude under the presence of finite geomagnetic declination angle and large zonal wind. We examined the seasonal and longitudinal variation of the effective wind with HWM14 model. In the equinox seasons, two longitudinal maxima were observed at around 140°E and 30°E. The longitudinal variation of the effective neutral wind is a candidate of these two maxima of He<sup>+</sup> concentration. These results suggest that the transport of ions in the topside ionosphere is strongly affected by the *F*-region neutral wind.

## *Fine Structure Interactions with Gravity Waves in the Mesosphere and Lower Thermosphere*

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An anelastic numerical model is used to characterize the influences of fine layer structures on gravity wave propagation in the Mesosphere and Lower Thermosphere (MLT). Recent lidar observations identify persistent layering structures in the MLT that have sharp stratification and vertical scales below 1 km. Gravity waves propagating through finely layered environments can trigger the evolution of small scale instabilities that significantly enhance the layering in these regions. Such layers in turn promote ducting or reflection, hasten the onset of self-acceleration dynamics, encourage wave/mean-flow interactions, and filter the outgoing wave spectra, defining the wave's influence as it propagates to higher altitudes. Using high resolution simulations of a localized gravity wave packet in a deep atmosphere, we identify the impacts of various wave and mean flow parameters to determine the major mechanisms driving these dynamics and complement recent state-of-the-art observations.

Keywords: Gravity Wave, Wave Mean-Flow Interactions, Mesosphere and Lower Thermosphere

## What Drives the Electrodynamics of the Low-Latitude Evening Ionosphere?

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Neutral and plasma dynamics are strongly coupled in the F region. In the low-latitude evening ionosphere an eastward neutral wind is accelerated by a strong eastward horizontal pressure gradient force that is incompletely balanced by ion drag and viscosity. Plasma convection is driven mainly by the zonal neutral wind in the lower Equatorial Ionization Anomaly (EIA) region, balanced by ion-neutral collisions in the E and lower F regions. Increased night-time E-region conductivity retards both ion convection and neutral winds in the F region. Unless the E-region night-time conductivity is large, the accelerating eastward ion convection draws plasma up from lower apex heights, producing the equatorial F-region pre-reversal enhancement of vertical ion drift.

## On the Relation between Sporadic-E and ENSO Observed by FORMOSAT-3/COSMIC

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In recent years, many studies have shown evidence for several types of atmosphere-ionosphere coupling. In this study, we show the possible relation between Sporadic-E (Es) and El Nino-Southern Oscillation (ENSO) by using the FORMOSAT-3/COSMIC S4 scintillation index and tropopause height from 2007 to 2014. The long-term variation of the monthly global median S4 index in the E-region shows similar trend to ENSO, suggest that Es may be related to ENSO. The wavelet analysis may help us to verify the similar trend between scintillation and ENSO, but the mechanism of this coupling phenomenon still needs to be discussed and further explored.

Keywords: Sporadic E, ENSO, Tides

## D-region oscillations of LF transmitter signals after the 2011 Off the Pacific Coast of Tohoku Earthquake

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Although a lot of studies for the F-region ionosphere associated with earthquakes have been reported so far, few studies for the D-region ionosphere have reported. It is difficult to observe the D-region electron density by MF/HF radio sounding method such ionosondes, because the MF radio waves are highly attenuated in daytime D-region, and HF radio waves penetrate into the D-region in both night and day. In this study, we investigate the D-region variations associated with the 2011 off the Pacific coast of Tohoku Earthquake (Magnitude 9.0) using intensity and phase of LF transmitter signals. The reflection height corresponds to electron density in the D-region. The propagation paths are Saga -Rikubetsu (RKB) over Japan and BPC (China)-RKB (Japan). As a result, there were two kinds of oscillations over both propagation paths after the mainshock: one was clear oscillations of the intensity with a period of about 100 s observed about 6 minutes after the mainshock, and the other was 30-90 s oscillations of the intensity and phase about 17 minutes after the mainshock. The one-to-one correspondence between the intensity and reflection height was not seen clearly. The changes of the intensity and reflection height for the oscillations were about 0.1 dB and 50 - 65 m, respectively. The time difference between the earthquake onset and the 100 s-oscillations was consistent with the propagation time of the Rayleigh waves (seismic waves) propagating from the epicenter to the LF propagation paths along the Earth surface, plus the propagation time of acoustic waves propagating from the ground to 68 km altitude vertically based on neutral atmosphere simulation. Thus, the LF oscillations may be caused by the acoustic waves excited by the Rayleigh waves. In the presentation, we will discuss the amount of change in the LF oscillations in more detail.

## Ground-satellite conjugate observations of daytime traveling ionospheric disturbances by the GPS-TEC network and the CHAMP satellite over Japan: Preliminary results

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We report preliminary results of ground-satellite measurements of daytime traveling ionospheric disturbances (TIDs) over Japan by using the GEONET GPS receiver network and the CHAMP satellite. We use GPS measurements of TEC (Total Electron Content) and neutral and electron densities measured by CHAMP satellite for the years 2002 and 2008. A total of twenty-five TID events with ground-satellite conjugate measurements are found. On 2002, conjugate events are observed in January, 1 event, and February, 4 events. On 2008, twenty events are observed around winter months (January (3 events), February (5), March (1), October (3), November (5), and December (3)). For all events, there are clear southward moving structures in the GPS-TEC measurements. For all events neutral and electron densities measured by CHAMP show quasi-periodic fluctuations throughout the passages. The CHAMP satellite crossed at least one clear TID phase front for all the events. We observed corresponding phase relationships between total electron content (GPS-TEC) and neutral and electron densities measured by CHAMP. We categorized events into three categories; out-of-phase, in-phase and changing phase. In the presentation, we report correspondence of these TID structures seen in the ground TEC and CHAMP electron and neutral densities and discuss their phase relationship to identify the source of the daytime TIDs at middle latitudes.

Keywords: Daytime Traveling Ionospheric disturbances (TIDs) observed at mid-latitudes, Total Electron Content by using GPS satellite (GPS-TEC) and CHAMP satellite conjugate observations, TIDs caused by gravity waves in the neutral atmosphere

# 全球TECデータに基づく磁気嵐時の電離圏・プラズマ圏構造の時空間変動 Temporal and spatial variations of the ionosphere and plasmasphere during geomagnetic storms on the basis of global Total Electron Content (TEC) data analysis

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It has been well-known that the global structures of the ionosphere and plasmasphere are drastically changed during the main and recovery phases of geomagnetic storms. These variations represent a complex response of the ionosphere-thermosphere-plasmasphere system to geomagnetic disturbances. Previous studies showed (1) a large enhancement of Total Electron Content (TEC) in the equatorial and middle-latitude regions within a few hours during a severe geomagnetic storm [e.g., Mannucci et al., 2005], (2) formation of storm-enhanced electron density (SED) extending from middle to high latitudes [e.g., Foster, 2013], and (3) physical process of SED formation and variation of the equatorial ionosphere on the basis of global SAMI3-Rice Convection Model (RCM) simulation [Huba and Sazykin, 2014]. However, these studies did not investigate detailed temporal and spatial variations of the ionosphere and plasmasphere with high time resolution during the main and recovery phases of geomagnetic storms using global TEC data. In this study, we clarify the temporal and spatial variations of the ionosphere and plasmasphere associated with development and decay of the geomagnetic storm occurred on October 11-12, 2010, on the basis of global TEC data obtained from Global Navigation Satellite System (GNSS) data. Moreover, we investigate the temporal and spatial variations of the plasmopause location from identification of ionospheric trough region from the latitudinal distribution of TEC. In this analysis, we used the geomagnetic Kp and SYM-H indices and global TEC data, and the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) data analysis tool [Tanaka et al., 2013]. These data are provided by World Data Center for Geomagnetism, Kyoto University, and Dense Regional And Worldwide INternational GNSS-TEC observation (DRAWING-TEC) project, NICT [Tsugawa et al., 2007], respectively. We first produced a global distribution of the 5-day quiet-time average TEC in a month of the investigated storm event. Here, we identified the 5 quiet days as a summation of the Kp index in each month. As a next step, we created a global map of difference of TEC (d-TEC) in between the storm-time and quiet-time periods, and investigated the global variation of the d-TEC during the main and recovery phases of the geomagnetic storm. During the pre-storm and initial phase of the geomagnetic storm, the d-TEC showed a small variation with the amplitude of less than 3 TECU for geographical latitude and longitude except for the equatorial and low-latitude (< 30 degrees, GMLAT: geomagnetic latitude). The spatial distribution of d-TEC did not almost change during this period. After the sudden commencement identified as a step-like increase of the SYM-H index, the d-TEC value began to increase in the middle-low latitudes (30-55 degrees) of the morning sector (9-10 h, LT: local time). As the geomagnetic storm is developed, the enhanced d-TEC region expanded to the afternoon sector (15 h, LT) within 4-5 hours. Moreover, 4 hours after the start of the main phase, the ionospheric trough region where the d-TEC value decreases significantly appeared in the afternoon sector (14 -17 h, LT), and the location moved equatorward (67 to 54 degrees, GMLAT) associated with the development of the geomagnetic storm. This indicates that the plasmopause moves earthward in association with an intensification of convection



electric field. On the other hand, in the high-latitude region ( $> 60$  degrees, GMLAT) of the morning sector (10-11 h, LT), a plume-like structure of d-TEC appeared, which corresponds to the SED phenomenon. The ionospheric trough and SED disappeared within 1 hour after the start of the recovery phase of the geomagnetic storm. The disappearance of these phenomena suggests that the SAPS/SAID activity and convection electric field decrease associated with the recovery phase of the geomagnetic storm.

キーワード：磁気嵐、全電子数 (TEC)、電離圏-プラズマ圏、電離圏電場、電離圏トラフ、プラズマ圏界面  
Keywords: Geomagnetic storm, Total Electron Content (TEC), Ionosphere-Plasmasphere, Ionospheric electric field, Ionospheric trough, Plasmapause

## SMILES-2 ミッション, 成層圏・中間圏・下部熱圏の衛星による観測計画 SMILES-2 mission, planned spaceborne observation of the stratosphere, mesosphere and lower thermosphere

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Spaceborne submillimeter-wave limb observation has a great advantage of measuring throughout the whole atmosphere from the stratosphere to the lower thermosphere with a single measurement technique. The variousness of atmospheric parameters to be observed, their precision, accuracy, and resolution are depends on the performance of submillimeter-wave receiver and antenna, which are the main components of submillimeter-wave limb sounding instrument, The SMILES-2 mission, which is a proposed spaceborne submillimeter-wave limb sounding mission proposed by our group, will be equipped with a highly-sensitive superconducting receiver and 1 m-class large aperture antennas. If the SMILES-2 mission is realized in full specifications, we expect the various observations to become possible. Temperature will be measured in a precision better than 1 K with a vertical resolution of 2-3 km in a height range between 15 and 80 km, in 5 K precision with 3-5 km vertical-resolution in a range between 80 and 120 km, and in 10 K precision with 10 km vertical-resolution in a range between 120 and 160 km. Wind will be measured in a precision better than 5 m/s with a vertical resolution of 2-3 km in a height range between 35 and 90 km, and in 10 m/s precision with 3-5 km resolution in a range between 90 and 160 km [Baron, 2015]. The frequency bands of the SMILES-2 receivers are selected to cover the emission lines from a variety of chemical species, which are important for the science in the stratosphere, mesosphere, and lower thermosphere. The species to be measured include O-atom, OH, O<sub>2</sub>, O<sub>3</sub>, H<sub>2</sub>O, CO, NO, NO<sub>2</sub>, N<sub>2</sub>O, ClO, HCl, HOCl, OClO, BrO, HNO<sub>3</sub>, CH<sub>3</sub>CN, CH<sub>3</sub>Cl [Suzuki, 2015].

The SMILES-2 receiver is a superconducting receiver. The spaceborne superconducting receiver was demonstrated in the successful international-space-station-borne mission, SMILES, in 2009. Comparing with 2 band receiver of SMILES at 624-626 GHz and 649-650 GHz, the SMILES-2 receiver will have many frequency bands, that is 485-489 GHz, 523-527 GHz, 556-558 GHz, 575-577 GHz, 619-627 GHz, 649-657 GHz, 1.8 THz and 2.06 THz. For THz band to observe OH and O-atom, a newly developed HEB mixer will be used. The main reflector of the SMILES-2 antenna will have about 1 m, which is made of CFRP with a reflection surface of aluminum. It is planned to have two antennas. Two antennas will see two directions, ahead and behind aslant, to observe an atmosphere twice from different directions so that the horizontal direction of wind is retrieved.

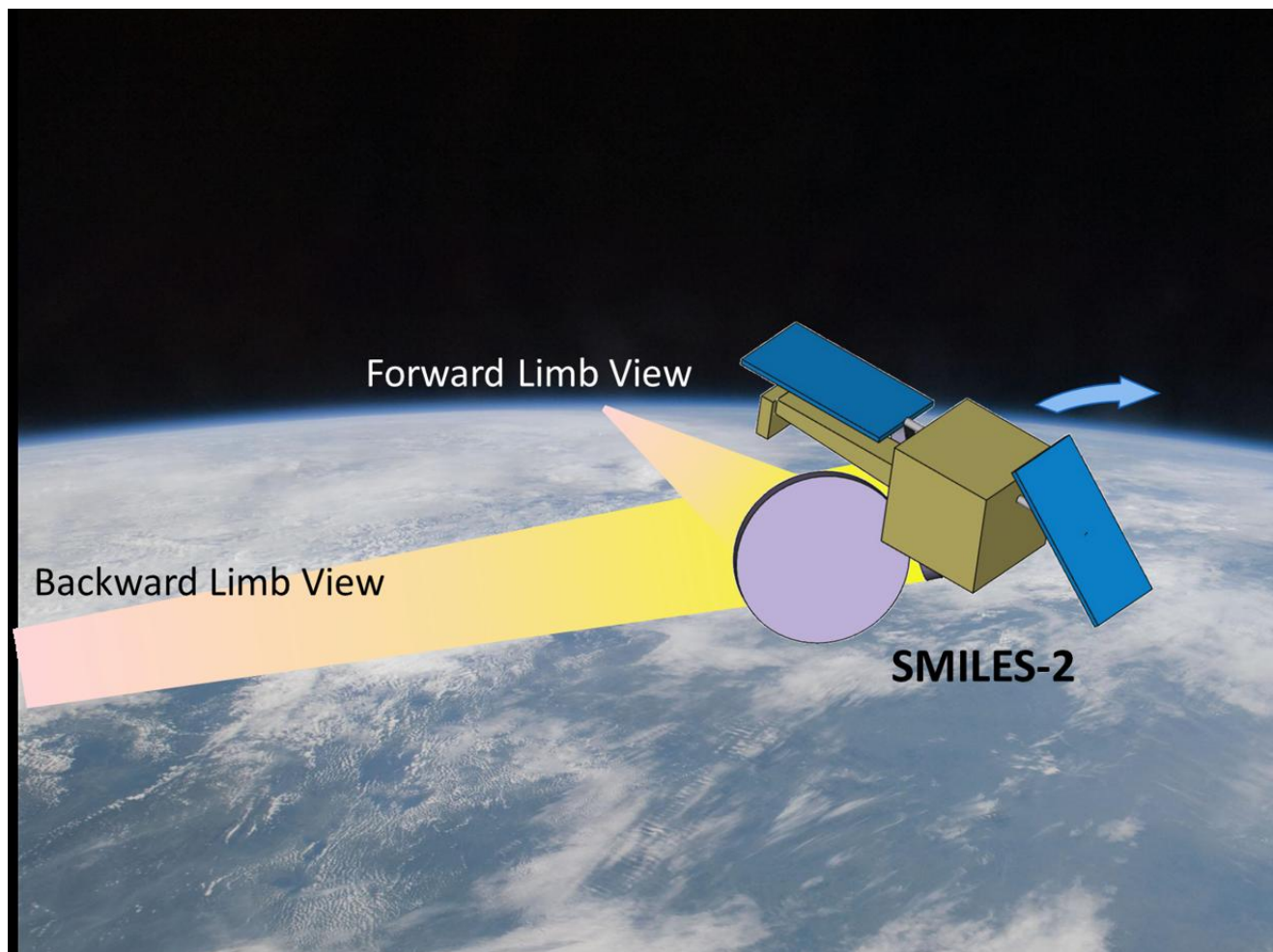
The satellite platform for SMILES-2 is assumed to be the JAXA small-size science satellite, whose weight can be about 700 kg. The satellite orbit is currently assumed to be a height of 550 km and an inclination of 66 degree. The conceptional design of the mission is now studied by SMILES-2 working group. The conceptional design of SMILES-2 will be compiled in the next year or later. If the proposal is selected by JAXA/ISAS, the mission may be launched in 2023 or later.

Baron et al. (2015), Proc. SPIE, 9639, doi: 10.1117/12.2194741.

Suzuki et al. (2015), Proc. SPIE, 9639, doi: 10.1117/12.2194832.

キーワード：衛星観測、中層大気、機器開発、サブミリ波、テラヘルツ、極低温

Keywords: satellite observation, middle atmosphere, instrument development, submillimeter wave, terahertz, cryogenic



## Thermosphere response to doubling CO<sub>2</sub>: simulation results with GAIA model

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Using the whole atmosphere model GAIA, we investigate the influence of doubling CO<sub>2</sub> on the thermosphere. Our results reveal consist cooling in the upper thermosphere as reported in previous work. Furthermore, we find that the cooling effect has distinct spatial and seasonal variation. First, it is stronger in polar regions than at lower latitudes. Second, it is stronger in local summer than in local winter. Third, it is stronger at night than at day. We investigate the mechanism for these variations by examining changes in the global circulation and composition.

キーワード : thermosphere、CO<sub>2</sub>、vertical coupling

Keywords: thermosphere, CO<sub>2</sub>, vertical coupling

## Simulation of LF propagation modulation caused by earthquake by means of wave-hop method

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Fine observation of LF standard frequency and time signals (SFTS) at Rikubetsu, Hokkaido (RKB) detected oscillating structures on the received signal intensity and phase after 2011 Tohoku Earthquake. Electric field at the receiving point is described as vectorial summation of the electric fields due to the ground wave and sky waves. Numerical LF prediction by means of wave-hop method adopted in the Recommendation ITU-R P. 684-6 entitled “Prediction of field strength at frequencies below about 150 kHz” estimates the every component waves in the steady conditions. Only a few dominant mode contributes the total signal strength at the receiver. The electric field deviation of each component wave is obtained by fluctuating the reflection height of the ionospheric reflection point. A little uplift of the reflection height provides increased field strength of the component wave due to decreased ionospheric absorption. However, total electric field at the receiving point depends on phase relations between component waves. Receiving signal fluctuation is simulated as follows: 1. Calculate steady state condition parameters and synthesis all the component waves, then get the field strength at steady state. 2. Modulate each reflection height following to the earthquake perturbation spreading concentrically from epicenter. 3. Recalculate the propagation parameters of the component waves such as the SFTS propagation path length, ionosphere/ground incident angles, and absorption factors under the modified conditions. 4. Finally obtain the fluctuated field strength. Calculated field strength is consistent with the observation under the appropriate condition.

キーワード：長波伝搬、標準電波、波線法、地震波動

Keywords: LF radio wave propagation, Standard frequency and time signals, Wave hop method, Earthquake wave

## Global features of ionospheric slab thickness derived from JPL TEC and COSMIC observations

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The ionospheric equivalent slab thickness (EST), defined as the ratio of total electron content (TEC) to F2-layer peak electron density (NmF2), describing the thickness of the ionospheric profile. In this study, we retrieve EST from Jet Propulsion Laboratory (JPL) TEC data and NmF2 retrieved from Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) ionospheric radio occultation data. The diurnal, seasonal and solar activity variations of global EST are analyzed. During solstices, daytime EST in the summer hemisphere is larger than that in the winter hemisphere, except in some high-latitude regions; and the reverse is true for the nighttime EST. The peaks of EST often appear at 0400 local time. The pre-sunrise enhancement in EST appears in all seasons, while the post-sunset enhancement in EST is not readily observed in equinox. The dependence of EST on solar activity is related to the inconsistent solar activity dependences of electron density at different altitudes. Furthermore, an interesting phenomenon is found that EST is enhanced from 0° to 120° E in longitude and 30° to 75° S in latitude during nighttime, just to the east of Weddell Sea Anomaly, during equinox and southern hemisphere summer.

Keywords: Slab thickness, Global features, COSMIC

## Effect of Kelvin Waves on stratospheric QBO during *El Nino* periods using ECMWF reanalysis data

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35-year long dataset of temperature from ECMWF reanalysis has been analysed to obtain characteristics of Kelvin waves to understand the effect of El Nino Southern Oscillation (ENSO) on the Quasi Biennial Oscillation (QBO). Enhanced Kelvin wave activity is observed during El Nino periods when the phase of the QBO was easterly. Slow waves of wavenumber one and periods greater than 12 days are the most prominent Kelvin waves in the stratosphere during these periods, and showed significant wave-mean flow interactions. Comparison with outgoing longwave radiation (OLR) showed that there is increased convective activity over the Indonesian region and the East Pacific region during these periods of enhanced Kelvin wave activity. However, the rate at which the zero wind line preceding the westerly descended from 10 hPa to 50 hPa was not quite high, as was observed in the case of the 2009/2010 El Nino period. Careful examination showed that, instead of fixing the initial height at 10 hPa, if the slope of the zero wind line was calculated from the height at which the enhanced Kelvin wave activity interacted with the mean flow, the westerly did indeed descend very fast. Thus we conclude that during those El Nino periods when the QBO was easterly, the subsequent westerly showed an anomalous descent. This study emphasizes the importance of wave-mean flow interactions in maintaining the large scale circulation of the Earth's atmosphere.

Keywords: El Nino Southern Oscillation (ENSO), Quasi Biennial Oscillation (QBO)

# Study on the Vertical Wavelength of the Atmospheric Kelvin Waves

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By using a length of 35-years old dataset of temperature from ECMWF re-analysis, the characteristics of the vertical wavelength of Kelvin waves to understand the effect of El Niño Southern Oscillation (ENSO) on the Quasi Biennial Oscillation (QBO) is analyzed. We concluded that the increased vertical wavelength could be the reason for the Kelvin wave not being able to interact with the mean flow. The observations indicated a clear modification in wave properties during the El Niño episode and emphasized the sensitivity of the atmospheric waves to various wave generation processes. An interesting event is the 12-day wave at wavenumber 1 whose vertical wavelength is approximately 10 km throughout the period of study and the phase lines do not 'see' the mean flow. The waves that do not interact with the mean flow must be traveling at higher altitudes. We also analyzed the temperature variation of upper atmospheric data to exam further details and the present study provides information regarding on the long-term morphology of the vertical wavelength.

Keywords: Kelvin Waves, ENSO/QBO, Long-term Morphology



## Reverse Ray Tracing of Mesospheric Gravity Waves over the Antarctic Peninsula

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The majority of studies of atmospheric gravity waves are concerned with waves observed at equatorial and mid latitudes. In the early 2000' s Utah State University and British Antarctic Survey initiated a long term study of these waves over the Antarctica utilizing mesospheric airglow imagers, which has progressed into a comprehensive Antarctic observation network (ANGWIN). A recent long term analysis of gravity wave characteristics from two observation sites: Halley and Rothera, has revealed a distinct difference in predominate propagation directions between the two. Though Halley exhibited propagation directions changing with seasons, Rothera showed a remarkable fixed preference for westward propagating waves. While the waves observed over Rothera revealed freely propagating characteristics in the observed mesospheric region, their source location and origin remains unanswered. In this project we have focused on investigating the propagation of the waves from the observation point to their origin through a simple reverse ray tracing scheme. By analyzing ray tracing trends over two years of data we provide a preliminary overview of propagation characteristics and discuss the impact of orographic generated waves over the Antarctic peninsula.

Keywords: Aeronomy , Gravity Waves, Ray Tracing

# Reverse Ray Tracing of Wintertime Mesospheric Gravity Waves Observed Over Interior Alaska

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While atmospheric gravity waves have been observed and studied in details for decades, there are still many questions to be addressed with respect to their propagation from the lower atmosphere into the mesopause region. Waves generated in the lower atmosphere are capable of transporting energy from their origin to the upper atmosphere as they propagate upward. While these energy transports have been known to impact large-scale circulation in the atmosphere, recent observations and model results have shown they also impact space weather and may play essential roles in climate changes. For the later, climate models often conclude at altitudes well below where we investigate the wave dynamics. New models increasing the top altitude have shown the importance of including the energy budget at these higher altitudes. Therefore, it has become increasingly important to characterize the wave propagation dynamics. A mesospheric airglow camera observed short-period gravity waves during the 2011-2014 winter months over interior Alaska. As an undergraduate research project we have developed a simple reverse ray tracing model to propagate the observed waves downward through the atmosphere to their respective points of origin. Here we present preliminary results of the reverse ray tracing algorithm and discuss propagation characteristics and possible source locations.

Keywords: Aeronomy, Gravity Waves, Ray Tracing

## An automatical method for identification of polar cap boundary and patches by using in situ plasma measurements and its application

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We have developed an automatical method to identify the polar cap boundary (PCB) and polar cap patches by using the in-situ plasma observations. Based on the difference of the typical source regions of the high-energy plasma, this method makes a double-Gaussian-like curve fitting to the integral energy flux with an energy range of 1392eV-30KeV for electrons and 4400eV-30KeV for ions, and then identifies the PCB by determining the poleward boundary of the regions where the energy flux are less than  $\pm 1.5$  times of the variance above the mean fluxes. Finally, we find the patch in the identified polar cap region by seeking the region where the plasma number density are more than twice larger than the average plasma density of the polar cap region. Applying this method, we automatic identified 15486 polar cap boundaries and more than 3000 patches from 2010-2014 passes of the polar region by the Defense Meteorological Satellite Program (DMSP) F16 and F17 satellites. We further differed dayside plasma blobs from patches by using the field-aligned current and precipitation energy flux observations, We Analyzing the in-situ plasma features inside these plasma irregularities and confirmed that rapidly moving patches are clear associated with ion upflow, and find the Poynting flux, associated with frictional heating, plays the dominated role for accelerating the ion upwelling at the center of polar cap region, while the field-aligned current, associated with electron heating, was mainly contributed to ion upflow in the dayside plasma blob.

Keywords: Identification of polar cap boundary from integral ion and electron energy fluxes, ionupflow associated with polar cap patch and dayside plasma blob

# Neutral-ion coupling in the auroral ionosphere during magnetospheric substorms

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At high latitudes, the coupled ionosphere-thermosphere system is highly affected by interactions between the solar wind and the magnetosphere. The magnetospheric energy can be efficiently transferred into the ionosphere during magnetospheric substorms, via electromagnetic energy exchanges and auroral precipitation. Due to substorm energy input, ion-drag force and pressure gradient produced by Joule heating can become dominant forces that control the thermospheric wind. Although a few studies have shown that thermospheric dynamics can be strongly affected by auroral activities, it is still unclear that how the ion-neutral coupling process depends on different substorm phases. In addition, the variation of the thermospheric wind may be affected by the location of the substorm onset in respect to the observation site.

To investigate the questions above, we used measurements from 2009 to 2016 by ground-based instruments installed in northern Scandinavia, including European Incoherent Scatter (EISCAT) radars, Fabry-Perot Interferometer, all-sky cameras, and magnetometers. Those instruments provide an opportunity to measure several ionospheric and thermospheric key parameters such as plasma density, electric field, conductivities, equivalent currents, and the neutral wind. We studied the substorm evolution of thermospheric winds by analyzing individual events and by statistical methods. In the evening sector, the neutral wind has a typical westward acceleration during the substorm growth phase, mainly due to the strong ion-drag force associated with the equatorward motion of the enhanced eastward electrojet. The westward acceleration is terminated at a time close to substorm onset. During the expansion phase, the wind changes from westward to eastward. The transition time from westward to eastward depends on the longitudinal location of the onset. During the evolution, mesoscale disturbances were often observed, which are affected by the local auroral activity. We will discuss the physical mechanisms that cause the wind accelerations by analyzing the relative importance between ion-drag force and Joule heating.

Keywords: ionosphere-thermosphere coupling, substorm, neutral wind, equivalent current, auroral activity

# Vertical and meridional propagations of 6.5DWs in stratosphere-MLT regions observed by satellite

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6.5-day-waves (6.5DWs) are one of the most dominant planetary wave components in mesosphere and the lower thermosphere (MLT) regions, especially during equinoctial seasons. 6.5DWs amplitudes are almost tripled in the lower thermosphere than in stratosphere, and their seasonal variations are different. Are 6.5DWs in MLT propagated from stratosphere, or re-excited in MLT? In this paper, relationships between 6.5DWs in MLT and in stratosphere are analyzed. Firstly, vertical propagation characteristics of 6.5DWs in mid-high latitudes in both hemispheres during spring and autumn seasons are obtained, respectively, based on SABER/TIMED global observations from 2002 to 2016. Then results in the Northern Hemisphere (NH) and the Southern Hemisphere (SH) are compared to obtain inter-hemispheric similarities and discrepancies. Given these results and by utilizing wind data observed by TIDI/TIMED as well, wave-flow interactions through vertical propagations of 6.5DWs are analyzed. We first obtain results from case study, and then draw general conclusions from statistics researches. Previous studies have inferred that 6.5DWs could probably propagate along meridional directions [Liu, et al., 2004, Belova, et al., 2008]. It has been showed that 6.5DWs in MLT regions of one hemisphere may be propagated from stratosphere of the other hemisphere, and their amplitudes could be strengthened in unstable regions along their paths. However, these suggestions need to be proved by more observation evidences. The second part of this paper discusses possible meridional propagations of 6.5DWs based on SABER/TIMED and TIDI/TIMED observations. Results obtained in this paper could be useful in improvement of future atmospheric models of stratosphere-MLT regions.

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Keywords: stratosphere-MLT, planetary waves, satellite observations

## Characteristics of travelling ionospheric disturbances observed by Kharkiv and Millstone Hill radars

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Travelling ionospheric disturbances (TIDs) represent a key dynamic process of energy transfer in horizontal and vertical directions, and one of the important sources of ionospheric variability. Acoustic gravity waves (AGWs) play a key role in coupling of different atmospheric regions through momentum and energy transfer, and TIDs are thought to be the manifestations of AGWs at ionospheric heights. The incoherent scatter method is well suited for TID studies as it enables TIDs detection in multiple ionospheric parameters (electron density, ion and electron temperatures, plasma velocity), and thus provides critical information needed to examine different hypothesis about association of TIDs with their sources.

In 2016, two coordinated measuring campaigns have been held near the vernal equinox and summer solstice using Kharkiv (49.6 N, 36.4 E) and Millstone Hill (42.6 N, 288.5 E) IS radars. The goal of joint observations was to detect TIDs and estimate their characteristics during these geophysical periods as well as to find similarities and differences in results obtained at various longitudes.

During the vernal equinox, the prevailing TIDs are observed near the sunrise and sunset solar terminators by both Kharkiv and Millstone Hill. The TID periods generally fall within the ranges of 40 –80 mins and 20 –40 mins. Relative TID amplitudes over Kharkiv are usually 3–15% and 2–10% of background electron density and plasma temperatures, respectively. At Millstone Hill, these values are greater and reach 10–35% for TIDs in electron density and 5–15% for TIDs in electron and ion temperatures. Larger values of TIDs amplitudes over Millstone Hill may indicate the longitudinal differences.

As for summer solstice, the overall wave activity was weaker. Despite the absence of solar terminators over Kharkiv at the heights above 250 km, TIDs occurred near the periods of terminator passage at lower heights. These results confirm the hypothesis that observed TIDs are caused by AGWs generated in the middle and lower atmosphere and propagating upward. The TIDs over Millstone Hill are mainly observed around solar terminator periods, similarly to the vernal equinox. Prevailing periods for TIDs over Kharkiv and Millstone Hill are of 40 –80 and 20 –40 mins. The values of relative amplitudes over Kharkiv are 8–20% and 3–8% of background electron density and plasma temperatures, respectively. These values are similar for Millstone Hill.

Conducting systematic long-term observations of wave processes in the ionosphere using all facilities available at Kharkiv and Millstone Hill observatories will enable to reveal longitudinal variability in TID characteristics, provide a better understanding of the mechanisms of TID generation and propagation, and improve regional and global ionospheric models.

Keywords: traveling ionospheric disturbances, gravity waves

## A simulation study of seasonal variations in the thermospheric upward propagation of migrating terdiurnal tide

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The migrating terdiurnal tide in the mesosphere and lower thermosphere (MLT) is suggested to contribute significantly to the formation of the Midnight Temperature/Density Maximum (MTM/MDM) in the upper thermosphere. In this study, the Thermosphere Ionosphere Electrodynamics Global Circulation Model (TIEGCM) and the extended Canadian Middle Atmosphere Model (eCMAM) are utilized to investigate the seasonal variations of the upward propagation of the migrating terdiurnal tide from the MLT. Three main conclusions are drawn from a series of controlled simulations: 1) The background thermospheric zonal and meridional winds and neutral temperature can affect the upward propagation of the terdiurnal tide. 2) The background zonal winds can play an important role in the variation of the vertical advection and adiabatic cooling/heating, especially in the low thermosphere, and as a consequence, the upward propagation of the terdiurnal tide is modulated. 3) The terdiurnal tide in the MLT influences not only on the latitudinal distributions and magnitudes of the terdiurnal tide in the upper thermosphere, but also on the effect of the background winds on the upward propagation of the terdiurnal tide.

Keywords: Terdiurnal tide, Upward propagation, Seasonal variation