Evidence of lower atmospheric influences/coupling in midlatitude long-term mesopause-region temperatures

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An unique midlatitude noctunal mesopause-region temperatures resulting from 25 years of Na lidar observations at Colorado State University and Utah State University reveals influences of tropospheric and/or stratospheric forcing. These includes signals of Mt. Pinatubo eruption and El Nino Southern Oscillation, as well as altitude-dependent (wave-like structures) responses to the 11-year and 27-day solar flux variability. Though the cause for these intriguing signals is not yet known, publications in 2015 by colleagues elsewhere have also shown similar effects in temperatures from satellite data.

Keywords: Mesopause temperatures, Lower atmospheric influences, 25 years Na lidar observation

Strong long-term cooling of the ionosphere observed by multiple incoherent scatter radars

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Compelling evidence for long-term changes in the upper atmosphere over the last several solar cycles has emergedfollowing a seminal modeling study by Roble and Dickson (1989), suggesting potential effects of increasedgreenhouse gases on the ionosphere and thermosphere. Direct measurements of the cooling trend come from in situ neutral density data available since 1960s, and from ground-based incoherent scatter radar (ISR) plasma temperature data available systematically at Millstone Hill (42.6N 288.5) since the late 1960s and elsewhere since the later years. Other observations also seem to show indirectly signs of the cooling which are not alwaysconsistent. However, the cool intensity from ISR data appear much more significant than expected from effects ofanthropogenic increases in the CO2 mixing ratio, as initially suggested by Millstone Hill data. We have now examined furth the strong cooling with additional new datasets of ISRs: the Sondrestrom (67.0N, 309.1E) ISR(1990-), which is typically located at cusp during the day, as well as Chatanika/Poker Flat (65.1N, 212.6E) ISRs(1976-) which is often considered as an aurora latitude site. New analyses of these observations continue toindicate strong ionospheric cooling, therefore imposing an important question as to what is really driving theselong-term changes in the upper atmosphere. We will make comparisons of these ISR results from mid- and highlatitudes, and discuss potential drivers for the unexpected strong cooling in the ionosphere.

Keywords: long-term change, ionosphere, incoherent scatter radar

Behaviour of the semi-diurnal tidal modes in the MLT using the SuperDARN meteor-radar chain

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Atmospheric tides in the mesosphere and lower thermosphere (MLT) have been shown to couple to the ionosphere, and may themselves be enhanced by the Joule heating associated with energetic particle precipitation. However, studies have shown that the efficiency of this coupling to and from the ionosphere depends on the spatial mode of the tides. While individual stations can provide accurate information on the temporal evolution of the tides, they do not allow the different spatial modes to be separated. Similarly, satellite observations can determine the spatial modes, but alias temporal changes in tidal amplitude and structure. A method has been developed to observe the spatial structure of atmospheric tides in the northern hemisphere (50°-66° N) MLT using neutral atmosphere winds derived from meteor trail drifts observed by a longitudinal chain of Super Dual Auroral Radar Network (SuperDARN) radars. The tidal amplitudes determined at each radar station in the chain can be combined to infer the zonal wavenumber 1 and 2 structure of the tide and its temporal evolution without the spatial-temporal aliasing present in satellite observations. Details of the method applied to the meteor radar data will be presented, and the amplitudes and temporal variations of the wavenumber 1 and 2 components of the semi-diurnal tide in the MLT will be examined during stratospheric warming and particle precipitation events.

Keywords: Dynamics, Tides, coupling

Coupling process among the mesosphere, thermosphere and ionosphere elucidated by the ISS-IMAP mission

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ISS-IMAP (Ionosphere, Mesosphere, upper Atmosphere, and Plasmasphere mapping) mission was installed on the Exposed Facility of Japanese Experiment Module of the International Space Station, EF of ISS-JEM, and consisted of two sets of imagers to observe the structures in the Mesosphere, Thermosphere and Ionosphere (MTI) region. Visible-light and infrared spectrum imager (VISI) of ISS-IMAP observed the airglow of 730nm (OH, Alt. 85km), 762nm (O2, Alt. 95km), and 630nm (O, Alt. 250km) in the MTI region, and Extra ultraviolet imager (EUVI) observed the resonant scattering of 30.4nm (He+) and 83.4nm (O+) from ion in the Ionosphere and Plasmasphere. ISS-IMAP was operated from 2012 to 2015. VISI elucidated global distributions of the airglow structures whose scale size is 50-500km in he nightside. The wavy structures that are interpreted to be generated by atmospheric wave were frequently observed. Some of them showed clear relationship with tropospheric phenomena as its source. EUVI elucidated global distributions of He ion. Its seasonal distribution indicates the thermospheric wind dominates the ion distribution of the topside ionosphere and the plasmasphere. Coupling processes among the MTI region and the lower atmosphere will be discussed in the presentation.

Keywords: Ionosphere, Thermosphere, airglow

3-years Occurrence Variability of Concentric Gravity Waves in the Mesopause Observed by IMAP/VISI

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We report the first statistical study on concentric gravity waves (CGWs) in the mesopause by using 3 years data obtained by IMAP/VISI. 235 CGWs events were found with horizontal wavelength ranging from 40 to 250 km and maximum radius of 200 to 3000 km. Occurrence of the CGWs was significantly higher during non-solstice months (February-May and August–November) than solstice months (June-July and December-January), suggesting low to moderate wind are preferable for CGWs upward propagation. The latitudinal distribution of the CGWs centers had peaks in mid latitude (40°N and 40°S) and minimum at low latitude (10°S). More events were found in the summer hemisphere mid-latitudes, with a clear transition between north and south hemisphere around equinoxes. The information of the preferable regions seen in the global distribution map and the seasonal distribution could be useful for region and seasonal selection of CGWs' future studies.

Keywords: Concentric gravity wave, O2 nightglow emission, Mesopause

A numerical study of the effects of migrating tides on thermosphere midnight density maximum

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We employed the NCAR Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) and the extended Canadian Middle Atmosphere Model (eCMAM) to investigate the role of the migrating terdiurnal tide on the formation and variation of the thermosphere midnight temperature maximum (MTM) and midnight mass density maximum (MDM). The migrating terdiurnal tide from the eCMAM was applied at the TIEGCM's lower boundary, along with the migrating diurnal and semidiurnal tides from the *Global Scale Wave Model (*GSWM). Several numerical experiments with different combinations of tidal forcing at the TIEGCM's lower boundary were carried out to determine the contribution of each tide to MTM/MDM. We found that the interplay between diurnal, semidiurnal and terdiurnal tides determines the formation of MTM/MDM and their structure in the upper thermosphere. The decrease of thermospheric mass density after MDM reaches its maximum at ~02:00 local time is mainly controlled by the terdiurnal tide. Furthermore, we examined the generation mechanisms of the migrating terdiurnal tide in the upper thermosphere and found that they come from three sources: upward propagation from the lower thermosphere, in-situ generation via nonlinear interaction and thermal excitation.

Keywords: thermosphere, midnight density maximum, migrating tides

Ionospheric Effects of Strong El Niño Southern Oscillation Conditions

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The occurrence of a very strong positive phase in the El Nino Southern Oscillation (ENSO) in late 2015 has had effects on weather around the entire planet. Furthermore, recent investigations show that ENSO-related changes in tropospheric water vapor and rainfall drive significant changes in the temperature and wind structure in the middle atmosphere, through the modification of the spectrum of atmospheric tides. Given that several components of the tidal spectrum can propagate into the thermosphere, ENSO-related changes at altitudes above the mesopause and into the ionosphere may be expected. Based upon historical events in 1997 and 1998, we will show the ionospheric and thermospheric variations one may expect for El Ni\~no and La Ni\~na conditions. We will also show middle atmosphere conditions measured by the NASA TIMED SABER instrument for the 2015-2016 event. These efforts are enabled in part by modeling capabilities developed for the upcoming NASA Ionospheric Connection Explorer mission.

Keywords: El Niño, Atmospheric physics, ionosphere, thermosphere

Impact of tidal variability on the mean state of the ionosphere and thermosphere during sudden stratosphere warmings

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Observations from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites reveal a global reduction in the zonal and diurnal mean F-region peak electron density (NmF2) during sudden stratosphere warmings (SSWs). In the present study we investigate the source of the global NmF2 decrease using Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) and Thermosphere-Ionosphere-Electrodynamics Global Circulation Model (TIE-GCM) simulations. The TIME-GCM simulations demonstrate that the reduction in the mean NmF2 coincides with an [O]/[N2] decrease, indicating that changes in thermosphere composition during SSWs drive the decrease in NmF2. To understand the source of the [O]/[N2] variability, we perform numerical experiments in the TIE-GCM using different forcing conditions at the model lower boundary (~97 km). The numerical experiments illustrate that variability in the migrating semidiurnal solar tide (SW2) during SSWs drives the changes in thermosphere composition. In particular, the enhancement of the SW2 during SSWs appears to alter the mean circulation in the MLT, leading to a reduction in atomic oxygen throughout the thermosphere. The results demonstrate that, in addition to modulating the low latitude electrodynamics, tidal variability during SSWs significantly impacts the mean state of the ionosphere and thermosphere.

Keywords: sudden stratosphere warming, ionosphere variability, thermosphere composition

Global Responses of Gravity Waves to Planetary Wave Variations during SSWs Observed by SABER

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This study describes the global responses of observed gravity waves (GWs) to winter planetary wave (PW) variations during stratospheric sudden warmings (SSWs) using TIMED-SABER temperature measurements. Previous studies have shown responses of atmospheric temperature and parameterized GW drag to SSWs; however, the responses of actual global GW observations to SSWs have not been presented before. The responses are shown by calculating correlations between vertical components of Eliassen-Palm (EP) fluxes in the winter polar stratosphere and global GW temperature amplitudes derived from SABER observations. Consistent with previous ground-based and satellite observations, winter EP fluxes show positive correlations with GWs in the winter hemisphere. More interestingly, winter stratospheric EP fluxes are positively correlated with GWs in the tropics and in the summer mesosphere, indicating global variations of GWs in response to PW variations in the winter hemisphere. To study the mechanism of GW response to SSWs, global wind simulations from SD-WACCM are used. Zonal wind anomalies (differences in the wind before and during SSWs) extend from the winter stratosphere to the summer mesosphere. By comparing anomalies in background winds to the observed patterns in the correlations between GWs and winter EP fluxes, we find that regions of positive correlation follow changes in background winds and zero-wind lines. The results indicate that responses of SABER GWs in the summer hemisphere to winter PW variations during SSWs are likely caused by changes in GW propagation due to the changes in winds and atmospheric circulation. These observed changes in global GWs during SSWs can affect the ionosphere and thermosphere, and studying global GW variation during SSWs is important for understanding mechanisms of vertical coupling.

Keywords: Inter-hemispheric Coupling, Gravity Wave, Stratospheric Sudden Warming

Tidal variabilities and their effects on the upper atmosphere during stratospheric sudden warmings studied with a long-term whole atmosphere-ionosphere simulation

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Recent studies have revealed that large-scale phenomena in the lower atmosphere have significant impacts on the upper atmosphere. For example, during the period of a prominent stratospheric sudden warming (SSW) in January 2009, the low latitude ionosphere was observed to perturb significantly. In previous study, we have simulated the event using a whole atmosphere-ionosphere coupled model called GAIA which implemented the meteorological reanalysis data in order to examine the effects of realistic lower atmospheric forcing. The model can reproduce overall main features in the middle and upper atmospheric variations during the SSW event, and the analysis suggests that the upward propagating planetary wave in the polar region can change not only global zonal wind distribution but also propagation of atmospheric tides, which leads to the perturbation of low latitude ionosphere [Jin et al., JGR, 2012]. In this study, we have carried out a longer run from 1996 to 2014, and analyzed statistically the effects of stratospheric sudden warmings on the upper atmosphere. We especially discuss the role of migrating tides in detail.

Keywords: stratospheric sudden warming, atmospheric tide, ionosphere, thermosphere, simulation, modeling

Quasi Two Day Wave Response in the Ionosphere Using TIME-GCM Nudged with NOGAPS-ALPHA

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The quasi two day wave (QTDW) is a planetary wave that can be enhanced rapidly to extremely large amplitudes in the mesosphere and lower thermosphere (MLT) region during the northern winter post-solstice period. The dissipation of the planetary wave can change the background dynamics and the composition of MLT. This feature can also drive robust variability of the ionosphere system, for example, the total electron content (TEC).
In this study, we present five January case studies of QTDW events (2005, 2006, 2008, 2009, 2010) by using the Thermosphere-Ionosphere-Mesosphere Electrodynamics-General Circulation Model(TIME-GCM) nudged with the Navy Operational Global Atmospheric Prediction System-Advanced Level Physics High Altitude (NOGAPS-ALPHA) Weather Forecast Model. With NOGAPS-ALPHA introducing a more realistic lower atmospheric forcing in TIME-GCM, we can investigate ionosphere system coupling with the MLT region when dramatic features associated with the QTDW occur in middle atmosphere. This work opens a new method to evaluate the physical mechanism of ionospheric coupling from below during QTDW events.

Keywords: Data Assimilation, Quasi Two Day Wave, TIME-GCM, NOGAPS-ALPHA, Ionosphere

Mesospheric, thermospheric, and ionospheric responses to acoustic and gravity waves at large amplitudes and small scales

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Acoustic and gravity waves (AGWs) are routinely observed in the Earth's mesosphere, lower thermosphere, and ionosphere (MLTI) from ground and space based platforms via remote sensing of mesospheric airglow intensity and ionospheric total electron content (TEC). Recent data from imagers and GPS receivers provide key insight into wave disturbances to the MLTI at high resolution above their respective sources, which include natural hazard events, orographic forcing, and tropospheric convection [e.g., Galvan et al., RS, 47(4), 2012; Nishioka et al., GRL, 40(21), 2013; Fritts et al., BAMS, 2015; Miller et al., PNAS, 112(49), 2015]. Gravity waves with short periods (~minutes) and small scales (~tens to hundreds of kilometers) may carry sufficient momentum to have very strong and localized effects on the state of the MLTI [Fritts et al., JGR, 119(24), 2014]. Evidence also suggests nonlinear impacts of acoustic waves (with periods ~minutes) in the ionosphere and thermosphere, for example as indicated by measured TEC depletions following the Tohoku 2011 earthquake [e.g., Kakinami et al., GRL, 39(13), 2012]; simulations by Zettergren and Snively [AGU FM, NH32C-02, 2015] also support this interpretation.
We investigate the observable features of acoustic and gravity waves at large amplitudes that can strongly perturb multiple layers of the MLTI system. New high-resolution, nonlinear, compressible, atmospheric dynamics models are used to drive airglow photochemical and ionospheric models [e.g., Snively, GRL, 40(20), 2013; Zettergren and Snively, JGR, 120(9), 2015]. Results elucidate the underlying dynamics of nonlinear short-period wave disturbances, in addition to the responses of both the mesospheric airglow and thermosphere-ionosphere systems to enable direct comparisons with data (airglow imagery and TEC). Modeling also reveals that apparently coherent AGWs, at large amplitudes consistent with observations, may have strong localized impacts that may (or may not) be readily observable. Observations and modeling of dynamics spanning multiple layers in the MLTI system may provide new insight into wave coupling processes, the evolutions of broad wave spectra, and wave effects over short time scales.

Keywords: Acoustic and Gravity Waves, Airglow, Ionosphere, Mesosphere and Lower Thermosphere

Relationship between ionospheric and atmospheric perturbations associated with typhoons

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It is known that ionospheric disturbances are caused by extreme weather conditions, such as tornadoes and typhoons. In this study, we have examined the relationship between ionospheric and atmospheric disturbances caused by typhoons, using HF doppler (HFD) and a microbarometer. HFD observation system used in this study is maintained by The University of Electro-Communications (UEC). The receiver is located at Sugadaira, Nagano Prefecture and the transmitters are located at Chofu Campus of UEC and Nagara, Chiba Prefecture. The microbarometer is also located at Sugadaira, Nagano Prefecture. In examining typhoons which came closer to Japan since 2004, we have found ionospheric perturbations associated with 8 typhoons. In almost events, the amplitude of the doppler shift is about several hertz, which is much less than the cases for earthquakes. By dynamic spectral analyses, it is found that spectral intensity of both of ionospheric and atmospheric perturbations at frequency from 5 mHz to 50 mHz were enhanced. These results imply that the effect of the typhoon to the ionosphere is quite smaller and that the atmospheric waves propagated to the ionosphere drive the ionospheric perturbations. In this study, as a typical example, the perturbations asssociated with Typhoon WIPHA (No.18 in 2013) at 30 mHz are examined in detail. This is because the wind direction in the transmitter (Chofu), the receiver (Sugadaira), and the middle point (Chofu) is quite stable (eastward) when Typhoon WIPHA was closest to Japan for several tens of hours. The temporal variation of the spectral intensity of ionospheric perturbation is almost the same as the wind speed at Sugadaira, where is the windward of Chofu. This result shows that the ionospheric perturbations associated with typhoons is affected by the atmospheric perturbations windwardly below the ionosphere.

Keywords: Ionospheric perturbation, Atmospheric perturbation, Typhoon, HF Doppler, Microbarometer

Behavior of Gravity waves in the thermosphere simulated by high resolution GAIA

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It has been recognized that gravity waves play an important role on the momentum and energy balance in the thermosphere. The effects of upward propagating gravity waves on the general circulation of the thermosphere are studied using a whole atmosphere-ionosphere coupled model (GAIA). The GAIA contains the region from the ground surface to the upper thermosphere (about 500km altitude), so that we can simulate excitation of gravity waves in the lower atmosphere and their upward propagation to the thermosphere. The high horizontal resolution of the neutral atmospheric part of GAIA is about 0.5 degree longitude by 0.5 degree latitude, and this model can simulate wide ranges of gravity waves in their thermosphere. In this study, we focus our attention on gravity wave activity in the winter thermosphere. Our simulation result indicates that some of gravity waves in the winter thermosphere is originated from the polar night jet in the stratosphere/mesosphere. Moreover, the impacts of thermospheric gravity waves on variability in the ionosphere are investigated.

Keywords: vertical coupling processes, atmospheric waves

An analysis on the momentum budget in the MLT region based on satellite and whole atmosphere model data

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In the middle atmosphere, gravity waves (GWs), tides (TWs) and Rossby waves (RWs) are dominant. By interacting with the mean flow, these waves maintain the thermal structure considerably different from that expected from a radiative balance. However, the momentum budget of the middle atmosphere has not thoroughly examined particularly for the mesosphere and lower thermosphere (MLT). In this study, the momentum budget in the MLT including piecewise contribution by each wave is examined by analyzing a satellite data and a whole atmosphere model data. An interplay of RWs and GWs is also focused on for the formation of barotropic (BT) /baroclinic (BC) instability. The analysis of the present study is mainly performed for climatology fields for each month in the zonal mean meridional cross-section. Used data are temperature and geopotential heights from Aura MLS observations as the satellite data (MLS data) and the neutral atmosphere data which was obtained by simulation using the GAIA model, which include a coupled neutral and ionized atmospheres from ground to lower thermosphere (LT) as the whole atmospheric model (GAIA data). The analyzed period is about 11 years from 8 August 2004–19 June 2015.
First, MLS data are analyzed. Magnitude of potential vorticity (PV) maximizes in low and middle (high) latitudes in the summer (winter) mesosphere. In the poleward side of these maxima, meridional gradient of PV (PVy) is negative, which is a necessary condition of BT/BC instability. EP flux (EPF) is strongly upward and EPF divergence (EPFD) is positive slightly poleward and above the PV maximum (PVM) in the summer mesosphere. Moreover the distribution of the occurrence frequency of positive EPFD accords well with that of negative PVy. These features suggest that RWs are radiated upward from the mesospheric PVM.
Second, the momentum budget is analyzed using GAIA data. EPF is divided into TW, RW and GW components. For the RW component, EPFD is significantly positive in the region where PVy is negative in the summer mesosphere. Strong upward EPF above the positive EPFD region is extended up to 0.0001 hPa in the LT. From a spectral analysis in this upward EPF region, it is seen that westward propagating waves having a 1.8 day period and s = 2–4 are dominant. This feature is similar to that of quasi-two day waves detected by previous observations. Moreover the feature that strong upward and equatorward EPF is observed above the negative PVy region suggests that these waves are generated through BT/BC instability. Next, the GW component is examined. GW EPFD is generally positive (negative) in summer hemisphere (SH) (winter hemisphere (WH)) in the MLT. It is seen from the direction of EPF that eastward (westward) waves are dominant in the SH (WH). The downward EPF (i.e. dominance of eastward waves) is particularly strong above the negative PVy region in the SH MLT, suggesting that GWs are generation there. The Richardson number in this region is frequently lower than 1/4, suggesting that the eastward GWs are generated by shear instability. EPFD due to all wave components is mainly positive (negative) in SH (WH) in the MLT. Among these, the GW component is most dominant. The forcing of subgrid-scale GWs (GWFP) is parameterized in the GAIA model. The GWFP maximizes around ~90 km in the upper mesosphere of the both hemispheres. The GWFP is comparable to the EPFD due to all resolved waves although the vertical distribution is different.
Last, the relation between GWFP distribution and negative PVy region is examined. GWFP is positive (negative) in low and high latitudes (all latitudes) of the SH (WH) mesosphere, and these maxima correspond to the location of the PVM. It is shown that the PVM is mainly contributed to by N2 in

WH and by both N2 and relative vorticity in SH. In addition, the rate of change of PV due to GWFP is directly estimated. The result indicates that the GWFP is likely responsible for the formation of PVM.

Keywords: Middle atmosphere, Rossby wave, Gravity wave, Barotropic / baroclinic instability, Momentum budget

Terahertz Limb Sounder for Lower Thermosphere Wind, Temperature, and Atomic Oxygen Density Measurements

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In this paper, we present the concept of a high-sensitivity heterodyne spectrometer operating at 2.0 Terahertz (THz) for global lower thermospheric neutral wind, temperature and atomic oxygen density measurements from a low earth orbit. The instrument, THz Limb Sounder (TLS) is aimed to provide, for the first time, global neutral wind/temperature/density profile measurements globally during day and night, with focus at altitudes of 100-150 km where most of the ion-neutral energy/momentum couplings take place. TLS is an ambient-temperature Schottky diode based all solid-state heterodyne spectrometer designed to extend the limb sounding technique employed by Microwave Limb Sounder for density/temperature/wind measurements by measuring the Doppler line shape of atomic oxygen (OI) fine structure emission at 2.06THz. This atomic oxygen line emission is very bright and distributed nearly uniformly globally (at all latitudes including highly spatially structured aurora particle precipitation regions) and temporally (at all local times during both day, night, and twilight), thus ideal for thermospheric remote sensing. The instrument concept, measurement methodology, receiver performance, and the expected measurement capability will be presented and discussed in this paper.

Keywords: Lower Thermosphere Wind, Temperature, and Density, Remote Sensing Technique and Instrument, TeraHz Spectrometer

A review on recent upper atmosphere atomic oxygen measurements

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Atomic oxygen is a key player in upper mesosphere and lower thermosphere chemistry, energy balance, and vertical as well as global coupling. In recent years, a few new global datasets of this species have been presented. They are based on airglow measurements from low earth orbit satellites. Surprisingly, the atomic oxygen abundance differs by 30-50% for similar atmospheric conditions. This paper gives an overview on the various atomic oxygen datasets available so far and presents most recent results obtained from measurements of the SCIAMACHY instrument on Envisat. Differences between the datasets are discussed.

Keywords: atomic oxygen, mesosphere, thermosphere, coupling, energy balance

Double Crests of Peak Height in the Equatorial Ionospheric F2 Layer Observed by COSMIC

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For the first time, we report daytime double crests of peak height (hmF2) in the F2 layer based on the COSMIC observations during 2007-2014. Evident double crests of hmF2 occurred at around ±10° geomagnetic latitude (MLAT) with a trough over the magnetic equator at low solar activity and at March equinox. This phenomenon is referred to as an Equatorial Height Anomaly (EHA) of the ionospheric F2 layer. The double crests became less obvious at September equinox and disappeared at solstices. At solstices only one crest was observed in the summer hemisphere, which is probably associated with trans-equatorial neutral winds. In addition, the double EHA crests generally take place during 10:00-14:00 local times. Our results indicate that the EHA favors the conditions of strong vertical plasma drifts and weak trans-equatorial neutral winds during low solar activity. The EHA feature is reproduced by the TIEGCM at March equinox and low solar activity.

Keywords: F2 layer peak height, Latitudinal variation, Equatorial anomaly, Ionospheric ceiling

Local time evolution and longitudinal difference of equatorial ionization anomaly in the low-latitude topside ionosphere

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The latitudinal structure of topside ion density (N_i) was investigated in detail based on the N_i observations of the ROCSAT-1 and DMSP satellites. EIA double-peak structure can exist at 600 km, depending on longitude, local time, season, and solar activity, while it cannot extend up to 840 km even in the case of the strong fountain effect at solar maximum sunset. The complete local time evolution of the EIA at 600 km was presented. The double-peak structure begins to appear at noontime, being later than the appearance of the EIA in F_2-peak region. The pronounced EIA induced by the strong prereversal enhancement at solar maximum begins to appear at 19:00 LT and can last to pre-midnight; and EIA crest-to-trough ratio (*CTR*) reaches a maximum at 20:00 LT, with the largest (lowest) *CTR* at March equinox (June solstice). EIA structure shows evident longitudinal difference. Pronounced EIA exists around about 100°E at 13:00 LT at the two equinoxes and June solstice, while it exists at more extensive longitudes (about 90°E to 240°E) at December solstice. The trans-equator plasma transport induced by neutral winds can weaken the double-peak structure in the topside ionosphere. The longitudinal difference in the EIA structure at 600 km is related to the longitudinal variations of equatorial upward plasma drift and geomagnetic declination.

Keywords: Low-latitude Ionosphere, Topside Ionosphere, Equatorial Ionization Anomaly

Realtime 3D tomography of the ionosphere based on GEONET GPS-TEC

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Measurement of ionospheric total electron content (TEC) by using the ground-based GPS receivers is now widely used. We refer to it as GPS-TEC. As there are always several GPS satellites available for the measurement, it is a very good tool for constant monitoring of the ionosphere. One of the most dense and wide network of the GPS network is GEONET operated by Geospatial Information Authority of Japan (GSI). This is the network of more than 1200 points over Japan. We have been developing 3D tomography of the ionospheric plasma density from the GEONET data. This tomography technique uses a constrained least squares fit to reconstruct the electron density distributions. Recently we further develop the software system to conduct the GPS-TEC analysis in the realtime basis. In this system we collect “every second” GPS data from GEONET, estimate satellite and receiver biases for true TEC measurement, and obtain 3D tomography reconstruction of the ionosphere every 15 minutes with 10 minutes latency. We will show current status of the 3D tomography analysis and the realtime system.

Keywords: 3D tomography, GPS TEC, GEONET, Realtime ionosphere monitoring

Extremely large longitudinal variation of ionospheric bubble generation and its possible relationship with ITCZ

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A close link between the atmospheric inter-tropical convergence zone (ITCZ) and ionospheric plasma bubble has been proposed since the last century. But this relationship has often appeared to be less than convincing due to the simultaneous roles played by several other factors, most importantly by the evening pre-reversal enhancement of eastward electric field (PRE) and its associated velocity shear, in shaping the global distribution of ionospheric bubbles. From simultaneous collaborative radar multi-beam steering measurements at Kototabang (0.2°S, 100.3°E) and Sanya (18.4°N, 109.6°E), conducted during September–October of 2012 and 2013, we find that there exists extremely large longitudinal variation in bubble generation but not in bubble occurrence. The total numbers of nights with bubble (i.e., occurrence rates) over the two stations are comparable, but the total number of nights with locally generated bubble (i.e., generation rate) over Kototabang is clearly more than that over Sanya. Further analysis reveals that a more active ITCZ is situated around the longitude of Kototabang. Considering that the two stations are separated only by 9.3° in longitude where the magnetic declination and the magnetic equator offset from the geographic equator are almost the same, the enhanced ionospheric bubble generation over Kototabang may be explained by upward propagating gravity waves (GWs) which could be generated frequently in the more active ITCZ and provide the seeding source for bubble development.

Keywords: ionospheric plasma bubble, atmospheric inter-tropical convergence zone, gravity wave

Equinoctial asymmetry in the east-west distribution of scintillation occurrence observed by GPS receivers in Indonesia

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We used GPS receivers installed in Pontianak (0.02°S, 109.3°E; 9.8°S mag. Lat.) and Bandung (6.9°S, 107.6°E; 16.7°S mag. Lat), Indonesia to observe azimuthal dependence of GPS-L1 scintillation occurrence rate. Crest of the equatorial anomaly region is located between both sites. We focus on analyzing east-west distribution of scintillation occurrences in equinox months. We collected scintillation data as indicated by S_4 index from those receivers for March and September from 2011 to 2015. Our findings statistically emphasized that scintillation occurrence rate is higher in the westward direction than that in eastward direction in March equinox. This east-west difference of scintillation occurrence is more distinct in March equinox than September equinox. In September equinox, the occurrence rate is almost comparable between westward and eastward direction. We can speculate that the equinoctial asymmetry in east-west distribution of scintillation occurrence could be likely caused by westward tilt of plasma bubble extending to higher altitudes/latitude, and that the plasma bubbles are more tilted westward in March equinox than in September equinox. We have analyzed zonal irregularity drift velocity observed by closely-spaced GPS receivers at Kototabang (0.2°S, 100.3°E; 9.9°S mag. Lat.), Indonesia for the same observation period. The results showed that eastward drift velocity decreases with increasing magnetic latitudes, and that the latitudinal gradient of eastward drift in March equinox is larger than in September equinox. Additionally, we used in-situ measurement of zonal wind velocity at ~400 km of altitude by CHAMP satellite in March and September from 2001 to 2005 for longitude 95-105°E. We found that latitudinal eastward wind velocity also show decrease of the magnitude with the increasing magnetic latitudes. The latitudinal gradient of eastward wind in March is larger than the latitudinal gradient in September. Thus, in March equinox, the large latitudinal gradient of irregularity drift and eastward wind velocity could be responsible for further westward tilt of plasma bubble extending to higher altitudes/latitudes. Consequently, the equinoctial asymmetry of east-west distribution of scintillation could be caused by the equinoctial asymmetry of tilted westward structure of plasma bubble.

Keywords: equatorial ionosphere, plasma bubble, irregularity, scintillation, equinoctial asymmetry, coupling neutral-plasma

Multiple excitation of large-scale traveling atmospheric disturbances (TADs) by solar wind fluctuations

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Fluctuations on timescales of minutes to hours are common in the solar wind. When the fluctuations encounter the Earth, they could excite gravity waves in the auroral regions. These gravity waves, particularly large-scale (> ~1000 km) gravity waves, will give rise to traveling atmospheric disturbances (TADs) with typical amplitudes of 20~40% in the upper thermosphere. We report here the detection of multiple excitation of large-scale TADs by Alfvén waves embedded in high-speed solar wind streams, and also by interacting coronal mass ejections.

Keywords: solar wind fluctuations, gravity waves, thermosphere

A link between high-speed solar wind streams and extratropical cyclones

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Databases of extratropical-cyclone tracks obtained from two meteorological reanalysis datasets are used in superposed epoch analysis of time series of solar wind plasma parameters and green-coronal emission line intensity. The time series are keyed to times of maximum growth of explosively developing extratropical cyclones during northern and southern winters. The new statistical evidence corroborates the previously published results (Prikryl et al., Ann. Geophys., 27, 1-30, 2009). This evidence shows that explosive extratropical cyclones tend to occur after arrivals of solar wind disturbances such as high-speed solar wind streams from coronal holes when large amplitude magneto-hydrodynamic waves couple to the magnetosphere-ionosphere system. These MHD waves modulate Joule heating and/or Lorentz forcing of the high-latitude thermosphere generating medium-scale atmospheric gravity waves. Ray tracing of aurorally-generated gravity waves show that the gravity waves propagate upward and downward through the atmosphere. Simulations of gravity wave propagation in a model atmosphere using the Transfer Function Model (TFM) (Mayr et al., Space Sci. Rev., 54, 297–375, 1990) show that propagating waves originating in the thermosphere can excite a spectrum of gravity waves in the lower atmosphere. At the tropospheric level, in spite of significantly reduced amplitudes, they can provide a lift of unstable air to release the moist symmetric instability thus initiating slantwise convection and forming cloud/precipitation bands (Prikryl et al., Ann. Geophys., 27, 31-57, 2009). The release of latent heat is known to provide energy for rapid development and intensification of extratropical cyclones.
Since 2009, Japan Meteorological Agency has archived detailed annual reports on calamitous severe weather events occurring nation-wide (http://www.jma.go.jp/jma/menu/menureport.html). The starting dates of the events attributed to low pressure systems are used as key times in the superposed epoch analysis of solar wind plasma parameters and green solar corona intensity. It is observed that the events of heavy rain or snow, strong wind and high ocean waves caused by low pressure storms, particularly in winter, tend to follow arrivals of high-speed solar wind. This is consistent with the statistical evidence based on the study of explosive extratropical cyclones in relation to solar wind.

Keywords: High-speed solar wind streams, Atmospheric gravity waves, Extratropical cyclones

Characteristics of mesosphere echoes over Antarctica obtained using PANSY and MF radars

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In the polar region characteristic radar echoes are observed from the mesosphere by using a VHF system. The nature of the echoes is distinctively different between summer and winter and those echoes are called Polar Mesosphere Summer Echoes (PMSEs) and Polar Mesosphere Winter Echoes (PMWEs), respectively. Since the PMSEs are usually very strong and can be easily measured with a small radar system, their nature is relatively well understood. On the other hand PMWEs are much weaker and they are still only poorly understood.
The PANSY radar (47MHz) at Syowa station (69S) is the only large aperture atmospheric radar in the Antarctic, and can continuously survey the dynamics of the middle atmosphere with high time and height resolutions [Sato et al., 2014]. Nishiyama et al [2014] reported the first study of PMWEs using PANSY radar and showed a seasonal and local time dependence of these echoes.
An MF radar system (2.4MHz) is co-located at Syowa, and has been operating for mesosphere and lower thermosphere observations. Although the MF radar has only a much poorer height resolution and is incapable of vertical wind measurement, it can almost continuously measure mesosphere day and night.
In this study the nature of the mesosphere echoes, mainly PMWEs, are being studied using the two radars based on the observation made in 2015. These radars are operated using largely different radio frequencies and can provide complementary information with each other such as wind velocities and also echo scattering mechanisms.
Horizontal wind velocities have been compared between the two radars with a great care mostly in the MF radar winds in order to avoid possible biases inherent in the correlation analysis technique employed for the MF radar wind measurement. A careful analysis has shown that the horizontal wind velocities agree well between the two systems with a high correlation coefficient around 0.8 throughout the height region of 65-85km.
Aspect sensitivities estimated using the MF radar data indicate that the winter time MF echoes in the lower mesosphere are more isotropic in winter than in summer, suggesting that the winter echoes are scattered by isotropic turbulences. A candidate that generates such isotropic structures is thought to be gravity waves, whose activity in the Antarctic mesosphere is maximized in winter [Dowdy et al., 2007; Yasui et al., 2016]. The height region of the low aspect sensitivity mostly corresponds to that of PMWEs, and this further suggests a possible connection between PMWEs and gravity wave activity. Aspect sensitivities based on the PANSY data are also to be analyzed and presented.

Keywords: Antarctic, PMWEs, MST radar, atmospheric gravity waves

Gravity Wave Instability Dynamics in Mesospheric Stratification and Shear Environments

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An anelastic numerical model is used to explore gravity wave instability dynamics in variable stratification and shear environments in the mesosphere and lower thermosphere (MLT). Recent computational advances facilitate the characterization of localized gravity wave packets in a deep atmosphere, enabling realistic amplitude evolution and enhanced sensitivity to transient nonlinear dynamics. The results reveal that gravity wave packets impinging on a sheet of high stratification and shear enable local Kelvin-Helmholtz instabilities (KHI) where gravity wave vertical displacements approach their maxima and mean and gravity wave shears combine. The KHI arise at smaller scales and evolve to larger scales with time, as seen in lidar, radar, and airglow observations. Such events tend to be highly localized and thus yield local energy and momentum deposition expected to have strong influences throughout the mesosphere, thermosphere, and ionosphere (MTI) region. These simulations illuminate one of the major mechanisms driving turbulence and mixing in the MLT at scales that are challenging or impossible to describe quantitatively with existing measurement capabilities.

Keywords: Atmospheric Gravity Waves, Gravity Wave Instability Dynamics

