Commission G Report

June 10, 2016

1. Meeting announcement/report

- JpGU Meeting 2016 was held at Makuhari, Chiba on May 22-26, 2016. There are Commission G-related sessions in the meeting. http://www.jpgu.org/meeting_2016/
- 2016 Beacon Scintillation Symposium will be held at Trieste, Italy on June 27 – July 1, 2016. This meeting is co-sponsored by URSI Commission G. http://t-ict4d.ictp.it/beacon2016
- 41st COSPAR Scientific Assembly will be held at Istanbul, Turkey on July 30 – August 7, 2016. http://cospar2016.tubitak.gov.tr
- AOGS 13th Annual Meeting will be held at Beijing, China on July 31 – August 5, 2016. http://www.asiaoceania.org/aogs2016/
- International Symposium on the Whole Atmosphere (ISWA) will be held at Ito Hall, The University of Tokyo on September 14-16, 2016. Observations and studies of all height of the atmosphere especially featuring PANSY radar will be discussed. http://pansy.eps.s.u-tokyo.ac.jp/iswa/
- MU radar /Equatorial Atmosphere Radar Symposium was held at RISH, Kyoto University on September 8-9, 2016. This is the annual meeting for the cooperative use of the facilities. Commission G of Japanese URSI co-sponsors this symposium.

2. Research Report

2.1. Report from National Institute for Polar Research (NIPR)
(Yasunobu Ogawa, NIPR)

=== Research activity of PANSY ===

A 1-year continuous full system observation of the PANSY radar started from late September 2015. It enables us to capture various temporal- and spatial-scale phenomena in the Antarctic troposphere, stratosphere, mesosphere, and thermosphere/ionosphere with high temporal and vertical resolution throughout the year and to contribute to improving global climate models for better understanding of future climate change.

In addition, the first international campaign based on a combination of GCM (General Circulation Model) simulations and simultaneous observations by several MST/IS radars over the world including PANSY and some complementary instruments such as MF (Medium Frequency) and meteor radars, lidars, imagers, and so on was successfully conducted from January 22 to February 17, 2016. This campaign was named the Interhemispheric Coupling Study by Observations and Modeling (ICSOM: see details at http://pansy.eps.s.u-tokyo.ac.jp/icsom/), and approved as a project for ROSMIC (Role Of the Sun and the Middle atmosphere/thermosphere/ionosphere In Climate) of SCOSTEP (Scientific Committee on Solar-Terrestrial Physics) under ICSU (International Council for Science). It is expected that these international collaborations including the PANSY radar will promote a more accurate understanding of the Antarctic atmosphere and interhemispheric coupling processes.

=== Recent papers ===

(PANSY related papers)

Minamihara, Y., K. Sato, M. Kohma, and M. Tsutsumi, Characteristics of vertical wind fluctuations in the lower troposphere at Syowa Station in the Antarctic revealed by the PANSY radar, *SOLA*, **12**, 116-120, doi:10.2151/sola.2016-026, 2016.

Using wind data over three years from July 2012 - June 2015 from the PANSY radar, an MST radar, newly installed at Syowa Station (39.59°E, 69.0°S), statistical characteristics of vertical winds and vertical momentum fluxes in the Antarctic lower troposphere are examined. Frequency spectra covering a wide frequency range from $(30\ d)^{-1}$ to $(8\ min)^{-1}$ are divided into three frequency regions obeying power laws with different scaling exponents. The transition

frequencies are different between horizontal and vertical wind spectra. Vertical fluxes of horizontal momentum were estimated for two wave period ranges of 8 min - 2 h and 2 h - 1 d and having almost equal logarithmic scales. The momentum fluxes are larger for longer period components. There are evidences showing that the vertical wind disturbances in the lower troposphere are due to gravity waves forced by topography aligned in the north-south direction. First, the strong disturbances are observed when horizontal winds are strong near the surface. Second, zonal winds tend to almost zero around the top of the disturbances. Third, frequency spectra are large at a wide range of frequency below a critical level, as is consistent with the phase modulation of mountain waves by unsteady mean flow.

Mihalikova, M., K. Sato, M. Tsutsumi, and T. Sato, Properties of inertia‐gravity waves in the lowermost stratosphere as observed by the PANSY radar over Syowa Station in the Antarctic, *Ann. Geo.*, **34**, 543-555, doi:10.5194/angeo-34-543-2016, 2016.

Inertia-gravity waves (IGWs) are an important component for the dynamics of the middle atmosphere. However, observational studies needed to constrain their forcing are still insufficient especially in the remote areas of the Antarctic region. One year of observational data (January to December 2013) by the PANSY radar of the wind components (vertical resolution of 150m and temporal resolution of 30 min) are used to derive statistical analysis of the properties of IGWs with short vertical wavelengths (≤ 4 km) and ground-based periods longer than 4 h in the lowermost stratosphere (height range 10 to 12 km) with the help of the hodograph method. The annual change of the IGWs parameters are inspected but no pronounced year cycle is found. The year is divided into two seasons (summer and winter) based on the most prominent difference in the ratio of Coriolis parameter f to intrinsic frequency ω distribution. Average of f/ω for the winter season is 0.40 and for the summer season 0.45 and the average horizontal wavelengths are 140 and 160 km respectively. Vertical wavelengths have an average of 1.85 km through the year. For both seasons the properties of IGWs with upward and downward propagation of the energy are also derived and compared. The percentage of downward propagating waves is 10.7 and 18.4% in the summer and winter season respectively. This seasonal change is more than the one previously reported in the studies from mid-latitudes and model-based studies. It is in agreement with the findings of past radiosonde data-based studies from the Antarctic region. In addition, using the so-called dualbeam technique, vertical momentum flux and the variance of the horizontal perturbation velocities of IGWs are examined. Tropospheric disturbances of synoptic-scale are suggested as a source of episodes of IGWs with large variance of horizontal perturbation velocities, and this is shown in a number of cases.

2.2. Report from Institute for Space-Earth Environmental Research (ISEE), Nagoya University
(Satonori Nozawa, Nagoya University)

== Recent papers ===

Dao, T., Y. Otsuka, K. Shiokawa, S. Tulasi Ram, and M. Yamamoto, Altitude development of postmidnight F region field-aligned irregularities observed using Equatorial Atmosphere Radar in Indonesia, *Geophys. Res. Lett.*, **43**, 1015-1022, doi:10.1002/2015GL067432, 2016.

Vertical rise velocities of post-midnight field-aligned irregularities (FAIs) at low geomagnetic latitudes have been examined near the June solstice by using two-dimensional maps of F-region FAI echoes observed with the Equatorial Atmosphere Radar in Indonesia for 3 years. A lower limit for the generation time of the post-midnight FAIs is estimated to be between 21:30 LT and 02:00 LT for 14 of the 15 events, indicating that this class of FAIs is distinct from the post-sunset FAIs.

Li, G., Y. Otsuka, B. Ning, M. A. Abdu, M. Yamamoto, W. Wan, L. Liu, and P. Abadi, Enhanced ionospheric plasma bubble generation in more active ITCZ, *Geophys. Res. Lett.*, **43**(6), 2389-2395, doi:10.1002/2016GL068145, 2016.

From simultaneous radar measurements with multi-beams at Kototabang, Indonesia and Sanya, China, we find that occurrence rate of the plasma bubble generated locally over Kototabang is clearly more than that over Sanya. More active intertropical convergence

zone (ITCZ) is situated around the longitude of Kototabang. We surmise that the enhanced ionospheric bubble generation at Kototabang longitude could be caused by a higher gravity wave activity associated with the more active ITCZ.

Jun C.-W, K. Shiokawa, M. Connors, I. Schofield, I. Poddelsky, and B. Shevtsov, Possible generation mechanisms for Pc1 pearl structures in the ionosphere, based on 6 years of ground observations in Canada, Russia, and Japan, *J. Geophys. Res. Space Phys.*, **121**, doi: 10.1002/2015JA022123, 2016.

We investigate pearl structures (amplitude modulations) of Pc1 pulsations simultaneously observed at Canada, Russia, and Japan. From 6 years of ground observations, we conclude that ionospheric beating effect could be a dominant process for the generation of Pc1 pearl structures. Through ionospheric duct propagation.

Sakaguchi, K., K. Shiokawa, Y. Miyoshi, and M. Connors, Isolated proton auroras and Pc1/EMIC waves at subauroral latitudes, in Auroral Dynamics and Space Weather, Geophysical Monograph 215, Edited by Yongliang Zhang and Larry J. Paxton, American Geophysical Union. Published by John Wiley & Sons, Inc., 2016.

In this study, spatial distribution and occurrence probability of isolated proton auroras (IPAs) were statistically investigated, as a proxy for regions of EMIC wave occurrence, using ground - based imaging data during 2006-2012 at Athabasca, Canada. The IPA occurrence probability are shown as function of local time, magnetic activity, solar cycle variation. Quantitative estimation is given for the IPA size, providing quantitative estimate the loss rate of energetic particles, contributing to space weather studies.

Nomura, R., K. Shiokawa, Y. Omura, Y. Ebihara, Y. Miyoshi, K. Sakaguchi, Y. Otsuka, and M. Connors, Pulsating proton aurora caused by rising tone Pc1 waves, *J. Geophys. Res. Space Phys.*, **121**, 1608-1618, doi:10.1002/2015JA021681, 2016.

We found rising tone emissions with a dispersion of ~1 Hz per several tens of seconds in the dynamic spectrum of a Pc1 geomagnetic pulsation (Pc1) observed on the ground. Simultaneously, a THEMIS panchromatic all-sky camera detected pulsations of an isolated proton aurora. The pulsations of the proton aurora close to the zenith of ATH have one-to-one correspondences with the Pc1 rising tones. This suggests that these rising tones scatter magnetospheric protons intermittently at the equatorial region.

Lin, F. F., C. Y. Wang, C. L. Su, K. Shiokawa, S. Saito, and Y. H. Chu, Coordinated observations of F region 3-m field-aligned plasma irregularities associated with medium-scale travelling ionospheric disturbances, *J. Geophys. Res. Space Phys.*, **121**, 3750-3766, doi:10.1002/2016JA022511, 2016.

Three - meter field - aligned irregularities (3 - m FAIs) associated with medium scale travelling ionospheric disturbances (MSTIDs) occurred on 5 February 2008 were observed by using the Chung - Li 52 MHz coherent scatter radar. The VHF radar echo structures from the 3 - m FAIs combined with the 630 nm airglow images provided by the Yonaguni all - sky imager are compared and analyzed. The results suggest that, through the nonlinear turbulence cascade process, the MSTID - associated 3 - m FAIs are very likely generated from the kilometer - scale plasma irregularities with large amplitude excited by the gradient drift instability.

2.3. Report from National Institute for Information and Communications Technology (NICT)
(Minoru Kubota, NICT)

=== Recent papers===

Maruyama, T., K. Yusupov, and A. Akchurin, Ionosonde tracking of infrasound wavefronts in the thermosphere launched by seismic waves after the 2010 M8.8 Chile earthquake, *J. Geophys. Res. Space Phys.*, **121**, 2683–2692, 2016, doi:10.1002/2015JA022260.

Maruyama, T., K. Yusupov, and A. Akchurin, Interpretation of deformed ionograms induced by vertical ground motion of seismic Rayleigh waves and infrasound in the thermosphere, *Ann. Geophys.*, **34**, 271–278, doi:10.5194/angeo-34-271-2016, 2016.

Ionospheric disturbances associated with the M8.8 Chile earthquake (35.91S, 72.73W) on 27 February 2010 were observed at Kazan, Russia (55.85N, 48.81E). Rapid-run ionograms at 1-min intervals exhibited multiple cusp signatures (MCSs) for more than 30 min, which have been observed several times after large earthquakes. The ionospheric disturbances were caused by infrasound propagating upward in the atmosphere launched by seismic Rayleigh waves, which modified the vertical electron density distribution through ion-neutral collisions. The density profiles at 1-min intervals allowed the tracking of the propagation of infrasound and provided information on parameters of acoustic waves, which was not possible from the previous radio measurements. The speed of acoustic waves in the thermosphere, and corresponding thermospheric temperature, was slightly higher than that calculated using the Mass Spectrometer and Incoherent Scatter Radar empirical model (NRLMSISE-00). One extreme case of MCS ionogram was characterized by steep satellite traces for which the virtual heights increased rapidly with frequency starting near the top of cusps and continuing for 0.1–0.2 MHz. Ray tracing model calculations revealed that the inclined periodic perturbation yielded oblique returns of sounding radio waves in addition to the nearly vertical returns of the main trace.

Jiang, C., G. Yang, C. Deng, C. Zhou, P. Zhu, T. Yokoyama, H. Song, T. Lan, B. Ni, Z. Zhao, and Y. Zhang, Simultaneous observations of F2 layer stratification and spread F at post-midnight over a northern equatorial anomaly region, *J. Geophys. Res. Space Phys.*, **120**, 10,979-10,991, doi:10.1002/2015JA021861, 2015.

Simultaneous observations of F2 layer stratification and spread F at postmidnight (00:00 LT to 05:00 LT) were carried out on 22, 23, and 28 November 2013, using ionosondes distributed over a northern equatorial anomaly region at three specific locations, i.e., Puer (PUR, 22.7°N, 101.05°E, dip latitude 12.9°N), Chiang Mai (CMU, 18.8°N, 98.9°E, dip latitude 9.04°N), and Chumphon (CPN, 10.7°N, 99.4°E, dip latitude 0.93°N). The results show that both the PUR and CMU stations observed the F2 layer stratification at postmidnight in the Northern Hemisphere, frequently accompanied with gravity waves (the periods~30–100min). It is reported that F2 layer stratification at postmidnight can be observed in the Northern Hemisphere for the first time. It is suggested that the thermospheric neutral wind triggered by gravity waves strongly contribute to the altitude dependence of the combined vertical plasma velocity, which consequently poses significant impacts on the occurrence of the low-latitude F2 layer stratification at postmidnight.

Tulasi Ram, S., T. Yokoyama, Y. Otsuka, K. Shiokawa, S. Sripathi, B. Veenadhari, R. Heelis, K. K. Ajith, V. S. Gowtam, S. Gurubaran, P. Supnithi, and M. Le Huy, Dusk side enhancement of equatorial zonal electric field response to convection electric fields during the intense geomagnetic storm of March 17, 2015, *J. Geophys. Res. Space Phys.*, **121**, 538-548, doi:10.1002/2015JA021932, 2016.

The equatorial zonal electric field responses to prompt penetration of eastward convection electric fields (PPEF) were compared at closely spaced longitudinal intervals at dusk to premidnight sectors during the intense geomagnetic storm of 17 March 2015. At dusk sector (Indian longitudes), a rapid uplift of equatorial F layer to >550 km and development of intense equatorial plasma bubbles (EPBs) were observed. These EPBs were found to extend up to 27.13°N and 25.98°S magnetic dip latitudes indicating their altitude development to ~1670 km at apex. In contrast, at few degrees east in the premidnight sector (Thailand-Indonesian longitudes), no significant height rise and/or EPB activity has been observed. The eastward electric field perturbations due to PPEF are greatly dominated at dusk sector despite the existence of background westward ionospheric disturbance dynamo (IDD) fields, whereas they were mostly counter balanced by the IDD fields in the premidnight sector.

Jiang, C., G. Yang, P. Zhu, M. Nishioka, T. Yokoyama, C. Zhou, H. Song, T. Lan, Z. Zhao, Y. Zhang, Reconstruction of the vertical electron density profile based on vertical TEC using the simulated annealing algorithm, *Adv. Space Res.*, **57**, 2167-2176, doi:10.1016/j.asr.2016.02.020, 2016.

This paper presents a new method to reconstruct the vertical electron density profile based on vertical Total Electron Content (TEC) using the simulated annealing algorithm. The present technique used the Quasi-parabolic segments (QPS) to model the bottomside ionosphere. The initial parameters of the ionosphere model were determined from both International Reference Ionosphere (IRI) (Bilitza et al., 2014) and vertical TEC (vTEC). Then, the simulated annealing algorithm was used to search the best-fit parameters of the ionosphere model by comparing with the GPS-TEC. The performance and robust of this technique were verified by ionosonde data. The critical frequency (foF2) and peak height (hmF2) of the F2 layer obtained from ionograms recorded at different locations and on different days were compared with those calculated by the proposed method. The analysis of results shows that the present method is inspiring for obtaining foF2 from vTEC. However, the accuracy of hmF2 needs to be improved in the future work.

2.4. Report from Chiba University
(Hiroyuki Nakata, Chiba University)

=== Recent papers===

K. Yoshikawa, K. Takaboshi, H. Nakata, T. Takano, M. Matsumura, H. Shinagawa, and I. Tomizawa, Quantitative Estimation of the Ionospheric Disturbances Associated with Earthquakes observed with HF Doppler by a Numerical Simulation of Neutral Atmospheric Waves, *IEEJ Transactions on Fundamentals and Materials*, **136**(5), 259-264, doi:10.1541/ieejfms.136.259, 2016.

In order to evaluate the relationship between the coseismic ionospheric perturbations and the ground perturbations, we compare the coseismic disturbances determined by a numerical simulation with those observed by HF Doppler. HF Doppler observation determines the ionospheric vertical drift speed of the reflection point. The numerical simulation calculates the temporal evolution of the neutral acoustic wave, In this numerical simulation, the ground perturbations observed by seismometers closest to the reflection points are used as sources of the perturbations. The speed estimated from HF Doppler is about an order larger than that calculated from numerical simulation. The difference is because the speed of the ionospheric vertical drift is not same as the neutral atmospheric wave. In order to fix this difference, the ionospheric neutral drift speed is modified considering the effects of the inclination of the magnetic field and the compression of ionospheric plasma. As a result, the both speed are comparable each other.

H. Nakata, K. Abe, A. Tokunaga, T. Takano, T. Tsugawa, and M. Nishioka, Spectral density analysis of total electron content perturbations associated with earthquakes, *IEEJ Transactions on Fundamentals and Materials*, **136(**5), 272-277, doi:10.1541/ieejfms.136.272, 2016.

We performed the frequency analysis of time-series data of TEC, and examined the variations of TEC associated with earthquakes. Using Fast Fourier Transform processing, the spectral densities of coseismic TEC variations were calculated. The coseismic variations of TEC were detected in 16 events out of 26 events where the earthquakes larger than M6.4 occurred around Japan since 2000. In most events, the variations at the frequencies of 4.17, 5.21 mHz were observed. The spectral densities reached their maximums about 11 minutes after the earthquake. Since this delay corresponds to the propagation time of acoustic wave from the ground to the ionosphere, it is confirmed that the coseismic variations are due to the acoustic wave generated by the ground/sea surface perturbations. The enhancement of the signal density increases with the magnitude of earthquake and the height of tsunami. Using the enhancement of the TEC variation, the magnitude of wave source can be estimated.

H. Nakata, K. Kawai, S. Akiyama, T. Chida, R. Tanaka, Y. Kawamura, T. Takano, and S. Shimakura, Estimation of direction of arrival of VHF radio wave by interferometers, *IEEJ Transactions on Fundamentals and Materials*, **136**(5), 278-285, doi:10.1541/ieejfms.136.278, 2016.

In order to examine the direction of arrival of VHF radio waves dependent on the natural phenomena, the interferometers have been installed at Katsuyama, Chiba Prefecture and Numata, Gunma Prefecture. In this study, the radio wave at the frequency of 77.1 MHz transmitted from Tokyo Tower (assigned to FM broadcasting of the Open University of Japan) is observed. The interferometers consist of four Yagi antennas and estimate the directions of arrivals of the radio wave. The observational results show that the directions of the wave are affected by the

disturbances in the ionosphere and the atmosphere. In this paper, the system of the interferometers is described and the examples of the observation results are presented.

2.5. Report from Electronic Navigation Research Institute (ENRI)
(Susumu Saito, ENRI)

=== Recent papers===

S. Saito, T. Yoshihara, and H. Nakahara, Performance of GAST-D ionospheric gradient monitor studied with low latitude ionospheric disturbance data obtained in a real airport environment, Proceedings of ION 2015 Pacific PNT meeting, 815-820, 2015.

In this paper, performance of ionospheric spatial gradient monitor (ISGM) for GNSS Ground-based augmentation system (GBAS) to support category-II/III approach and landing is evaluated in a real airport environment located at Ishigaki (24.4N, 124.2E), Japan. The performance of the ISGM in the nominal ionospheric conditions are shown to be satisfactory. It was also found that there were some events of enhanced ISGM outputs, which may potentially cause false alarm of ISGM. It was shown that they are likely to be tropospheric origin as speculated by previous studies. This study is the first to support the existence of sharp tropospheric delay gradient with dual-frequency measurements.

S. Saito, T. Yoshihara, A. Kezuka, S. Saitoh, and S. Fukushima, GAST-D flight experiment results with disturbed and quiet ionospheric conditions, Proceedings of the 28th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2015), Tampa, Florida, September 14-18, 2015, pp.1494-1499, 2015.

This paper reports on the results of flight experiments with a prototype of GNSS Ground-based augmentation system (GBAS) to support category-II/III approach and landing. The prototype is located at Ishigaki (24.4N, 124.2E), Japan. The main target of the flight experiment was to evaluate the performance with presence of plasma bubbles. Plasma bubble occurrences were monitored by an all-sky airglow imager and GNSS scintillation receivers located near the prototype. It was shown that the safety was maintained even with presence of well-developed plasma bubbles. One of the integrity monitors onboard aircraft was shown to respond to the ionospheric disturbances by using real data for the first time. Scintillation effects on GNSS signals by plasma bubbles are shown to be severe to degrade availability of the system, and multi-constellation and multi-frequency GNSS would be desired for the future development.

2.6. Report from Research Institute for Sustainable Humanosphere (RISH), Kyoto University
(Mamoru Yamamoto, RISH)

=== Masterplan 2017 ===

Research Institute for Sustainable Humanosphere (RISH), Kyoto University, National Institute of Polar Research (NIPR), Institute for Space-Earth Environmental Research (ISEE), Nagoya University, and International Center for Space Weather Science and Education (ICSWSE), Kyushu University proposed the research project “Coupling process in the solar-terrestrial system” (PI: Prof. Toshitaka Tsuda at RISH) to Masterplan 2017 of Science Council of Japan. This is a project to study the solar energy inputs into the Earth, and the response of Geospace (magnetosphere, ionosphere and atmosphere) to the energy input, which follows success of the same project in Masterplan 2014. We plan to install large atmospheric radars with active phased array antenna at the equator and the Arctic regions. One is Equatorial MU (EMU) radar by RISH in Sumatera Island, Indonesia, and the other is EISCAT_3D by NIPR in northern Scandinavia under international collaborations. We develop the global observation network is planned (ISEE, ICSWSE with other institutions). The joining institutions have already started budget request of their facilities.

=== Lecture “Introduction to Radio Science” ===

Kyoto University holds the Institute for Liberal Arts and Sciences (ILAS) to integrate the efforts of various schools and departments for planning, coordination, and implementation of liberal arts and sciences programs. From April 2016 a class named “Introduction to radio science” has been started as a part of ILAS seminar course. The class teachs fundamental knowledge for the radio

and its propagation, and introduce variety aspects of radio science studies. Visits to several sites/labs of the research field are also planned.

=== Recent papers===

C. H. Chen, A. Saito, C. H. Lin, M. Yamamoto, S. Suzuki and G. K. Seemala, Medium-scale traveling ionospheric disturbances by three-dimensional ionospheric GPS tomography, *Earth Planet Space*, **68**:32, DOI 10.1186/s40623-016-0412-6, 2016.

In this study, we develop a three-dimensional ionospheric tomography with the ground-based global position system (GPS) total electron content observations. Because of the geometric limitation of GPS observation path, it is difficult to solve the ill-posed inverse problem for the ionospheric electron density. Different from methods given by pervious studies, we consider an algorithm combining the least-square method with a constraint condition, in which the gradient of electron density tends to be smooth in the horizontal direction and steep in the vicinity of the ionospheric F2 peak. This algorithm is designed to be independent of any ionospheric or plasmaspheric electron density models as the initial condition. An observation system simulation experiment method is applied to evaluate the performance of the GPS ionospheric tomography in detecting ionospheric electron density perturbation at the scale size of around 200 km in wavelength, such as the medium-scale traveling ionospheric disturbances.

Marzuki, H. Hashiguchi, T. Kozu, T. Shimomai, Y. Shibagaki, and Y. Takahashi, Precipitation microstructure in different Madden-Julian Oscillation phases over Sumatra, *Atmospheric Research*, **168**, 121-138, DOI:10.1016/j.atmosres.2015.08.022, 2016.

Intraseasonal variations of precipitation and its microstructure are investigated using measurements of the Equatorial Atmospheric Radar (EAR) facilities at Kototabang, west Sumatra, Indonesia (0.20°S, 100.32°E, 864 m above sea level). Raindrop size distribution (DSD) observations are obtained from a 2D-Video Disdrometer (2DVD) with a near continuous record of operation over eight consecutive years (2003-2010). Precipitation types are classified using 1.3-GHz wind profiler observation, and are partitioned according to active and inactive convective phases of Madden-Julian Oscillation (MJO). It is found that precipitation systems during the inactive phase are more continental in nature than those during the active phase. Cloud propagation from brightness temperature data indicates that Sumatra receives the rainfall mainly from maritime clouds during the active phase, while it is mainly from the continental clouds (land-based convection) during the inactive phase. Other remarkable differences between active and inactive phase precipitation systems are also observed from the vertical structure of precipitation. The precipitation during the inactive phase has deeper storms, a higher reflectivity aloft, more lightning activity and less stratiform characteristics, as compared to the active phase. Assessment of cloud effective radius of the Moderate Resolution Imaging Spectroradiometer (MODIS) data also shows a slight difference in the cloud droplet between the active and the inactive MJO phases. Different convective storms in different MJO phases lead to different DSD characteristics and Z-R relationships. The DSD during the inactive phase tends to have a higher concentration of medium and large-size drops than the active counterpart, consistent with the previous study during the first campaign of Coupling Processes in the Equatorial Atmosphere project. Although the DSD parameters and coefficient of Z-R relationships fall within the range of tropical maritime precipitation, mass-weighted mean diameter (Dm) for the deep convective rains during the inactive phase are somewhat larger than that for maritime and closer to the continental cluster. Therefore, continental-like DSDs are somewhat dominant during the inactive phase, consistent with the intraseasonal variation of precipitation structure. The causative processes of the observed difference in the DSD for the two phases have also been discussed with the help of satellite and radar data. Evaporation and updraft associated with the intense convection during the inactive phase seem to eliminate the small-sized drops from the spectra. Finally, radar reflectivity during the inactive phase is larger than that during the active MJO phase, at the same rainfall rate. This condition can limit the accuracy of radar-derived rainfall estimates for the tropics when applying a single Z-R relation to the two MJO phases, particularly for deep convective rains.

Jenn-Shyong Chen, Yen-Hsyang Chu, Ching-Lun Su, Hiroyuki Hashiguchi, and Ying Li, Range Imaging of E-region Field-Aligned Irregularities by Using a Multifrequency Technique: Validation and Initial Results, *IEEE Transactions on Geoscience and Remote Sensing*, **54**(7), 3739-3749, DOI:10.1109/TGRS.2016.2521702, 2016.

This paper reports the first use of a multifrequency range imaging (RIM) technique for observing E-region field-aligned irregularities (FAIs) in the midlatitude ionosphere. The Middle and Upper atmosphere Radar (MUR; 34.85°N, 136.10°E) was used to conduct experiments with five equally spaced frequencies between 46.25 and 46.75 MHz. Three types of RIM data were examined: data with 13-element binary Barker codes, with 16-element binary complementary codes, and without phase codes. Moreover, two calibration approaches were adopted to validate the applicability of the RIM technique, which functioned as intended. Excellent RIM performance such as the ability to resolve several striations in an echo region of FAIs was demonstrated. However, sidelobe echoes caused by pulse coding mechanisms were occasionally observed at altitudes above and below the source regions in the coded data. Therefore, a procedure was developed according to one of the calibration approaches to identify and remove such kind of sidelobe echoes, which was shown to be applicable for the complementary-coded data. In addition to FAIs, a thin plasma layer with a thickness of approximately 1 km was identified as being structured with some tilted finer structures, which could not be observed in the original intensity images with a range resolution of 600 m. Preliminary estimates of the Doppler velocities indicated that a wind shear effect could be the cause of such tilted finer structures.

Oigawa, M., E. Realini, and T. Tsuda, Study of Water Vapor Variations Associated with Meso-γ Scale Convection: Comparison between GNSS and Non-Hydrostatic Model Data, *SOLA*, **11**, 27-30, March 11, 2015.

Water vapor variations associated with a meso-γ scale convection were investigated using GNSS (Global Navigation Satellite System) derived PWV (precipitable water vapor) and high resolution numerical model data with a 250 m horizontal grid interval. A rapid increase of GNSS-derived PWV that occurred prior to the initiation of surface rainfall was well simulated by the numerical model. In the model, PWV values began to increase 16 min before the rainfall occurred at the surface. A local maximum of PWV was formed because of the generation of shallow free convection and surface water vapor flux convergence due to a lifting of an air parcel at approximately 1 km elevation by a preceding surface wind convergence. Due to the existence of a stable inversion layer between 2.2 and 3.5 km elevation, the shallow free convection took 11 min to rise above the inversion layer to form a deep convection. These results suggest that observation of local distributions of GNSS-derived PWV is useful for monitoring the generation of deep moist convection.

Ando, H., T. Imamura, T. Tsuda, S. Tellm ann, M. Pätzold, and B. Häusler, Vertical Wavenumber Spectra of Gravity Waves in the Venus Atmosphere Obtained from Venus Express Radio Occultation Data: Evidence for Saturation, *Journal of the Atmospheric Sciences*, **72**, 2318-2329, doi:10.1175/JAS-D-14-0315.1, 2015.

By using the vertical temperature profiles obtained by the radio occultation measurements on the European Space Agency (ESA)'s Venus Express, the vertical wavenumber spectra of small-scale temperature fluctuations that are thought to be manifestations of gravity waves are studied. Wavenumber spectra covering wavelengths of 1.4–7.5 km were obtained for two altitude regions (65–80 and 75–90 km) and seven latitude bands. The spectra show a power-law dependence on the high-wavenumber side with the logarithmic spectral slope ranging from −3 to −4, which is similar to the features seen in Earth's and Martian atmospheres. The power-law portion of the spectrum tends to follow the semiempirical spectrum of saturated gravity waves, suggesting that the gravity waves are dissipated by saturation as well as radiative damping. The spectral power is larger at 75–90 km than at 65–80 km at low wavenumbers, suggesting amplitude growth with height of unsaturated waves. It was also found that the wave amplitude is larger at higher latitudes and that the amplitude is maximized in the northern high latitudes. On the assumption that gravity waves are saturated in the Venusian atmosphere, the turbulent diffusion coefficient was estimated. The diffusion coefficient in the Venusian atmosphere is larger than those in

Earth's atmosphere because of the longer characteristic vertical wavelength of the saturated waves.

Mehta, S. K., M. Fujiwara, T. Tsuda, and J.-P. Vernier, Effect of recent minor volcanic eruptions on temperatures in the upper troposphere and lower stratosphere, *Journal of Atmospheric and Solar-Terrestrial Physics*, vol.**129**, 99-110, doi:10.1016/j.jastp.2015.04.009, 2015.

The impact of the recent minor volcanic eruptions during 2001-2010 in the temperature of the upper troposphere and lower stratosphere (UTLS) is investigated using data from the Global Positioning System Radio Occultation (GPS RO), three radiosonde compilations and two reanalyses (ERA-Interim and MERRA). The volcanic signals are identified in the residual temperature time series after removal of the linear trend, the quasi-biennial oscillation and El Nino Southern Oscillation components. Eight minor volcanic eruptions (six from the tropics and two from midlatitude) over the last decade (2001-2010) are analyzed in this study. We found significant volcanic signals in the UTLS temperature only in association with the tropical Soufrière Hills and Tavurvur eruptions (in May 2006 and in October 2006, respectively). Other four tropical eruptions had very small aerosol perturbations and did not show any significant UTLS temperature change. Out of the two midlatitude eruptions, Sarychev peak had similar stratospheric aerosol perturbations as Soufrière Hills and Tavurvur eruptions, but did not show any significant UTLS temperature change. The volcanic signals in the UTLS temperature from the tropical Soufrière Hills and Tavurvur eruptions were observed for the period of 7 months after August 2006. A warming of 0.5-0.8 K in the tropical 16-18.5 km (100-70 hPa) layer was observed in association with these two tropical eruptions.

Realini E., Sato K., Tsuda T., Oigawa M., Iwaki Y., Shoji, Y., Seko, H., Local-scale precipitable water vapor retrieval from high-elevation slant tropospheric delays using a dense network of GNSS receivers, International Association of Geodesy (IAG) Symposia, PP1-6, 07 July 2015, DOI:10.1007/1345_2015_167, 2015.

Local-scale monitoring of the temporal and spatial variability of precipitable water vapor (PWV) is crucial to improve the nowcasting and forecasting of localized meteorological hazards. While GPS is now routinely employed to retrieve PWV from estimated tropospheric delays (GPS meteorology), even the densest GPS networks available have a spatial resolution of the order of tens of kilometers, which is too coarse for detecting local fluctuations of water vapor. A densification of existing networks, at least in urban areas, is necessary to provide reliable and continuous water vapor monitoring with sufficiently high horizontal resolution. Densifying existing networks down to few kilometers of inter-station distances, however, introduces at least two issues: first, a horizontal smoothing effect occurs, induced by the significant overlapping of the inverse cones above low elevation angles typically used for GPS observation processing; second, an issue of economic nature might arise if geodetic receivers are used for large-scale densifications (e.g. for early warning systems serving large cities). We tackle the first issue by using only high-elevation slant delays for PWV retrieval, and in particular by exploiting the Japanese Quasi-Zenith Satellite System (QZSS), and the second issue by investigating the use of low-cost single-frequency receivers with local ionosphere delay models. In this work we describe the results obtained in PWV retrieval from high-elevation GPS and QZSS slant delays, estimated using a dense network of receivers installed near Kyoto, Japan.

Noersomadi and T. Tsuda, Global distribution of vertical wavenumber spectra in the lower stratosphere observed using high-vertical-resolution temperature profiles from COSMIC GPS radio occultation, *Ann. Geophys.*, **34**, 203-213, doi:10.5194/angeo-34-203-2016, 2016.

We retrieved temperature (T) profiles with a high vertical resolution using the full spectrum inversion (FSI) method from the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) GPS radio occultation (GPS-RO) data from January 2007 to December 2009. We studied the characteristics of temperature perturbations in the stratosphere at 20–27 km altitude. This height range does not include a sharp jump in the background Brunt–Väisälä frequency squared (N2) near the tropopause, and it was reasonably stable regardless of season and latitude. We analyzed the vertical wavenumber spectra of gravity waves (GWs) with vertical wavelengths ranging from 0.5 to 3.5 km, and we integrated the (total) potential energy EpT.

Another integration of the spectra from 0.5 to 1.75 km was defined as EpS for short vertical wavelength GWs, which was not studied with the conventional geometrical optics (GO) retrievals. We also estimated the logarithmic spectral slope (p) for the saturated portion of spectra with a linear regression fitting from 0.5 to 1.75 km.

Riggin D.M., T. Tsuda, A. Shinbori, Evaluation of momentum flux with radar, *Journal of Atmospheric and Solar-Terrestrial Physics*, **142**, 98-107, doi:10.1016/j.jastp.2016.01.013, 2016.

The statistics of gravity wave momentum flux estimation are investigated using data from the MU radar at Shigariki, Japan (136°E, 35°N). The radar has been operating during campaign periods since 1986. The first part of the paper focuses on a multi-day campaign during October 13–31, 1986. The second part of the paper investigates data after 2006 when the radar was operated in a meteor scatter mode. Momentum fluxes are derived from both the turbulent scatter and the meteor scatter measurements, but the techniques are quite different. Probability Distribution Functions are formed using turbulent scatter data. These show that wave packets sometimes have momentum flux magnitudes in excess of 100 m^2 s^{-2}. The technique for meteor radars, introduced by Hocking (2005), has been widely adopted by the radar community in recent years. The momentum flux estimated using this technique is found to be anti-correlated with the background tidal winds. A validation investigation is carried out for periods with a high meteor echo data rate. The conclusion was that the method can be used to calculate the sign of momentum flux, but does not accurately specify the magnitude.

Matsumoto, N., A. Shinbori, D. M. Riggin, and T. Tsuda, Measurement of momentum flux using two meteor radars in Indonesia, *Ann. Geophys.*, **34**, 369–377, doi:10.5194/angeo-34-369-2016, 2016.

Two nearly identical meteor radars were operated at Koto Tabang (0.20° S, 100.32° E), West Sumatra, and Biak (1.17° S, 136.10° E), West Papua, in Indonesia, separated by approximately 4000 km in longitude on the Equator. The zonal and meridional momentum flux, *u'w'* and *v'w'*, where *u*, *v*, and *w* are the eastward, northward, and vertical wind velocity components, respectively, were estimated at 86 to 94 km altitudes using the meteor radar data by applying a method proposed by Hocking (2005). The observed *u'w'* at the two sites agreed reasonably well at 86, 90, and 94 km during the observation periods when the data acquisition rate was sufficiently large enough. Variations in *v'w'* were consistent between 86, 90, and 94 km altitudes at both sites. The climatological variation in the monthly averaged *u'w'* and *v'w'* was investigated using the long-term radar data at Koto Tabang from November 2002 to November 2013. The seasonal variations in *u'w'* and *v'w'* showed a repeatable semiannual and annual cycles, respectively. *u'w'* showed eastward values in February–April and July–September and *v'w'* was northward in June to August at 90–94 km, both of which were generally anti-phase with the mean zonal and meridional winds, having the same periodicity. Our results suggest the usefulness of the Hocking method.