COMMISSION F：Wave Propagation and Remote Sensing (November 2013 －October 2016)

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A. Effects of Atmosphere

An overreach measurement method that simultaneously monitors RSSI and CNR of the TV waves and RSSI of FM waves is newly proposed. The results of measurements conducted in Hiroshima prefecture show that our proposed method can evaluate the level of overreach interference in the TV waves and also identify the source of the interference. Total 43 overreach interference events were found in the proposed method from one-year measurement in 2012. Based on M profile data, this paper also shows that the main factor of the overreach interference in this measurement is duct propagation due to meteorological condition [Nishi et al., 2014a].

Terrestrial TV waves and FM waves from Korea to Japan were measured to investigate overreach interference in digital TV waves. In order to evaluate co-channel interference in the TV waves, we proposed a measurement method that monitored both RSSI and CNR of the digital TV waves and RSSI of FM broadcasting waves from several cities at the same time. Based on measurements of TV and FM waves, this study clarified that our proposed method was effective to evaluate the interference from Korea [Nishi et al., 2014b].

In western Japan, UHF band terrestrial digital TV waves have been sometimes affected by co-channel overreach interferences from Korea. To evaluate the co-channel interferences, we have measured both RSSI and CNR of the digital TV waves and RSSI of FM broadcasting waves at Kyushu Institute of Technology in Fukuoka prefecture. In this study, we tried to estimate the overreach interference sources based on our proposed method monitoring FM waves transmitted from stations nearby the several candidates of interference sources. From the measurement results, it was found that the main overreach interference was from Korea, and that the main factor of the interference was an atmospheric duct propagation occurred over the sea [Nishi et al., 2015].

Also, the terrestrial digital TV waves have possibilities of influences by co-channel overreach interferences from not only Japan but also Korea. We have been observing the interferences based on our original measurement method using FM waves for identifying the interference of TV wave. In this study, we evaluated seasonal characteristics of overreach interferences from Japan and Korea using our method. It was found that the main overreach interferences were from Korea, not from Japan [Taniyama et al., 2016].

The human detection system using UHF band TV waves was proposed and evaluated for the car security. The measurements were performed in the parking space by the human detection system using software-defined radio with four receiving antennas. As a result, it was confirmed that human detections measured by the one receiving antenna were limited to specific areas such as vicinities of receiving antennas. In order to improve human detection performances, we evaluated the human detection using multiple frequencies. As a result, we found that detection probabilities became higher in almost all areas, and the human detected area was expanded [Shin et al., 2016].

B. Effects of Vegetation

The loss characteristics of radio propagation in 920-MHz band in a farm were investigated. An experiment was carried out in a mulberry field of the area of 50 m × 50 m in order to obtain fundamental data of the path loss in the field. Received Signal Strength Indicator (RSSI) according to the distance between the transmitting antenna (Tx) and the receiving antenna (Rx) was investigated. Tx was placed at a height of 1.5 m, and Rx was placed at three different heights of 0.5 m, 1.5 m, and 2.5 m. The polarization was set in two different directions; horizontal and vertical polarization. These data are needed to precisely calculate a link budget of a wireless network [Tsutsui et al, 2014].

To design a wireless sensor network for farms, it is necessary to understand and predict the effect of vegetation. In this study, the change in the propagation loss characteristics in 920-MHz band is examined during the growth of mulberry bushes. The received signal strength indicator (RSSI) is measured as a function of the distance between the transmitting antenna (Tx) and the receiving antenna (Rx) in a 50×50m mulberry field. The Tx and Rx are placed at a height of 1.5m. Moreover, the horizontal and vertical polarizations are measured and the differences are shown. Three empirical vegetation attenuation models are introduced, and the measured data have been fitted to each model. The results show that the non-zero gradient model is the best model at predicting the vegetation attenuation in a mulberry farm regardless of the polarization or mulberry growth. It is found that the attenuation dependence on the plant height is linear. Furthermore, the results have revealed that the horizontal polarization had about 1.5 times as large an effect on the vegetation attenuation as the vertical polarization [Hara et al., 2016].

C. Others

In fracturing rock, radio wave emission was found experimentally. This phenomenon could be used to detect a rock fracture during an earthquake or a volcanic activity. The cause of the radio wave is expected to be micro-discharges, which are generated by an inhomogeneous potential distribution around micro-cracks. In order to better understand the phenomena and clarify the cause of radio wave emission, we carried out experiments to detect the emission in the cases of a collision or contact between various materials [Takano et al., 2014].

It was confirmed that radio waves were generated when metallic parts in the experiment system collided each other. Therefore, it is absolutely needed to discriminate these signals that were not originated by rock fracture itself. Recently, we have remodeled the experiment system, of which all metallic pars are electrically shorted. Accordingly charging effect of the metallic parts is prevented in the rock fracture process. This paper describes the constitution of the experimental system and measured results [Takano et al., 2015a].

In order to discriminate the real signals generated in the rock fracture process from the interference signals due to metal collisions in the pressing machine, the conditions of the radio-wave signal generation should be studied. Therefore, we renewed the pressing machine and carried out experiments to detect radio-waves for the purpose of the experiment system reexamination. First, we used various lighting instruments, and clarified that the signal generation depends on the discharge mechanism. Then, various metals were made collide or touch each other. In all cases, the signals were detected. Resultantly, it has been concluded that inhomogeneous potential distribution which causes micro discharges should be suppressed. In the subsequent experiments, we have shorted all parts in the pressing machine using thick wires [Takano et al., 2015b].

There was a concern that the desired microwave emission by rock fracture would be contaminated by the emission originated by the metal contact. Therefore, we improved the machine by connecting and shortening all parts of the machine with wires to keep the homogeneous distribution of potential. As a result, we demonstrated that the emission due to metal contact was almost completely suppressed. This paper presents first the experimental results of radio wave emission due to metal contact. Then, the modification of the pressing machine, and the experimental results of radio wave emission due to rock fracture will be described [Takano et al., 2016].

A model for predicting path loss at the VHF band for low antenna heights is presented. Differences between path loss characteristics at the VHF band and at bands above the UHF band are clarified. The model is shown to be able to predict measurement results accurately [Sasaki et al., 2014a, 2014b].

F1.2 Satellite Radio System

A. Effects of Rain

The indexes of the degradation of C/N, ΔT/T and I/N, which can be converted from one to another, are used to evaluate the impact of interference on the satellite link. However, it is not suitable to intuitively understand how these parameters degrade the quality of services. In this paper, we propose to evaluate the impact of interference on the performance of BSS (Broadcasting Satellite Services) in terms of the increase rate of the outage time caused by the rain attenuation. Some calculation results are given for the 12GHz band BSS in Japan [Shogen, et al., 2016].

Speeds and directions of the motion of rain areas that cause the attenuation of Ku-band satellite communications links are estimated from the broadcast satellite (BS) signal levels simultaneously obtained at three locations of Osaka Electro-Communication University (OECU; Neyagawa, Osaka), the Research Institute for Sustainable Humanosphere (RISH; Uji, Kyoto) and the Shigaraki MU radar observatory (Koga, Shiga) of Kyoto University. The speeds and directions of rain area motion are compared with the ground wind velocities observed by a nearby AMeDAS station from 2008 to 2011. A correlation coefficient of nearly 0.6 is found between the directions of the rain area motions and the ground wind velocities although the directions tend to be rotated slightly anti-clockwise on the ground. Thus, the AMeDAS data seems to be important to determine the direction of satellite stations when the site diversity techniques are conducted [Maekawa et al., 2014, 2015].

The speeds and directions of rain area motion estimated from the BS signals at three locations are also compared with those of rain fronts obtained from image analyses of real time weather charts and rain cloud images recently published in the website by Japan Meteorological Agency. The speeds and directions are in fairly good agreement with those estimated from rain front and rain cloud Images down loaded from the websites, although the speeds tend to be faster in the BS signal measurements than in the images of the websites. So, the information on the rain area motions expected to be useful for site diversity techniques will be easily obtained by the image analysis methods presented by this study [Kubota et al., 2015, 2016].

The effects of site diversity techniques on Ku-band rain attenuation are investigated using two sets of simultaneous satellite signal observations, which have been conducted among Osaka Electro-Communication University (OECU) in Neyagawa, Kyoto University in Uji, and Shigaraki MU Observatory in Koga for about past nine years, and among the headquarters of OECU in Neyagawa and their other facilities in Shijonawate and Moriguchi for about past six years. The site diversity effects are found to be largely affected by the passing direction of rain areas. The diversity effects primarily depend on the distance between the sites projected to the rain area motions, and the time percentages of rain attenuation can be reduced down to about 60 % of the ITU-R predictions between the fixed two sites, by choosing a pair of the two sites out of the three, which is aligned nearest to the rain area motion in each rainfall event [Maekawa et al., 2016b].

The long-term rain attenuation statistics of cumulative time percentages are obtained from Ku band satellite signal observations conducted at Osaka Electro-Communication University in Neyagawa, Osaka, from 1988 to 2016. The long-term statistics for about 20 years up to 2006 are in very good agreement with the recent ITU-R predictions obtained from the 0.01% rainfall rate, and their 0.01% values indicate fairly large yearly variations which amount to about 20% of each value. Besides the yearly rainfall rate statistics, these variations seem to be caused by those of the equivalent rain path length at each year, which becomes longer as the average ground temperature at rain time from May to October becomes higher. However, the increase of the equivalent rain path length is not simply explained in term of the rise of rain height proportional to the ground temperature, but rather related to the occurrence of rain attenuation due to tropical-type rainfall such as shower and typhoon in summer time. Also, the equivalent path length tends to increase further for the last 10 years since 2006, and this tendency seems to be related to the overall increase of the average ground temperature at rain time in each year. It is actually found that the average ground temperature at rain time becomes higher by 1-2° primarily in summer time since 2006. New prediction models which take into account recent climate change and meteorological conditions will be expected in the near future. [Miura and Maekawa, 2016]

Rain attenuation statistics are obtained for both up and down links of Ku-band Superbird C, which connects the earth stations at Equatorial Atmosphere Radar (EAR) in West Sumatra, Indonesia and Research Institute of Sustainable Humanosphere (RISH) of Kyoto University in Uji, Kyoto during four years from Sept. 2002 to Sept. 2006. The rain attenuation characteristics are compared with distribution of precipitation cloud echoes simultaneously measured by the X-band meteorological radar over EAR. The duration time of rain attenuation is estimated from the horizontal distribution and moving speed of the X-band radar echoes. It is found that some of the duration time can be much longer than in Japan even for extremely large rainfall rate exceeding 50 mm/h [Takemoto et al., 2014, 2015a, 2015b]. The X-band radar observations also indicate that the core of the precipitating clouds passes over EAR at the speed of about 5 m/s, on an average. This value is much slower than that of the precipitating clouds in Japan, which is usually 10-30 m/s, and seems to give rise to considerably longer duration time of the rain attention in both wet and dry seasons. The slower moving speed is also confirmed by the atmospheric motions directly measured by EAR in the higher altitude [Tama et al., 2014, 2015a, 2015b].

B. The Effects of Other Factors

Rapid changes in cross-polarization discrimination (XPD) of Ka-band satellite radio wave signals caused by thunder-storm events are presented. Their yearly statistics and yearly variations are discussed using the co-polar and cross-polar signals received for the past 17 years from 1990 to 2006.

The number of thunderstorm events and rapid changes in XPD shows large yearly variations in a time scale of about five or six years. These long-term yearly variations may be related to periodic cycles of the equatorial climate, such as El Nino and La Nina, which tend to bring weak and strong convective activities, respectively, to the summertime weather in Japan [Maekawa, 2016a].

(Y. Maekawa)

F1.3 Mobile Radio Systems

A. Propagation for Cellular Systems

A new method for extracting the variation of multi-path fading, shadow fading, and path loss components from measurement field strength data is presented. The method is based on wavelet transformation and can extract precisely and easily each variation. The analyzed results based on measurement data in urban macro-cellular environment are also shown [Imai et al., 2014a].

Path loss variation characteristics at 26 GHz band based on measured data with wavelet analysis are shown. The analysis results clarify that the variation characteristics can be evaluated by taking reflection paths at building walls into account, in addition to the ground waves and LOS paths [Sasaki et al., 2015a].

Characterization of correlation coefficient between elements of MIMO channel matrix with movement by cumulative distribution is presented. The cumulative distributions are studied by theoretical and simulation values under condition of LOS or not NLOS, and antenna configuration with 2×2 and 4×4 line-line, 4×4 square-square. The results reveal some characteristics of the correlation coefficients under the case of movement on a straight line and with random direction [Kanemiyo et al., 2015].

Propagation characteristics for a MIMO adaptation transmission using an eigen-mode transmission in line-of-sight of street microcell environments by computer simulations are presented [Q. H. Nguyen et al., 2015]. And small-scale and large-scale propagation characteristics for spatial polarized MIMO using the eigen-mode transmission in line-of-sight of street microcell environments are also presented. As the propagation characteristics for the eigen-mode transmission, the weight polarization ratios of antenna, power distribution ratios, and SNR characteristics for the each stream are revealed by computer simulations [Q. H. Nguyen et al., 2016].

Frequency-agile path loss models for urban street canyons are presented. The models are floating intercept (FI), fixed reference (FR), and ITU-R M.2135 urban microcellular (UMi) line-of-sight (LOS) and Manhattan-grid non-LOS (NLOS) models. These models are parameterized based on channel sounding campaigns in three cities covering radio frequencies ranging from 0.8 to 60 GHz. Applicability of the proposed models to other street canyons is also discussed using independent path loss measurements [Haneda et al., 2016]. Improvement of ray tracing in urban street cell environment of Non Line-of-Site (NLOS) with consideration of building corner and its surface roughness is presented. Propagation characteristics for a MIMO adaptation transmission using an eigen-mode transmission in line-of-sight of street microcell environments are clarified by computer simulations using the proposed ray tracing model [Omaki et al., 2016].

The measurement results of the outdoor urban cellular wideband channels at 11 GHz are presented. The measurements at various urban cellular environments that are classified into macrocell, microcell and street-cell were conducted. And large scale characteristics of 11 GHz wideband channels including path losses, shadowing, cell coverage, polarization properties and delay spread are presented [Kim et al., 2015a].

B. Channel Estimation and Channel Sounding Method

Development of 24 x 24 MIMO channel Sounder are introduced. And an example of channel measurement and modeling in urban residential area is presented [Takada et al., 2016].

A wideband full polari-metric directional channel measurement results at 58.5 GHz in a small office room environment assuming an indoor access-point scenario in the next generation mobile systems are presented. The delay resolution was 2.5 ns, and the double directional angular characteristics are achieved by rotating high gain horn antennas at both sides of transmitter and receiver. By identifying scattering objects from the measurement data analysis, some important observations about the channel properties are also reported [Kim et al., 2015b].

Novel clustering approach which utilizes scattering points obtained from the measurement-based ray tracer is proposed. The performance of the algorithm is evaluated with 11 GHz channel sounding data in an indoor environment and good performance of the proposed method is shown [Hanpinitsak et al., 2016].

11 GHz band MIMO channel measurements are conducted in a line-of-sight (LoS) indoor environment to clarify the characteristics of diffuse scatterings in the higher frequency band. The frequency, angular, and the polarization domain dense multipath component propagation parameters are estimated by using the RiMAX-based estimator. The result is expected to be utilized for the novel MIMO channel model proposal in the higher frequency band that includes the contribution of dense multipath components [Saito et al., 2016].

C. Formulations of Mobile Propagation

A formulation model for generating path shadowing number due to pedestrian walking in sidewalks of a straight road is presented. It is shown that the path shadowing number can be used in an evaluation of path shadowing loss due to moving people [Nishii et al., 2014].

D. Machine-to-Machine/Infrastructure Propagation

A regression formula of propagation loss in obliquely crossed road for Inter-vehicle communications is proposed. It is revealed that the angle between two straight roads is a variable parameter, but there is no shadowing in any propagation path. [Kanda et al., 2014].

E. Indoor/Outdoor-to-Indoor Propagation

A new method that uses radio data obtained from users' daily lives to estimate material parameters for precisely modeling indoor radio propagation is presented. Experimental evaluations demonstrated it decreased the number of data items needing to be collected [Inomata et al., 2014].

An indoor propagation model for TV white space (TVWS) is developed, which is useful for evaluating secondary-secondary interference in TVWS scenarios, and its empirical parameters are derived according to measurement results. The proposed model is based on components of free space path loss, penetration losses of walls and floors, an attenuation coefficient against distance, and an attenuation constant [Yamada et al., 2014a].

The characteristics of direct and scattered waves based on a measurement at 3.35 GHz in an indoor environment are investigated. The characteristics of each scattered ray such as the received level, delay time, and azimuth angle of arrival (AOA) are shown [Kitao et al., 2014]. In order to take the impact of pedestrians on the channel model into consideration, the estimation method of clusters' power variation properties is presented. The method is based on the MIMO channel sounding experiments in a cafeteria in a weekday lunch time in the 3 GHz band assuming the use of LTE based cellular systems [Saito et al., 2014e].

A spatio-temporal channel model is proposed based on measurement channel data obtained at 3.35 GHz in an indoor environment. The model includes the characteristics of each scattered ray such as the received level, delay and azimuth angle of arrival (AOA). The model represents these characteristics by a log normal distribution and gradient linear lines [Kitao et al., 2015a]. The large scale parameters of wideband multipath channels based on extensive measurement campaigns in various indoor environments are presented. The measurements are conducted with a wideband multiple-input multiple-output channel sounder having a bandwidth of 400 MHz at 11 GHz. Polarization characteristics of path-loss, shadowing, cross-polarization power ratio, delay spread and coherence bandwidth are characterized [Kim, et al., 2014].

In order to evaluate outdoor-to-indoor propagation characteristics, the performance of a theoretical analysis method that is a hybrid of ray-tracing and physical optics is evaluated with respect to the calculation accuracy. As the results, the impact on the accuracy and computational burden are shown [Imai et al., 2014b]. Elevation directional channel properties at a base station (BS) in a microcell outdoor-to-indoor environment which is significant for 3D-MIMO using 2D array antennas are investigated based on measurement results using a vector channel sounder. The properties of the elevation angular spread (ESD) and mean Elevation angle of Departure (EoD) are specifically shown [Omaki et al., 2014a].

Investigations on an outdoor-to-indoor penetration loss between measured result and the result by a hybrid method of ray-tracing (RT) and physical optics (PO) (RT-PO method) are presented. It is shown that the measured result and RT-PO method agree well with each other than the 3GPP model [Kimoto et al., 2015a]. The frequency characteristic of radio propagation loss at the bands from 0.8 to 4.7 GHz in outdoor-to-indoor environment is studied. As the results, a new path loss model modified from 3GPP model considering an indoor penetration loss factor is presented [Kimoto et al., 2015b]. A new model for predicting the outdoor-to-indoor penetration loss is presented. The model can predict by the simple equation with only the incident angle and the transmit distance and show more accurate estimation than the 3GPP model [Nishimori et al., 2015], [Kimoto et al., 2016].

In order to clarify frequency dependency of path loss and channel properties, outdoor-to-indoor path loss characteristics are investigated based on the measurement from 0.8 to 37 GHz in urban microcell scenario. An extension of conventional O2I models is presented [Imai et al., 2016a]. Outdoor-to-indoor channel characteristics at 20 GHz band are clarified based on the measurement using a channel sounder with a 50 MHz bandwidth. The propagation mechanism is also analyzed based on estimating single scattering positions of multipath [Imai et al., 2016b], [Tran et al., 2016]. An O2I channel measurement result at 58.5 GHz assuming an outdoor hotspot access scenario in 5G mobile systems and WLANs is presented. Comparing the measurement results with ray-tracing simulation, dominant propagation mechanisms are identified. From the analysis, the propagation mechanism of eight multi-path clusters is identified [Kim, et al., 2016a].

F. Blocking Effect of Human Bodies

Evaluations of 4x2 MIMO channel performance as propagation paths are usually shadowed by moving people in an indoor environment is evaluated. It is described that the population density is a variable parameter in it [Mugiura et al., 2014].

A method of analyzing characteristics of human body shadowing based on the calculation of the scattering from a lossy dielectric flat plates using uniform geometrical theory of diffraction (UTD) is presented. The effectiveness of the proposed method are shown by comparing between calculated results and measured results [Tran et al., 2014b, 2015].

Long-term fading, shadow fading, and fast fading characteristics of path loss at 4.7 and 26.4 GHz in a crowded area with pedestrians are presented. It is revealed that these fading characteristics of measured path loss broadly match the Nakagami-Rice distribution, and K-factor becomes low with the increase in frequency from the results of the analysis with two frequencies [Nakamura et al., 2016].

Frequency characteristics of change in received level when pedestrians walk in indoor environment are investigated experimentally to clarify influence of human body shadowing in higher frequency band. Measurements are performed at 0.81GHz, 2.2 GHz and 19.85 GHz in indoor environment [Kitao et al., 2016]

(N. Kita)

G. Millimeter-wave, THz and Optical Propagation

Assuming the adoption of the higher frequency band for future cellular systems than the currently used spectrum such as 800MHz, 2GHz, 3GHz, etc., the radio propagation in the millimeter-wave in cellular mobile radio system has been actively studied.

A model for predicting path loss from the microwave band to the millimeter wave band for street microcell environments is presented. Developed on the basis of measurement results, the model uses visibility to predict path loss characteristics. The model reduces the root mean square errors of prediction results by more than 2.5 dB at bands above 26 GHz, demonstrating its ability to predict measurement results accurately [Sasaki et al., 2015b].

A site general type path loss prediction model for fifth-generation (5G) system radio link design is investigated for the frequency band above 6GHz in a non-line-of-sight (NLOS) microcell environment. Based on measurement data, extending the applicable frequency range of the path loss prediction model for a hexagonal layout in a NLOS microcell environment for under 6 GHz, which is defined in Report ITU-R M.2135, is investigated. The root mean square of the prediction error (RMSE) of the original M.2135 prediction model increases with an increase in frequency; however, the model modifies the frequency term of M.2135 which improves the RMSE at higher frequencies [Kitao et al., 2015b].

The 5G mobile communication systems will benefit immensely with the extension of their operation to millimeter-wave bands. To this end, understanding the system-level performance of millimeter-wave cellular networks carries critical importance. The average signal-to-interference plus noise ratio (SINR) distribution (geometry) performance for indoor and outdoor mobile stations (MSs) in millimeter-wave cellular networks using 3GPP system-level simulations is investigated in a paper. The authors consider urban micro (UMi) and urban macro (UMa) environments for our evaluations. Simulation results show that, when operating at 60 GHz or higher frequencies, almost all the indoor MSs and more than 35% (65%) of outdoor MSs experience geometry performance less than 0 dB, in UMi (UMa) environments [Rupasinghe et al., 2016].

Path loss characteristics in an indoor office environment are also studied. It is clarified that the path loss exponents vary depending on the frequency and the floor height when Tx and Rx are placed on the same floor. A prediction formula is developed for the frequency characteristics of path loss exponents by using the measurement results and it is confirmed that it can predict measurement results more accurately than conventional formulas. In particular, it can improve the RMS prediction error of 3.7 dB in 37 GHz bands [Sasaki et al., 2016a]. Floor penetration loss characteristics and their frequency dependency are analyzed by measuring in multiple frequency bands, including those above 6 GHz, in an indoor office environment. Measurement and analysis results show that the floor penetration loss depends on two dominant components: paths through floors and outside buildings. It was clarified that the characteristics of these paths determine the frequency dependency of the floor penetration loss [Sasaki et al., 2016b].

Propagation characteristic from outdoor to indoor is another topic of interest in the high frequency band. A paper proposed the path loss model which can cover the high frequency bands above the 6 GHz. The path loss characteristics are analyzed on the basis of measurement results obtained using the 8 to 37 GHz band in outdoor-to-indoor environments. It is clarified that the characteristics depend on incident angle of azimuth, incident angle of elevation and frequency. By taking these dependencies into account, the proposed model can decrease the root mean square error of prediction results to about from 2 dB to 6 dB in the 8 to 37 GHz band [Inomata et al., 2015]. The measurement results of outdoor-to-indoor path loss characteristics in multiple frequency bands from microwave to millimeter wave are described. It is clarified in the paper that the path loss characteristics depend on frequency. Moreover, ray tracing is used to analyze the propagation phenomena causing frequency dependence. A comparison between measured and calculated results clarified the dominant paths that are multiple reflected at an outdoor building and then diffracted into building. These results show that the value of the root mean square error is about from 4 dB to 8 dB in 0.8 to 37 GHz band. The authors confirm that these paths are dominant and affect the frequency dependence of outdoor-to-indoor path loss [Inomata et al., 2016].

High frequencies such as high SHF (above 6 GHz) and EHF (30-100 GHz) are expected to be applied for outdoor or indoor small cell; hence it is critically important to investigate the characteristics of propagation and model it. Additionally, characteristics of ‘Outdoor-to-Indoor (O2I) propagation’ and its modelling are necessary from system design point of view. A report presents extensive investigation for “Extension of 3GPP model below 6 GHz” [Imai et al., 2015b].

The frequency dependency characteristics of path loss was obtained based on the measured data. In order to analyze the frequency dependency, measurements are carried out with multiple frequency bands from 0.8 GHz to 37.1 GHz. The measurement environments are a street canyon and an indoor office, which respectively correspond to an urban micro cell and an indoor hot spot of mobile communication system scenarios. On the basis of the obtained measurement results, path loss characteristics are clarified and path loss models are proposed for the street canyon and indoor office environments. The models validity is also verified [Sasaki et al., 2016c].

Fading and shadowing in the high frequency band have also been analyzed. In the high frequency bands, besides the higher propagation losses, the propagation channel tends to suffer more severe shadowing by pedestrians in the environments. Measurements in the 26GHz band was carried out in an indoor quasi-static environment for figuring out the received power characteristics of the upper SHF band. The results show that the more severe received power variation occurred in the 26GHz band compared with the 2GHz band [Saito et al., 2014a]. Tran et al. [2014a] clarify basic propagation characteristics and shadowing loss due to human body shadowing in the SHF (over 6 GHz) bands based on measurements [Tran et al., 2014a].

One important issue to enable a high frequency (over 6GHz) band is clarifying the propagation characteristics in the bands. A paper presents the channel characteristics in the 20 GHz band for an indoor office environment. Measurements are performed using a channel sounder in the 20 GHz band with a 50-MHz-bandwidth orthogonal frequency-division multiplexing signal. A 19 dBi horn antenna is rotated in azimuth and elevation on the receiver side in order to measure the power delay profile (PDP) at each angle. By combining all the PDPs, the channel characteristics are estimated as if using an omni-directional antenna. The measured and estimated results show that the path loss values are lower than those in free space. The averages of the delay spread, azimuth angle spread, and elevation angle spread are 60.4 ns, 64.7 degrees, and 3.6 degrees, respectively. The standard deviations of the delay spread, azimuth angle spread, and elevation angle spread are 9.7 ns, 10.7 degrees, and 3.1 degrees, respectively [Tran et al., 2015b].

Ray-tracing is one of the most general method to analyze propagation characteristics in wireless communication systems. The usability of the method in the high frequency was examined. In a paper, the characteristics of radio propagation loss in a street cell environment for high-SHF and EHF bands are investigated using Ray-Tracing (RT) method. The accuracy of RT calculation is evaluated by comparing with measurement result. The trends of the accuracy are different between Line-of-Site (LOS) and Non Line-of-Site (NLOS) situations and between different routes. For further investigation, the number of rays in RT simulation is studied for the purpose of improving the accuracy [Omaki et al., 2014a, 2015a, 2015b].

Frequency identification for the mobile communication system in 275-450 GHz was started in the World Radiocommunication Conference 2015. Therefore, propagation model is required to enable sharing and compatibility studies between the land-mobile, fixed and passive services. In this study, indoor propagation characteristics at 300 GHz is measured and analyzed to develop path loss models. Measurements have been carried out in office and corridor environments in line-of-sight situation, and the path loss coefficients are extracted. The coefficient of office environment is roughly identical with the free space loss of N=20, and the coefficient of corridor environment was slightly decreased to N=19.5 [Sawada et al., 2016].

Dominant propagation mechanisms in an outdoor open area environment through the channel measurement and ray-tracing simulation at an mm-wave band of 58.5 GHz assuming an outdoor hotspot access scenario in 5G mobile systems and WLANs are presented. Extracted statistical channel model parameters of the random components by using ray-tracing simulation are also presented [Kim et al., 2016b].

H. Others

MIMO-related propagation studies were actively carried out in this period. Massive MIMO enables the improvement on the transmission rate without increasing the burden on the signal processing by employing a large number of antennas at a base station. Even if the interference cancellation techniques are not employed, the interference signal can be mitigated thanks to a narrow beam by the massive MIMO transmission. An actual propagation channel was measured by using a wideband channel sounder with 96 elements in 2 GHz band at small cell environment. Moreover, the effectiveness of the interference rejection when using antenna sector selection was verified [Kataoka et al., 2014]. Real propagation channels for massive MIMO are measured by using a wideband channel sounder with horn antenna in 20-GHz band in an actual indoor propagation environment. Moreover, the performance of the interference rejection is evaluated when virtual circular array antenna with 24 elements is assumed [Kataoka et al., 2015a].

The interference reduction performance between zero forcing (ZF) and maximum ratio combining is compared. Moreover, the characteristics with the smaller number of antennas at the base station are clarified, in order to simplify the burden of signal processing on the ZF algorithm [Kataoka et al., 2015b]. An actual propagation channel was measured by using a wideband channel sounder with cylindrical array in 2 GHz band at a microcell environment. Moreover, the effectiveness of the interference rejection is verified when using the hybrid algorithm which employs the MRC on the analog part and zero forcing (ZF) in the digital processing part [Kataoka et al., 2015c, 2015d, 2015e].

The interference reduction performance is investigated when considering the cylindrical array based massive MIMO in a real micro cell environment. The channel state information is obtained by using a wideband channel sounder in a 2 GHz band at an urban area. In the paper, the interference reduction performance between zero forcing (ZF) and maximum ratio combining is compared. The characteristics with the smaller number of antennas at the base station is also investigated, in order to simplify the burden of signal processing on the ZF algorithm [Nishimori et al., 2016].

2GHz MIMO channel measurement was carried out in an urban railway station vicinity. As the result of comparison between the measurement result and ITU-R M.2135 channel model, it was shown that the channel capacity of LoS case was underestimated in the channel model. In the NLoS case, the variability of the capacity was different when the BS antenna spacing was changed [Saito et al, 2014b]. Channel sounding experiments outside a crowded urban railway station are carried out in the 2 GHz band assuming the use of LTE-based cellular systems. To elucidate the influence of pedestrians on the channel properties, the measurements were carried out both in the daytime and in the midnight. The measurements result showed that the received power decreased about 4-5 dB in the daytime due to the shadowing by the pedestrians. In addition, the delay spreads decreased and AoAelv and AoDelv spreads increased in the daytime due to the change of propagation environment caused by the pedestrians [Saito et al., 2014c].

In crowded environments, propagation paths are frequently shadowed by moving objects, such as pedestrians or vehicles. These shadowing effects can cause time variations in the delay and angle-of-arrival (AoA) characteristics of a channel. A method for modeling the shadowing effects of pedestrians in a cluster-based channel model is proposed. The proposed method uses cluster power variations to model the time-varying channel properties. A novel method for estimating the cluster power variation properties from measured data is also proposed. In order to validate the proposed method, channel sounding in the 3GHz band is conducted in a cafeteria during lunchtime. The results for the K parameter, delay spreads, and AoA azimuth spreads are compared for the measured data and the channel data generated using the proposed method. The results indicate that the time-varying delay-AoA characteristics can be effectively modeled using our proposed method [Saito, et al. 2014d].

The user rate performance of massive MIMO small cells in hot-spot areas is evaluated. In particular, with the use of the 28GHz millimeter wave band ray-tracing channel data generated according to the realistic map in Shinjuku, Tokyo, Japan, the user-specific rates in an area of 150 m × 120 m is investigated. The results show promising rate performances with the use of a variety of beamforming schemes in both cellular and distributed manners [Wang et al., 2016].

The performance analysis of a proposed auto-regressive (AR) model-based linear predictor algorithm with Kalman filtering (KF) is reported in a paper. The relationship between the optimum

AR order and the channel correlation coefficient is investigated by means of the Akaike Information Criterion (AIC). Through our analysis, 2nd-order differential model based on the AR model-based linear predictor algorithm with KF has the best performance and prediction accuracy. Its performance is about 0.5dB better than a linear predictor algorithm [Yamada et al., 2014b].

To develop an accurate and reliable method to estimate field distributions in train cars so as to advance radio link design of wireless LANs operating inside the cars, effects of reflected waves due to tunnel wall and/or train passing on opposite track on propagation characteristics inside the high-speed train cars in a typical railway tunnel is studied. Field distributions created by a 2.4 GHz band wireless transmitter inside cars are analyzed and exemplary propagation characteristics are determined statistically from large-scale numerical analysis results [Shirafune et al., 2014, 2015].

A method named Double Aperture Field Method for calculating electrical field passing through two apertures between transmitting and receiving points is proposed. The comparison between calculations and experiments data carrying out in an anechoic chamber is shown. The proposed method has excellent agreement with experiments [Hasegawa and Taga, 2015]. Also formulations named Single Aperture Field Method is proposed for calculating electrical field passing through apertures between transmitting and receiving points. This formulation can be used with ray tracing method, because of the propagation path through the aperture radiated from a center of aperture as a secondary source point. The comparison between calculations and experiments carrying out in an anechoic chamber is shown. The proposed method has excellent agreement with experiments [Kondo and Taga, 2015].

(H. Iwai)

F2 Remote Sensing
F2.1 Atmosphere

A. Ground-based Remote Sensing Studies

Atmospheric radars generally called MST (mesosphere, stratosphere, and troposphere) radars, ST (stratosphere and troposphere) radars, or Wind Profiling Radars (WPR) are capable of continuously monitoring three-dimensional winds, waves, turbulence, and atmospheric stability over the wide altitude range. This excellent capability has been used extensively to study various dynamical disturbances in the Earth's atmosphere.

The middle and upper atmosphere radar (MU radar) is a major observation facility in the Shigaraki MU Observatory of the Research Institute for Sustainable Humanosphere (RISH), Kyoto University. The MU radar is an excellent system having 25 receiver channels to carry out observation using a spaced antenna (SA) technique. 50MHz band atmospheric radars can detect clear air echoes and hydrometeor echoes simultaneously. However, in order to calculate spectral parameters of the clear air echo accurately, the clear air echo must be separated from the hydrometeor echo well. Gan et al. [2015] proposed methods (top method and two-echo method) for calculating the spectral parameters in precipitation region. The top and two-echo methods are used when raindrops or solid hydrometeors with small and large echo intensities exist, respectively. Measurement results obtained by the vertical beam of MU radar during a precipitation event on 26 October 2009 demonstrate that the top and two-echo methods are useful for reducing errors of spectral parameters.

Strong meteor trail echoes are interferences in the wind velocity estimates made from mesosphere radar observations. Contaminated spectra are detected by their discontinuity and are removed at the risk of greater fluctuations of spectra, leading to a severe reduction of the signal-to-noise ratio (SNR) and inaccurate wind estimates for weak atmospheric echoes. Hashimoto et al. [2014] presents an adaptive signal processing technique for the suppression of spectral contaminations by meteor trail echoes. The method is based on the norm-constrained and directionally constrained minimization of power (NC-DCMP), which balances the capability of canceling the clutter and the robustness of beam shaping, at the cost of a slight decrease in the SNR, which can be determined in advance. Simulation results show that with a 3-dB decrease of the SNR being allowed, the method improves the signal-to-interference ratio (SIR) by 15 dB, giving wind estimates that are about 8 m/s better in terms of root-mean-square error and providing 4 times as wide an observable range when compared with the results of the ordinary non-adaptive beamforming method. The results for an actual observation show that the improvement of both the SIR and the observable range are achieved as in the simulations, which implies that the method should provide the simulated accuracy for the estimation of wind velocity from actual observations.

Chen et al. [2016] reports the first use of a multi-frequency range imaging (RIM) technique for observing E-region field-aligned irregularities (FAIs) in the mid-latitude ionosphere. The MU radar was used to conduct experiments with five equally spaced frequencies between 46.25 and 46.75 MHz 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.

Many experimental studies were conducted using the MU radar. The refractivity turbulence in the troposphere was detected and quantified from radiosonde and VHF band radar data [Luce et al., 2014]. Balloon data processing methods based on Thorpe sorting can be applied for a direct identification of turbulent layers from the in situ profiles. The MU radar can be operated in range-imaging mode for detecting and monitoring turbulent layers at high time and range resolutions (of the order of 10s and a few tens of meters, respectively). It is demonstrated that radar and balloon observations of turbulence are consistent between each other and that new insights on tropospheric turbulence can be obtained by the two techniques as stand-alone systems.

Deep turbulent layers can sometimes be observed on the underside of clouds that extend above upper-level frontal zones. The numerically simulated midlevel cloud-base turbulence (MCT) was compared with a turbulent layer detected by the MU radar during the passage of an upper-level front topped by clouds [Kudo et al., 2015]. The simulations were initialized with thermodynamic parameters derived from simultaneous radiosonde data. It was found that some important features of the simulated MCT (such as the scale of convection and vertical wind velocity perturbations) agreed quantitatively well with those reported in radar observations.

Based on the Program of the Antarctic Syowa MST/IS Radar, the first Mesosphere–Stratosphere–Troposphere/Incoherent Scatter (MST/IS) radar in the Antarctic region, called PANSY radar, has been installed. Sato et al. [2014] reports the project's scientific objectives, technical descriptions, and the preliminary results of observations made to date. The PANSY radar is designed to clarify the role of atmospheric gravity waves at high latitudes in the momentum budget of the global circulation in the troposphere, stratosphere and mesosphere, and to explore the dynamical aspects of unique polar phenomena such as polar mesospheric clouds (PMC) and polar stratospheric clouds (PSC). The katabatic winds as a branch of Antarctic tropospheric circulation and as an important source of gravity waves are also of special interest. Moreover, strong and sporadic energy inputs from the magnetosphere by energetic particles and field aligned currents can be quantitatively assessed by the broad height coverage of the radar which extends from the lower troposphere to the upper ionosphere.

The PANSY radar is a large VHF monostatic pulse Doppler radar operating at 47 MHz, consisting of an active phased array of 1045 Yagi antennas and an equivalent number of transmit–receive (TR) modules with a total peak output power of 500 kW. From engineering points of view, the radar had to overcome restrictions related to the severe environments of Antarctic research, such as very strong winds, limited power availability, short construction periods, and limited manpower availability. These problems were resolved through the adoption of specially designed class-E amplifiers, light weight and tough antenna elements, and versatile antenna arrangements.

At the first stage, the PANSY radar was installed at Syowa Station (69.0S, 39.6E) in early 2011, and is currently operating with 228 antennas and modules. Although the radar is currently operating with only about a quarter of its full designed system components, interesting results on the Antarctic troposphere, stratosphere and mesosphere, such as gravity waves, multiple tropopauses associated with a severe snow storm in the troposphere and stratosphere, and polar mesosphere summer echoes (PMSE) have been obtained.

Characteristically strong vertical wind disturbances (VWDs) with magnitudes larger than 1m/s were observed in the Antarctic troposphere using PANSY during 15–19 June 2012 [Tomikawa et al., 2015]. In the same period, two synoptic-scale cyclones approached Syowa Station and caused a strong wind event (SWE) at the surface. The VWDs observed during the SWE at Syowa Station had a nearly standing (i.e., no phase tilt with height) phase structure up to the tropopause and a power spectrum proportional to the 25/3 power of frequency. On the other hand, the observed VWDs were not associated with systematic horizontal momentum fluxes. Meteorological fields around Syowa Station during the SWE were successfully simulated using the Nonhydrostatic Icosahedral Atmospheric Model (NICAM). A strong VWD was also simulated at the model grid of 70.0S, 40.0E in NICAM, which had a standing phase structure similar to the observed ones. An analysis based on the Froude number showed that the simulated VWD was likely due to a hydraulic jump leeward of the coastal mountain ridge. The Scorer parameter analysis indicated that the observed VWDs at Syowa Station during 16–17 June 2012 were likely due to the hydraulic jump similar to that in NICAM. On the other hand, a possibility of lee waves was also suggested for the VWD observed on 18 June 2012.

Multiple tropopauses (MTs) defined by the World Meteorological Organization are frequently detected from autumn to spring at Syowa Station [Shibuya et al., 2015]. The dynamical mechanism of MT events was examined by observations of PANSY, and of radiosondes on 8–11 April 2013. The MT structure above the first tropopause is composed of strong temperature fluctuations. By a detailed analysis of observed three-dimensional wind and temperature fluctuation components, it is shown that the phase and amplitude relations between these components are consistent with the theoretical characteristics of linear inertia–gravity waves (IGWs). Numerical simulations were performed by using a nonhydrostatic model. The simulated MT structures and IGW parameters agree well with the observation. In the analysis using the numerical simulation data, it is seen that IGWs were generated around 65S, 15E and around 70S, 15E, propagated eastward, and reached the region above Syowa Station when the MT event was observed. These IGWs were likely radiated spontaneously from the upper-tropospheric flow around 65S, 15E and were forced by strong southerly surface winds over steep topography (70S, 15E). The MT occurrence is attributable to strong IGWs and the low mean static stability in the polar winter lower stratosphere. It is also shown that nonorographic gravity waves associated with the tropopause folding event contribute to 40% of the momentum fluxes, as shown by a gravity wave–resolving general circulation model in the lower stratosphere around 65S. This result indicates that they are one of the key components for solving the coldbias problem found in most climate models.

Nishiyama et al. [2015] reported height and time variations in polar mesosphere winter echoes (PMWE) based on the PANSY radar observations. PMWE were identified for 110 days from March to September 2013. PMWE occurrence frequency increased abruptly in May when two solar proton events occurred. PMWE were also observed even during periods without any solar proton events, suggesting that a possible cause of the PMWE is ionization by energetic electron precipitations. The monthly mean PMWE characteristics showed that occurrence of PMWE were mainly restricted to sunlit time. This fact indicates that electrons detached from negatively charged particles play an important role. While PMWE below 72 km in altitude completely disappeared before sunset, it was detected above that altitude for a few hours even after sunset. This height dependence in the altitude range of 60–80 km can be explained qualitatively by empirical effective recombination rates.

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 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 5 resolution of 30 minutes) are used to derive statistical analysis of the properties of IGWs with short vertical wavelengths (≤ 4km) and ground-based periods longer than 4 hours in the lowermost stratosphere (height range 10km to 12km) with the help of the hodograph method [Mihalikova et al., 2016]. 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 10 parameter (f) to intrinsic frequency (ωˆ) distribution. Average of f /ωˆ for the winter season is 0.40 and for the summer season 0.45 and the average horizontal wavelengths are 140km and 160km respectively. Vertical wavelengths have an average of 1.85km 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 dual-beam 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 20 with large variance of horizontal perturbation velocities, and this is shown in a number of cases.

The 47-MHz Equatorial Atmosphere Radar (EAR) has been operated at Kototabang (0.20S geographic lat., 100.32E geographic lon., and 10.4S geomagnetic lat.), West Sumatra, Indonesia since 2001 and has been very successfully used for the study of equatorial atmosphere dynamics. Observations of wind components and convection systems were made using suite of instruments centered on the EAR during April-May 2004 in the first Coupling Processes in Equatorial Atmosphere (CPEA) campaign [Dhaka et al., 2014]. Analysis of five convection events revealed that vertical wavelength of gravity waves mostly dominated in the range of 1-3 km between 10 and 20 km heights immediately after passing the convective storm over the radar sites.

Using the fan sector backscatter maps of 47 MHz EAR, the spatial and temporal evolution of equatorial plasma bubbles (EPBs) were examined to classify the evolutionary-type EPBs from those which formed elsewhere and drifted into the field of view of radar [Ajith et al., 2015]. In general, both the evolving-type and drifting-in EPBs exhibit predominance during the post-sunset hours of equinoxes and December solstices. The responsible mechanisms for the genesis of fresh EPBs during post-midnight hours were discussed in light of equatorward meridional winds in the presence of weak westward electric fields.

The unusual evolution of fresh and intense field-aligned irregularities (FAI) near sunrise terminator which further sustained for more than 90 min of post-sunrise period was observed by EAR during a minor geomagnetic storm period [Tulasi et al., 2015a]. These FAI echoes were initially observed around 250–350 km altitudes, growing upward under eastward polarization electric fields indicating the plasma bubbles that are fully depleted along the flux tube. A minor geomagnetic storm was in progress which did not appear to cause any large electric field perturbations at preceding post-sunset to midnight period over Indonesian sector.

Vertical rise velocities of post-midnight 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 EAR for 3 years starting in May 2010 [Dao et al., 2016]. Fifteen freshly growing FAIs ware found at post-midnight between May and August during the 3 years. The rise velocities of FAIs are smaller at post-midnight than at post-sunset, and most post-midnight FAIs do not exceed an altitude of 450 km.

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 pre-midnight 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 [Tulasi et al., 2015b]. In contrast, at few degrees east in the pre-midnight sector (Thailand-Indonesian longitudes), no significant height rise and/or EPB activity has been observed. This study brings out the significantly enhanced equatorial zonal electric field in response to PPEF that is uniquely confined to dusk sector.

To reveal the temporal change of the equatorial ionization anomaly (EIA) asymmetry, a multipoint satellite-ground beacon experiment was conducted along the meridional plane of the Thailand–Indonesia sector. Successive passes captured rapid evolution of EIA asymmetry, especially during geomagnetic disturbances [Watthanasangmechai et al., 2015]. The penetrating electric fields that occur during geomagnetic disturbed days are not the cause of the asymmetry. Instead, high background TEC associated with an intense electric field empowers the neutral wind to produce severe asymmetry of the EIA. Such rapid evolution of EIA asymmetry was not seen during nighttime, when meridional wind mainly controlled the asymmetric structures.

The solar energy can mainly be divided into two categories: the solar radiation and the solar wind. The former maximizes at the equator, generating various disturbances over a wide height range and causing vertical coupling processes of the atmosphere between the troposphere and middle and upper atmospheres by upward propagating atmospheric waves. The energy and material flows that occur in all height regions of the equatorial atmosphere are named as “Equatorial Fountain.” While, the electromagnetic energy and high-energy plasma particles in the solar wind converge into the polar region through geomagnetic fields. Tsuda et al. [2016] propose to clarify these overall coupling processes in the solar-terrestrial system from the bottom and from above through high-resolution observations at key latitudes in the equator and in the polar region. In this proposal, construction of large radar with active phased array antenna, called the Equatorial Middle and Upper atmosphere (EMU) radar, is planned to construct in west Sumatra, Indonesia and participate in construction of the EISCAT_3D radar in northern Scandinavia are planned. The development of a global observation network of compact radio and optical remote sensing equipment from the equator to polar region is also planned.

Predawn plasma bubble was detected as deep plasma depletion by GNU Radio Beacon Receiver (GRBR) network and in situ measurement onboard Defense Meteorological Satellite Program F15 (DMSPF15) satellite and was confirmed by sparse GPS network in Southeast Asia [Watthanasangmechai et al., 2016]. In addition to the deep depletion, the GPS network revealed the coexisting submesoscale irregularities. A deep depletion is regarded as a primary bubble. Submesoscale irregularities are regarded as secondary bubbles.

A new digital receiver was developed for a 1.3-GHz range imaging atmospheric radar [Yamamoto et al., 2013]. The digital receiver comprises a general-purpose software-defined radio receiver and a commercial personal computer. Because the program code for real-time signal processing is written in a popular programming language (C++) and widely used libraries, the signal processing is easy to implement, reconfigure, and reuse. From radar experiments using a 1 micro-sec sub-pulse width and 1 MHz frequency span, it is demonstrated that range imaging in combination with oversampling, which was implemented for the first time by the digital receiver, is able to resolve the fine-scale structure of turbulence with a vertical scale as small as 100 m or finer.

Using numerical simulations, a method for calculating the spectral parameters from Doppler spectra collected by high-resolution wind profiler radars (WPRs) was investigated [Gan et al., 2014]. The proposed method has two steps. In the first step, the echo range (Recho), in which the Doppler spectrum point with peak intensity is contained and all the smoothed Doppler spectrum points have intensities that are greater than the noise intensity, was determined. For producing the smoothed Doppler spectrum, a running average with equal weight (RA) was used. In the second step, the spectral parameters were calculated using the Doppler spectrum points within Recho.

Yabuki et al. [2016] had constructed a scanning Raman lidar to observe the cross-sectional distribution of the water vapor mixing ratio and aerosols near the Earth's surface, which are difficult to observe when a conventional Raman lidar system is used. The Raman lidar is designed for a nighttime operating system by employing a ultra-violet (UV) laser source and can measure the water vapor mixing ratio at an altitude up to 7 km using vertically pointing observations. The experimental observations using the scanning lidar were conducted at night in the Shigaraki MU Observatory. The root mean square error (RMSE) between the temporal variations of the water vapor mixing ratio by the scanning Raman lidar and by an in-situ weather sensor equipped with a tethered balloon was 0.17 g/kg at an altitude of 100 m.

B. Space-based Remote Sensing Studies

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) is a successful mission to observe vertical distributions of ozone and other atmospheric constituents in the stratosphere and mesosphere. The SMILES was operated a half year in the winter of 2009/2010 on the Japanese Experiment Module "Kibo" of the International Space Station (ISS). The highly sensitive measurements revealed a small perturbation of the ozone vertical distribution in the mesosphere during a solar eclipse, which provide us a unique opportunity to study the mesospheric ozone photochemistry [Imai et al., 2015a]. In addition to the high sensitivity, the SMILES data has an advantage of diurnal variation measurement due to the non-sun-synchronous orbit of the ISS. From the SMILES data, it becomes widely recognized that the diurnal variation of the ozone distribution causes the sunset-sunrise difference of the ozone mixing ratio measured by the sensors on satellites of sun-synchronous orbit [Sakazaki et al., 2015].

Baron et al. [2015] derived the global distribution of horizontal wind in the stratosphere and mesosphere by estimating the Doppler frequency of the atmospheric emission lines measured by SMILES. Since stratospheric wind measurement is a unique aspect of submillimeter-wave limb sounding, a number of submillimeter sounder for wind observation are now proposed in the world. A concept of the future submillimeter satellite, SMILES-2, is proposed by Japanese group to observe the winds in the stratosphere, mesosphere and lower thermosphere. SMILES-2 will also have a capability of measuring atmospheric constituents. The frequency bands and the sensitivity to the constituents for SMILES-2 were studied [Suzuki et al., 2015].

F2.2 Hydrometeors and Other Particles

A. Ground-based Remote Sensing Studies

For the study of drop size distribution (DSD) of rainfalls, various ground-based instruments such as a 2 dimensional video disdrometer (2DVD) and a disdrometer have been used, to count the number of drops with a finite drop bin size.

Intraseasonal variations of precipitation and its microstructure are investigated using measurements of the Equatorial Atmospheric Radar (EAR) facilities at Kototabang, west Sumatra, Indonesia [Marzuki et al., 2015]. Raindrop size distribution (DSD) observations are obtained from a 2D-Video Disdrometer (2DVD). 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. 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.

B. Space-based Remote Sensing Studies

The Global Precipitation Measurement (GPM) Core Observatory, a joint mission between NASA and the JAXA, was launched on Feb. 27, 2014. Two observation instruments are onboard the core observatory: the Dual-frequency Precipitation Radar (DPR) developed by Japan, and the GPM Microwave Imager (GPM) developed by the U.S. The DPR is a successor of the Precipitation Radar (PR) loaded onto the GPM's predecessor, the Tropical Rainfall Measuring Mission (TRMM). The 35.5 GHz radar (KaPR) was additionally installed onto the PR at 13.6 GHz (KuPR) for high accuracy observation. The role of core observatory is to improve the accuracy of precipitation observation by microwave imagers on a constellation of satellites through simultaneous observations with the radar and the microwave imager. Rain retrieval algorithms for the DPR have been extensively studied by the science team.

Kubota et al. [2014] evaluates “at-launch” codes of DPR precipitation algorithms, which will be used in GPM ground systems at launch, using synthetic data based upon the TRMM PR data. Results from the codes (Version 4.20131010) of the KuPR-only, KaPR-only, and DPR algorithms were compared with “true values” calculated based upon drop size distributions assumed in the synthetic data and standard results from the TRMM algorithms at an altitude of 2 km over the ocean. The results suggest that the underestimation of KaPR algorithm is caused by a problem in the attenuation correction method, which was verified by the improved codes.

A new attenuation correction method called the HB-DFR-SRT method (H-D-S method) has been developed for DPR. The new method is based on Hitschfeld and Bordan’s attenuation correction method (HB method), but the relationship between the specific attenuation k and the effective radar reflectivity factor Ze (k–Ze relationship) is modified by using the dual-frequency ratio (DFR) of Ze and the surface reference technique (SRT). The H-D-S method mitigates the negative bias by means of the SRT. The attenuation correction methods were tested with a simple synthetic DPR dataset [Seto et al., 2015]. The H-D-S method did not produce the best results for both weak and heavy precipitation, but the results are stable. Quantitative evaluation should be done with real DPR measurement datasets.

Awaka et al. [2016] describes the version 4 (V4) of the rain type classification algorithm module for the GPM DPR and some statistical results on the rain type and on the detection of bright band (BB).

F2.3 Land

A. Land Surface

On May 24, 2014, ALOS2, the follow-on satellite of ALOS, was launched. The L-band Synthetic Aperture Radar (PALSAR2) on ALOS2 provides images with the higher resolution (3m) and wider swath (50km) in high resolution mode as compared with the images of former L-band SAR (PALSAR) on ALOS [Yamaguchi et al., 2014a, 2016a, 2016b, Yamaguchi, 2015]. After the launch, the initial functional confirmation and calibration operations were carried out. From November 25, 2014, the regular provision of PALSAR2 observation data has started.

Since PALSAR2 has a function of polarimetric observation by utilizing horizontal (H) and vertical (V) polarized waves both in transmission and reception, full polarimetric data can be obtained. The observed polarimetric data is expected to be utilized for various remote sensing applications.

Moriyama [2015] discusses the polarimetric calibration and assessment of polarimetric data obtained by PALSAR2. The channel imbalance and cross-talks estimated from Amazon's polarimetric data are reported and the polarimetric signatures of trihedral corner reflector before and after polarimetric calibration are shown. Moreover, results from Tomakomai data was compared with that from Amazon data.

Fully polarimetric radar and its utilization and applications to various fields have been investigated. The main topics were focused on the decomposition of fully polarimetric data sets including the model-based three/four-component scattering power decomposition, which tries to incorporate 100% second order statistical polarimetric information [Chen et al., 2014a, 2014b, 2014c, 2014d, Cui et al., 2014a, 2014b, 2015, Xiao et al., 2014, Bhattacharya et al., 2015a, 2015b, Kusano et al., 2015, Yamaguchi et al., 2016c].

Moreover, the expression method of decomposed polarization data with color was investigated by Chiang et al. [2016].

The NICT has developed the second X-band airborne polarimetric and interferometric synthetic aperture radar (Pi-SAR2) system (Yamaguchi et al. [2014b]). The polarimetric calibration has done by Satake et al. [2015].

Because Pi-SAR2 uses two vertically placed antennas for V- and H-polarization, the polarimetric phase is suffered with ground height difference. Moriyama et al. [2014a] proposed the phase compensation method to remove an interfering phase in Pi-SAR-X2 POLSAR data by using the elevation data which is acquired with the slave-V antenna displaced in the cross-track direction (for interferometric observation). Moreover, Moriyama et al. [2014b] proposed the phase compensation method based on the reciprocity principle to remove the phase error in Pi-SAR-X2 POLSAR data due to the mismatch between the flight navigation data and polarimetric raw data. The experimental results showed the usefulness of these proposed methods.

The techniques for analysis using multi-baseline SAR data obtained by Pi-SAR2 including SAR tomography have investigated by Kato et al. [2015], Yamada et al. [2016a, 2016b].

The applications of SAR data to environmental monitoring have been investigated. Applications for snow and glacier monitoring were investigated by Park et al. [2014], Singh et al. [2014a, 2014b], and Surendar et al. [2015]. For landslide, Shibayama et al. [2014, 2015], and Yamaguchi et al. [2016d] were investigated. The applications for flood area and wetland [Yamaguchi et al.,2016e, 2016f], crop information [Singh, 2015], and debris evaluation [Koyama, 2016] were also investigated. The application for urban area monitoring were investigated by Sato et al. [2015, 2016a, 2016b] and Masaka et al. [2015]. These applications were utilized for damage analysis by Kumamoto earthquakes [Yamaguchi et al., 2016g].

The results obtained using remote sensing data have to be compared with ground truth, and some effects of environment also have to be evaluated by field experiments. Such fundamental studies were done by Kobayashi et al. [2014], Watanabe et al. [2014], and Kato et al. [2014, 2015].

B. Subsurface Objects and Landmine Detection

During the past 80 years, ground-penetrating radar (GPR) has evolved from a skeptically received glacier sounder to a full multicomponent 3D volume-imaging and characterization device. Because of its high resolution, GPR is a valuable tool for quantifying subsurface heterogeneity, and its ability to see nonmetallic and metallic objects makes it a useful mapping tool to detect, localize, and characterize buried objects. To improve the range resolution, the UWB antenna system has been investigated [Liu et al., 2013]. To improve the ability to linear object detection, the hybrid dual-polarization system has also investigated [Liu et al., 2015]. The signal processing of GPR has also investigated for improvements tailored to actual situations [Feng et al., 2014, Yi et al., 2016]. Karlina et al. [2016] applied the compressive sensing to land mine detection. Not only to detect, but also to map UXOs, the self-tracking total station with electromagnetic sensor has been investigated [Takahashi et al., 2014a].

The land mime detection using GPR is influenced from the interior change of soil property [Takahashi et al., 2014]. The ability to detect the change of soil property has been applied to the interior soil heterogeneity [Takahashi et al., 2015, Takamura et al ,2016].

The GPR is being used for various purposes. Liu et al. [2014a] measure the thickness of snow and ice. Zhu et al. [2014] applied the GPR for tree roots measurement. Liu et al. [2014b] applied for concrete thickness measurement.

(A. Nadai)

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