COMMISSION F: Wave Propagation and Remote Sensing (November 2007 – October 2010)

Edited by Yoshio Yamaguchi

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A. Effect of Precipitation

Terrestrial radio systems are expected to provide broadband services economically. The millimeter-wave has been received substantial attention because of its high-speed data transmission capability and generation of new frequency resource. One of disadvantages is large rain attenuation. But the large rain attenuation can be used for estimation of rain rate. This paper presents the possibility of rain rate estimation using the measured rain attenuation in the 25GHz band. The proposed method can be used for the accident prevention system for intensive heavy rain [Hirano et al., 2010].

Rain fade dynamics is one of the important characteristics for a millimeter-band radio system design. The rain event occurrence and the duration of rain rate are basic parameters in the rain fade study. It is reported that the applicability of exponential types of formula to estimate the number of rain events for a temperate climatic zone. As a generalized exponential distribution, the Weibull distribution is also examined. The applicability of the lognormal formula to a tropical area is reconsidered. The applicability of the exponential type of formula, which includes the Weibull distribution, is studied using measured data obtained in a temperate climatic zone. The results indicate that the exponential type of formula can be applied to estimate the annual number of rain events in a range including tropical to temperate climate zones. A solution is also proposed that employs a lognormal formula to avoid the inconvenience caused by a peak in the estimated values [Sato, 2008].

B. Effect of Atmosphere

Atmospheric effect such as refractivity variation influences especially on long distance radio systems.

Measurement results of fading characteristics in a fixed radio link in the frequency band of 4 to 6 GHz for a period of two years are reported. Based on the results, the relationship between the occurrence factor of multipath fading and some parameters of the fade duration distribution was clarified, and a new method for estimating the outage intensity (OI) due to multipath fading was proposed [Ito et al., 2010].

Interference characteristics are also affected by the atmospheric condition. In order to evaluate the interference level for frequency sharing in the microwave band, conducting propagation studies in a low altitude atmospheric layer is important. A long distance propagation test in a coastal area is performed and the enhancement is evaluated using an existing estimation method. Diurnal characteristics of the interference level are also described. The propagation mechanism is also studied and a method to evaluate the effect of irregular reflection is presented [Sotoyama et al., 2010].

According to the propagation study on a over water path, propagation characteristics over the Seto Inland Sea are evaluated based on actual measurement data for 18 months. As a result, it was clarified that we could estimate characteristics of UHF band radio propagation over the Seto Inland Sea by use of Two-Ray model with taking into account variations of atmosphere refraction and sea level [Iwami et al., 2009].

In the case of observing non-line-of-sight FM radio waves, the atmospheric refractivity on the propagation path should be considered. It is described the propagation characteristics of non-line-of-sight FM radio waves of 88.0MHz from Oita and 83.2MHz from Miyazaki observed at Kajigamori for 3 years. From those observational results, it was found that the received levels of non-line-of-sight FM radio waves had seasonal variations in their fluctuations according to the M profiles [Yoshida et al., 2010].

For the purpose of clarifying some relationships between earthquake activities and the propagation characteristics of FM waves, over-horizon FM broadcasting waves at Niijima near the focal region of the anticipated Tokai Earthquake had been observed. It was concluded that affections of meteorological conditions should be considered to observe earthquake activities by over-horizon FM broadcasting waves [Higashi et al., 2009]. It was the first opportunity to observe characteristics of the FM radio wave propagated over the epicenter. The observation system observed fluctuations of the FM radio wave of 82.3MHz on the two Niigata Prefecture earthquakes on October 23 in 2004 and on July 16 in 2007. From carefully checking the data, it was concluded that some EM anomalies were not due to seismic but meteorological phenomena [Yoshida et al., 2010a].

C. Others

The microwave band fixed wireless access (FWA) systems are expected to operate in NLOS environments. The measurements to obtain characteristics of DOA at subscriber station in suburban area for NLOS-FWA systems were carried out. The measurement results were presented and a DOA model for microwave band FWA in NLOS environment was proposed [Ito et al., 2008].

In order to improve the detection performance in a human detection system using TV waves, we have studied the new human detection method with the time difference decision, which could extract the maximum fluctuation levels obtained in multiple different time differences. It was clarified that the new detection method could achieve 90% detection probability by use of 1-second sampling data of received level for 8 seconds, even if the received levels were depending on the Nakagami-Rice distribution with the parameter K of 10 dB [Nishi et al., 2010]. The human detection system around a detached house using UHF band transmitters is newly proposed, for the purpose of crime-prevention on the premises. In this system, 400 MHz band or 800 MHz band specified low power radio stations were used as radio transmitters. From the measurement results, it was found that both 400 MHz and 800 MHz band system were able to detect human motion around the detached house and that the detection probabilities were over 80 % in most areas on the premises [Nishi et al., 2010a].

F1.2 Satellite Radio System

A. Effects of Rain

The Frequency band from 21.4 to 22 GHz is allocated to Broadcasting Satellite Services (BSS) in Europe and Asia (that is Region 1 and 3 countries categorized by ITU-R). Satellite broadcasting in this band is expected to transmit large-capacity signals planned in the future advanced broadcasting services. Especially in Japan, ultra high definition TV called Super Hi-Vision (SHV) was proposed. Nihon Hoso Kyokai (NHK), or Japan Broadcasting Corporation has been developing cameras, projectors, disk recorders, and audio equipment for the SHV. Several SHV programs have been produced with these pieces of equipment and the transmission experiments using the SHV signals via satellite were demonstrated in some exhibitions. However, the 21-GHz band suffers from large amounts of rain attenuation. In this regards, European Space Agency (ESA) and NHK have been studying fading mitigation techniques, respectively. In order to compensate rain attenuation, the radiation power is increased locally in the area of heavy rainfall while keeping uniform power in the other whole area with a same frequency.

To design such a satellite broadcasting system, it is necessary to evaluate service availability when using the locally increased beam technique. The rain attenuation data should be derived from the rainfall rate data. A method to transform rainfall rate into rain attenuation in the 21 GHz band was developed. Then, they the simulation that applied the method to the analysis of the service availability for an example phased array antenna configuration was performed. The results confirmed the service availability increased with the locally increased beam technique [Nakazawa et al., 2008].

New method to control the radiation pattern dynamically in accordance with the movement of the rain area assuming array-fed reflector antenna using 61 horns and a reflector with the aperture diameter of 2.2m was investigated. Then they compared the number of the outage areas using dynamically controlled radiation pattern formed by the array-fed reflector antenna with that using static radiation pattern formed by shaped reflector antenna while assuming the same input power to the antenna. According to the simulation during 7 days, the accumulated number of outage points using dynamic radiation pattern was reduced to less than 50% compared to that using static radiation pattern [Nakazawa et al., 2010a].

It is effective for improving the service availability to adopt the fading mitigation technique in this band. ESA and NHK share the same concept of fading mitigation technique in the 21-GHz band BSS. In realization of the fading mitigation technique, some differences between ESA and NHK are exists for example the propagation modeling, the general schemes for reconfigurable antenna system and so on. The research activities of the fading mitigation techniques in the 21-GHz BSS of ESA and NHK, and the propagation research activities in Europe are introduced [Nakazawa et al., 2010b].

Propagation studies on a satellite communication are still active to develop a broadband system with high reliability in above around millimeter band.

Four-year rain attenuation statistics are obtained for both up and down links of Ku-band Superbird C, which connects the earth stations in Equatorial Atmosphere Radar (EAR) in West Sumatra, Indonesia and Research Institute of Sustainable Humanosphere (RISH) of Kyoto University in Uji, Kyoto. Their long-term statistics agree well with the ITU-R predictions except for high attenuation range in Indonesia. A year-to-year variation of the worst month statistics is larger in Japan, while that of the attenuation ratio of up to down links is larger in Indonesia. A very large daily variation of the attenuation statistics is found in Indonesia, indicating the decrease and increase of the time percentages by more than two orders in the morning and the afternoon, respectively. Also, worst hour statistics calculated on hourly basis show much larger difference from the yearly average statistics than the worst month statistics [Maekawa et al., 2008a].

Compared with the rainfall rates with the same time percentages, equivalent path lengths of the satellite signal against the rain area are reduced down to 2 km at EAR, which is remarkably shorter than those at RISH in Japan. The almost same attenuation values and annual statistics are, however, obtained from the X-band radar observations simultaneously conducted at EAR. In this calculation, the radar reflectivity factors are corrected using the attenuation of the radar radio waves that may arise from rain drops along the two way propagation paths from the radar to the observational points. This suggests that long-term radar observations of convective clouds are more effective to estimate rain attenuation statistics of the satellite signals in the tropical regions, even if rain gauge data are available [Maekawa et al., 2009a, Miyamoto et al., 2010].

The effects of site diversity techniques on Ku-band rain attenuation are investigated using two sets of simultaneous BS (Broadcasting Satellite) signal observations at three locations, which have been conducted among Osaka Electro-Communication University (OECU) in Neyagawa, Kyoto University (RISH) in Uji, and Shigaraki MU Observatory in Koga for about past five years [Maekawa et al., 2008c], and among the headquarters of OECU in Neyagawa and their other two facilities in Shijonawate and Moriguchi for about past three years [Maekawa et al., 2008d]. The site diversity effects are found to be largely affected by the passing direction of rain areas characterized by each rain type, such as warm, cold, and stationary fronts or typhoon, for the horizontal site separations of 3-50 km. Also, the improvement factor of the diversity effects primarily depends on the distance between the sites projected to the rain area motions. Furthermore, this improvement factor can be reduced down to about 60 % of the ITU-R predictions, compared with fixed two sites, by choosing a pair of the sites aligned nearest to the rain area motion at each rainfall event.

The rain area motions inferred from the time differences in the rain attenuation at OECU, RISH and MU are compared with the wind velocities measured by the MU radar at the rain height. The MU radar wind observations at the height of 2-6 km are found to agree fairly well with those rain area motions detected on the ground. There are also tendencies that the wind velocities, in general, become larger and approach eastward as the height increases, indicating a vertically-sheared structure of horizontal wind velocities [Noyama et al., 2010a, b]. Also, scintillation amplitudes obtained from the Ku-band BS signals are compared with echo intensities and wind velocities simultaneously observed by vertical and off-vertical beams of the MU radar in the lower troposphere at the height of 2-6 km. When the scintillation occurs, the MU radar echoes are enhanced primarily at 2-4 km height. At the same time, the vertical wind velocities tend to show large variations in summer, while vertical wind shear of the horizontal wind velocities seem to become large in winter. There is also a tendency that the echo power ratio of vertical to off-vertical beams decrease and increase in summer and winter, respectively. On the other hand, the correlation coefficients between two BS signals received at 1-5 m distances are found to indicate the almost same values for both horizontal and vertical directions in summer, while the correlation becomes much smaller for the vertical direction compared with horizontal direction in winter. Such a feature of the spatial correlations agrees well with the enhancement of isotropic and anisotropic turbulence in summer and winter, respectively [Maekawa et al., 2010b].

Angular dependence of the satellite diversity effects on Ku- and Ka-band rain attenuation is investigated using the radio wave signal levels obtained from Japan's domestic geostationary satellite, JCSAT, SCC, BS, and CS-3 (N-STAR), in 1995-1998 and 2003-2008 at Osaka Electro-Communication University (OECU), and in 2005-2007 at Kyoto University (RISH). The improvement factor of the satellite diversity does not exceed a factor of 2 or 3, as far as the time percentages are greater than 0.01%, while it may exceed a factor of 10 as the time percentages become smaller than 0.01% with the Ku-band attenuation of greater than about 10 dB [Maekawa et al., 2008b]. It is found in both Ku and Ka bands that the improvement of unavailable time percentages of 0.1-0.01% is increased by more than one order, as the time delayed diversity of about 60 min is also introduced between the two satellite paths. The improvement is shown to be more effective when the time delay is applied to the satellite with its orbital position westward to the other one. Also, these effects are more conspicuous in rainfall events with cold or stationary fronts than typhoon or shower [Maekawa et al., 2009b].

Detailed attenuation fluctuation characteristics are presented using the Ka-band satellite signal levels observed at 1 sec interval at OECU from 1997 to 2006. Long-term statistics of the duration time and the fade slope are in fairly good agreement with the ITU-R predictions. As compared with rain types in more detail, however, the ITU-R predictions for the duration time are more applicable in the case of cold fronts, while those for the fade slope are more appropriate in the case of warm fronts. Spectral analysis of the attenuation fluctuation reveals that the spectral components of the rain attenuation are confined in a frequency range of less than 0.1 Hz, i.e., in a time scale of more than 10 sec. According to the rain types, however, there seems to be no clear difference in the slope of each spectral density, indicating similar spectral components for any rain types [Sawai et al., 2009]. Also, rapid changes in cross-polarization discrimination (XPD) of the Ka-band satellite radio wave signal (19.45 GHz) are observed at 1 sec interval in the thunderstorm events from 1990 to 2006. About one third of the rapid changes are found to coincide with the cloud-to-ground lightning strokes which occurred on the south side of our earth station at the distance up to 20 km. The distribution of the lightning location indicates that the center of thunder clouds primarily exists to the westward of the radio wave propagation path. At the moment of the rapid changes, more than half the observed data indicate the decrease in XPD. Also, more than two thirds of them show the changing direction of cross-polar phases toward -90 deg, which means the decrease in canting angles of ice crystals possibly causing the depolarization changes. The decrease in XPD may be related to cancellation effects of depolarization due to the difference in canting angles between the ice crystals near the lightning and those in other places far from the lightning [Maekawa et al., 2010a].

The long-term rain attenuation characteristics are obtained from Ka and Ku band satellite signal observations conducted at OECU from 1986 to 2006. The 0.01% values of Ka and Ku band attenuation indicate fairly large yearly variations which amount to about 20% around the mean values. Besides the yearly rainfall rate statistics, these variations seem to be caused by difference in the equivalent path length in each year, which becomes longer as the average ground temperature at the rain time from May to October becomes higher. However, the increase of the equivalent path length is not fully explained by that of rain height, but rather related to the rain types which frequently appear in summer time with much larger cloud sizes [Maekawa et al., 2010c].

The frequency diversity characteristics between Ka-band received signal of WINDS and Ku-band signal from JCSAT-2A against the rain attenuation are evaluated from the state transition matrix analysis. Satellite availability estimated from the state transition matrix is compared with that obtained from the measured Ka- and Ku-band satellite signals when the duration time is set at one second. Also the satellite availability in terms of duration time is estimated from the state transition matrix [Teramoto et al., 2010].

B. Effects of Other Factors

Propagation studies on an ionospheric effect are reported. By using a simple experimental set up utilizing the commercially available, portable, handheld GPS receiver, The propagation data from many GPS satellites were obtained in order to evaluate the mobile satellite signal performance due to the effect of the ionosphere in the low-latitude region (Sarawak, Malaysia). They were compared with the open space results obtained in the mid-latitude region (Fukuoka, Japan). Results are evaluated in terms of the received SNR, fade difference with respect to the averaged measured SNR and also the cumulative distribution function of fading signal [Abidin et al., 2008]. In addition, a novel approach is presented to determine the mobile satellite signal quality by using a portable, handheld and commercially available GPS receiver with built-in small-size antenna that imitates the actual receiver used by the mobile satellite users. Propagation data for the open space environment are measured and used as reference to determine the mobile satellite signal quality for the tree shadowed and building shadowed environments. Comparisons are made with the results obtained using different type of receiver system to show the feasibility of this type of receiver [Abidin et al., 2008a].

The effects of the atmospheric turbulence on satellite communication systems are reported.

The BER derived from the received power were analyzed numerically using the mutual coherence function on a receiving antenna as well as the BER derived from the integration of the average intensity on a receiving antenna. From a result of the analysis, influences of spot dancing and spatial coherence of received waves caused by atmospheric turbulence on BER of the GEO satellite communication in Ka-band at low elevation angles were considered [Hanada et al., 2008, 2008a].

The analysis was executed against the BER derived from the average received power, which is obtained by the second moment of received waves, for the down link communications. An influence of atmospheric turbulence on the BER is analyzed in terms of the correlation function of random dielectric constant which is assumed to be the Gaussian model. From a result of analysis, it is shown that the BER for the downlink communications increases if the spatial coherence of received waves is not kept enough within an area of a receiving antenna [Hanada et al., 2009]. The statistical characteristics of random fluctuation of the dielectric constant are assumed to be given by the Kolmogorov model which is known to be a good approximation for atmospheric turbulence. From the analysis, we discuss influences of spot dancing, wave form distortion and the spatial coherence of received wave beams caused by atmospheric turbulence on BER for the satellite communications [Hanada et al., 2009a]. The average BER for the GEO satellite uplink communications in Ka-band was analyzed by using the PDF of the intensity for a Gaussian wave beam in the quadratic approximation. It is assumed that the correlation function of random dielectric constant is given by the Gaussian model. From the analysis, an influence of spot dancing of received wave beams due to atmospheric turbulence on BER of the GEO satellite uplink communications in Ka-band is discussed [Hanada et al., 2009b, 2009c]. (A. Sato)

F1.3 Mobile Radio Systems

A. Formulation of Mobile Propagation

In order to formulate the propagation characteristics, various aspects of mobile communication propagations are studied in the period.

For macrocell and microcell environments, numerous studies have been carried out. A simple model of incoming waves at base station is proposed to evaluate the performance of inter-sector handover in mobile communication systems. The validity of the proposed model is confirmed by comparing the difference between signal levels in BS sectors that are calculated using the proposed model and the measured power azimuth spectrum. [Kitao and Ichitsubo, 2007] The frequency characteristics of the radio wave propagation in mobile communication systems is made clear based on references reported up to now. The examined subjects of radio propagation are path loss, penetration loss, delay profile and angular profile in outdoor and indoor environments. The examination result is shown that the most propagation characteristics do not change by frequencies. [Ichitsubo, 2010] A scale model approach is proposed to clarify channel impulse response in urban areas. To verify reproducibility using the scale model, a one-hundredth scale model of an urban area using concrete blocks is constructed and power delay profiles are measured using 2 GHz and 10 GHz bands. The measured r.m.s. delay spreads are small values compared to those for a real environment. The cause is the measurement frequency. [Iwakuma et al., 2010] A site-general type prediction formula for propagation loss is created based on the measurement results in an urban area in Japan. The application range of the prediction formula is that the frequency range is from 0.8 to 8 GHz, the distance range is 0.1 to 3 km, and the base station height range is from 10 to 100m. The extension of existing formulae such as the Okumura-Hata, Walfisch-lkegami, and Sakagami formulae for 4G systems is examined and a prediction formula based on the Extended Sakagami formula is proposed. [Kitao and Ichitsubo, 2008]

In indoor environments, correlation properties of polarization are discussed. In estimation of correlation property between diversity reception branches, no correlation between vertically polarized (V) and horizontally polarized (H) waves arrived into a receiving point from the same direction has been assumed. However, those cross polarized components are varied at the same time when the path is shadowed by a moving obstacle such as a human body, since those both polarized waves are V- and H-components of the same path. It is therefore considered that there is strong correlation between them. The calculated and measured results about the correlation characteristics between V- and H-polarized components when a human body shadows a propagation path are presented. [Taga et al., 2008] A path-shadowing model for indoor populated environments developed based on computer simulation is presented. The propagation paths between the transmitting and receiving points in an empty rectangular space are determined using a ray tracing method in which moving quasi-human bodies that are modeled as cylinders with finite height are generated in this space, and intersections of the paths with the bodies are counted. As a result, the shadowing probabilities, durations, and intervals are evaluated for each propagation path, and this shadowing process is characterized as a Markov process. The measurement results of path shadowing characteristics using a 5.2 GHz high resolution channel sounder are presented and the validity of this model is confirmed. Similar measurement results using a photo-electric sensor is also presented to reinforce the channel sounding measurement results. [Kashiwagi et al., 2010] A prediction formula of building penetration loss (outdoor-to-indoor propagation loss) is proposed and is derived based on measurement results of 71 floors in 17 buildings in an urban area. The measurement results showed that the attenuation based on the penetration distance is 0.6 dB/m, the floor height gain is 0.6 dB/m, the constant value for the penetration loss is 10 dB, and there is no frequency dependence of the penetration loss in the frequency range from 0.8 to 8 GHz. [Okamoto et al., 2009]

Evaluation and analysis methodologies of propagation characteristics are studied. A method for evaluating the mean effective gain (MEG) of mobile antennas in line-of-sight (LOS) street microcells with low base station is investigated. The received power patterns of incident radio waves along typical streets have been measured in actual street microcells in urban areas of Tokyo, and a two-dimensional statistical distribution model is proposed, which follows a Gaussian distribution in azimuth, but are concentrated in the horizontal plane in elevation. It is also shown that the MEG values in street microcells are changed by the relative direction of the radio waves arriving at the mobile station antennas. The measured and calculated MEG values (MEG patterns) of the whip antennas used in the experiments are in good agreement. The proposed model is valid and effective in both estimating the MEG values of mobile antennas and designing the LOS street microcell systems with low base station antennas. [Ando et al., 2008] The effective gain of the BS antennas is evaluated, which are calculated using the measured vertical power angle profile (PAP). Moreover, the application of a simple incoming wave model to the evaluation of the antenna effective gains is examined. In the model, the average power of the incoming waves is set to the Laplacian function and each wave is changed to a lognormal distribution. The antenna effective gain calculated using the model agrees well with that calculated using the measured PAP. [Kitao et al., 2008] [Kitao and Imai, 2009] Accelerating the ray-tracing process while maintaining a high level of prediction accuracy is an important problem. In order to solve the problem, the ray-tracing acceleration technique employing the genetic algorithm or GA is proposed, and also its performance by computer simulation is clarified. [Imai, 2008] A developed ray-tracing system for propagation prediction in urban macrocell environment is presented. In order to accelerate the ray-tracing process, proposed various techniques are applied to this system. In addition, it is presented that the system is practical by evaluating the processing time and prediction accuracy through comparison with measurement data. [Imai, 2009] Predicting propagation characteristics using the ray-tracing method requires detailed landform data, structure data, and a high-level workstation that can quickly calculate a heavy load of ray-tracing calculations. Therefore, it is very difficult for each user to build such a system. The construction and performance of a ray-tracing system are shown which is called 3D-PRISM that any user can easily use at anytime and anywhere. [Mizuno et al., 2009]

System-oriented propagation studies are also found. Assuming W-CDMA system as the target and the effects of shaping the vertical radiation pattern using the genetic algorithm to maximize the downlink capacity is evaluated. The results clarify the actual required number of antenna elements with the cell radius and angular spread as parameters. [Mizuno and Imai, 2010] The accuracy of the spatial channel emulator developed for the MIMO OTA testing is estimated considering the power angular spectrum of a cluster model taking the received power and correlation corresponding to the rotation angle for antennas under test as the criteria. [Okano and Imai, 2010] The basic configuration for the spatial channel emulator is clarified while taking into consideration the MIMO channel model, which is standardized in the 3GPP and WINNER II project. Furthermore, a theoretical criterion for the array configuration of probe antennas in the radiation part of the emulator is proposed. [Imai et al., 2009] Detailed technical specifications of spatial channel emulator, especially the number of probe antennas (and channel ports) in the emulator, have not yet been established. A theoretical analysis method is proposed in order to obtain the adequate number of probe antennas, and clarifies the adequate number of probe antennas in the emulator when assuming a single-cluster model (SCM) and a multi-cluster model (SCME) as the power angular spectrum around a mobile terminal. [Imai et al., 2010] A flexible subcarrier channel estimator with a narrowband interference detection for wideband OFDM signals is proposed using a previously proposed technique for estimating time of arrival and angle of arrival. The results indicate that it is possible to detect a narrowband interfering system within the wideband OFDM bandwidth. Experimental validation of the scheme is also presented. [Iwakiri and Kobayashi, 2010]

B. MIMO

The characterization of MIMO channels has been investigated. The effectiveness of the directional antenna to the MIMO array branch in the street microcell environment is presented. This study is based on the result of the measurement in a real environment. As a result, capacity of MIMO system with directional antenna in LOS condition can improve according to the antenna gain. And the simple propagation model is proposed on the basis of the results of MIMO propagation measurement. The effectiveness of the model is shown by the comparison with the measurement result. [Yamada et al., 2008a] New techniques to simulate a MIMO propagation channel using the ray-tracing method for the purpose of decreasing the computational complexity are proposed. The estimation accuracy calculated using the proposed techniques is evaluated based on comparison to the results calculated using imaging algorithms. The results show that the proposed techniques simulate a MIMO propagation channel with low computational complexity, and a high level of estimation accuracy is achieved. [Yamada et al., 2009a] To evaluate the basic performance of MIMO cooperative transmission systems, a simple prediction method which calculation complexity is decreased for evaluating indoor MIMO cooperative transmission is proposed. Simple prediction method of MIMO channel matrix is used to simulate the MIMO channel. The simulation results are compared to the measurement results. Based on this comparison the proposed prediction method can accurately estimate the characteristics of indoor MIMO cooperative transmission systems. [Yamada et al., 2008b] Doppler spectrum analysis is carried out based on measurement. Doppler characteristics are statistically evaluated based on the bell-shape function, for which the spectrum model was standardized in IEEE 802.11 TGn. However, the current measurement results show that the parameters proposed for the TGn channel models overestimate the Doppler spectrum for all of the measurement results. Consequently, novel empirical formulas that consider the differences in the Doppler spectrum based on Tx-Rx distance were proposed. [Yamada et al., 2009b] For establishing the simulation method of wideband time-variant (T-V) channel to evaluate MU-MIMO systems, T-V delay profiles based on measurements in an office environment are studied. Level variation characteristics depending on power of delay profile and realistic parameter of Doppler spectrum characteristics is derived. In addition, simulation of wideband time varying channel is performed, and it is shown that short term variation could be traced accurately. [Yamada et al., 2010] An evolution and standardization trends of the wireless channel modeling activities towards IMT-Advanced are described. Two well-known MIMO channel models for cellular systems, namely, the 3GPP/3GPP2 Spatial Channel Model (SCM) and the IMT-Advanced MIMO Channel Model (IMT-Adv MCM) are compared, and their main similarities are pointed out. [Chong et al., 2009a and 2009b] The basic studies of the spatio-temporal dynamic channel properties are reported based on the measured data obtained using the channel sounder in an outdoor environment to establish the dynamic channel model for the spatial fading emulator in order to evaluate MIMO UEs. [Kitao et al., 2009] Based on the calculation the alignment of probe antennas are investigated for a spatial channel emulator considering the power angular spectrum of cluster model taking an antenna correlation that has a substantial impact on MIMO performance as the criterion and clarifies that probe antennas should be appropriately aligned, in terms of spacing and numbers, depending on an intended angular spread of arriving waves and an element spacing of antennas under test. The result of the MIMO OTA testing is also presented based on three types of channel models as practical applications of the spatial channel emulator employing the practical antenna configuration mounted on the mobile phones as antennas under test. [Okano et al., 2009 and 2010] The result of 2GHz channel measurements is provided in a typical urban environment and the dynamic channel property of the environment is investigated. [Kitao et al., 2010] As a basic multipath property required to allocate the pilot signal in orthogonal frequency division multiplexing (OFDM) and compose antennas in the multiple-input multiple-output (MIMO) technique, correlation coefficients of the envelope in the received signal level, re(Dx), and phase, rp(Dx), in multipath channels were studied theoretically and by computer simulation in a domain with time, frequency, and space axes. The theoretical values of re(Dx) and rp(Dx) agree with the simulated ones. [Kozono et al., 2009]

A broadband transmission system using MIMO configuration is developed. A 64-state 16-QAM space-time trellis code (STTC), which uses two transmitting antennas, is proposed and applied to a 2x2 MIMO-OFDM system for outdoor mobile transmission in the 800-MHz band. Although STTCs have been analyzed theoretically and the error performances have been simulated by many researchers, experimental results have rarely been reported. Therefore, Nakagawa et al. evaluated the performance of our 2x2 STTC-MIMO-OFDM in both a simulation and experiment in the 800-MHz-band urban mobile environment. As a result, excellent bit error rate (BER) performance obtained in the simulation was verified by the experiment. [Nakagawa et al., 2009] The Millimeter-wave Mobile Camera developed by Japan Broadcasting Corporation (NHK) uses millimeter-wave band (42GHz/55GHz) to transmit Hi-Vision TV picture with high quality and low latency. Multiple-input multiple-output (MIMO) technology which uses a number of antennas at both the transmitter and receiver can be adapted to use to transmit higher quality picture. The camera was intended to be used in a studio environment where there is a high degree of multi-path, however there are intentions for the Millimeter-wave Mobile Camera to be used outdoor. This will present a different channel statistics where the camera will be operating in a near line-of-sight environment without much reflected waves. Suzuki et al. have conducted an outdoor transmission test and measured the outdoors transmission performance of the Millimeter-wave Mobile Camera. They presented the findings of this test and it also confirmed that channel correlation of the MIMO propagation channels were suppressed by using orthogonally polarized waves and bit error rate (BER) characteristics with respect to the average receiving carrier-to-noise ratio (CNR) was improved. [Suzuki et al., 2009] Iterative low-density parity-check (LDPC) coded multiple-input multiple-output (MIMO) systems are known to be able to theoretically achieve excellent performance by computer simulation. If the systems can exploit time interleaving long enough to cover a fading cycle, excellent error rate performance should be obtained in mobile line-of-sight (LOS) environments. Mitsuyama et al., described an iterative LDPC minimum mean square error with soft interference cancellation (LDPC-MMSE-SIC) receiver with a time de-interleaver before the MMSE detector and evaluated it using channel state information (CSI) acquired in outdoor measurements, showing that the iterative receiver with time interleaving improves the error rate performance significantly in mobile LOS environments and outperforms an LDPC maximum likelihood detection (LDPC-MLD) receiver with the same error correction and interleaving. [Mitsuyama et al., 2010a] Suzuki et al., have developed a millimeter-wave wireless Hi-Vision TV (HDTV) camera, which is called the "Millimeter-wave Mobile Camera (MiMoCam)". Its transmission technology was standardized in Japan under the "ARIB STD-B43 standard" in June 2008, and Japan Broadcasting Corporation (NHK) has used it in TV program productions. The millimeter-wave link system for the MiMoCam uses a multiple-input multiple-output - orthogonal frequency division multiplexing (MIMO-OFDM) transmission or a diversity reception using maximum ratio combining (MRC) method. The maximum transmittable video TS rate is 160 Mbps, and the delay is less than one HDTV video frame (33 ms). This level of performance enables comfortable switching between the pictures of cable-connected cameras and MiMoCams. They described the features of the MIMO-OFDM and MRC techniques and their application to millimeter-wave links. The capabilities of the MiMoCam were also detailed. Examples of employing MiMoCams in live golf and music programs were also described. Use of the MiMoCam can greatly increase freedom of operation and create diverse opportunities in live TV productions. [Suzuki et al., 2010] Mitsuyama et al., have been developing an advanced wireless link for use at sports events, such as road races, to transmit high definition television signals. To achieve high spectrum efficiency, multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) has been tried. In conventional OFDM-based wireless link systems, the radio signals are picked up using distributed antennas and relayed to a switching center (SWC) via a radio-on-fiber (RoF) link, and the signal with the best quality is selected. When using the MIMO system for road race relay broadcasting, distributed MIMO (D-MIMO) systems have to be considered. They have to address delay differences among antenna branches due to the RoF link when using D-MIMO, because delay differences larger than the guard interval (GI) length of the

OFDM signal seriously degrade system performance. First, they proposed a practical delay difference correction (DDC) technique that could perfectly compensate for a large delay difference due to the RoF link. Second, they showed by a computer simulation of road race relay broadcasting that D-MIMO systems could achieve good coverage performance compared to centralized MIMO (C-MIMO) systems. [Mitsuyama et al., 2010b] Research on the next generation of digital terrestrial broadcasting is conducted by Japan Broadcasting Corporation (NHK), to enable high-capacity services such as Super Hi-Vision. Murayama et al., have developed a key high-capacity transmission technology for the next-generation broadcasting format, and conducted successful field tests transmitting 60 Mbps (four Hi-Vision programs) on a single, 6-MHz terrestrial broadcasting channel. The format uses ultra-multilevel OFDM and dual-polarized MIMO technologies. Ultra-multilevel OFDM increases transmission capacity by extending carrier modulation from 64QAM, used in the current digital terrestrial broadcasting, to 1024QAM. They have also verified dual-polarized MIMO technology able to transmit two different signals simultaneously using two waves polarized horizontally and vertically. It also accurately separates the two signals at the receiver, correctly demodulating the information. They will continue research and development to further expand transmission capacity and enable implementation of stable, high-quality services, and will continue to report on NHK's ongoing initiatives toward digital terrestrial broadcasting of Super Hi-Vision. [Murayama et al., 2010]

C. Ultra Wideband

Propagation characteristics for Ultra Wideband systems are energetically carried out in a university. Frequency dependence of spatio-temporal ultra wideband radio channels is experimentally studied. Fullband channel modeling utilizing 3.1 to 10.6 GHz as well as sub-band analyses were outlined. Analyses reveal that propagation mechanisms in higher bands had less power composition of specular propagation paths than in lower bands. [Haneda et al., 2007] An ultrawide-band channel sounding scheme is presented using an antenna array for OFDM signals using a previously-proposed technique for estimating time of arrival and angle of arrival. Experimental validation of the scheme is also presented. [Iizuka et al., 2009] An ultrawide-band channel sounding scheme is proposed with an antenna array using a technique for estimating time of arrival and angle of arrival. Experimental validation of the scheme is also presented. [Iwakiri and Kobayashi, 2007a] An improving ultrawide-band channel sounding scheme is presented with an antenna array using a technique for estimating time of arrival, angle of arrival, and angle of departure. Experimental validation in indoor environments is also presented. [Iwakiri and Kobayashi, 2007b] An extended version of ultrawide-band channel sounding scheme is presented with an antenna array using a technique for estimating time of arrival, angle of arrival, and angle of departure for two and three arrival paths. Experimental validation of the scheme is presented. [Iwakiri and Kobayashi, 2007c] A fundamental idea of ultrawide-band channel sounding scheme is presented with an antenna array using a transformation between frequency and time domain signals for estimating time of arrival and angle of arrival. Experimental validation of the scheme is also presented. [Iwakiri and Kobayashi, 2008a] A joint time of arrival and angle of arrival spectra technique is proposed with an antenna array in indoor environments. This technique is capable of resolving dominant multipath components including a direct path, a single reflection, and a single diffraction. Experimental validation of the scheme in indoor environments is also presented. [Iwakiri and Kobayashi, 2008b] An extended version of joint time of arrival (TOA), and angle of arrival (AOA) and angle of departure (AOD) with an antenna array in indoor environments is proposed. The level distributions including dominant multipath components could be viewed as clusters. Experimental validation of the scheme in indoor channels was also presented. [Iwakiri and Kobayashi, 2009] Measurement and characterization of radio propagation within spacecrafts are presented with a view to replacing (at least partially) wire harnesses with wireless links. While narrowband results in a number of dead spots within the conductive enclosures, ultra wideband yields none. It is also found that delay spreads can be suppressed by partially paneling a radio absorber on the inner surfaces to facilitate high data rate transmission. [Matsubara et al., 2009] Ultra wideband communication is evaluated within a closed space, with a view to partly replacing onboard data buses with wireless connections. Even within the empty shield box, the delay spreads are adequately suppressed to accommodate a data rate exceeding 100 Mb/s, when a radio absorber panel covers typically 8% of the total inner surface. [Matsubara et al., 2010] An ultra wideband spatio-temporal channel sounder, employing an orthogonal frequency division multiplexing signal and a receiving virtual array antenna was prototyped and evaluated in a narrowband interference environment. [Sugizaki et al., 2010] Effects of Bragg scattering on ultra-wideband signal transmission from periodic surfaces are reported. Frequency dispersive property of Bragg scattering is theoretically and experimentally confirmed. Then direct sequence UWB transmission simulations are conducted. [Tsuchiya et al., 2008] Ultra wideband propagation channels are experimentally studied for both line-of-sight (LOS) and non-LOS (NLOS) between an indoor base station and two types of antennas located in the vicinity of a human body. The channels are evaluated in terms of equivalent antenna gain, which includes the shadowing and diffraction caused by a human body and the effects of a body on voltage standing wave ratio and radiation pattern. Reception power versus occupied bandwidth is also derived from the measurements. [Yamamoto and Kobayashi, 2007] Ultra wideband path losses are measured between on-body antennas in three different surrounding environments. The maximums, minimums, and medians of the path losses of UWB and CW (6.85 GHz) are derived. The variation ranges in UWB are smaller than those in CW (in particular, 20-dB smaller in NLOS). This is because nulls caused by interference are cancelled out by the ultra wide bandwidth. The results indicate that UWB technologies are more advantageous than narrowband ones from the viewpoint of reducing fading margins. [Yamamoto and Kobayashi, 2008a] Effects of cable configurations on short-range UWB propagation measurements are experimentally studied by using the commonly used meanderline antennas. It is found that perpendicular configuration of cables to feed the transmitting and receiving antennas yields the least effects of the coupling, compared with other configurations. [Yamamoto and Kobayashi, 2008b] Liquid UWB phantom material (1.0-mol/l aqueous solution of sucrose) is developed and applied to arm and torso phantoms. It is concluded from the comparison with human volunteers that these phantoms properly simulated the electromagnetic responses of the respective parts of the human body and were usable for experimental evaluation of UWB antennas and propagation. [Yamamoto and Kobayashi, 2008c] Ultra wideband radio propagation is experimentally studied in WBAN scenarios between on-body small antennas in three surrounding environments. Small rooms yield higher reception power than larger rooms while the r.m.s. delay spreads are larger. This was attributed to the affluent multipath from the nearby floor, walls, and ceiling. [Yamamoto and Kobayashi, 2009a] Ultra wideband radio propagation is examined between on-body small antennas in three environments. Parameters in a conventional UWB propagation loss model are derived from measured results for both upper and lower bodies. Propagation mechanisms are also studied for the body sections in different environments. A new model considering the impact of room volume is proposed and its parameters are estimated. [Yamamoto and Kobayashi, 2009b] Measurements and modeling of propagation losses are carried out for full-, low-, and high-band UWB wireless communications around the human body. The parameters in the conventional propagation loss model are derived from the data measured in the five different rooms. A modified model considering the impact of the room volume is proposed for individual body sections and the UWB bands. Probabilistic distributions of propagation on the whole body surface are examined. The lognormal distributions are found to provide the best fit to the propagation losses in these environments. [Yamamoto and Kobayashi, 2010a] The UWB propagation losses were measured between on-body antennas in three different surrounding environments envisioned for WBAN scenarios. The cases of the small room yielded higher reception power than the cases of larger rooms. This was attributed to the ample multipath from the nearby floor, walls, and ceiling. The UWB maximum propagation losses in three environments were smaller than ones of CW. This is because nulls caused by interference were cancelled out by the ultrawide bandwidth. [Yamamoto and Kobayashi, 2010b]

D. Wireless Body Area Network

New propagation studies on Wireless Body Area Network (WBAN) have become active in this period. An implantable WBAN path-loss model for a capsule endoscopy used for examining digestive organs is developed by conducting FDTD simulations and simple experiments. [Aoyagi et al., 2009 and 2010] Recent advances are reviewed in ultra wideband (UWB) radio propagation measurements and modeling for wireless body area networks (WBAN). [Kobayashi, 2009]

Stochastic channel models are proposed for wireless body area networks on the human body. Parameters of the channel models are extracted from measured channel transfer functions in a hospital room. Measured frequency bands include ultra wideband, the industry, science and medical bands, and wireless medical telemetry system bands. [Takizawa et al., 2008] Channel models are presented on path loss and power delay profile for wireless body area networks. These models are derived from measured channel transfer functions by using a vector network analyzer for the frequency bands of 430, 611, 953, 2450 MHz, and ultra wide bands. [Takizawa 2009]

(H. Iwai)

F2 Remote Sensing
F2.1 Atmosphere

A. GPS Meteorology
GPS (Global Positioning System) meteorology is a sounding technique of the atmosphere, by measuring propagation delay time of radio waves transmitted by GPS satellites. It provides us with information of electron density in the ionosphere, temperature in the stratosphere and humidity (water vapor) in the troposphere. The receiver could be located on the ground, ship, airplane, or satellite. A global observation of atmosphere with a very high vertical resolution can be obtained by LEO (Low Earth Orbit) satellite with the RO (radio occultation) method. Such LEO measurements (e.g. CHAMP, COSMIC) have been used to study characteristics of tropopause, Kelvin and GW (gravity waves) in the troposphere and stratosphere. Hayashi et al. [2009] validated COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) measurements in terms of refractivity through the troposphere and lower stratosphere.

Quasi-stationary temperature structure in the upper troposphere over the tropical Indian Ocean was investigated by using COSMIC RO data [Nishi et al. 2010]. Horinouchi and Tsuda [2009] investigated the horizontal structures of GWs obtained directly by using multiple profiles based on the GPS RO data of successively passing COSMIC satellites. Alexander et al. [2008a] studied winter mean stratospheric E_p (*Eliassen-Palm* flux) in Northern Hemisphere. Large E_p at 17–23 km is mostly associated with the sub-tropical jet and shows significant longitudinal variability.

In the equatorial region, Alexander et al. [2008b] studied GW potential energy associated with waves and their interaction with the background QBO (quasi-biennial oscillation) wind. Results show evidence of vertically propagating convectively generated gravity waves interacting with the background mean flow. Tsuda et al. [2009] compared the seasonal averaged E_p with the cloud top temperature from outgoing long-wave radiation and the convective rain rate from the TRMM (Tropical Rainfall Measuring Mission) precipitation radar. The spatial and seasonal variations of E_p are closely related to the distribution of clouds, implying that convective wave generation is very important in the tropics.

In the Arctic region, Hei et al. [2008] studied the climatological behavior of atmospheric GW in the polar stratosphere. Wave potential energy shows an annual variation with maximum in winter, consistent with the zonal mean horizontal wind, and E_p.

As the ground-based GPS measurement PWV (precipitable water vapor) can be derived from the phase delay of GPS radiowave detected by ground-based GPS receiver. Shoji [2009] developed a near real-time analysis system to derive PWV from GEONET (the nationwide ground GPS network) in Japan.

Shoji et al. [2009] conducted data assimilation experiments of GPS-derived PWV with JMA (Japan Meteorological Agency)'s Meso 4D-Var (mesoscale 4 dimensional variational assimilation system), and found that PWV derived from GEONET improved the prediction of the observed heavy rainfall. Seko et al. [2010] simultaneously assimilated the ground-based GPS data and GPS RO data with Meso 4D-Var aiming to evaluate their impact on the prediction of a heavy rainfall.

B. Various Techniques of Observation in Troposphere with MST Radars
Atmospheric radars generally called MST (mesosphere, stratosphere, and troposphere) radars or ST (stratosphere and troposphere) radars are capable of continuously monitoring three-dimensional winds, waves, turbulence, and atmospheric stability over the wide altitude range 1-100 km in the Earth's atmosphere. In the last three decades, this excellent capability has been used extensively to

study various dynamical disturbances in the Earth's atmosphere, developing new frontiers of atmospheric research on, primarily, mesoscale and micro-scale phenomena. Fukao [2007] reviewed these advances.

Many experimental studies were conducted using the MU radar (Middle and Upper Atmosphere Radar of Kyoto University) whose height resolution was improved with a range-imaging technique using the Capon processing method. Very good agreements were shown between high resolution profiles of radar- and radiosonde-derived M^2, as well as profiles of N^2 [Luce et al. 2007]. Kelvin-Helmholtz (KH) billow structures were found to have horizontal wavelengths of about 5.3 km and vertical extents between 0.5 and 1.0 km around 16-km altitude in the upper part of the jet stream [Luce et al. 2008]. From simultaneous observations with 35-GHz and 9.8-GHz weather radars, a KH instability occurring at a cloud base and its impact on modulating cloud bottom altitudes were described [Luce et al. 2010a]. Based on simultaneous measurements of water vapor with Raman lidar, it was shown that the range-imaging could be used for continuously monitoring the thin positive and negative gradients of humidity [Luce et al. 2010b]. Clear-air turbulence underneath a cirrus cloud base was described owing to coincident observations from the MU radar, a Rayleigh-Mie-Raman (RMR) lidar, and a balloon radiosonde [Luce et al. 2010c]. Hassenpflug et al. [2008] demonstrated 3-D imaging using 5 frequencies and 25 digital receivers. 3-D imaging results suggested that wind-shear tilted/KHI (KH Instability) layers contributed a significant part of the radar-measured mean vertical wind in the middle troposphere [Chen et al. 2008]. Yu et al. [2010] showed the suppression of clutter contamination by capitalizing the capability offered by multiple receivers and multiple frequencies with maintaining resolution gained by imaging mode. The effects of radar beam width and scatterer anisotropy on the performance of range imaging were examined in addition to numerical simulation [Chen et al. 2010].

The momentum flux of the atmospheric motions in the height ranges of 6-22 km observed with the MU radar during a 3 day period in the winter season were studied and both the 72 h averaged upward flux and downward flux of zonal momentum were negative at nearly each height, meaning that the upward flux was dominated by westward propagating waves while the downward flux was dominated by eastward propagating waves [Kuo et al. 2008]. The horizontal structure of the atmospheric gravity waves (AGW) in the same height ranges observed during a 3 day period in the winter and a 4 day period in the summer were studied and the waves with periods in the range of 30 min similar to 6 h had horizontal scales ranging from 20 km to 1500 km, vertical scales from 4 km to 15 km, and horizontal phase velocities from 15 m/s to 60 m/s [Kuo et al. 2009]. Sakazaki et al. [2010] studied diurnal variations of upper tropospheric and lower stratospheric winds over Japan in 1986-2008 mainly using data from the MU radar and global reanalysis data sets and output data from Global Scale Wave Model, and showed that the diurnal amplitude monotonically increased with height above 15-20 km, and the diurnal phase was an upward progression up to 15-20 km but a downward progression above 15-20 km in most months.

The 47-MHz Equatorial Atmosphere Radar (EAR) has been operated at Kototabang, West Sumatra, Indonesia since 2001 and has been very successfully used for the study of equatorial atmosphere dynamics. A research project called Coupling Processes in the Equatorial Atmosphere (CPEA) was conducted for studying the coupling processes in the equatorial atmosphere during 2001-2007 [Fukao et al. 2009]. Horizontal winds at 700 hPa over Sumatra analyzed by NCEP/NCAR reanalysis were compared with those observed with the EAR during 2001-2007 and the amplitude of NCEP/NCAR-reanalysis zonal and meridional winds showed a better agreement when radiosonde wind data at Padang were reported through Global Telecommunication System (GTS) for assimilation into NCEP/NCAR reanalysis [Seto et al. 2009]. Five years of tropospheric data below 12 km from the EAR were examined for seasonal and interannual gravity wave activity and were compared with data from the TRMM satellite [Alexander et al. 2008c]. Vertical wind variations measured by the EAR in 2004 have been statistically analyzed to study the characteristics of wind variances associated with convective activity, which is then related to gravity wave generation and propagation. Correlation analyses between vertical wind variations and rainfall show that the wind variances have a clear diurnal variation indicating probable effects of tropospheric convection [Kozu et al. 2009c]. Yamamoto et al. [2008] demonstrated that a combination of the EAR and a millimeter-wave Doppler radar was a key tool for observing particle fall velocity in cirriform clouds. Variations of vertical air velocity in the midlevel shallow-layer clouds were described by a case study observed with the EAR and a 532-nm Mie lidar in the nighttime [Yamamoto et al. 2009]. The regional characteristics and internal structure of migratory cloud systems with a diurnal cycle over Sumatera Island during CPEA-I observation campaign were examined using data from an X-band Doppler radar, the EAR, radiosondes, and the geostationary meteorological satellite [Sakurai et al. 2009]. Detailed structure of KH instability in the tropical tropopause layer was investigated using the range imaging mode of the EAR, and enhanced radar echoes above the temperature minimum had a thin layered structure less than 200 m in depth and showed upward wisp-like structures resulting from KH instability [Mega et al. 2010]. Long-term data of vertical air velocity obtained with the EAR and the Indian MST radar were investigated and its seasonal mean profiles showed descending (ascending) motion below (above) 8-10 km in most of the seasons [Rao et al. 2008].

The 11 semidiurnal components from meteor wind radars (MWRs) at Kototabang and Jakarta were compared with the extended Canadian Middle Atmosphere Model (extended CMAM) which is a general circulation model extended from the surface to about 210 km. The CMAM reconstructions were generally larger than the radar results by a factor varying between one and two. The phases in the radar data were typically stationary with respect to height, whereas they generally decrease with height in the CMAM reconstruction [Du et al. 2007]. The horizontal wind data acquired by MF radar at Tirunelveli, India in 1993-2006 were used to study long-term variability of equatorial mesosphere and lower thermosphere (MLT) winds. The monthly mean zonal wind exhibited dominant semiannual variability with westward winds during equinox and eastward winds during solstice [Sridharan et al. 2007]. Sridharan et al. [2008] investigated an eastward propagating Kelvin wave of period near 7 days observed in the radiosonde winds and temperature in the upper troposphere and lower stratosphere (UTLS) region and a wave of similar periodicity observed simultaneously in the MLT winds acquired by MF radar at Pameungpeuk during the CPEA-I campaign. Sridharan et al. [2010] studied changes in monthly mean winds and tides observed by MF radar at Tirunelveli in 1993-2007 with respect to long-term variabilities, namely, the stratospheric quasi-biennial oscillation (QBO), the El Nino-Southern Oscillation (ENSO), and the solar cycle (SC). Both zonal and meridional winds showed negative QBO response in the altitude region 84-94 km and negative ENSO response above 90 km. The response of meridional diurnal tide was positive to ENSO (above 90 km) and stratospheric QBO and was negative to SC. Jiang et al. [2008] investigated a strong mesospheric 6.5-day wave event occurred during April-May 2003 using wind data detected by six ground-based radar systems located in equatorial and midlatitude belts. The seasonal variation of short-period (< 2 h) gravity wave activity in the troposphere and lower stratosphere were analyzed using the wind observations made with the Indian MST radar [Dutta et al. 2008]. Rao et al. [2009] investigated the influence of the intraseasonal variations (ISV) in the lower tropospheric convective activity associated with the MJO on the longitudinal behavior of ISV of the zonal winds in the equatorial MLT using simultaneous observations with MWRs at Cariri and Ascension Island and two MF radars at Tirunelveli and Pamuengpeuk.

Stationary intensive observations over the Indian Ocean with the research vessel Mirai were conducted using shipborne lower troposphere radar (SB-LTR) on the Mirai Indian Ocean Cruise for the Study of the MJO-convection Onset (MISMO) field experiment in 2006. When small cloud clusters passed over Mirai, strong updrafts were observed by SB-LTR up to 1.5 km altitude above the level of free convection (LFC), the mixing layer observed by SB-LTR showed large diurnal variations, and specific humidity decreased around the surface of the sea. When super cloud clusters related to the MJO proceeded eastward over Mirai, horizontal winds showed a large-scale convergence, specific humidity, and the equivalent black body temperature (T_{BB}) showed similar time-height variations [Kawano et al. 2009]. Adachi et al. [2009] studied the evolution of two thin-line echoes that were observed in the radar reflectivity field over the Kanto Plain of Japan as Typhoon Higos (0221) passed in October 2002 using observations from a Doppler radar, a wind profiler, and a meteorological tower.

With the 443 MHz WPR at the Ogimi Wind Profiler Facility of the National Institute of Information and Communications Technology (NICT) in Okinawa, Japan, hourly data have been collected. The data during the warm season months of three years were used to develop a climatology of the low level jet (LLJ) over Okinawa. Characteristics of the LLJ were investigated in two subperiods: during the Baiu season and the post-Baiu season when the Baiu front had moved further north of Okinawa. The result shows that stronger LLJs occur more frequently during the Baiu season, when heavy precipitation is mostly observed compared to the post-Baiu season [Pham et al. 2008].

C. Mesosphere and Lower Thermosphere (MLT) Region

Mesosphere and lower thermosphere region exhibits special interests because it is a transient region between the neutral and ionized atmospheres, and eddy diffusive and molecular diffusive atmospheres. Variability of this region has been studied intensively by using ground-based/space-borne observations, and theoretical works. Since ionospheric studies have been presented by the Commission G, some studies on non-ionized environment are presented in this section.

Lower-thermospheric winds at high latitudes during moderately-disturbed geomagnetic conditions were studied using data obtained with the European Incoherent Scatter (EISCAT) Kiruna-Sodankylä-Tromsø (KST) UHF radar system on 9–10 September 2004. The vertical neutral-wind speed at 109 km, 114 km, and 120 km heights showed large upward motions in excess of 30 m/s in association with an ionospheric heating event. Large downward speeds in excess of −30 m/s were also observed before and after the heating event. The meridional neutral-wind speed suddenly changed its direction from equatorward to poleward when the heating event began, and then returned equatorward coinciding with a decrease in the heating event [Oyama et al. 2008]. Simultaneous observations of mean zonal wind at 88 km obtained by the meteor radars at Cariri (7.4°S, 36.5°W) and Ascension Island (7.9°S, 14.4°W) and two medium-frequency radars at Tirunelveli (8.7°N, 77.8°E) and Pamuengpeuk (7.7°S, 107.7°E) were used to investigate the influence of the intraseasonal variations in the lower tropospheric convective activity associated with the Madden-Julian oscillation on the longitudinal behavior of intraseasonal oscillations (ISO) of the zonal winds in the equatorial MLT [Rao et al. 2009].

D. Radio Acoustic Sounding System (RASS)

RASS is a radar remote-sensing technique to monitor high-temporal resolution temperature profiles by combining a wind profiling radar (WPR) and ground-based acoustic transmitters. An acoustic pulse transmitted produces the atmospheric sinusoidal fluctuation of refractive index, which scatters radio-wave transmitted from a WPR. Atmospheric virtual temperature can be calculated from the Doppler shift of the back-scattered radio signal, because the sound speed depends on the atmospheric virtual temperature.

The RASS system for the MU radar (the MU radar-RASS) can obtain the temperature profiles in the troposphere and lower stratosphere with the temporal resolution of a few minutes. The dataset of virtual temperature in the upper-troposphere and lower-stratosphere (UTLS) region was examined to study high-frequency changes in the stability in the UTLS region. Changes in the UTLS kinetic energy dissipation rate showed significant high-frequency fluctuations embedded within layers that persisted for at least 1 day [Alexander and Tsuda 2008].

The RASS technique was applied to the other radar systems to monitor temperature profiles in the subtropical region, where severe meteorological disturbances frequently strike. Shinoda et al. [2010] enabled RASS for the 443 MHz WPR installed at the Ogimi Facility of NICT in Okinawa, Japan. They developed software to switch active speakers adaptively by considering the real-time raytracing results of acoustic wavefronts. Virtual temperature profiles obtained using the 443 MHz WPR/RASS were evaluated by comparison with the data from radiosondes launched from the radar site. Mikami et al. [2010] analyzed a meso-γ-scale convective system in July 2007 by using the virtual temperature, the Brunt–Vaisala frequency squared, and three components of wind velocity profiles from the 443MHz WPR/RASS data. They elucidated the mechanism of the generation of the convective system by simultaneously employing the forecast data of a non-hydrostatic meso-scale (NHM) numerical model. The synergetic effects of the low static stability below 1 km and convergence by the collision of sea-breeze from both the east and west coasts of Okinawa island seemed to trigger the generation of a convective system, which eventually grew to 11 km over the radar site.

The RASS observation technique developed in Japan was also adapted to foreign countries in tropics such as Indonesia and India. Sarma et al. [2008] demonstrated capability of the RASS application with the Indian Gadanki MST radar, which will be used for continuous monitoring of the temperature profiles in the troposphere and lower stratosphere region. The height profiles of atmospheric virtual temperature were obtained between 1.5 km and 10 km and occasionally up to 14 km.

E. Spaceborne Sensors

The Greenhouse gases Observing SATellite (GOSAT) were built by JAXA to provide measures of the global distributions of carbon dioxide (CO_2) from space. GOSAT achieved a successful orbit on January 23, 2009, while the Orbiting Carbon Observatory (OCO) built by NASA's Jet Propulsion Laboratory (JPL) to provide CO_2 measurements like GOSAT failed its launch attempt on February 24, 2009. Both sensors detect absorptions at the 0.76-μm oxygen band and at the weak and strong CO_2 bands at 1.6 and 2.0 μm, respectively. In order to establish the uncertainties and biases between the respective data products, the OCO and GOSAT teams had planned a number of cross-comparison studies, including the validation of the prelaunch absolute radiometric calibrations. The cross-comparison campaign to validate this OCO approach was performed at NASA's JPL in April 2008. The OCO reference detectors and three GOSAT radiometers viewed the OCO sphere and radiometric standard. Then, to validate the GOSAT preflight calibration, the cross-calibration experiment continued at JAXA's Tsukuba Space Center in December 2008, where the same radiometers measured the two GOSAT spheres. These studies gave confirmation that the flight instruments had been calibrated to within their uncertainty requirements (±5%) [Sakuma et al. 2010].

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was successfully launched and attached to the Japanese Experiment Module (JEM) on the International Space Station (ISS) on 25 September 2009. Ochiai et al. [2008] gave the observation capabilities of SMILES. JEM/SMILES has been making atmospheric observations since 12 October 2009 with the aid of a 4 K mechanical cooler and superconducting mixers for submillimeter limb-emission sounding in the frequency bands of 624.32-626.32 GHz and 649.12-650.32 GHz. On the basis of the observed spectra, the data processing has been retrieving vertical profiles for the atmospheric minor constituents in the middle atmosphere, such as O_3 with isotopes, HCl, ClO, HO_2, BrO, and HNO_3. Results from SMILES demonstrated its high potential to observe atmospheric minor constituents in the middle atmosphere [Kikuchi et al. 2010].

F2.2 Hydrometeors and Other Particles

A. Ground-based remote sensing studies

A C-band polarimetric radar in Okinawa (128º 03’ 50’’ E, 26º 35’ 11’’ N), known as “COBRA”, is located at the Nago Rainfall Radar Facility of the NICT) in Okinawa, Japan and its data have been used for various studies. An intensive observational campaign using the COBRA and radiosonde was conducted in July 2005. The evolution of the convective boundary layer (CBL) and the initiation of clouds above the Okinawa Island were investigated. These soundings exhibited diurnal variations in the potential temperature and water vapor in the atmospheric boundary layer. COBRA observed clear-air radar echoes (CAEs) within a 10-km radar range, and the CAE height showed a diurnal variation as well. To investigate the nature of the CAEs and to describe the dynamics of the CBL structure, a high-resolution cloud resolving model simulation was performed for two cases; a cumulus street and a distinct roll cloud [Minda et al. 2010]. Large-scale bird migrations over the western Pacific Ocean were observed by the COBRA. The birds generated interesting polarimetric signatures, representing bird behavior [Minda et al. 2008]. Characteristics of polarimetric radar variables in three rainfall types in a Baiu front event over the East China Sea observed in June 2004 were studied and compared using COBRA. The selected rainfalls are common types in the Baiu season in this area: (1) stratiform type (ST), (2) isolated convective type (ICT) and (3) embedded convective type (ECT). Around the 0°C level, overall decrease in correlation coefficient between horizontal and vertical polarization signals and increase in differential reflectivity (Zdr) were observed in ST and ECT, which indicated the presence of a layer of mixed-phase precipitation. By contrast, significant decrease in rhv and increase in Zdr were not found in ICT [Shusse et al. 2009]. COBRA succeeded to obtain the three-dimensional and high spatial resolution data of the eyewall of the typhoon Man-yi in July 2007. The typhoon was in its mature stage with minimum sea-level pressure of 940 hPa and maximum Doppler velocity of more than 60 m/s. Shusse et al. [2008] described the characteristics of polarimetric radar variables, distribution of hydrometeors, and typical raindrop sizes in the eyewall of the typhoon based on the polarimetric radar observation.

B. Space-based remote sensing studies

Rain type classification algorithm 2A23 by the TRMM Precipitation Radar (PR) detects bright band (BB) and classifies rain into three main categories, those are stratiform, convective, and other. Awaka et al. [2009] gave outline of the rain-type classification and some statistical properties of BB detected. The standard TRMM PR algorithms are planned to be updated from the current version 6 to the new version 7. Among other things, estimation of the freezing height of the 2A23 will be changed to use analysis data, instead of using a climatological data, to improve the detection of BB [Awaka and Okamoto 2010]. Iguchi et al. [2009] presented the basic structure and the flow of the rain profiling algorithm 2A25, and discussion was made on the major assumptions and sources of errors in the algorithm. The rain rate retrieval algorithm utilizes the path integrated attenuation (PIA) values of the surface normalized radar cross section (NRCS) in the surface reference technique (SRT) to perform the rain attenuation correction. An estimate of the NRCS under no rain condition is used as a reference value for computing PIA. Okamoto et al. [2010a] introduced new physical parameters, the NDVI (Normalized Differential Vegetation Index), the surface roughness, and the soil moisture for estimating reference NRCS in order to increase the accuracy of the estimated reference NRCS. Aonashi et al. [2009] described a precipitation-retrieval algorithm for the TRMM Microwave Imager (TMI) that was developed under the Global Satellite Mapping of Precipitation project (GSMaP). Improvements of the GSMaP algorithm were given.

Takahashi and Iguchi [2008] investigated the characteristics of system noise sampled by the TRMM PR. The characteristics of the system noise of three rain categories – "rain certain", "rain possible," and "no-rain" - were examined by taking a histogram. The results was explained by saying that the rain-possible pixels were obtained when the sampled noise level was made accidentally small by the fading effect. Therefore, a fixed noise level threshold was introduced to the rain/no-rain classification for a more reliable rain-possible classification. Tagawa et al. [2009] presented a correction of the TRMM PR received power for mismatched-beam data after the orbit was boosted. The current standard algorithm employs a beam-mismatch correction algorithm based on the rain-echo radar equation and there remains a need for improving the estimated power of the mismatched-pulse echo returned from the Earth's surface and weak rain because the echo is represented with the surface-echo radar equation and the noise-power level. The error in the current method causes a negative bias (around 1 dB) in the PR received power near the main lobe clutter. They formulated an improved estimate of the mismatched pulse, and then evaluated numerically and experimentally with the actual TRMM PR data. The consistency of the data sets between preboost and postboost was improved by eliminating the negative bias.

Appropriate modeling of raindrop size distribution (DSD) is important to develop various spaceborne rain radar algorithms. Kozu et al. [2009a] proposed a "2-scale" DSD model over a spatial or temporal domain in which a statistical rain-parameter relation exists. In this model one DSD parameter is allowed to vary rapidly and the other is constant over a certain space or time domain. The result was applied to the DSD model for the TRMM PR algorithm, 2A25 [Kozu et al. 2009a]. To statistically study the temporal variation of a DSD parameter following the "2-scale" model using ground-based rainfall data such as those from disdromters, it is preferable to extract the DSD variation automatically for large amount of data processing. Kozu et al. [2010] proposed a state-space approach to extract the change in the amplitude parameter of normalized DSD (N_0^*) automatically and showed its statistical properties at several locations in Asia [Kozu et al. 2010]. Using the DSD model for the 2A25 algorithm, Kozu et al. [2009b] studied the feasibility of estimating a DSD parameter from the PR measurements. The DSD parameter they estimated is "a" in the Z-R relation $Z = aR^b$ for radar beam-by-beam basis. Comparisons of PR- and ground-based disdrometer-estimated a were generally in good agreement at various locations over both land and oceanic sites. The adaptively pointing antenna scanning, which was first proposed in 1980's, is recognized as a potentially useful technique to improve the accuracy of radar reflectivity measurement in next-generation spaceborne rain radar observation. Shimomai et al. [2008] performed a comprehensive simulation study of the adaptive scan using the TRMM PR data. They showed that more than 3-dB improvement in "effective" signal-to-noise ratio can be achieved for about 40 % of total observation.

Okamoto et al. [2009, 2010b, 2010c] proposed a new spaceborne system for rain observation, which is a combined system of radar and microwave radiometer. The Ku-band radar and microwave radiometer commonly share a same reflector antenna. The rain at the same instantaneous field of view is observed almost simultaneously by the radar and the microwave radiometer. This system aims at rain measurement accuracy enhancement from space. They analyzed the noise power from rain received by the TRMM precipitation radar receiver. They also performed the preliminary system design of the combined system of the Ku-band radar and microwave radiometer.

The large-scale distribution of precipitation and latent heating (LH) profiles in the tropics, subtropics, and part of the midlatitudes was studied using a 9-yr dataset derived from TRMM PR observations, with emphasis on the contribution of warm rain. Warm rain was weak over land but widely distributed over oceans, especially along the intertropical convergence zone (ITCZ) and the western part of the subtropical oceans. The amount of warm rain over ocean was positively correlated with sea surface temperature (SST); this dependency was found in the tropics, subtropics, and part of the midlatitudes, whereas dependency of SST on total rain was confined to the tropics [Kodama et al. 2009]. The rain/no-rain threshold value of cloud liquid water (CLW) is important for the microwave precipitation retrieval algorithms. Kida et al. [2008, 2009] determined rain/no-rain threshold value of CLW using CloudSat precipitation product and Aqua/AMSRE products. The threshold values of CLW from CloudSat precipitation product were lower than 0.5 kgm-2 for GSMaP over all regions. The threshold value of CLW was found at its peak in the Tropics and decreased poleward. The threshold value divided by the zonal mean storm height from TRMM PR3A25 was employed on the parameterization of threshold value of CLW. The result showed that GSMaP with new parameterization could detect the shallow rain observed by CloudSat. Kida et al. [2010] compared the fractional occurrence of precipitation over ocean derived using the GSMaP algorithm for the Advanced Microwave Sounding Unit (GSMaP_AMSU) and the Microwave Surface and Precipitation Products System Day 2 rainfall algorithm (NOAA_AMSU) for the Kwajalein radar site and over tropical and subtropical ocean.

A Cloud Profiling Radar (CPR) will be installed on satellite mission named Earth Clouds, Aerosols and Radiation Explorer (EarthCARE). EarthCARE mission, proposed by European and Japanese scientists, has been selected for implementation as sixth Earth Explorer Mission of European Space Agency's, focuses on clouds and aerosols effect on the earth radiation flux budget. EarthCARE/CPR is millimeter-wave radar which has high sensitivity. Horie et al. [2010] presented methods and accuracies of the external calibration for EarthCARE/CPR. CPR will be operated only nadir direction during nominal operation. The external calibration using Active Radar Calibrator will be performed. In addition, the EarthCARE satellite has the special operational mode for external calibration using sea surface, which is rolled by satellite, then normalized radar cross-section of sea surface in various incident angle will be obtained. Schutgens [2008] presented a new technique for generating range oversampled profiles of Doppler radar signals that had been backscattered by distributed targets. The technique used an accurate description of covariances between voltages measured for different pulses and at different positions (range gates) along a profile. In particular, it dealt with target variability in a physically consistent manner, accounting for the effects of inhomogeneity both within the instantaneous field of view and between subsequent pulses. It was showcased with examples of simulated 95-GHz Doppler radar observations by the EarthCARE mission.

C. Others

The possible detection, tracing, or quantification of volcanic ejecta by radars would be very useful for preventing disasters that have resulted from volcanic eruptions. In the radar detection of volcanic clouds, the most fundamental parameter is the dielectric properties of ash particles. The dielectric properties of volcanic ash from five volcanoes in Japan were measured by using the transmission/reflection coaxial line method of a network analyzer, in a frequency range from 3 to 13 GHz [Oguchi et al. 2009]. The measured permittivity of powdered ash was then converted to that of solid ash (dense rock equivalent) with the aid of effective medium theory. The values of solid-ash relative permittivities for the five volcanoes revealed that they were in a relatively narrow range. Their real part was generally in a range from 5 to 6 in magnitude, while their imaginary part was in a range from 0.08 to 0.18.

F2.3 Ocean and Ice

A study was carried out to extract ships in the offshore of South Korea using the dual-polarization ENVISAT ASAR C-band amplitude and MLCC (Multi-Look Cross-Correlation) coherence images [Yang and Ouchi 2008a, 2008b]. Different algorithms of ship detection by SAR were then compared using ALOS-PALSAR L-band images over the Tosa Bay, Japan with 3 small fishing boats propagating in range direction [Hwang et al. 2009]. The algorithms tested were those based on amplitude threshold, CFAR (Constant False Alarm Rate), MLCC, and polarimetric analyses. Different algorithms showed their characteristics, and a difficulty of automatically finding the threshold coherence level by MLCC was pointed out. This difficulty was overcome by applying CFAR to the MLCC coherence images as demonstrated by Hwang and Ouchi [2010] and Ouchi and Hwang [2010].

Applications were sought to retrieve the parameters of ocean waves by SAR [Yang and Ouchi 2008c]. Shiroto and Ouchi [2010] introduced a waveheight retrieval algorithm of range traveling waves by using the HH- and VV-polarization radar cross section (RCS) ratio. They obtained good agreement between the wave buoy data with estimated waveheight using ALOS-PALSAR polarimetric data over the waters around Izu Islands, Japan.

On December 7, 2007 (local time 07:30), the collision of an oil tanker spilled out a huge amount of crude oil over the Yellow Sea near the west coast of South Korea. Spatial and temporal changes of oil slick were monitored by multi-polarization multi-frequency spaceborne SARs including X-band TerraSAR-X, C-band RADARSAT and ENVISAT, and L-band ALOS-PALSAR [Yang et al. 2009]. The radar backscatter cross section was also computed using the physical optics and moment methods to improve the measurement accuracy [Yang et al. 2010].

Ichikawa et al. [2008] studied the position and speed of the Kuroshio by a combination of high-resolution high-frequency (HF) ocean radar and wide-coverage altimetry data. These two were found to be well correlated for mesoscale variations with periods for a few months, as the Kuroshio tended to be faster (or slower) when its axis moved south (or north). Satake et al. [2008] applied a C-band multi-parameter weather radar in the Okinawa (COBRA) to ocean wave measurements. Its full polarimetric and Doppler velocity measurement capability would be very powerful tool for observing ocean surface properties. Located at the top of a mountain in the middle of the island, the radar has good view of its surrounding ocean. Having observed ocean surfaces in different wind conditions, the results showed that the radar cross-section was larger when the wind speed was larger, and relatively smaller in the downwind side of the island, as expected. Measured Doppler velocities also showed azimuth variation depending on the wind speed and direction.

F2.4 Land, Vegetation, Subsurface Objects and Others

A. Land and Vegetation

Polarimetric radar remote sensing and its applications have been attractive in the period. A book dealing with polarimetric information utilization in Japanese was published by IEICE in 2007. This served and stimulated the understanding of polarimetric radar remote sensing, with various decomposition techniques presented for the utilization of quad-polarization data sets [Yamaguchi, 2007]. Classification of terrain is one of the most important applications of Polarimetric Synthetic Aperture Radar (POLSAR) image analysis. Yamaguchi et al. [2008a] presented a simple method to classify terrain by the use of the correlation coefficients in the circular polarization basis together with the total power of the scattering matrix in the X-band. It was shown that forest areas and oriented building blocks were easily detected and identified. Yajima et al. [2008] analyzed seasonal changes of a wetland by a modified polarimetric four-component scattering power decomposition method, with L- and X-band POLSAR data, acquired by the NICT/JAXA airborne polarimetric and interferometric synthetic aperture radar system (Pi-SAR) in 2004. Since there existed a deficiency in the currently adopted decomposition schemes in that negative powers appear in a few pixels, they modified the approach taking into account physical conditions, to show that the seasonal changes and features of the vegetation near Sakata Lagoon in Niigata, Japan, are observed clearly. Nakamura et al. [2008] presented a coherent decomposition scheme for POLSAR data. Based on the scattering matrix acquired with an FM-CW POLSAR system, a simple decomposition technique using the coherency matrix was devised for identifying scatterers. It was shown the scattering mechanisms were well recovered and the orientation angles of wire scatterer were precisely measured. POLSAR data was also utilized to monitor water surface changes [Yamaguchi et al. 2008b, Sato et al. 2008a, 2009b]. Yamada and Yamaguchi [2008] presented scattering model decomposition technique with Pol-InSAR (polarimtric interferometric SAR) data sets, based on the scattering mechanisms corresponding to surface, double, and volume scattering. A problem that the power of the decomposed components becomes negative is caused by assumptions in the decomposition technique. Those assumptions are necessary, as the number of observables is limited in the fully polarimetric SAR data. However, when an interferometric pair of fully polarimetric SAR data is available, additional observables can be obtained. These new observables will be available to resolve the difficulty of negative power in the conventional decomposition technique. Yamada et al. [2009] proposed a decomposition technique with Pol-InSAR image pair. Based on the ESPRIT (Estimation of Signal Parameters via Rotational Invariance Technique), it can decompose without any assumptions when a suitable set of candidates for volume scattering covariance matrix is prepared. Experimental results of SIR-C/X-SAR were provided as an example. Yamada et al.[2010] proposed an alternative technique with POL-InSAR dataset. They applied a generalized volume scattering model proposed by Arii et al. [2009] to the ESPRIT-based POL-InSAR decomposition technique and verified the estimation performance experimentally. Arii et al. had applied the model to the POLSAR dataset with the adaptive non-negative eigenvalue decomposition technique.

Wada et al. [2008] applied three-component (H/α/A) decomposition analysis and four-component (P_s, P_d, P_v and P_c) analysis to ALOS-PALSAR quad-polarized data of Izu-Oshima and Miyakejima volcanoes to monitor volcanic activities. The results demonstrated clear discrimination of forest, urban and volcanic deposit areas, indicating a high possibility of detecting land-cover changes at volcanoes by space-borne POLSAR observations. Sato et al. [2008b] analytically examined polarimetric scattering for a simplified man-made structure model, by utilizing the finite-difference time-domain (FDTD) method. The model simulated a building in mountainous environment and was composed of a dielectric rectangular parallelepiped on finite rough and/or inclined plate. The statistical FDTD analysis on two polarimetric indices, the scattered power decomposition and the polarimetric correlation coefficient, with respect to squint angle change was carried out. The considered polarimetric indices were valid even when the surface of the ground plate had small roughness and gentle slope. Sato et al. [2009a] proposed an accuracy improvement of the vegetation area classification based on the POLSAR image analysis, when vegetation and man-made areas were both included in the radar target region. They introduced a simple compensate polarimetric marker, T_{13} or T_{31} (T is a coherency matrix), to accurately distinguish the unexpected scattering from the obliquely oriented man-made targets and the complex volume scattering generated from vegetation area. By appropriately utilizing T_{13} (T_{31}), one can extract only the vegetation area from the mixed target region.

POLSAR images describe objects via polarization synthesis and present much richer information than monopolarized SAR images. Furthermore, multidirectional flights of POLSAR can see 3-D stereo objects in different angles. The height and the location of the 3-D objects can be retrieved from the POLSAR images in multidirectional flights. A tractable approach for the reconstruction of 3-D stereo buildings from two airborne Pi-SAR images taken from opposite directions (at X-band with a spatial resolution of 1.5 m) was presented [Dai et al. 2008]. Fukuchi et al. [2008] estimated area-averaged urban parameters with POLSAR data taken by Pi-SAR and PALSAR, to obtain urban buildings density or building orientation. Iribe and Sato [2007] analyzed polarization orientation angle shifts induced by artificial structures and attempted to combine target orientation information which characterizes an urban area with the polarization orientation angle information extracted by the circular-polarization method. The X-band POLSAR datasets of Sendai City acquired by Pi-SAR were used. Based on Kimura's idea that the variation of the polarization orientation angle shifts depends on the artificial structures, particularly for the target rotation angle, they found that the polarization orientation angle shift was also affected by the relative relationship between the target rotation angle and the flight direction. From these results, it was possible to estimate the target rotation angle via computation of the polarization orientation angle shift from POLSAR data. Yamaguch et al. [2010a] presented a new four-component scattering power decomposition using a rotation of the coherency matrix to distinguish vegetation and oriented urban area with respect to the direction of radar illumination in the volume scattering mechanism. It is known that oriented urban area and vegetation signatures have similar polarimetric responses and are decomposed into the same volume scattering mechanism in the decomposition. Using ALOS-PALSAR data sets, oriented urban areas were clearly distinguished from volume scattering as double bounce objects by the rotation of coherency matrix. The approach using the scattering power decomposition with appropriate polarimetric rotation provides us with high accurate man-made target detection, regardless of the direction of their alignment. Using airborne Pi-SAR data sets, oriented urban areas were clearly distinguished from volume scattering as double bounce objects by the rotation of coherency matrix. [Sato et al. 2010a, Yamaguchi et al. 2010b]

Venkataraman et al. [2010] assessed the capability of fully polarimetric L-band ALOS PALSAR data for snow discrimination from other targets. Eigenvaluve based polarization fraction value was determined for assessing the capability. Radar snow index was developed using polarization fraction and normalized third eigenvalue of coherency matrix. The radar snow index is more robust and simple to implement that supervised classification.

NICT have developed a high performance airborne SAR system,"Pi-SAR2," as a successor to the Pi-SAR (X-band). Pi-SAR2 has polarimetric and interferometric functions with high spatial resolution of 0.3-0.6 m in along track direction and 0.3-0.5 m in cross track direction at X-band. Matsuoka et al. [2009] presented the ground based calibration experiment using active radar calibrators (ARC) and corner reflectors (CR) in conjunction with the Pi-SAR2 test flight.

A trihedral corner reflector is often used for SAR polarimetric calibration. However, the scattering property of the reflector used for the calibration may not be correct if the high frequency approximation is not satisfied or if an incident angle deviates from the symmetric axis of the reflector. Kusano and Sato [2009] evaluated the polarimetric response of the reflector by a numerical simulation using the method of moment (MoM). It was found that allowable incident angle deviation was 5 degree to azimuth direction and 4 degree to elevation direction for precise SAR polarimetric calibration when the size of the reflector was 7.5 times larger than the wavelength of an incident wave.

Forests take an important role in carbon cycle and absorbing carbon dioxide for mitigation of global warming, and SAR is known to be an effective sensor to estimate forests biomass. The accuracy of the regression model based on the *K*-distribution of high-resolution cross-polarized SAR amplitude fluctuations and the coniferous tree biomass was investigated using the L-band Pi-SAR images of the Tomakomai forests in Hokkaido, Japan. The result showed the accuracy of 85% [Wang and Ouchi 2008a]. This model requires PDF (probability density function) which fits best the data. Wang and Ouchi [2010] proposed a new regression model for estimating tree biomass based on the second moment of image intensity. The advantage of the model over the previous *K*-distribution model is no need to estimate PDF as long as the image shows non-Gaussian texture. The accuracy of this new model was tested using the same Tomakomai data, resulting in the similar model accuracy of 86%.

When trees fall by a typhoon, the tree structure changes. It is then possible to estimate the damage area by comparing the backscattering mechanisms by polarimetric analysis before and after the typhoon. An investigation was made using the Pi-SAR L-band data over the Tomakomai forests which suffered substantial damage by the typhoon “Songda” in September 2004. The preliminary results indicated that the accuracy of damage estimation by the 4-compionent scattering decomposition analysis was approximately 78% [Wang et al. 2010].

POLSAR data have potential of improving the measurement accuracy and extending the field of applications. The scope of polarimetric applications was extended to estimating the heights of bridges over water by the mapping and projection algorithm together with de-orientation theory. Fully polarimetric data of airborne Pi-SAR at X-band were applied to the inversion of the height and width of the Naruto Bridge in Japan, and also the ALOS-PALSAR single-polarization data were used to estimate these parameters of the Eastern Ocean Bridge in China. The results showed a good feasibility of the bridge height inversion by the proposed method [Wang et al. 2009].

B. Subsurface Objects and Landmine Detection

A fully polarimetric borehole radar system with four combinations of dipole and cylindrical slot antennas was developed to acquire fully polarimetric datasets in drilled boreholes. Zhao and Sato [2008] experimentally implemented and evaluated two polarimetric calibration approaches, namely (1) cross-hole and (2) single-hole polarimetric calibration, utilizing fully polarimetric datasets acquired at a specific borehole test site. Both polarimetric calibration approaches can guarantee the further implementation of radar polarimetry techniques, and especially, the single-hole polarimetric calibration will be very meaningful to practical applications.

Ground-penetrating radar (GPR) is recognized as a promising sensor for detecting buried landmines. Feng et al. [2009a] proposed techniques to enhance the target signal through common midpoint (CMP) antenna array and data processing techniques, including velocity spectrum and CMP multifold stacking. The method was tested using experiment data over a rough ground under which small plastic antipersonnel landmines was shallowly buried. The result showed the signal-to-clutter ratio was dramatically improved. In estimating the ground surface topography from radar returns, the popular method, searching for the brightest pixel in the ground-penetrating radar profile, cannot achieve accurate surface topography in the sharp variable surface case because of the effects of diffraction waves. Feng et al. [2009b] proposed a method to solve the problem and improve the accuracy of surface topography. A migration technique was introduced to refocus the diffraction waves before searching for the brightest pixel. Experimental data was used to show that the method can dramatically estimate accurate surface topography even in the sharp variable surface area. In many GPR applications, targets are veiled by the strong waves reflected from the ground surface, so that we need to apply a signal processing technique to separate the target signal from such strong signals. A pulse-compression technique is used to compress the signal width so that it could be separated out from the strong contaminated clutter signals. A filter algorithm was introduced to carry out pulse compression for GPR data, using a Wiener filtering technique. The filter was applied to synthetic and field GPR data acquired over a buried pipe [Gaballah and Sato 2009]. Two design methods of a filter in a frequency-spatial frequency (*f-k*) domain were developed for bistatic GPR. The methods suppressd the direct wave, which caused significant artifacts in radar images, and were evaluated by laboratory measurements. Two methods to design the *f-k* filter were presented, those used a difference of an apparent horizontal velocity between a direct wave and a reflection from a target. Both methods were applied to an experimental data set which was acquired by a bistatic radar measurement to detect a buried landmine model with a depth of 10 cm. It was confirmed that they could suppress the undesired fluctuation of the images nearly one-tenth and help the reliable detection of a buried object [Hayashi and Sato 2010]. Khuut and Sato [2009] reported an implementation of GPR survey at a site that corresponds to a ruined castle. The objective of the survey was to characterise buried archaeological structures such as walls and tiles in Van Khan Tooril’s Ruin, Mongolia, by 2D and 3D GPR techniques. Two datasets were collected, using GPR with 500 MHz and 800 MHz frequency antennas. They used instantaneous parameters to detect archaeological targets such as tile, brick, and masonry by polarimetric GPR for extraction of target scattering characteristics.

C. Others

Microwave emission due to material destruction by hypervelocity impact with several km/sec was found at 2 GHz and 22 GHz, and its power was calibrated. Hypotheses on the mechanism were proposed, based on the dynamic relative motion of an atom's nucleus and the outermost electron and lead to dipole radiation. The relationship between the emitted power and the target plate thickness was derived. The models were numerically analyzed in consideration of the experimental data. In the most promising model, a projectile molecule flicks the nucleus out and the outermost electron is left out of the orbit of the atom. Accordingly, the material is polarized or ionized to form an impulsive dipole, which leads to microwave emission. This model was compatible with material ionization by mechanical excitation such as rubbing and peeling, or triboelectricity. The calculated energy showed good agreement with the experimental value [Takano et al. 2010].

In order to extract a local and faint variation generated by a specific source from a physical value obtained by a remote-sensing satellite, we should focus on the difference between physical values at two points. A new data restructuring algorithm based on this concept was developed. It enables us to obtain a distribution of physical values at any interval and to calculate the difference between any two points regardless of the sensor-sampling interval. Based on the algorithm, Maeda and Takano [2008] established a new data processing method and analyzed the brightness-temperature data obtained by a microwave radiometer. As a result, they successfully extracted the feature associated with a volcanic eruption.

The possibility to detect natural disasters such as earthquakes and volcanic eruption via microwaves emitted in rock fracture was presented. The method is based on the experiment in which microwave emission was detected in association with rock fracture in the laboratory for the first time in the world. The emitted microwave power was calibrated, and then a model of the microwave emission and propagation to a satellite was proposed. The advantage of microwave is to penetrate the earth's ionosphere, as is different from the lower frequencies than several tens MHz. The received power by a receiver aboard the satellite was estimated, and showed that the satellite could detect the microwave signal originated from an earthquake. With the estimation, the data taken by a remote sensing satellite in orbit was analyzed in the case of Morocco earthquake in 2004. The microwave signatures at 18.7GHz were successfully extracted out of many kinds of noise and disturbances [Takano et al. 2009a]. It was experimentally confirmed that microwave energy was emitted during the compression of rocks. Land-surface deformations are likely to be accompanied by rock failures. From the experimental results, the microwave signals generated by rock failures near the land surface may be detectable by a satellite-borne radiometer. Maeda and Takano [2010] developed an algorithm to evaluate the microwave energy generated by rock failures on the land surface and applied the algorithm to the data of the Advanced Microwave Scanning Radiometer for the Earth Observing System for the earthquake that struck Al Hoceima, Morocco, on February 24, 2004. They detected definitive microwave signals around the epicenter two days before the earthquake only in the entire observation period of six years. The microwave emission at 22 GHz, 2GHz and 300 MHz in association with rock crash could be applied to detect earthquakes or volcanic eruption phenomena which are accompanied with the rock crash. To confirm the microwave emission in natural phenomena, Takano et al. [2009b] planned a field test at the volcano of Miyake-jima. They reported the estimation of the signal to noise ratio of the test, the test site and the measuring system. The obtained data and their analysis showed successful detection of signals at 300 MHz.

(M. Satake)

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