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F1.Wave Propagation
F1.1 Terrestrial Fixed Radio System

A. Effects of Atmosphere

After the Hyogoken-nanbu earthquake in 1995, it was reported that the propagation anomalies of the non-line-of-sight 77.1 MHz FM radio waves broadcasted from Sendai were detected. It was then hypothesized that the propagation anomalies were due to ionospheric or atmospheric disturbances. The observation results for the non-line-of-sight FM radio wave of 77.1 MHz broadcasted from Sendai to Nobeyama, Yokosuka, and Hitachi EM observatories are described. The observation period was for 3 years from January 2006 to December 2008. From the observation results, it was found that the received levels had seasonal variations in their fluctuations. It was concluded that the non-line-of-sight 77.1 MHz FM radio waves were characterized by terrestrial propagations with atmospheric refractivity variations [Nishi et al., 2011a]. Seismic electromagnetic waves in FM broadcasting frequency band from 76 MHz to 90 MHz have been observed. From observations at Ibaraki by the dual frequency method using two different frequencies, nine events of co-seismic electromagnetic waves were observed for seven years from January 1, 2002 to December 31, 2008. Received electromagnetic levels rose up at the same moment of arrival of seismic waves. Further, we examined

the relation between the co-seismic broadband electromagnetic waves and the seismic parameters. It was confirmed that the detected peak electromagnetic levels were well correlated with the peak ground accelerations of the earthquakes [Shin et al., 2011a].

An estimation method of equivalent earth radiuses (K) was proposed from measured path losses based on the two wave model. The estimation method using measured UHF band TV broadcasting waves over the Seto Inland Sea has been investigated. From a result, it was found that fluctuation ranges of K increased in summer season. Further, it was clarified that accurate path losses were estimated by the estimation method [Yanase et al., 2011].

Electromagnetic waves in the FM broadcasting frequency band have been observing at our eleven observatories in Japan. Anomalous FM radio waves have been frequently observed due to reflection by the ionospheric sporadic-E layer, and due to the tropospheric duct propagation. For large amounts of data observed in years, it is important to classify them automatically. Thus, a method to classify above two FM radio waves based on their propagation characteristics is proposed. The method was evaluated by using data observed at Hiroshima and Aso from 2005 to 2010. As a result, it is confirmed that the classification method worked correctly [Shin et al., 2011b].

An original human detection system around detached houses using UHF band transmitters was proposed. This paper newly studies installation positions of the transmitting and receiving antennas in the system to improve the detection performances. Based on the measurement using 400 MHz and 800 MHz band radio waves, this paper evaluates the detection probability of the systems in LOS and non-LOS cases. From the measurement results, it was confirmed that detection probability in the non-LOS case was over 70 % in average and was higher than that in the LOS case. And in the non-LOS case, only 2 sec monitoring time was required to detect human motion around the detached house with detection probability over 99 % [Nishi et al., 2011b]. In non-line-of-sight VHF radio wave observation, anomalous propagations due to ionospheric sporadic-E (Es propagation) and tropospheric duct (tropospheric ducting) have been frequently observed. In this paper, a method to classify above two anomalous propagations automatically is shown. Procedures of the method are based on their propagation characteristics, received signal strength and dual frequency method. In order to evaluate the method, we examined the occurrence of the Es propagation and tropospheric ducting detected by the above method using the data observed from 2005 to 2010. Observation results had the same tendency as past observations at mid-latitude. Since propagation characteristics of the FM radio waves have been clearly shown, it was confirmed that the classification method worked effectively [Shin et al., 2012].

Multiple Detection (MD) method in the human detection system is newly proposed using terrestrial digital TV broadcasting waves. In the Single Frequency Network (SFN) environment, our measurement results indicate that the RSSI hardly fluctuates even under condition of human presence and the detection method only using RSSI has a possibility of overlooking the human motion. In the proposed MD method, not only RSSI but also Carrier to Noise Ratio (CNR) and Bit Error Rate (BER) are utilized for human detection. In this paper, based on the practical measurements by using the digital TV tuners, we evaluate the fluctuation performances of RSSI, CNR and BER affected by human motion in a wooden detached house, and clarify that the MD method can effectively detect human motion even in the SFN environment [Nishi et al., 2012a]. A cooperative Sensing method in the human detection system using terrestrial digital TV broadcasting waves is newly proposed. In the proposed method, antennas are placed not only in-door but also out-door for reducing false detection. In a wooden detached house, we evaluate the fluctuation performances of RSSI affected by human or auto motion in both in-door and out-door. It was clarified that the proposed method can effectively detect human motion and can reduce false detection even in the disturbance environment [Maeda et al., 2012]. Because the digital terrestrial broadcasting system utilizes the same channels in neighboring prefectures, it is difficult to identify the source of over-reach digital TV waves. So we have proposed attention on VHF band FM radio waves which were from almost the same transmission sites, in order to identify the source of the over-reach TV waves. And we considered that the over-reach of the TV waves can be estimated by that of the FM radio waves. In this study, we simultaneously observed the

analog TV waves and the FM radio waves from Yamaguchi to Hiroshima, in order to estimate over-reach propagation of digital terrestrial broadcastings using FM radio waves. We analyzed the propagation losses of analog TV waves and FM waves based on observational results, and evaluated correlation coefficient between them. Consequently, it was clarified that the propagation losses of TV waves were estimated by a linear approximation of the propagation losses of FM radio waves [Komori et al., 2013].

The observation results on received levels of ionospheric MF band radio waves over 6 months period in Japan and Kiruna, Sweden are described. From the results, the received levels of the MF band radio waves in night time are 20 dB or 30 dB higher than those in day time, both in the Arctic and the mid-latitude regions. And the time of rising and falling was related to that of sunrise and sunset. Only in the Arctic, there were unusual variations of the received levels without rising up, which were observed a few days after the solar flare occurred. At the same time of the unusual variations, aurora borealis also were observed. It was found that the ionospheric radio propagations in the MF band in the Arctic were more sensitively affected by the solar flare than propagations in the mid-latitude region [Nishi et al., 2012b].

B. Effects of Vegetation

A preliminary investigation of the influence of the foliage on the radio wave propagation in cellular scenarios is reported. The purpose is to evaluate the dispersion caused by vegetations in mobile radio channels, hence we employed a channel sounder to measure the received signals behind dense vegetations in the rural areas in Kanagawa, Japan. In the measurement campaign the transmitter antenna is set-up in 5 different elevations (2 of which are above the vegetation height) to evaluate the foliage influence -possibly by different mechanisms- on the propagation channel. The dispersion of the direct path caused by the vegetation in delay and azimuth are investigated by deriving the first and second moments of the diffuse component distribution. For the sake of robustness to forbid the dependency to the signal model and distribution, beam-forming is used to extract these parameters [Ghoraishi et al., 2010a]. Dense vegetation areas are traditionally considered as homogeneous random scattering media. In the current paper we argue that this may not be the case when looking at the receiving radio wave with high resolution in angular domain. The identification of clusters of received multipath for the data collected in the measurement with double-directional channel sounder indicates that other than forward scattering by the foliage obstructing the line-of-sight-normally used as the main mechanism in different approaches - there can be other significant propagation mechanisms. It seems airy spaces in the vegetated area can have crucial influence in directing the radio signal toward specific directions, to be redirected to the receiver by a foliage with the line-of-sight toward the receiver [Ghoraishi et al., 2012].

In order to predict the rural coverage accurately for the wireless systems, it is required to recognize the propagation characteristics through foliage. In this paper, the spatial coherence of the radio wave propagation through foliage has been studied. In the experiment, received signal levels of various frequencies (400 MHz, 800 MHz, 2 GHz, and 3 GHz) were investigated in terms of frequency dependency of angular power spectrum, and coherence distance. The relation between angular spread and coherence distance is derived assuming the uniform angular power spectrum. Then the normalized autocorrelation function of the measured power distribution is calculated and the coherence distance is determined. By substituting the measured coherence distance into the theoretical relation, the angular spread is estimated. The results show that the angular spread decreases according to the frequency [Phakasoum et al., 2010]. The angular spread due to the propagation through the foliage is further investigated. Assuming von Mises angular spectrum under Rayleigh fading condition, the theoretical coherence distance is related to the measured coherence distance to estimate the spread parameter. For the propagation range of about 100 m, the average angular spread was found to be about 25 degree within the frequency range of 450 MHz to 3.35 GHz, and the base station antenna height within 5 m to 15 m, and no significant impact of these parameters was found [Phakasoum et al., 2011].

The effect of the foliage on the radio wave propagation has been analyzed by using the space-alternating generalized expectation-maximization (SAGE) algorithm, in order to evaluate the directional characteristics of dispersion caused by trees in the radio channel. A wideband channel sounder was employed to perform measurements of polarimetric signals through dense foliage in the rural areas in Kanagawa. The analysis results show that the azimuth direction spread for horizontal (H) polarization is always more than that of vertical (V) polarization, and the opposite is true in the case of the co-elevation direction spread. The mean azimuth direction spread was found to be about 25° and the mean co-elevation direction spread was about 6° [Hung V. Le, et al., 2012a]. It has been shown that the estimates given by SAGE algorithm agree well with the geometry of the measurement site. The analysis results show that the azimuth direction spread for V polarization is always more than that for H polarization, and the opposite is true in the case of co-elevation direction spread. The average azimuth direction spread was found to be about 25° and the average co-elevation direction spread was about 6° [Hung V. Le, et al., 2012b].

C. Others

An asymptotic method was derived to calculate the received intensity of multipath millimeter waves transmitted over a road surface undulating along the transmission direction, based on the physical optics integral expression of scattered waves from the surface [Ihara and Seki, 2012]. Applicability of this asymptotic method was verified through laboratory controlled propagation experiments performed at 60 GHz both over sinusoidally undulating conductive surfaces and over a reduced scale conductive surface that simulates an actual road surface profile [Seki et al, 2013].

Opportunistic use of white space spectrum, i.e. unused frequency spectrum in time and space domains, has been a hot topic for these ten years since FCC (Federal Communications Commission) in US has released the Spectrum Policy Task Force report in 2002. FCC has found that the majority of the frequency bands are allocated but unused from the microscopic view point in terms of time and space domains. The report recommends introducing cognitive radio technology for the secondary use of unused spectrum, with the guarantee of the services of primary users. Several countries and regions have introduced the policies of using the white space particularly for terrestrial TV band. This paper reports the current status and future direction of TV white space in Japan [Takada, 2013a].

F1.2 Satellite Radio System

A. Effects of Rain

The relations among 10-minute precipitation, rainfall intensity and rain attenuation are evaluated and shown by using experimental data of Ku-band satellite communication observed at three different locations in Kyushu Island, Japan [Fujisaki et al., 2010]. The average value of received power can be obtained by the second moment of a Gaussian wave beam, and then the BER derived from the average received power is formulated for satellite communications in Ka-band. Also, the method to estimate effects of atmospheric turbulence on satellite communications is provided by analyzing the degradation in BER performance due to the decrease in the average received power [Hanada et al., 2011]. The vertical profiles of the structure constant from radiosonde data are measured in Fukuoka, Japan by applying the above statistical method, and then analyze BER for satellite communications in Ka-band at low elevation angles using the predicted profiles of the structure constant [Hanada et al., 2012].

The rainfall rates across Japan were investigated based on measured rainfall data in the Automated Meteorological Data Acquisition System (AMeDAS). Rain attenuation in 12-GHz band measured from 2005 to 2009 in Setagaya, Tokyo was compared to the prediction from the rainfall rate. Comparison of estimated rain attenuation in 21-GHz band between a long-term frequency scaling and prediction from the rainfall rate was also performed [Kamei et al., 2011]. The relationships between the distribution of rain attenuation measured by a 12 GHz-band broadcasting satellite and 10-minute rainfall rates were evaluated. In order to evaluate the difference between the yearly rainfall rates, data

measured in Tokyo with a R0.01 of about 70 mm/hour and in Kagoshima with a R0.01 of about 95 mm/hour were compared [Kamei et al., 2013].

The effects of satellite orbital diversity as a countermeasure to rain attenuation of earth-space communication link are demonstrated as a result of two-year-long measurements of four geostationary-satellite links operating in the Ku band [Iwasa et al., 2012]. The effects of frequency diversity to improve communication capacity during rain attenuation were investigated for an earth-satellite link with Ku-, Ka-band and millimeter-wave frequencies [Tripathi et al., 2011 and 2012].

Long-term rain attenuation statistics and variability are discussed using Ka and Ku band satellite signal observations conducted at Osaka Electro-Communication University in Neyagawa, Japan, 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. Also, the occurrence probability of heavy summer time precipitation such as typhoon and thunderstorm in Japan seems to be closely correlated with the tropical climate change caused by the sea surface temperature anomalies in the equatorial region [Maekawa, 2011 and 2013].

Detailed attenuation characteristics of the Ka-band satellite signal levels are studied using those data observed at 1 sec interval at Osaka Electro-Communication University in Neyagawa, Osaka, from 1997 to 2007. 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 [Nakajo and Maekawa, 2011]. Long-term statistics of the duration time and the fade slope are in fairly good agreement with the ITU-R predictions. In more detail, however, the cumulative probabilities of the duration time become comparatively higher in the typhoon and stationary front events as the duration time increases, while the distribution of the fade slope becomes wider in the cold front events for any threshold levels [Nakajo and Maekawa, 2012].

Ku-band satellite signal levels have been simultaneously observed at Osaka Electro-Communication University (OECU, Neyagawa, Osaka), the Research Institute for Sustainable Humanosphere (Uji, Kyoto) and the Shigaraki MU radar observatory (Koga, Shiga) of Kyoto University since September 2002. The speed and direction of rain area motions are estimated from the time differences in the attenuation detected at these three locations, and compared with the wind velocity (speed and direction) measured by the MU radar at the rain height. As a result, the wind velocities at the height of 2-6 km are shown to agree well fairly with those of the rain area motions detected on the ground. The wind speeds, in general, tend to become larger as the height increases. Also, the wind directions approach eastward in higher altitudes in the case of cold fronts [Noyama et al., 2011].

These rain area motions are further compared with the ground wind velocities observed at a nearby AMeDAS station, and considerable correlations are also found between them, although the ground wind speeds are much smaller [Inamori et al., 2012]. This suggests that the direction and speed of the rain areas which is important to site diversity techniques may be easily estimated from the ground wind velocity measurements such as AMeDAS [Maekawa et al., 2013].

Rain attenuation characteristics of the Ku-band up-link satellite signals of Superbird C are investigated at Equatorial Atmosphere Radar Observatory (EAR) in Indonesia. The estimation of the up-link attenuation using the simultaneous X-band radar observations along the propagation path at EAR is in good agreement with the direct measurement of the satellite signals, including their annual statistics for the cumulative time percentages. Thus, the radar observations of tropical precipitating clouds that have localized structure are very effective to estimate the attenuation statistics of satellite

propagation path, and seem to be essential to exactly know the equivalent path length through tropical rain areas [Maekawa et al., 2011].

B. The Effects of Other Factors

The effect of the phase patterns of antennas to the 2-way and 4-way Doppler measurements onboard flying spin satellites was reported. The antennas were dipole and patch antennas onboard two flying spin satellites, Rstar and Vstar in the Japanese lunar mission, KAGUYA. At first, they had detected higher harmonics in the spin frequency up to an order of 26 in the Doppler frequency. In order to remove the influence of phase patterns and to precisely conserve information on the lunar gravity field, they developed a low-pass filter (LPF) using a Kaiser window, with the optimal parameters empirically determined. After using LPF, a high degree of accuracy of about 0.001 Hz was achieved for the 2-way Doppler measurements, and signals that reflected the gravity field on the far side of the Moon were first detected from the 4-way Doppler data. It was also suggested a method for estimating the phase response of satellite antennas using the Doppler frequency variations. In order to estimate the Doppler frequency variation, a filtering technique was adopted to extract the harmonics of interest in the residual signal, from which the antenna phase pattern was derived [Liu et al., 2011]

In maritime mobile satellite communications, received satellite signal level varies due to direction and motion of a ship. Then sometimes the communications are interrupted, because the receiving satellite signal level decreases when the ship's body shadows the antenna. Thus it is important to evaluate how qualities of satellite communications vary during ship operations. However, precise temporal level fluctuations during ship movement are not yet studied. To evaluate temporal variances of receiving satellite signal level of the ship in motion, modeling and numerical simulations were performed with considering the effect that the ship's body shadows the antennas. Effects of pitching, rolling and yawing were taken into accounting the calculations. In addition, electric field levels around the ship were estimated when transmitting antennas are in proximity to the ship body [Aoyagi et. al., 2012a]. In maritime mobile satellite communications, mechanically controlled tracking systems are used to compensate changes of antenna orientation due to changes of a ship attitude caused by waves or winds of the sea. Orientations of antennas on a ship are limited so that transmitted electromagnetic waves are not affected by structures on the ship. Thus it is allowed to transmit waves when a clearance angle is greater than certain criteria. Fundamental relation between clearance angles and interferences for other satellites or other systems on the ship by numerical simulations for a simplified model has been researched. In this report, a realistic ship model is assumed for the simulations. As a result, a clearance angle, which interferences to the receiving satellite are small, has been found out under the conditions of the simulations. A simple model which described interferences to received levels of the aiming and neighboring satellites was presented [Aoyagi et. al., 2013a]. (Y. Maekawa)

F1.3 Mobile Radio Systems

A. Macrocell/Microcell Systems

Various aspects of propagations in macrocell/microcell sysmtes are studied in the period. 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]. Radio propagation models for cellular mobile communication depend on line-of-sight (LOS) or non-line-of-sight (NLOS) states between base and mobile stations (BS and MS). The path visibility was evaluated by using a ray tracing with a building database in Japan and the United State [Iwakiri et al., 2013]. A reflector is located near a base station antenna to improve the received level in low received level areas on the upper floors of buildings. The reflector reflects the waves radiated from the sidelobes of the base station antenna, which do not

contribute to the coverage of the existing service area, in the direction of the low received level area. Moreover, the effect of the method is investigated using an evaluation model based on a physical optics (PO) approximation. It is clarified that the PO approximation is effective in evaluating the proposed method based on a comparison between the calculation results using the PO approximation and measurement results at 2 GHz. Furthermore, the proposed method is applied in a typical environment and the appropriate reflector size and position are determined based on computer simulations [Kitao et al., 2013a].

B. MIMO Channel Modeling and Measurement Method

The characterization of Multiple-Input Multiple-Output (MIMO) channels has been investigated. To clarify MIMO channel correlation for various cells and environments, the correlation is described analytically by computer simulation. A MIMO channel model is prepared consisting of base and mobile antenna configurations and a delay profile with arriving and incident wave angles in LOS and NLOS. Then, the general correlation formula was derived. It shows that the correlation is expressed as a directive wave term added to the product of mobile site correlation and base site correlation in NLOS path [Nakabayashi et al., 2012]. A spatial correlation and eigenvalue in MIMO channel are described. A MIMO channel model with a multipath propagation mechanism was proposed and the channel matrix was shown. The spatial correlation coefficient formula between MIMO channel matrix elements was derived for the model and was expressed as a directive wave term added to the product of mobile site correlation and base site correlation without LOS path, which are calculated independently of each other.

A method for applying interlink correlation to evaluate a multiuser-multiple input multiple output system was proposed. The proposed method is validated through comparison of measurement results to those of the conventional MIMO propagation channel model. The results show that the proposed method employing the Weichselberger model can handle the interlink correlation property, and accurately reconstructs a MIMO propagation channel [Yamada et. al., 2011].

A MIMO spatial fading emulator is presented. It is used to represent a street microcell environment. The fading emulator can reproduce a multipath radio propagation environment with either a uniform or non-uniform angular power spectrum (APS) in the horizontal plane. In the paper, the emulator to measure the 2-by-2 MIMO characteristics of four handset arrays with two monopoles in a multipath environment with one spatial cluster of incoming waves is used. From the investigation, good agreement was obtained between the results from the emulator and data measured in a radio propagation test in a street microcell. This demonstrates that the emulator is effective in evaluating the MIMO performance in a multipath propagation environment [Yamamoto et al., 2010a]. There have been significant numbers of investigations into over-the-air (OTA) testing methodology for evaluating handset MIMO antennas. A spatial fading emulator using a set of antenna probes, attenuators and phase shifters is proposed. This paper presents a spatial fading emulator suitable for evaluation of a MIMO array. This enables us to measure RF performance of array antennas in a multipath radio propagation environment [Yamamoto et al., 2010b]. Multiple-antenna technique (MIMO system) has appeared as a key for the next generation wireless systems. However, the use of multiple antennas results in the increase of equipment size. Adoption of polarization diversity technique into the MIMO systems can be a solution for this issue. At the same time, the performance of polarized-MIMO systems is determined by the channel condition, but to know the depolarization effects in the propagation channel is still a major challenge. This study figures out the path loss behavior of different polarization pairs and the causal factors of depolarization in the propagation channel based on the measurements in the real environments [Konishi et al., 2010].

FDM channel sounder is designed for the analysis of the propagation channel at 11.0 GHz with a band-width of 400 MHz. It is expected that phase noise in such a high frequency and wide band-width affect the performance of the propagation channel analysis. The simulation results however suggest that the estimated parameters of the propagation channel are not significantly affected by the phase noise [Ghoraishi et al., 2010b]. A novel channel sounding system based on MIMO software defined

radio architecture was proposed. It was developed for the evaluation of the beyond 4 G mobile communication systems operating at 11 GHz in which the multi-link MIMO technology will be adopted. 4x4 MIMO channel sounder was developed as the first prototype, and the advantages and issues are discussed based on the several performance tests. As a result, the fundamental performance of the prototype sounder was assessed, and hence the validity of proposed channel sounding technique was verified [Konishi et al., 2011]. The development of MIMO channel sounder operating at 11 GHz with 400 MHz bandwidth is reported. The sounder utilizes the software radio architecture to measure the full MIMO channels simultaneously, since the same hardware can be also used to test the real-time data transmission [Takada et al., 2011]. A novel architecture of MIMO channel sounding is presented, which use hybrid multiplexing scheme in time and frequency division. It offers high scalability and flexibility for both directional MIMO channel and multi-link MIMO channel measurements. Through the computer simulations the validity of the proposed technique and the robustness to the IQ imbalance of RF front-ends will be illustrated [Kim and Takada, 2011]. The calibration techniques for the fully parallel MIMO sounder were introduced. A simplified B2B calibration measurement method was also proposed. With the automatic calibration processes and the simplified B2B measurement method, it is possible to shorten the time greatly for the calibrations, which provides a solution to the major drawback in a fully parallel architecture of the developed MIMO channel sounder [Chang et al., 2012]. The results from multi-link measurements in an indoor hall scenario at 11 GHz are presented. By utilizing the capability of the scalable channel sounder, the observed inter-link correlations are explained by the identified propagation mechanisms [Konishi et al., 2012].

A novel MIMO channel sounding technique with a fully parallel transceiver architecture that employs a layered scheme of frequency and space-time division multiplexing is presented. It offers inherent scalability of the number of antennas by a combination of multiple transceiver units and flexibility for both directional MIMO channel and multi-link MIMO channel measurements. The paper describes the principle of the channel sounding technique and formulates the signal processing that makes possible various scalable unit configurations. The influence of the transceiver imperfections such as I/Q imbalance (IQI) and phase noise (PN) on the measurement accuracy is discussed, and a multitone allocation scheme that is robust against IQI is also introduced. Using computer simulations, the measurement accuracy in the presence of IQI and PN is evaluated using the normalized mean square error, which provides a design guideline for the realization of hardware [Kim et al., 2012a]. The measurement results of indoor wideband MIMO channels at 11 GHz will be presented. The path loss and delay spread for different polarizations will be shown and the empirical models will be presented as well. Then, the channel capacity of the dual polarized MIMO configuration will be evaluated [Kim et al., 2013a]. A low-cost MIMO channel sounding technique with a fully parallel transceiver architecture that employs a simple time division multiplexing scheme is presented. It aims at both of directional channel measurement using MIMO antennas and MIMO channel measurements for transmission performance evaluation. The paper describes the principle of the channel sounding technique and discusses the system design with respect to the influence of the most critical transceiver imperfections such as PN and I/QI [Kim et al., 2013b]. Four year activities and outcomes of development of full MIMO 24x24 channel sounder operating at 11 GHz with the bandwidth of 400 MHz are summarized, for the development of microwave frequency for the super high bit-rate mobile communications. The back ground motivation, design criteria, technical challenges and significant results are presented. Since the development of the channel sounder was the project goal, the detailed analyses of the double directional channels are left for future study [Takada et al., 2013b].

A method of estimating spatial degrees of freedom (DoF) from measured multipath propagation channels in the multiple-input single-output regime is presented. The DoF of the multipath channels on the transmit (Tx) side is derived by means of the spherical-wave expansion of electromagnetic fields radiated from a Tx antenna array having a certain aperture size. The DoF estimates are independent of particular realization of antenna elements on the Tx aperture. For a given aperture size, the DoF provides the number of the Tx antenna elements for efficient improvement of the system

performance by utilizing the spatial diversity. Having confirmed the soundness of our DoF estimation method by channel measurements in an anechoic chamber, the DoF of indoor multipath channels is analyzed. The DoF on the Tx side of the considered multipath channels reveals larger values when the antenna aperture size is increased at a fixed frequency, and when the frequency increases for a fixed antenna aperture size. For a fixed frequency, increasing the antenna aperture size is more effective in observing extra DoF in the obstructed and NLOS channels than in the line-of-sight channels. Furthermore, for a fixed antenna aperture size, the use of the higher frequency brings larger DoFs in many propagation scenarios. The results also show that electrically smaller antennas are more efficient in observing the DoF. Finally, the solid angle of multipath is derived as a Tx antenna-independent metric of the multipath richness. It is defined as an angular range of dominant multipath clusters subtended on a unit sphere. The analysis method is extendable to the multiple-input multiple-output regime in a straightforward manner [Haneda et al., 2013].

The estimation accuracy of ray-tracing for dynamic channel properties is evaluated by using the correlation coefficient between the channel parameters such as mean angle, angle spread from the ray-tracing and that obtained from the measurements [Kitao et al., 2011]. The elevation directional channel properties at a BS is evaluated based on ray-tracing simulation to evaluate the performance of 3D beamforming that controls the main beam direction of a BS antenna over both the azimuth dimension and elevation dimension. Results show that the average power elevation spectrum (PES) and the distribution of the elevation angular spread at BS do not depend on the BS antenna height. Moreover, it is confirmed that when a MS exists in the vicinity of a BS in a LOS situation, the more the BS antenna height decreases, the more the elevation angular spread increases. Furthermore, the dispersion of the elevation median angle at BS is small compared to that for the azimuth case [Kitao et al. 2013b].

Nihon Hoso Kyokai (NHK), or Japan Broadcasting Corporation has developed a wireless high-definition TV (HDTV) camera, called the "Millimeter-wave Mobile Camera", which can transmit HDTV pictures with high-capacity and low delay. The camera was improved in transmission capacity and link reliability by the application of 42-GHz band wave and transmitter/receiver diversity, so the camera is extensively used at many TV program productions in outdoor environment such as "Golf tournament" and in indoor environment such as "Charity concert". The receiving IF (Intermediate Frequency) signals in indoor and outdoor real environment of TV program productions were recorded, and the channel characteristics from the receiving IF signals were analyzed. In addition, the differences of channel characteristics between indoor and outdoor environment were analyzed [Suzuki et al., 2012].

C. Formulations of Mobile Propagation

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

In order to study complex correlation applied to various environments and systems, an analysis model was proposed using a domain with space, frequency, and path axes. The general complex correlation coefficient was derived. The correlation integrates with three terms, i.e., the direct wave term and the frequency-correlation and autocorrelation terms without direct waves [Kozono et al, 2012]. A systematization of complex correlation is presented in a domain with space, frequency, and path axes need to a system design for a mixture of transmission technologies in various environments. The analysis model was proposed in the domain. The general complex correlation coefficient was derived and integrated as a direct wave term added to the product of a frequency correlation and autocorrelation; moreover, these three terms can be calculated independently of each other [Kozono et al., 2013].

A path loss model with an over-roof propagation path between mobile terminals in a residential area was proposed. Measured results showed that the path loss of over-roof propagation can be estimated by using a double knife-edge diffraction model. This new model can improve estimation error compared to existing model [Sasaki et al., 2011]. A new path loss model of interference between

mobile terminals in a residential area with a curved road was proposed. On the basis of measurement results, prediction formulas were derived for the attenuation coefficient along a straight road in an NLOS area. Additional loss resulting from road angles along the curved road is also shown. The model was constructed from the prediction formulas. Its validity was verified by taking measurements in a residential area different from that used for deriving the formulas [Sasaki et al., 2012]. Applicability of proposed path loss model to different environment was studied. Measurements taken in different building situation showed that proposed model was able to predict path loss accurately in various environments [Sasaki et al., 2013].

In ray tracing simulations, curved surfaces and edges are difficult to handle. The approximation of dividing the curved surface into smaller flat plates is not so accurate as the size of smaller plates may not satisfy geometrical optics assumption, and the reflection point which satisfies Fermat's principle may not exist. In this work, a new ray tracing method which models the reflection on the curved surface was implemented and the physical optics method was applied on the caustics region. To test this method, path gain simulation results for a square and horseshoe cross-section model are compared with measurements made inside an arched tunnel. To further improve the simulation results, the effect of rough surface is introduced, and the results are again compared with measurement [Kishiki et al., 2010a, 2010b, 2010c and 2013].

Indoor propagation channel is modelled for wireless communications. The propagation channel of laboratory room at 2.4 GHz is characterized based on the ray tracing approach. The two types of rays are considered which are: 1) direct ray; and 2) reflected rays. 3-dimensionals is built by using SketchUp. After that, the database is imported to RapLab program which is used ray tracing program approach to the propagation channel in term of root mean square (rms) delay spread and the power delay profile (PDP) [Maw et al., 2011]. For the propagation prediction model, the complex furniture such as table and chair are typical objects that cannot be accurately modeled in the ray tracing simulation. Therefore, the effects of scattering on ultra wideband (UWB) signal from furniture are discussed in this paper. The extension of the radar equation in the complex transfer function to evaluate the radar cross section (RCS) is introduced. The time gating method is applied to remove the effect of multipath, which occurred in indoor environments. The RCS results of sample furniture with vertical and horizontal polarizations using horn antennas are shown. These results are useful to apply for indoor propagation prediction using ray tracing technique [Maw et al., 2013].

Accurate radio wave propagation prediction is crucial in designing wireless instruments for medical use. The 60 GHz radio channel in a hospital ultrasonic inspection room is simulated using ray tracing based on single-bounce scattering. The scattering is calculated with a single-lobe directive model and the room structure is modeled with a large point cloud, acquired via laser scanning. It is shown that the scattering model is able to predict the power delay profile with a proper scattering parameter. It is also noticed that measuring the environment dimensions with laser scanning is a suitable method in order to obtain appropriate prediction of the propagation channel [Jarvelainen et al., 2012].

D. Ultra-wideband

Propagation characteristics for UWB systems are energetically carried out in two universities in Japan.

A channel estimator with an interference detector was developed to implement and test it's functionality in a multiband system. The effective design and the detection error rate were evaluated via verification tests in an anechoic chamber and computer simulations [Iwakiri and Kobayashi, 2010]. UWB spatio-temporal channel sounder, employing an orthogonal frequency division multiplexing (OFDM) signal and a receiving virtual array antenna was prototyped and evaluated in a narrowband interference environment. The TOA and the AOA of the wideband signal were estimated within reasonable bounds of error in the presence of narrowband interference [Sugizaki et al, 2010]. Comparisons were carried out between the VNA- and the OFDM-based channel sounders in terms of experimental estimation of time-of-arrival (TOA) and angle-of-arrival (AOA) in an indoor three-path

environment. Delay profiles and AOA estimation results agreed reasonably well with ray tracing calculations and the proposed design of the OFDM-based channel sounder was validated [Sugizaki et al., 2011]. A prototype UWB monopulse radar equipped with a two-element receiving antenna array reported based on measurement results. And the measurements were analyzed employing matched filtering and eigen decomposition, and then multipath components were extracted to examine the behavior of received UWB monopulse signals [Hashimoto et al., 2011a]. UWB radio propagation measurements and characterization, experimental evaluation of a detect-and-avoid scheme, and rationale of restriction on UWB transmitting power are presented in an invited paper [Kobayashi, 2011a].

UWB Propagations are studied particularly for Wireless Body Area Network (WBAN). Radio propagation around the human body was measured in various rooms. Parameters in a conventional loss model derived from the measurements were found to significantly diverge and depend on room volume. A modified model considering the impact of room volume has been proposed [Yamamoto et al., 2010]. A new UWB propagation loss model was proposed to take into consideration the impact of the room volume, based on the measurements. And Effects of a subject's position within a room and the ceiling height were measured characterized for on-body UWB propagation [Koiwai and Kobayashi, 2011]. Measurements and modeling of UWB Radio propagation for wireless body area networks are presented [Kobayashi 2011b]. Delay profiles around the human body were measured within various rooms, and there from a modified model considering the impact of room volume has been derived [Koiwai et al., 2012]. Results of an indoor experiment for 2.45 GHz dynamic wearable WBAN using multiport vector network analyzer is reported. Statistical characteristics and correlations between individual receiving points are reported [Aoyagi et al., 2012b]. A statistical modeling of on-body UWB radio channels for WBAN applications was presented considering room volume. Realizations of the impulse responses are presented based on the proposed model and compared with the measured average power delay profiles [Hirose et al., 2012a, 2012b and 2012c].

Experimental evaluation of UWB wireless transmission was carried out with a view to replacing wired interface buses in spacecraft. Effects of apertures perforated on the outer surface of satellites on the UWB propagation and transmission for low-(4.2-4.8GHz) and high-band (7.4-7.9GHz) UWB. The larger total area of apertures resulted in lower UWB propagation gains, shorter delay spreads, and (slightly) higher link throughput [Matsubara et al., 2010, Hamada et al., 2012a]. UWB radio propagation and transmission were measured and characterized within spacecraft. And effects of apertures were presented the outer surface of satellites and transmission for low- and high-band UWB within a shield box. The propagation study was followed up with experimental evaluation of UWB link throughput within a simulated spacecraft [Hamada et al., 2012b and 2013a]. UWB and narrowband propagation were measured within a small spacecraft. Polarization configurations were found to produce almost no effect on average power delay profiles and substantially small effects on the throughputs [Hamada et al., 2013b]. UWB channels within a small scientific satellite was measured and statistically analyzed, based on a modified Saleh-Valenzuela model, which modeled indoor UWB propagation channels. The received power of both the cluster and the rays within a cluster decays exponentially [Hirose 2013].

UWB technology has become an attractive choice for high precision indoor localization. Pulse based UWB is found to be suitable for overcoming the signal TOA ambiguities due to multipath. Much work has been done on UWB TOA estimation in general. However, the effect of the radiation patterns of antennas used in localization applications have not been considered. This paper investigates the effect of antenna directivity on the detection of the direct path in a typical indoor scattering environment. It is experimentally shown that the ranging error is reduced by using directional transmit antennas. The results are obtained in a LOS propagation environment and are based on the TOA based ranging technique [Dashiti et al., 2010a]. The dispersive nature of UWB channels makes TOA estimation extremely challenging, where the first-arrival-path is not necessarily the strongest path. Among TOA estimation algorithms, threshold-based method is specifically attractive due to its low complexity and computational burden. In this paper, an optimum and practical

threshold selection approach based on the standard channel model is introduced. Based on the proposed TOA estimation algorithm, this paper investigates the effect of antenna directivity on the detection of the FAP in a typical indoor scattering environment. Moreover, this paper introduces a technique to synthesize the antenna patterns with desired directivity for the purpose of this study by employing virtual array principle and Fourier expansion expression of azimuthal radiation patterns [Dashti et al., 2010b]. TOA estimation technique used with UWB transmission can be used for accurate indoor ranging. In the indoor multipath rich environment, these techniques often suffer from significant inaccuracy in ranging estimation. It is generally believed that the main cause of the TOA estimation error in the LOS scenario is noise, usually modeled as white Gaussian noise. Through the established analytical framework for the analysis of the TOA estimation error, it is argued in this paper that the TOA estimation errors are caused by multipath interference and the fading statistics of the direct path. Therefore, variance of fading statistics of the direct path is considered on top of the noise variance for better prediction of the TOA estimation error. A comparison of predicted error with those obtained based on experimental measurements in an indoor environment confirms the validity of our analytical approach [Dashti et al., 2010c]. TOA estimation used with UWB technology has become the most popular technique for accurate indoor localization. Much work has been done on UWB TOA estimation in general. However, the effect of the radiation patterns of antennas used in localization applications has not been considered. This paper investigates the effect of user terminal (UT) antenna pattern on the detection of the direct path. The paper aims at presenting the ranging error in a practical scenario considering the fact that antenna pattern of UT are distorted by human body and the user orientation is random. The results are obtained in a typical industrial indoor environment for LOS scenario and are based on the TOA-based ranging technique. Moreover, this paper introduces a technique to synthesize the desired antenna patterns for the purpose of this study by employing spherical wave expansion tool [Dashti et al., 2010d].

The accurate estimation of time-of-arrival in a dense multipath environment is vital for reliable performance of time-based ranging techniques. The radiation pattern of antennas used for the UT and access-point (AP) sensors in localization applications have significant effect on the system performance. This paper introduces a technique to synthesize the channel impulse responses while specific antenna pattern is used at AP node. The proposed methodology provides the opportunity to examine ranging performance with different type of antenna without any need to repeat channel measurements. The influence of antenna orientation and directivity are investigated by using this methodology. The preliminary results are presented [Dashti et al., 2011a]. A method is proposed for setting the threshold for UWB threshold-based ranging in indoor scenarios. The optimum threshold is derived based on the full analysis of the ranging error, which is equivalent to the probability of correct detection of first arriving signal in time-based ranging techniques. It is shown that the probability of correct detection is a function of first arriving signal, which has variations with two independent distributions. On the one hand, the first arriving signal varies in different positions with the same range due to multipath interference and on the other, it is a function of distance due to free space path-loss. These two distributions are considered in the derivation of the ranging error, based on which the optimum threshold is obtained. A practical method to derive this threshold is introduced based on the standard channel model. Extensive Monte Carlo simulations, ray-tracing simulations and ranging measurements confirm the analysis and the superior performance of the proposed threshold scheme [Dashti et al., 2011b].

UWB impulse radio (UWB-IR) system can be extremely distorted through a channel even for free space transmission because of antenna dispersion. Therefore, the understanding the antenna characteristics, which effects on waveform distortion, is necessary. This paper studies the free space transmission in UWB-IR system. The link budget is usually evaluated by using the Friis' transmission formula. However, it is not directly applicable to the UWB-IR transmission system. The link budget evaluation formula attended from conventional Friis' transmission formula that takes into account the transmitted waveform, its distortion due to the antennas, the channel and the correlation receiver is proposed. Since the antennas are significant pulse-shaping filters in UWB-IR system, the various

kinds of the antennas are experimentally examined, especially focused on the effect of the template waveforms [Promwong et al., 2010a]. The example kind of the log-periodic dipole antenna (LPDA) is experimentally examined [Promwong et al., 2010b].

Path loss is important parameter to analyze and design link budget. For indoor environment, there is fading that occurs in path loss. Therefore, accurate path loss model, which is considered fading, is necessary. Three-ray path loss model is proposed for UWB-IR systems. The rectangular passband is used as UWB-IR transmitted signal. The extension of Friis' transmission formula is applied for UWB-IR three-ray channel. The received signal is evaluated. The closed form formula of three-ray path loss model is derived based on average power loss. The path loss from proposed model is illustrated and compared with ground reflection model (two-ray model) and free space model. This model can be used to study the characteristic of fading and extended to multi-ray path loss model for indoor environment [Supanakoon et al., 2011a]. Study of waveform distortion is necessary for designing optimum UWB-IR systems because the distortion of waveform degrades the performance of correlation receiver. In this paper, the novel quantitative parameter of waveform distortion that is peak to average loss ratio is proposed and derived in the closed form formula for UWB-IR transmissions. The peak to average loss ratio is defined as the ratio between peak power loss and average power loss from transmitter to receiver (Rx). The free space and ground reflection channels are considered. The results obtained from proposed formula are compared with measurement. This proposed parameter is useful to define the quantity of waveform distortion in UWB-IR systems [Supanakoon et al., 2011b]. Correlation coefficient is an important parameter that indicates the efficiency of correlation receiver for UWB-IR systems. The correlation coefficient is also used to analyze the waveform distortion. In this paper, the closed form formulas of correlation coefficient are derived using the rectangular passband waveform and the extension of Friis' transmission formula. The free space and ground reflection channels are considered. The results obtained from proposed formulas are compared with measurement. For ground reflection channel, the proposed formula of correlation efficient corresponds with measurement [Supanakoon et al., 2011c].

E. Others

Rainfall effects, constituted of backscatter from raindrops (rain clutter) and rain attenuation were examined for UWB and mm-wave radar at Ka-band. Numerical calculation revealed that the rain clutter was negligibly small in comparison with typical radar signals [Hashimoto et al., 2011b].

A new equation for calculating the electric field strength is proposed, embracing the effects of variations in space impedance. Numerical results yielded by the conventional and proposed equations were compared with the experimental data measured in a radio anechoic chamber [Nakayama 2012]. A new equation for calculating the electric field strength is proposed embracing the effects of variations in space impedance expressed by Padé approximation of the half-wavelength dipole antenna. Numerical results yielded by the conventional and proposed equations were compared with the experimental data [Nakayama and Kobayashi, 2013a and 2013b].

Digital narrowband transmission channel in aeronautical mobile communications was evaluated by computer simulations and flight experiments under the specifications of VDL mode 2/3 systems. The flight experiments show that flight interval of 500—1000 m was a reasonable data processing range to calculate received levels and the K factor. The K factor increased up to about 20 dB depending on the distance from a ground station. Consequently, we confirmed the evaluation was made by using of the received levels, K factor, and normalized the Doppler frequency [Kitaori et al., 2012].

To establish a wireless link system employing RFID tags and sensors set in underground facilities that are to be inspected such as manholes, outdoor measurements were conducted. The results showed that approximately 10 and 12 dB higher received signal levels are obtained for receiver antenna heights 1.7 m or higher above ground for vertical and horizontal polarization at distances far from the manhole cover (MC), respectively. The received signal levels for vertical polarization are from 7 to 9 dB higher than those for horizontal polarization both near and far from the MC [Ando et al., 2011].

A propagation model and fading characteristics for a wireless relay system between long-haul train cars under both static and moving conditions was examined. The proposed model was constructed based on the observation results of a measurement campaign using an actual long-haul high-speed train. The measurement results indicate that the propagation loss between relay stations is greatly affected by waves that re-enter the train. The proposed propagation model, which comprises two wave components, is established based on the results. One wave component comprises the waves traveling inside the train cars, and the other represents waves that re-enter the car from outside of the train cars. The fading characteristics between the relay stations in the train cars were also revealed based on the proposed propagation model. The fading variations of both the wave component traveling inside train cars and the re-entering wave component indicate Nakagami-Rice fading. Hence, the total fading characteristics between the relay stations in the train cars can be accounted for by considering the results of the combination of those two Nakagami-Rice fading components [Ito et al., 2011]. Electrical magnetic field distributions established in two adjacent train cars due to a 5.2 GHz wireless LAN terminal was estimated. Based on field distribution analyses, the energy absorption effects of the passengers' bodies were determined. Six models, with occupancy rates of 0, 20, 40, 60, 80 and 100 %, were developed and used in the numerical analyses of field distributions. It was found that if both cars were full with passengers, the field intensity in the car that held the transmitter might be about 16 dB lower in compared to no-passenger case. The intensity in the adjacent car might be 40 dB lower than the no-passenger case [Hikage et al., 2011]. Electrical magnetic field distributions established in high-speed train cars as experienced by a 5.2 GHz wireless LAN terminal were estimated. Based on field distribution analyses, the energy absorption effects of the passengers' bodies were determined. This absorption cannot be neglected inside train cars. The proposed numerical estimation method can evaluate the degradation in quality and service availability of wireless access due to the absorption effects quantitatively [Hikage et al., 2012].

On-body communication channels are gaining increasing interests as more and more wireless devices are wearable in the fields of medicine, military, and personal communications. An experimental investigation of the dynamic features of time-varying on-body channels with continuous movements of human body was presented. Channel response at 10 antenna positions in two dynamic scenarios, walking and standing up and sitting down, have been measured in the anechoic chamber. Based on the statistical analyses of fading duration, a five-state Fritchman model that considers channel dwelling time at a given quality is proposed. Parameters of the Fritchman model are estimated from the measured data. The characteristics of simulated burst channels are in good agreement with the measurements [Zhen et al., 2010].

The channel response and antenna movement data were acquired from vector network analyzer and commercial motion capture equipment, respectively. The channel responses of UWB-BAN have been observed in dynamic scenario of off-body communications. The investigation of direct and ground reflected components that were dominant in the channel impulse response showed their relevance to the onbody antenna movement that was measured by motion capture equipment. The delay of those two components can be predicted from the travel distance, while the path gain from the antenna rotation can be predicted by considering the antenna radiation pattern. The prediction showed good agreement with the measurement data in delay prediction, but some differences were found on path gain prediction probably due to the simplification of antenna model [Iswandi et al., 2010a]. The channel of dynamic WBAN has significantly influenced by the human body motion on which the device is attached. In this study, the effect of the on-body antenna motion as the result of the body motion has been investigated by using motion capture equipment system and vector network analyzer to the channel fluctuation [Iswandi et al., 2010b]. Six human movement simulations are performed by commercial software (Poser7). Finite-Difference Time Domain (FDTD) simulations were performed for body area network propagation with one transmitter and six receivers. Received amplitudes were calculated for every time frame of 1/30 s interval. A polarization diversity effectiveness for dynamic wearable body area network propagation is also presented [Aoyagi et al., 2011a and 2011b]. Research activity of the body area channel related studies by Tokyo Institute of Technology and National

Information and Communications Technology, Japan is presented. One of their goals is to make a practical wearable body area network propagation channel model during arbitrary body motions. The numerical simulated electromagnetic wave propagation wearable body area network channel during various human motions at 403.5 MHz and modeling dynamic on-body channel based on the three dimensional motion of on-body antennas are presented. The simulation results were verified to the measured channel responses from the network analyzer operated simultaneously with motion capture [Aoyagi et al., 2011c, Aoyagi and Takada, 2012c]. The skeleton model to generate human body models for predicting dynamic BAN channels was proposed by considering the simplified body geometry in analytical study. The numerical human body model was exported into skeleton in bvh (bio-vision hierarchy) file format. The cylinder body model is constructed by shaping the necessary bones of skeleton by cylinder. The feasibility of model is assessed by FDTD simulation. The results show reasonable agreement between channels calculated from the complex and simplified body models. By using skeleton, the motion data can be transferred into a small size file without losing necessary information for channel prediction [Iswandi et al., 2012]. Results of an indoor experiment for 2.45 GHz dynamic wearable WBAN using multiport vector network analyzer is reported. Temporal changes of propagation characteristics for two human male subjects are measured for six antenna positions on-body simultaneously. Statistical characteristics and correlations between individual receiving points are reported [Aoyagi et al., 2012d]. Basic characteristics of an electrically small antenna in proximity of human body are examined. Basic characteristics of the antenna and radiated electric fields and magnetic fields are calculated in case of the antenna is close to a block of dielectric material, which simulates human body. Changes of the input impedance and the resonance frequency caused by distance between surface of body and antenna are also examined. These results will be used in the future study for BAN channel characterization with antenna de-embedding [Aoyagi et al., 2013b].

The shadowing correlations among the multiple links between a coordinate node and sensor nodes in WBAN systems were investigated by measurements under everyday-life scenarios. A body-worn RSSI (receive signal strength indicator) logging system was developed with off-the-shelf ZigBee sensor devices at 2.4 GHz for long time continuous and synchronized measurement among sensor nodes. The cross correlation coefficients calculated within a short time window were statistically characterized. The shadowing correlation will become useful information to develop and evaluate a multi-hop relay and a cooperative transmission scheme for increasing the reliability and power efficiency [Kim et al., 2012b]. Because BAN should provide reliable links, radio channel property in the vicinity to the human body should be studied intensively. FDTD method is one of the common approaches for BAN simulations [Naganawa et al., 2012]. The narrowband wireless on-body channels is characterized under specific action scenarios by measurement at the three different sub-GHz frequencies of 444.5, 611, and 953 MHz, which are the candidate frequency bands of narrowband body area network systems with low data rates in IEEE 802.15.6 standard. The channel responses at ten different antenna positions were measured in an office room environment for the two dynamic action scenarios of “walking on the spot” (Action I) and “standing up/sitting down” (Action II). The paper provides generalized on-body channel models of Nakagami-m and Weibull distributions for Actions I and II, respectively. Notably, the paper shows that the shadowing effect due to body movement is dominant over the multipath fading. The results were obtained by the statistical analyses of channel fading properties at three different frequencies including level crossing rate, average fade duration and channel dwelling time [Kim and Takada, 2012]. In the simulation of the BAN channel, various postures and motions of the human body should be examined for robustness. However, generating this motion data consumes time and is costly since experience with 3D animation software or complex motion capture systems with multiple cameras is required. Therefore, the utilization of Kinect is proposed, a motion capture gaming device, for the BAN channel simulation. The data from Kinect, namely the series of joints, depth, and image are converted into series of voxel models. Then, FDTD simulation using the generated voxel models is performed [Fujie et al., 2013]. In order to design reliable wireless BAN systems, studies of the propagation channels associated with

human body motions are important. FDTD method has been utilized for this purpose. Although FDTD method has advantage of using realistic body model and eliminating uncertainty issue such as cables and antenna attachment, simulations have been limited in star topology due to the computational effort. Therefore, the paper presents a simulation of BAN channel in mesh topology during body motion such as walking [Naganawa et al., 2013]. (H. Iwai)

F2 Remote Sensing
F2.1 Atmosphere

A. Ground-based Remote Sensing Studies

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

The middle and upper atmosphere radar (MU radar) is a major observation facility in the Shigaraki MU Observatory of the Research Institute for Sustainable Humanosphere (RISH), Kyoto University. The MU radar is an excellent system having 25 receiver channels to carry out observation using a spaced antenna (SA) technique. Kumar et al. [2013] conducted the observation for full-array transmission and reception of signal with 25 receiver channels and showed SA results were in good agreement with the results obtained using Doppler beam swinging (DBS) technique and GPS radiosondes. The multi-receiver system of the MU radar enables us to do software beam synthesis by postset beam steering (PBS) technique to derive the horizontal wind velocities. Sureshbabu et al. [2013a] investigated beam synthesizing in optimum directions to reduce the error in the measurement of horizontal wind velocities using the PBS technique. Moreover, Sureshbabu et al. [2013b] investigated the advantages of subspace-based eigenvector spectral estimator to improve the power spectrum and the quality of calculations in spectrum parameter estimation.

The aspect sensitivity of atmospheric refractivity irregularities causes a small error in an effective line-of-sight direction in vertical beam observations leading to a serious degradation of vertical wind estimates due to contamination by horizontal wind components. Chen and Furumoto [2013] estimated the aspect angle with multiple-receiver coherent radar imaging (CRI) of the MU radar. They considered the radar beam weighting effect on the CRI brightness distribution [Chen and Furumoto, 2011, Chen et al., 2011]. Nishimura et al. [2012] developed an adaptive beamforming technique for a multi-channel MST radar, which makes it possible to measure the vertical wind velocity with higher accuracy by adaptively generating a countersteered reception beam against an off-vertically shifted echo pattern. The maximum contamination was suppressed to 1/10 even for the most imbalanced aspect sensitivity.

Many experimental studies were conducted using the MU radar whose height resolution was improved with a range-imaging technique using multi-frequencies. Luce et al. [2012] reported trains of Kelvin-Helmholtz billows of similar to 100-1500 m in depth persisting for about 60 hours at the south extremity of a tropopause fold. Fukao et al. [2011] reviewed characteristics of large-amplitude (>150 m) Kelvin-Helmholtz (KH) billows in the lower atmosphere with emphasis on the turbulent properties.

Ueda et al. [2012] investigated eddy diffusivities for momentum in the upper troposphere and lower stratosphere during clear-air conditions derived from direct measurements of the Reynolds stress and vertical gradient of mean wind velocity measured by the MU radar. Mikami et al. [2011] observed a meso-gamma-scale convective system in July 2007 using a 443-MHz wind profiler radar (WPR) with a radio acoustic sounding system (RASS) in Okinawa, Japan. They concluded that the synergetic effects of the low static stability and convergence triggered the generation of a convective.

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. Dhaka et al. [2011] analyzed hourly radiosonde data and the EAR data during four days (two with convection and two with no convection) as a part of an intensive observation period in CPEA-II campaign over Kototabang. Gravity waves with periods similar to 10 h and similar to 4-5 h were found dominant near tropopause on all days. Vertical propagation of gravity waves were seen modified near heights of the three identified strong wind shears due to wave-mean flow interaction. Kaur et al. [2012] analyzed temporal and spatial evolution of Atmospheric Gravity Waves (AGW) in the troposphere on December 7-8, 2005 during CPEA-II campaign. AGWs with vertical wavelength of 2-3.5 km, horizontal wavelength of similar to 20-25 km and wave period of similar to 55-65 min were observed in the troposphere (3-10 km heights) during convection events. Mega et al. [2012] reported results from simultaneous measurements of vertical air velocity, particle fall velocity, and hydrometeor sphericity in stratiform precipitation based on the EAR and 532-nm polarization lidar observations.

1.3-GHz WPR network was constructed at Kototabang, Pontianak, Manado, and Biak over equatorial Indonesia. Tabata et al. [2011a] compared the WPR observations with horizontal wind data obtained by some global reanalyses. ERA-Interim had the highest correlation with the WPR winds. It can be explained that ERA-Interim used four-dimensional variational analysis (4D-var) for data assimilation, whereas the other reanalyses used 3D-var. Moreover, Tabata et al. [2011b] investigated variations in the diurnal precipitation cycle over equatorial Indonesia using 1.3-GHz WPRs and rain gauges installed at each site. At Kototabang and Pontianak, the afternoon-to-evening precipitation had the characteristics of a mesoscale convective system (MCS), namely stratiform precipitation after the peak deep convective rain rate was predominant, and the transition from convective precipitation to stratiform precipitation was clearly apparent. At Manado and Biak, the peak rain rate in the early afternoon was characterized by a short period (1-2 h), and the precipitation after the convective precipitation was not clear.

The bistatic Doppler velocity measurement, with one traditional transmitting radar associated with one or more passive radar receivers, is a useful way to retrieve the 2D or 3D wind field with low costs. In that measurement, the sidelobe contamination is the serious problem because low-gain wide beamwidth receiving antennas are usually used. Kawamura et al. [2011] proposed a new measurement system by which the sidelobe itself is reduced with an array receiving antenna.

B. Spaceborne Sensor

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) is an atmospheric observation sensor of unprecedented high sensitivity with superconducting technology [Kikuchi et al., 2010]. SMILES was deployed on the Japanese Experiment Module "KIBO" of the International Space Station (ISS) in 2009, and operated for six months, to observe stratospheric ozone and minor atmospheric constituents such as ClO relating to ozone depletion. It measured atmospheric limb emission spectra in 640-GHz band [Manabe et al., 2012, Mizobuchi et al., 2012, Ochiai et al., 2012 and 2013], which provide extensive opportunity to study atmospheric composition, such as O3, HCl, ClO, HO2, and BrO [Baron et al., 2011, Kasai et al., 2013, Khosravi et al., 2013, Kreyling et al., 2013, Sagawa et al., 2013, Sato et al., 2012, Sugita et al., 2013] and other atmospheric properties[Baron et al., 2013, Millan et al., 2013].

F2.2 Hydrometeors and Other Particles

A. Ground-based Remote Sensing Studies

For the study of drop size distribution (DSD) of rainfalls, various ground-based instruments such as a 2 dimensional video disdrometer (2DVD) and a disdrometer have been used, to count the number of drops with a finite drop bin size. Marzuki et al. [2012] made a comprehensive study on the best representative drop size for a given drop-size channel, using simulated and 2DVD-measured DSDs.

They concluded that the use of "mid-size" of each channel is acceptable, and the error depends on the method of DSD model parameter estimation. In equatorial regions, the raindrop characteristics such as DSD, fall velocity and axis ratio are still insufficient. Marzuki et al. [2013] made a follow-up analysis of raindrops measured by a 2DVD at Kototabang, West Sumatra.

A bistatic Ku-band broad-band radar (BBR), which can transmit and receive wide band signals, to estimate the radar reflectivity factor at low altitude with high range resolution. Yoshikawa et al. [2010] examined the vertical structure of DSD in the lower atmospheric boundary layer (ABL) below 300m, where conventional radars typically do not observe. The DSD retrieved using the BBR showed excellent agreement with the DSD measured with a co-located 2DVD. A short-baseline weather radar network consisting of the BBR is useful for rapidly and accurately detecting and analyzing small-scale weather phenomena such as localized scattered thunderstorms, tornadoes, and downbursts. The BBR network project planned to deploy three BBRs in the north Osaka, Japan [Yoshikawa et al., 2012].

A fast-scanning phased array weather radar (PAWR) with a digital beam forming receiver has been developed. It is important to form a stable and robust main lobe and adaptively suppress sidelobes with a small number of pulses in order to accurately estimate precipitation profiles. A minimum mean square error (MMSE) formulation with a power constraint gives adaptively formed beams that satisfy these demands. The MMSE beam-forming method was compared with traditional beam-forming methods, to show that the MMSE method is appropriate to the fast-scanning PAWR concept [Yoshikawa et al., 2013]. The PAWR was used to analyze structures of thunderstorms producing lightning narrow bipolar events (NBEs). Heights of NBEs observed can be used to monitor severe thunderstorms [Wu et al., 2013].

B. Space-based Remote Sensing Studies

The Global Precipitation Measurement (GPM) Core Observatory, a joint mission between NASA and the JAXA, was launched on Feb. 27, 2014. Two observation instruments are onboard the core observatory: the Dual-frequency Precipitation Radar (DPR) developed by Japan, and the GPM Microwave Imager (GPM) developed by the U.S. The DPR is a successor of the Precipitation Radar (PR) loaded onto the GPM's predecessor, the Tropical Rainfall Measuring Mission (TRMM.) The 35.5 GHz radar was additionally installed onto the PR at 13.6 GHz for high accuracy observation. The core observatory's role is to improve its precipitation observation accuracy for microwave imagers on a constellation of satellites by simultaneous observations with the radar and the microwave imager. Rain retrieval algorithms for the DPR have been extensively studied by the science team [Kubota et al., 2011, Seto and Iguchi, 2011, Awaka et al., 2012, Kubota et al., 2012, Iguchi et al., 2012, Kubota et al., 2013].

A ground-based dual Ka-band radar system was developed by the JAXA for the DPR algorithm development. Consisting of two identical Ka-band radars, it can measure both the specific attenuation and the equivalent radar reflectivity. Along with other instruments, it had been used to reduce the uncertainties of the parameters in the DPR algorithm, to verify improvement of rain retrieval with the DPR [Nakamura et al., 2012]. A mobile precipitation observation system (MPOS) was developed for the dual Ka-band radar field campaign, consisting of 2DVD, disdrometer, Laser Optical disdrometer (Parsival), Precipitation Occurrence Sensor System (POSS). Observations using the MPOS were performed in Okinawa, Mt. Fuji, and some other sites in Japan. Using these observed DSD data, the specific attenuation and the radar reflectivity for Ka and Ku-band were estimated [Nakagawa et al., 2013].

Spatial correlation characteristics of rainfall are estimated from the data measured by the TRMM PR and those of ground-based rain gages, found to be consistent with those reported in literatures around Tokyo and to show regional dependence in central and western Japan [Manabe and Jozaki, 2011]. In order to increase the sensitivity of spaceborne rain radars, adaptive scan in which the antenna is scanned twice (a fast, rain-detection scan over the swath and the following, measurement scan to concentrate the rainy regions) was studied. Shimomai et al. [2011] and Kozu and Shimomai [2011] made a comprehensive simulation study using actual TRMM PR radar reflectivity profile data. They

used a wide-band noise modulation to increase the number of independent samples in short scan time, and found that the method proposed can achieve the effective noise ratio improvement for about 50% of the rainy scan. The spatial resolutions (in cross-range) of TRMM PR and GPM DPR are about 5 km which may be much larger than localized rain cells that can significantly affect the accuracy of rain rate estimation. In order to improve the spatial resolution for along-track, a basic design of dual-frequency synthetic aperture spaceborne precipitation radar was conducted by Kozu et al. [2012]. They found that the resolution of about 0.7 km can be obtained with the sensitivity comparable to or better than GPM DPR, using a 4-m by 5-m antenna for Ku-band. Algorithms for estimating precipitation rates from observations of apparent radar reflectivity depend on procedures for correcting for attenuation, especially in regions where intense deep convection occurs. The well-known problem of non-uniform beam filling is a source of error in the estimates, caused by unresolved horizontal variability in highly correlated characteristics of precipitation, such as specific attenuation, rain rate, and the effective radar reflectivity factor, that are fundamentally related to the DSD. Short et al. [2012] presented an empirical test of a theoretically based procedure for correcting for attenuation by means of a simulation study with data from a ground-based radar in Okinawa, to show that the correction has the potential to improve retrievals of rain rate in intense convection. The strength of surface return echo (sigma-zero) from air/space borne radar reflects accumulated attenuation through its ray path. The cloud profiling radar (CPR) onboard CloudSat measures sigma-zero as well as cloud echo. Takahashi [2011] evaluated the cloud liquid path (LWP) of CloudSat products by accumulating the sigma zero data for each LWP categories, and the mean value was compared with the total path attenuation. Since the attenuation data is less sensitive to the DSD of cloud than radar reflectivity factor, it can give more accurate estimation. Takahashi et al. [2012] utilized both CloudSat and TRMM PR data to characterize the cloud-precipitation system globally. The global map of combined contoured frequency by altitude diagram (CFAD) (10 × 10 degree boxes) showed good correspondence with the conventional climate classification and indicated varieties of cloud-precipitation processes.

The Cloud Profiling Radar (CPR), which will be the world's first W-band (94GHz) Doppler radar aboard a satellite, has been developed by JAXA in cooperation with National Institute of Information and Communications Technology (NICT). It will be aboard the Earth Clouds, Aerosols, and Radiation Explorer (Earth CARE). The CPR has Doppler speed sensor functions, to measure not only the vertical structure of clouds, but also the ascending and descending movement of clouds. To calibrate the Doppler velocity, an active radar calibrator (ARC) is needed, which measures antenna beam angles as the satellite velocity may contaminate radial velocity of the radar. An experiment was performed using the signal from CPR of CloudSat [Horie et al., 2012a]. In order to estimate the vertical Doppler velocity from CPR data, it is needed to develop a Doppler correction algorithm for CPR. Preliminary study and simulation for the algorithm was made by Ohno et al. [2013]. Because the satellite velocity and the beam width spread Doppler spectrum and make coherency low, the measurement errors of the Doppler velocity are increased. To make simulation data for the algorithm development, Horie et al. [2012b] developed the new simple calculation method using an integrated antenna pattern.

F2.3 Ocean

Spaceborne multi-temporal SAR and multi-spectral optical data were used to monitor the changes of bar morphology in the Han Estuary on the North Limit Line (NLL) between North and South Korea from the years 2000 to 2009 [Yang and Ouchi 2012]. Since the access has been limited, the area has retained its own natural character as an estuary. The effects of tide and rain on the sediment transport, land-cover, and morphology of bars were identified, and topographical map of bars was produced. Jung et al. [2012] applied the entropy/anisotropy/alpha polarimetric classifier to ALOS-PALSAR (Advanced Land Observing Satellite - Phased Array L-band SAR) fully polarimetric data of the fjord Kongsfjorden in Spitsbergen to classify fast ice, ice floe, snow, and glacier into 18 classes with supporting ground-truth data.

Sugimoto et al. [2012a, 2013c] presented an experimental proof of the equivalence between the 4-component scattering power decomposition (4-CSPD) algorithms based on rotation of covariance matrix and coherency matrix, and the ambiguity in the rotation of these matrices, using POLSAR (polarimetric synthetic aperture radar) data acquired by ALOS-PALSAR over Tokyo Bay. They also pointed out that there was ambiguity in minimizing the cross-polarized scattering power to enhance the double-bounce scattering component by rotation of polarimetric matrices, and that removal of this ambiguity optimally enhances the double-bounce component, and improves classification of targets, such as man-made structure on the sea, including ships and above-water laver cultivation nets [Sugimoto and Ouchi, 2011]. Sugimoto and Ouchi [2012a] and Sugimoto et al. [2012d] examined the entropy and alpha angle derived by the eigenvalue analyses of HH/VV dual- and quad-polarization SAR data. They used ALOS-PALSAR PLR (polarimetric) and TerraSAR-X images of Tokyo Bay, showing that both the dual-polarization entropy and alpha were nearly equivalent to the quad-polarization values over waters, forests, low vegetation and urban areas. Over waters, in particular, the dual-polarization data are as capable as quad-polarization data in the eigenvalue decomposition mainly because the HV polarization component has little contribution to the radar backscatter from the sea surface. They then demonstrated the capability of the dual-polarization data in the eigenvalue analysis for extracting laver cultivation nets and ship detection [Sugimoto et al., 2012e and 2013d]. Based on the difference in the radar backscattering mechanisms from the sea and man-made targets such as ships, Sugimoto et al. [2012b] developed a novel band-stop filter combined with CFAR (constant false alarm rate) for ship detection from fully polarimetric SAR data. They tested the filter using ALOS-PALSAR data of the waters around Portsmouth, UK [Sugimoto et al., 2013a] and those of the Portsmouth waters and Tokyo Bay [Sugimoto et al., 2013e], showing the improved detection ability of ships and even buoys and beacons on the sea. Marino et al. [2013] developed a polarimetric notch filter similar to that of Sugimoto et al. [2013a], and its effectiveness was proven using the ALOS-PALSAR data of Tokyo Bay with ground-truth data.

The ship detection algorithm based on multi-look cross-correlation (MLCC) was found to be effective to extract ships “invisible” in SAR images [Ouchi, 2011 and 2013], but it was not optimum as noted by several researchers. The main reason is that the inter-look image positions of a moving ship are different due to the center time difference between looks, and hence the center of the cross-correlation axis, which is used as an output to the coherence image, does not always take a maximum correlation value. To overcome this problem, Won and Ouchi [2011a, 2011b] developed a simple new algorithm of improved MLCC (IMLCC) by taking the maximum value in the cross-correlation function as an output of the coherence image. IMLCC was tested using ALOS-PALSAR images of ships in Tosa Bay and Tokyo Bay, and showed substantial improvement in the detection accuracy. When detecting ships equipped with AIS (Automatic Identification System) by SAR, their image positions often do not match with those of the AIS information. Chaturvedi et al. [2011, 2012] compared the ALOS-PALSAR images of ships with AIS signals in Tokyo Bay and Incheon Bay (Korea), and developed an algorithm to identify the ships from SAR images using the nearest neighbor method, resulting in satisfactory agreement.

In general, underwater objects such as laver cultivation nets cannot be detected by SAR. However, the sea surface above the nets tends to be smoother than that without nets. Due to little radar backscatter from the smooth surface, the SAR image is then contaminated by the random system noise. Based on this scattering characteristic, Won et al. [2013] and Won and Ouchi [2011c] applied the eigenvalue analysis of fully polarimetric ALOS-PALSAR images of Tokyo Bay, and showed that the polarimetric entropy is capable of extracting the underwater laver nets with much higher accuracy than the amplitude images. Yang et al. [2011] also showed the effectiveness of polarimetric entropy for extracting underwater laver nets in the west coast of Korean Peninsula. Due to the almost equivalent nature of the dual- and quad-polarization eigenvalue analyses, Sugimoto and Ouchi [2012b] and Sugimoto et al. [2012c, 2013b] compared various parameters derived from the quad- and dual-polarization data over Tokyo Bay acquired by ALOS-PALSAR and TerraSAR-X, including Pauli, entropy, alpha angle, HH/VV correlation, for extracting above-water and underwater laver

cultivation nets. As expected, the entropy derived from HH/VV dual-polarization data had highest and similar performance to that from quad-polarization data when the laver nets were underwater. When the nets were above-water, HH/VV coherence showed highest contrast against the background waters, and the 4-component power decomposition analysis outperformed any other parameters from quad-polarization data in a same manner as for ship detection.

Yang et al. [2013] developed an algorithm to compute radar backscatter from the sea surface covered by oil spills. In the algorithm, a one-dimensional oil-covered rough sea surface for different oil thickness was numerically generated from a waveheight spectrum under various wind speeds using the Monte Carlo technique. The radar backscattering coefficients were then computed using the method of moment (MoM) for different incidence angles, polarizations, and radar frequencies. Good agreement was obtained with ENVISAT-ASAR C-band and TerraSAR-X X-band SAR images of an oil-spilled sea surface caused by an oil tanker in the east coast of Korean Peninsula in 2009.

F2.4 Land, Vegetation, Subsurface Objects and Others

A. Land and Vegetation

Since its launch in January 2006, the ALOS PALSAR had observed earth surfaces and its data has been used in various areas including disaster mitigation, forest monitoring, natural environment maintenance, agriculture, and compiling a topographical map. On April, 2011, a power generation anomaly caused a communication loss, then on May 12, 2011, JAXA sent a command to stop the onboard transmitter and batteries of the ALOS to complete its operation. Technologies acquired from the ALOS operation will be succeeded to the ALOS-2.

Fully polarimetric radar and its utilization and applications to various fields have been investigated. The main topics were focused on the decomposition of fully polarimetric data sets including the model-based three/four-component scattering power decomposition, which tries to incorporate 100% second order statistical polarimetric information [Yamaguchi et al., 2011, Cui et al., 2012, Sato et al., 2012, Cheng et al., 2013, Singh et al., 2013a and 2013c]. Its application to disaster monitoring have been investigated [Yamaguchi, 2012, Park et al., 2013, Singh et al., 2013b], as well as environmental monitoring and ship detection [Cui et al., 2013]. Moriyama [2011, 2013a and 2013b] applied Particle Swarm Optimization (PSO) to the polarimetric decomposition, to reduce calculation time.

Most PolInSAR data processing procedures and their applications are based on the polarimetric complex coherence descriptor. Its reliable estimation requires selecting sufficient homogeneous pixels for generating an unbiased estimator. Two indicators using only polarimetric and both polarimetric and interferometric information are derived as the similarity measures for complex Wishart distributed PolInSAR covariance matrix, respectively. Using these indicators, a double similarity test scheme, which shows high sensitivity to both polarimetric and interferometric properties, was proposed for similar pixel selection [Chen et al., 2012]. Deorientation processing has been incorporated into model-based decomposition to cure the overestimation of volume scattering contribution, by rotating the coherency matrix to minimize the cross-polarization term. Further to the investigation of the deorientation effect, Chen et al. [2013a] focused on oriented built-up patches, introducing a parameter, named dominant polarization orientation angle (DPOA), to label each patch.

On detection of natural disaster affected area by polarimetric SAR, Watanabe et al. [2012] analyzed ALOS PALSAR data on the areas damaged by the Iwate-Miyagi Nairiku earthquake in 2008. They observed the dominance of surface scattering of the three-component scattering model in the landslide areas and improved the estimation of the possible landslide areas by combining the surface scattering and the σ0 VH filter. PolSAR images from ALOS PALSAR were utilized to investigate the tsunami damage. The observed reduction in the double-bounce scattering was due to a change into odd-bounce scattering, since a number of buildings were completely washed away, leaving relatively a rough surface. Polarization orientation (PO) angles in built-up areas were also investigated. After the tsunami, PO angle distributions spread to a wider range and fluctuated more strongly than those from

the before-tsunami period [Chen and Sato, 2013b]. To assess the damage of buildings caused by the devastating 2008 Sichuan (Wenchuan) earthquake in China, Wang et al. [2011b] applied a spatial homogeneity index based on local autocorrelation function, the Getis statistic to ALOS PALSAR amplitude images of Beichuan city before and after the earthquake. It was found that the totally and partially collapsed buildings were approximately 80% which is in close agreement with official record of 75% of totally collapsed buildings. Sato et al. [2012] demonstrate the importance and the potential of full polarimetric SAR images for damage assessment with ALOS PALSAR and the airborne Pi-SAR2 data acquired just after the March 11, 2011 East Japan Earthquake.

NICT has developed the second X-band airborne polarimetric and interferometric synthetic aperture radar (Pi-SAR2) system. Its performance is much better than that of the first Pi-SAR [Uemoto et al., 2011, Kobayashi et al., 2012, Kojima et al., 2013]. Its performance was verified with calibration instruments [Satake et al., 2011]. Since 2008 Pi-SAR2 observations have been carried out and applied to research in various fields such as hydrology, geology, oceanography, and environmental and disaster monitoring [Satake et al.,2012, Kobayashi et al., 2013].

Studies on the forests damaged by typhoon were made using airborne Pi-SAR X- and L-band polarimetric and X-band interferometric data over the Tomakomai forests, Japan [Ouchi and Wang, 2011]. Based on the height difference of tree-covered and clear-cut areas, an attempt was made to extract deforest areas using cross-track InSAR data before and after the damage [Wang et al., 2011a], and comparison was made with the results of the 4-component scattering power decomposition analysis (4-CSPD) of polarimetric data [Wang and Ouchi, 2011]. The latter technique showed good agreement with the ground-truth data, but the former method was not accurate enough due to phase noise and phase unwrapping problems. Nose and Ouchi [2012] applied a PCI (principal component analysis) to the Pi-SAR L-band polarimetric data and QuickBird multi-spectral data of the Tomakomai forests. The results showed that the optical brightness, SAR intensity, and correlation between NDVI (normalized difference vegetation index) and amount of vegetation correspond respectively to the first, second, and third principle components, and the first three components occupied 90% of the total components. Classification of forest and non-forest areas was then made by the maximum likelihood method, yielding substantial improvement in accuracy by the PCI with fused data in comparison with optical or SAR data alone.

B. Subsurface Objects and Landmine Detection

During the past 80 years, ground-penetrating radar (GPR) has evolved from a skeptically received glacier sounder to a full multicomponent 3D volume-imaging and characterization device. Because of its high resolution, GPR is a valuable tool for quantifying subsurface heterogeneity, and its ability to see nonmetallic and metallic objects makes it a useful mapping tool to detect, localize, and characterize buried objects [Slob, 2010]. Handheld GPR system is one of the technologies that has been researched as a means of improving landmine detection efficiency. The imaging processed by migration with interpolation is used in the dual sensor, advanced landmine imaging system (ALIS), and two sets of ALIS have detected more than 80 AP-mines since 2009 [Feng et al., 2011]. A multisensor system could offer an effective solution to land-mine detection. A handheld dual-sensor system with a position tracking system was developed, which can acquire GPR and metal detector (MD) data with 2-D space coordinates. A modified migration algorithm with continuous-root-mean-square velocity was proposed to process irregular GPR data, and an interpolation algorithm was recommended to process irregular MD data [Feng et al., 2012].

The utilization of a full polarimetric subsurface borehole radar measuring system for efficient characterization of subsurface fractures was investigated. Polarimetric datasets acquired at Mirror Lake, USA, were divided into four category fracture sets depending on polarimetric analysis of alpha, entropy and anisotropy decomposition analysis. It was found that distributions of the polarimetric parameters differ with the fracture roughness property which validates the polarimetric analysis of the measured data [Mansour et al., 2012].

Images from the ALOS/PALSAR L-band sensor have been used to detect and delineate the subsurface structures in Egypt. The circular polarization proved to be the best transformation for revealing buried faults in various strike directions [Gaber et al., 2011].

C. Others

To verify a newly discovered phenomenon of microwave emission due to rock fracture in a volcano, a field test was carried out in Miyake Island. Characteristic microwave pulses were intermittently detected at 300 MHz measuring system, during the period of that large-scale collapses occurred on the crater cliff. Seismograms obtained by nearby observatories strongly suggested that the crater subsidence occurred simultaneously with microwave signals [Takano et al., 2013]. It was shown through laboratory experiments and theoretical considerations that microwaves were generated by micro-discharge across micro cracks in a rock. Therefore, it is possible to detect such natural disasters via microwave, which can be received by a satellite in an orbit. The fundamentals of the experiments focusing on the receiving and recording system and the obtained data were introduced for quartzite, granite, gabbro, and basalt. The content of quartz is one of important factors to affect the emitted power, but the other factor should be also considered as gabbro emits more power than granite [Takano et al., 2011]. Radio wave emission due to rock fracture was measured at four frequency bands from 1MHz to 18GHz. The obtained results suggested the wave source to be quite narrow electrical signals, and show a possible application to the detection of an earthquake or volcanic activity [Takano et al., 2012].

Microwave radiometer data are attractive for monitoring land-surface deformations, but have difficulties as chaotic microwave signals emitted from the Earth's surface are reactions for various phenomena such as land surface temperature, soil moisture, water vapor in the atmosphere, etc. In order to detect microwave signals generated by rock failures, special algorithm for a satellite-borne microwave sensor was proposed and the application case studies for some earthquakes were presented [Maeda and Takano, 2010]. They investigated an analysis method to detect local and faint changes from the data of microwave radiometer. This analysis method, originally developed to detect microwave signals generated by rock failures in association with an earthquake, was modified for volcanic monitoring, and applied it to a volcanic eruption case of Chaiten volcano in the south of Chile. It was detected that microwave energy was emitted from the ground surface around the volcano from several months before the eruption. They have been verifying the obtained analysis results, to convince it is applicable to monitor volcanic activity [Maeda and Takano, 2011]. (M. Satake)

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