COMMISSION F: WAVE PROPAGATION AND REMOTE SENSING

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F1.1 Terrestrial Fixed Radio System

A fixed wireless access (FWA) system enables to provide a broadband wireless access service with a user bit-rate of more than 10Mbps. Propagation studies have been carried out to clarify the multipath characteristics in several environments and frequency bands for developing that system.

A 5-GHz band is expected to be available for wireless access systems and a residential area is an important service area. A new delay profile model for estimating multipath characteristics in a residential area was proposed [Kita, *et al*., 2001a]. It enables to calculate the delay spread considering three different wave components; the front, the primary scattering, and the secondary scattering wave components. Experimental studies using 2GHz/5GHz-dual band antenna show new propagation models for path loss and height gain in residential area [Kita et al., 2000; Kita et al., 2001b; Kita et al., 2001c]. These studies make possible to evaluate the influence of the multipath interference in a region of antenna height from a few meters to around 10m.

Urban street area is also a service area for high-speed wireless access services with over 10Mbps-transmission speed. Delay spread measurements in such areas were carried out at 5-GHz band and a relation between median value and the 90% value of the cumulative probability of the delay spread is formulated [Kita, et al., 1999].

In addition to UHF and SHF, quasi-millimeter band has been available for a point-to-multipoint wireless access system. In an urban area, reflected and scattered waves from buildings cause a multipath interference. A study of delay characteristics in such an environment reports the dependency of the delay profile on the height of the base station antenna [Izuka, *et al*., 2001]. For calculating the delay profile, the propagation path visibility is used for taking account of building parameters.

The foliage attenuation affects radio transmission characteristics as a degradation factor in a high frequency region such as above quasi-millimeter band. Experimental studies of the foliage attenuation show some compared results between 5GHz and 29GHz [Kajiwara 2000]. It is also shown that swaying foliage in wind causes a significant fading at 29GHz, ranging over 10dB, while the fading depth at 5GHz is approximately 2dB.

The rain attenuation still has been an important parameter for a design of wireless systems and its prediction method has been improved for higher accuracy. For extending a local estimation method to a worldwide use, a new prediction method, which considers the thunderstorm ratio, is proposed [Ito, *et al.*, 1999a, 1999b]. This prediction method of the one-minute rain rate distribution is derived from an original databank, which is richer in content than the ITU-R databank.

The motion of a rain area was observed by using a 12-GHz satellite-broadcasting wave [Hayashi, *et al.*, 2001]. Analyzing received level variations at three stations indicates the direction, moving speed, height and width of the rain area. It is also reported that the size of the rain area is less than 20km in most cases.

A scattering of the aircraft may cause interference in a long-distance radio link and a broadcasting system. Temporal variations of the interference level were simulated considering the movement of the aircraft, positions of transmitting and receiving stations, and antenna pattern of those stations [Takagi, *et al*., 2000]. Measurement was done in Thailand using a FM broadcasting station. The simulated result shows good agreement to the measured temporal fluctuation caused by a B747 aircraft.

(A. Sato)

F1.2 Satellite Radio System

First, in the fixed satellite radio systems, rain attenuation problems that are significant in the frequency bands higher than 10 GHz, such as Ku and Ka bands, are extensively investigated in the research fields of short or long distance site diversities, integration time of rainfall rate statistics, frequency scaling techniques between Ku and Ka bands and so on.

As for site diversity characteristics, short or long distance (10-1400 km) statistical characteristics are investigated among several earth stations in Sapporo, Tokyo, Osaka, and Fukuoka, using VSAT networks of JSCAT-1 as a joint experiment of the Digital Satellite Communication University Corporation Research Organization. Each earth station transmitted QPSK signals from these different areas, and one in Sapporo, Hokkaido measured their signals and processed them in order to estimate the site diversity characteristics. The measured results are relatively in good agreement with ITU-R Rep.564-4 [Hatsuda *et al*.,1999].

The problems for integration time of rainfall rate statistics are studied in extremely intense rain events in Tokyo. In such a heavy rain event with rainfall rate of larger than 100 mm/h, the cumulative distribution of clock-10 sec. rainfall rate is shown to be largely different from log-normal or gamma distribution, while the measured rain attenuation statistics, in general, follow the ITU-R predictions [Yamada *et al.*, 2000]. Also, these problems are considered using a worldwide databank of rainfall rates with different integration time collected from many literatures, and M distribution is proposed in order to obtain 1-min rainfall rate distribution, which is required for radio wave propagation study, from long integration time rainfall rates [Ito and Hosoya, 2000].

As regards the frequency scaling, rain attenuation ratio of Ka- to Ku-band satellite signals is investigated related to the kinds of rain fronts, on the basis of the long-term observational data of both frequency bands obtained for the past 13 years in Osaka. A comparatively large attenuation ratio was primarily found when the cold fronts passed over the earth station in Baiu season. In contrast, a comparatively small ratio was primarily obtained when the earth station was located to the south of the stationary fronts in Akisame season. A small ratio was also found in summertime shower. This difference seems to be caused by a dominant kind of raindrop size distribution in each season [Maekawa, 2001].

Also, the airplane effects on the earth-space path were measured by the VSAT system using JSCAT-1 near Fukuoka Airport, Kyushu. The observation suggests that serious airplane effects even occurs when airplanes fly over a town at a low altitude such as 800m, in addition to the direct effects of landing and takeoff [Fujisaki *et al*., 2000]. Post-PARTNERS project conducted a number of Ku-band satellite signal propagation experiments with Thailand, Indonesia, and Philippine using JCSAT-3 and collected a large amount of precious propagation data in the tropical or sub-tropical South-East Asia region. Some of these experiments indicate very intense rainfall rates and rain attenuation statistics with time percentage of much higher than the ITU-R prediction [Igarashi *et al*., 2001].

In the field of broadcast satellite systems, on the other hand, some preventive countermeasures for the rain attenuation using boosted power beams are proposed, based on the analyses of 1 h or 10 min rainfall rate data obtained from AMeDAS (Automated Meteorological Data Acquisition System). Computer simulations using these data suggest that with the aid of multi-beam or beam steering antennas for the satellite radio transmission, nearly 90% of

unavailable time due to rain attenuation may be compensated even in the Ka-band (21 GHz) advanced broadcast-satellite system [Yoshino and Ito, 1999], [Minematsu and Nomoto, 2001].
Next, in the mobile satellite radio systems, mobile communication and navigation systems are recently proposed using quasi-zenith satellites together with geostationary satellite [Tanaka, 2000]. As for navigation systems, the accuracy analysis on internal delays of satellites and earth stations demonstrates that the Japanese domestic systems with unknown delays of a few hundred meters may only cause a horizontal error as small as 1 m [Kawase, 2000].
Also, the urban propagation characteristics and satellite-diversity characteristics of mobile broadcast geostationary satellite systems were studied using GPS (Global Positioning System) signals for elevation angles of 40-50 deg. It is found from the measurements on a vehicle that a heavy signal fade is primarily caused by shadowing buildings on urban roads in east-west direction. As regards the satellite diversity effects, more than 90% satellite visibility can be achieved in the urban city by selecting two diversity satellites with separation angles more than about 45 deg [Hatsuda *et al*., 2001].

(Y. Maekawa)

F1.3 Mobile Radio Systems

A.Street micro cell systems

Many experimental and theoretical approaches have been established for investigating the mobile radio propagation characteristics of street micro cells in which the antenna height of base station (BS) is lower than that of the buildings around the BS. Furuno *et al*. carried out DOA and TOA measurements using a 2.6 GHz band directional antenna with the 3 dB beam-width of 10 degrees and a channel sounder based on a PN correlation receiver with the bandwidth of 60 MHz, and identified the propagation path for each received ray. The propagation mechanisms and the effectiveness of the ray tracing calculation were then clarified [Fururno *et al*., 2000]. Similarly, Masui *et al*. carried out DOA measurements in both line-of-sight (LOS) and non LOS (NLOS) environments by using a 8.45 GHz band directional antenna with beamwidth of 4 degrees and a similar channel sounder with bandwidth of 100 MHz; they investigated the angle spread of arrival waves and the time delay spread [Masui *et al*., 2000]. Since the LOS street is the main radio zone from the BS in street micro cell systems, most investigations considered the LOS environment, such as the measurement and modeling of time delay characteristics [Taga *et al*., 1999a; Ichitsubo *et al*., 2000; Masui *et al*., 1999b; Masui *et al*., 1999c] and path loss measurements, a regression analysis, and channel modeling in the 3 to 15 GHz band [Oda *et al*., 2000; Takahashi *et al*., 1999; Kage *et al*., 1999, Kage *et al*., 2000]. Masui *et al*. further investigated the impact of traffic density on the break point [Masui *et al*., 1999a, Masui *et al*., 2001]. Taga investigated experimentally the variation characteristics of arrival rays as resolved from time delay spectra [Taga *et al*., 1999c]. An advance system in which the time delay spread is reduced using a directional antenna at both the BS and mobile station (MS) was also proposed and its effectiveness was investigated experimentally [Taga, 2000]. The time delay spread and the path loss characteristics were also measured in LOS and NLOS environments in a suburban area, and were characterized by regression analysis [Shimizu *et al*., 2000].

B.Macrocell / micro cell systems

Ichitsubo *et al*. investigated experimentally the frequency correlation characteristics of the channel when the MS moves from ground level to a high position like a building's roof

[Ichitsubo *et al.*, 1999]. Fujii *et al*. analyzed the number of rays available for RAKE reception in the CDMA systems [Fujii and Imai, 1999]. These results are useful when evaluating the coherent frequency bandwidth and the performance of RAKE receivers. Asano proposed a method for estimating the probability density distribution of the wave arrival at the MS antennas, and compared the predicted results with measured ones [Asano, 2000]. This analysis seems to be a step toward modeling the arrival waves in the MS antenna. Zhang *et al*. proposed a deterministic model based on a ray tracing calculation method for predicting the received signal level in an indoor environment for the case in which the transmitted waves come from an outer BS and pass through the windows or penetrate the wall [Zhang *et al.*, 1999]. Taga *et al.* proposed a model to predict the path loss using ray tracing calculations with a loss layer model in an open scenario over which some large buildings and vegetation are distributed; they showed excellent agreement between the predicted and measured results [Taga *et al.*, 1999b].

C.Entrance systems

The BS antennas in systems beyond IMT-2000 will be mounted on the tops of buildings, not radio towers, because of the large number of BSs needed. Kitao *et al*. reported the time delay characteristics observed in the entrance link between the BSs mounted on building roofs and the time delay reduction achieved by using directional antennas to establish the entrance link [Kato *et al.*, 1999].

D.Formulations of mobile propagation

There has been a lot of investigations in the mobile radio communication field toward formulating the radio propagation characteristics to evaluate the transmission quality of wideband signals. Inoue *et al.* proposed a theoretical method based on an eigenvalue decomposition technique for analyzing the received level variation characteristics of wide band signals in Raleigh fading environments [Inoue and Karasawa, 1999]. Yan *et al.* proposed a theoretical method for expressing the received level variation by using a key parameter called equivalent received bandwidth (ERB) which is given as the product of the received bandwidth and the maximum difference of path lengths [Yan and Kozono, 1000a; Yan and Kozono, 1999b; Yan and Kozono, 2000]. Nakabayashi *et al*. also used ERB in their experimental investigation of the propagation charac teristics [Nakabayashi and Kozono, 2000; Nakabayashi *et al.*, 2001]. These studies appear to clarify the relation between the spatio-temporal propagation characteristics of waves arriving at the receiving antennas, the signal's bandwidth, and the received level of waves combined in the received antenna.

E. Indoor propagation

Several reports used the ray tracing method to predict indoor propagation characteristics and the effectiveness of this technique has been confirmed. Imai *et al.* proposed algorithms for efficiently calculating reflection and diffraction from partitions, pillars, and furniture in a room [Imai and Fujii, 2000a]. They constructed a prediction tool using these algorithms and confirmed their accuracy in a comparison with measurement results [Imai *et al.*, 2000b]. Tachikawa *et al*. used a ray tracing calculation for estimating the time delay reduction possible by using a tilt beam antenna in the MS when an Ad Hoc network between MSs is constructed in an indoor radio LAN environment [Tachikawa *et al.*, 2001].

F. Spatio-temporal channel modeling and measurement method

Recently, many research organizations have been studying and investigating spatio-temporal channel models. Ray tracing is one candidate that yields useful predictions. Zhu *et al*. presented a 2D-3D hybrid ray tracing method and calculated the TOA and DOA characteristics for some stationary environments; they validation its effectiveness experimentally [Zhu *et al*., 1999; Zu *et al*., 2001].

As a method of measuring TOA and DOA characteristics in mobile propagation environments, Sekizawa *et al*. developed a system consisting of a linear array antenna and a PN correlation channel sounder, and a method for obtaining the solution of rays by using 2D-DFT [Sekizawa *et al*., 2000]. They carried out an experimental investigation using the equipment in an urban street micro cell environment, and have presented their results [Sekizawa *et al*., 20001]. Tanabe *et al*. studied the DOA/TOA solution method using 2D-MUSIC [Tanabe *et al*., 2000], and Mori *et al*. studied a DOA estimation method using a sector antenna or a DBF antenna [Mori *et al*., 2000; Mori *et al*., 2001]. Unfortunately, such antennas are not used in practice yet. Takeuchi *et al*. developed a channel sounder using PN correlation detection with high TOA resolution of 0.5 [ns] [Takeuchi *et al*., 2001]. Multi-path propagation structure, coupled DOA, TOA and relative field strength, in the urban mobile communication environment of 25GHz band was measured by means of super resolution techniques [Kuwahara *et al*., 1999]. These detailed investigation of the propagation mechanism is continuing to advance the spatio-temporal channel model.

G. Others (Tunnel, ITS)

Several reports considered ray tracing methods for predicting the propagation characteristics in tunnels. Uchida *et al*. clarified the conditions for achieving sufficiently accurate ray tracing calculations, which radius of tunnel curvature is larger than 20 wavelengths [Uchida *et al*., 1999]. Fujimori *et al*. used ray tracing to determine the optimum beamwidth of BS antenna in order to realize a radio zone in a tunnel efficiently [Fujimori and Araki, 1999].

For the intelligent transport system (ITS), Suwa *et al*. presented the time delay characteristics in the propagation environment established when the MS antenna is mounted on a car and the BS antenna set up at the road side with and without shadowing due to others car, and the time delay reduction effect achieved by using beam antenna at both MS and BS [Suwa *et al*., 1999]. Karasawa used ray tracing to estimate the impact of the ground reflected rays on car-to-car communication in the 60 GHz band [Karasawa, 2000].

Arai *et al*. presented a propagation simulator to evaluate the performance of portable handsets in a quasi practical field [Arai *et al*., 2000].

(T. Taga)

F2.1 Atmosphere

In this section, remote sensing of atmosphere from the ground to the altitude of about 100 km is reviewed.

A.GPS meteorology

GPS (Global Positioning System) meteorology is a novel sounding technique of the atmosphere, by measuring propagation delay time of radio waves transmitted by GPS satellites. It provides us with information of electron density in the ionosphere, temperature in the stratosphere and humidity (water vapor) in the troposphere. A ground-based GPS receiver network by Geographical Survey Institute of Japan can provide precipitable water vapor (PWV) with a horizontal resolution of about 50 km every 12 hours, which compares well with objective analysis data [Iwabuchi *et al*., 2000]. With the receiver on board the LEO (Low Earth Orbit) satellites, the global measurement and a better vertical resolution could be obtained. From GPS/LEO observations, temperature profiles between the upper troposphere and stratosphere have been analyzed and global distribution of atmospheric gravity waves, which is a major phenomena of transporting momentum and energy from troposphere to upper middle atmosphere, has been presented [Tsuda *et al*., 2000a]. Global distribution of tropopause height was also reported by Nishida and Tsuda [2000]. Global distribution of sporadic E layer and ionospheric irregularity have also been observed using GPS/LEO [Hocke and Tsuda, 2001; Hocke *et al*., 2001]. It is noteworthy that holographic analysis of GPS/LEO data could provide high resolution profiling and detailed structure in D-region ionosphere (60-95km) with 300-500 m resolution has been reported by Igarashi *et al.* [2000].

B. Various techniques of observation in troposphere with MST radars
(MST = Mesosphere Stratosphere Troposphere)

1) Spatial domain interferometer (SDI)

Among interferometric technique in atmospheric radar, SDI has a longest history. The MU radar of Kyoto Univ. is suitable to carry out different setup of SDI method because of its flexible system design. Horizontal wind velocity could be obtained accurately even in the presence of high aspect sensitivity using multi-beam SDI method [Kawano and Fukao, 2001]. Tilt of turbulence layer due to meteorological disturbance has also been clarified using such a technique [Kawano *et al*., 2001]

2) Frequency domain interferometer (FDI)

FDI using two (or multiple) radar frequency has been developed significantly in this three years, using the MU radar. About the estimation of layer thickness using FDI method, biases due to multiple scattering layer [Luce *et al*. 1999], limited horizontal extent [Luce *et al*., 2000a], tilts of the scattering layers [Luce *et al*., 2000b] are carefully discussed. Furthermore, FII (Frequency domain interferometric imaging) technique by means of multiple radar frequency has been executed and complex structure associated with Kelvin Helmholtz instability has been observed in detail [Luce *et al*., 2001a, b]

3) Many beam method

By using the rapid beam steerability of the MU radar, many beam observations with beam numbers between several tens to hundreds have been carried out. Such observations could detect detailed structure of the echo intensity and wind velocity fields. Significance of the vertical shear of horizontal wind to the echo power is suggested, which is associated with gravity waves and affects the measurement of vertical wind velocity in atmospheric radar [Worthington *et al*., 1999a, b]

4) Application to the meteorological observation

Wind structures around Baiu front [Shigaraki *et al*., 2000] and gravity waves associated with the front [Ogino *et al*., 1999] have been reported by using MU radar and other observation techniques such as radiosondes, C/Ku band radars etc. Structure of a typhoon has also studied using MU and L-band boundary layer radar [Teshiba *et al*., 2001].

C. Radio Acoustic Sounding System (RASS)

RASS is a technique of tropospheric and stratospheric temperature sounding using acoustic wave sources and a radar. By measuring Doppler velocities of the radar waves scattered by acoustic wave front, temperature can be derived. Using this technique, turbulence energy dissipation and vertical eddy diffusivity in the troposphere has been studied in detail by the MU

radar [Hermawan and Tsuda, 1999]. Furthermore, estimation method of energy dissipation rate has been carefully investigated and it has been found that the previous measurement using radar echo intensity could be biased due to humidity profile, and advantage of spectral width method has been proved using
MU radar/RASS experiment [Furumoto and Tsuda, 2001]. It should also be noted that humidity profiles can be derived by combining RASS and turbulent echo intensity observation with the VHF radar, which is a novel technique of sounding humidity with high time resolution [Tsuda *et al.*, 2001].

D. Mesosphere and lower thermosphere (MLT)

MLT region is the atmosphere of 50 - 150 km altitude. This region has recently become of great interest because it is a boundary region between the neutral atmosphere and the upper atmosphere. The former is changed with the meteorological variation and climate change of the lower atmosphere, and the latter varies under a strong effect of solar activity. For example, temperature of MLT region is considered to be cooled largely corresponding to the greenhouse effect due to the change of radiative balance in the middle atmosphere. Therefore, the precise measurement of MLT region and clarification of variation and trend of the physical parameters of this region, as well as understanding of the dynamical process there, is of great importance.
Continuous monitoring of this region has been carried out using meteor radars and MF (medium frequency) radars, and wind velocities and various atmospheric waves have been studied. MST (Mesosphere Stratosphere Troposphere) radars have also contributed especially to the observation of short period (down to 5 min in period) gravity waves. Mean wind and its variation have been extensively observed with MF radars in Wakkanai (45 deg N) and Yamagawa (31 deg N) [Namboothiri *et al.*, 2000; Kishore *et al.*, 2000]. On the other hand, as an MST radar the MU radar in Shigaraki (35 deg N) has been observing the mesosphere for a long time since 1986, and interannual variability of mean winds has been closely analyzed [Namboothiti *et al.*, 1999; Gavrilov *et al.*, 1999]. Signals of QBO (quasi-biennial oscillation) and longer term variability have been found. Atmospheric waves which transport energy and momentum in the middle atmosphere have also been studied extensively with these radars. These studies includes intensity and momentum fluxes of gravity waves with the MU radar long term observations [Gavrilov *et al.*, 2000a, b; Gavrilov and Fukao, 1999], and semidiurnal and diurnal tides by MF radars [Hocke and Igarashi, 1999; Igarashi *et al.*, 1999].
It is also notable that Japanese observation in equatorial region, especially in Indonesia has contributed to the understanding of equatorial atmospheric dynamics. Atmospheric tides and ultra fast Kelvin waves have been intensively studied with Jakarta meteor radar (6 deg S), Pontianak MF radar (0 deg N) and international collaboration with other radars [Tsuda *et al.*, 1999; Yoshida *et al.*, 1999].
It should also be stressed that coordinated observation of radar and optical measurement (lidar, airglow imager, photometer) has been extremely promoted in the last three years [Tsuda *et al.*, 2000a]. Cooperative sodium lidars and MU radar observation clarified the association between dynamics and atomic sodium layer/sporadic sodium layer [Miyagawa *et al.*, 1999; Kobayashi *et al.*, 1999]. Airglow imaging observation has contributed to the studies of small scale gravity waves, especially on the propagation characteristics in the middle atmosphere [Nakamura *et al.*, 1999; Ejiri *et al.*, 2001; Shiokawa *et al.*, 1999]. Rotational temperature measurement using OH airglow and cooperative observation with radar-derived winds has provided important information on the structure of gravity waves in the MLT region [Takahashi *et al.*, 1998, 1999; Buriti *et al.*, 2000].

Important technical advances in this three years are 1) high altitude (up to 120 km) wind observation using MF radar meteor echoes [Tsutsumi *et al*., 1999], 2) evaluation of bias in wind measurement due to signal saturation in MF radar [Yamazaki *et al*., 2000], 3) new analysis method to improve height range of mesosphere observation with an MST radar [Takeda *et al.*, 2001].

E. Spaceborne Sensors

National Space Development Agency (NASDA) and Communications Research Laboratory are collaborating to develop a spaceborne submillimeter-wave limb sounder called Superconducting Submillimeter-Wave Limb-Emission Sounder (JEM/SMILES) to be aboard the Japanese Experiment Module (JEM) of the International Space Station. JEM/SMILES is designed to observe global three dimensional distributions of stratospheric ozone-depletion-related gases such as O3, ClO, BrO, HCl, HNO3, and HO2 in submillimeter-wave bands around 640 GHz by a highly sensitive SIS receiver operating at 4.5 K. Simulation studies based on the detailed instrumental design have demonstratated its capability of retrieving stratospheric minor constituents. JEM/SMILES is scheduled to be attached to the Exposed Facility of JEM in 2005 [Seta, et al., 2000; SMILES Mission Team, 2001].

(T. Nakamura)

F2.2 Hydrometeors and Other Particles

Measurements of precipitation and cloud have been among major remote sensing research areas in Japan, a part of which is a continuation and expansion from rain-attenuation studies for Earth-space communication links using ground-based radars. The other expertise comes from radar meteorology and hydrology for weather forecast and disaster prevention, and related atmospheric science studies. In 1997, the Tropical Rainfall Measuring Mission (TRMM) satellite [Kummerow *et al*. 2000] was launched as a joint project between the U.S.A. and Japan that carries the first spaceborne rain radar [Kozu, *et al*. 2001]. Because of the rapid progress in spaceborne sensor technology, many studies on space-based remote sensing have also been performed in recent years.

In the following, recent research activities in Japan are reviewed by classifying into ground-based and space-based remote sensing techniques and observation results.

A. Ground-based remote sensing studies

The main target of weather radars has been precipitation particles. They have two functions, one of which is to observe the amount of precipitation (including the liquid equivalent of frozen hydrometeors). The other function is to observe wind velocity field through the Doppler effect of the scattered electromagnetic wave from moving particles.

Recently, radars with shorter wavelength have appeared to observe the non-precipitating, floating particles. Their main targets are cloud and fog.

For the observations of precipitating particles, many researches have been made to translate the echo intensity into the amount of precipitation. This relation is called Z-R relationship. It is well known fact among radar meteorologists that this translation is not unique. While the echo intensity is proportional to the distribution of 6^{th} power of diameter of falling particles, the amount of precipitation is proportional to the distribution of 3^{rd} power of diameter and falling velocity of the particles.

Moreover estimation of the rain rate by echo intensity has non-negligible error for an echo region that lies behind a strong echo region due to attenuation of scattered wave through the strongly precipitating region.

To overcome these problems, many efforts have been made. One type of approach is to compare echo intensity with the drop size distribution by using disdrometer [Maki *et al.* 2001] or wind profiler [Kobayashi and Adachi 2001] and to establish new Z-R relationships depending on the types of precipitations (convective type or stratiform type etc.). The other type of approach is to use dual-polarization Doppler radar that has many parameters to determine rainfall rate without using echo intensity [Timothy *et al.* 1999].

As the Doppler velocity is a component of a velocity vector along the beam direction, it is often unsatisfactory for meteorologists who want to know the real wind vector field. Recently new Doppler radar system called bistatic Doppler radar system was developed. This system is composed of a traditional Doppler radar and single or multiple receivers that can determine the wind velocity vector with high precision because a single Doppler radar illuminates the targets. As the receivers catch obliquely scattered electromagnetic wave, geometrical aspect of signal processing is much more complicated than the usual Doppler radars that use only backward scattering. Satoh and Wurman [1999, 2001] discussed this geometrical issue with observed data. Takaya and Nakazato [2001] theoretically argued the precision of the determined velocity vector by a bistatic Doppler radar system.

Fog observation by scanning weather radar was first realized with Ka band (35GHz) radar. Akaeda *et al.* (2001) observed marine advection fog to reveal that there are three types of fog; stratiform, roll and open cell. Hamazu *et al.* [2001] compared their wind data by Ka-band Doppler radar with the data by the MU radar (50 MHz), to confirm the proper acquisition of Doppler velocity by their radar. Applying it to marine advection fog, they made clear that the movement of the fog is governed by the wind just above the fog layer. An observation was made by a W-band (95GHz) polarimetric Doppler radar to observe the internal structure of deep stratiform ice cloud [Fujiyoshi *et al.* 1999]. The cloud showed convective cell structure at its upper level, streaks at midlevel and thin stratiform structure at lower level.

More sophisticated multi-parameter radar (dual polarization and dual wave length) was developed to observe a precipitation system from its formation stage that is a cloud system without precipitation [Iwanami *et al.* 2001, Wakayama *et al.* 2001]. It is also reported that UHF wind profilers can even be used to observe cirrus cloud properties [Kobayashi *et al.* 2001]. It is advantageous to observe the cloud "downward" to avoid severe attenuation by rain. A multi-parameter (multi-polarization and Doppler) airborne cloud radar (SPIDER) was developed [Horie *et al.* 2000] for scientific studies and as a test-bed for future spaceborne cloud radar.

In measuring rain with a millimeter wave dual-polarization radar, multiple scattering effects can be significant in polarization signatures and care has to be taken in the interpretation of the observed result. A basic theoretical and experimental study for the multiple scattering properties was done by Tazaki *et al.* [2000].

B. Space-based remote sensing studies

Studies on precipitation and cloud remote sensing from space in Japan may be categorized in the following four aspects; (i) system study and development, (2) algorithm development and related precipitation modeling, (3) validation of space-based measurements, and (4) basic studies for next-generation spaceborne radars.

Major activities in the category (1) are to summarize the development of TRMM Precipitation Radar (PR) based on in-orbit verifications [Okamoto 2000; Kozu *et al.* 2000; Kozu *et al.* 2001], studies for the TRMM-follow-on mission concepts and system studies [IHAS and ESTO 1998], and studies for a cloud observation space mission with a millimeter-wave radar [CRL and ESTO 2000]. It should be noted that the TRMM PR still functions normally and keeps almost the same performance after 4 years in orbit, which enhances the value of long-term global distribution of rainfall and 3D rain structure database.

There have been many studies regarding the category (2). "Standard algorithms" used for the TRMM PR have been developed in joint efforts by Japan and the U.S.A. [Okamoto, 2000] and still are under-improvement, especially after the TRMM altitude was raised to 400 km from the original 350 km in order to extend the life time. Since the radar reflectivity data from the TRMM PR are well calibrated [Kozu *et al*. 2001], interfaces between algorithms for "Level-1" (*i.e.* received power and reflectivity) and "Level-2" (rain rate, surface radar cross-section and rainfall-type) products are well defined. However, there are various difficulties in making the Level-2 algorithms stable for various surface conditions and rainfall properties, in particular for off-nadir observations (greater than about 10 degrees). It has been reported that the rain rate from the TRMM PR is somewhat lower than those from other TRMM products and ground-based raingauge measurements [Kummerow *et al*. 2000]. Outlines of the PR Level-2 algorithms and improvement efforts are described in Meneghini *et al*. [2000], Iguchi *et al*. [2000]; and Awaka [2000].

In addition to the "standard algorithms", Aonashi and Liu [2000] have been developing and improving passive microwave algorithms utilizing the simultaneous active and passive measurements by TRMM. They concluded that the inclusion of 10-GHz channel into the passive microwave retrieval is effective to improve the retrieval accuracy and that a general way to make correction for the inhomogeneity of rain within a radiometer field of view (especially for 10-GHz channel) has to be developed. The beam filling error correction is also crucial even in the PR measurement that has much finer spatial resolution (4.3 km) than TMI [Kozu and Iguchi 1999; Iguchi *et al*., 2000].

The information of rain height and vertical structure is important because it is closely related to the vertical profile of latent-heating, to improving both active and passive rainfall retrieval accuracies, and to improving the accuracy of attenuation prediction for satellite-Earth paths. The TRMM PR made it possible to globally measure the rain height and vertical structure with high reliability. Short and Nakamura [2000] made a comprehensive statistical analysis of TRMM PR-derived rain height and found that a distinct "bimodal" distribution exists over the oceans (not over land areas), with the lower and upper modes of about 2 km and 5 km, respectively. Thurai and Iguchi [2000] compared the 0 degree isotherm height model given by the ITU-R Rec.839 with the bright band height statistics (zonal mean) obtained from the TRMM PR, and found that they agree very well considering that the bright band "peak" (the height of peak reflectivity) generally appears several hundreds meters lower than the 0 degree isotherm height. Comparisons classified into continental and oceanic areas may be necessary to validate the ITU-R model in more detail.

The validation of TRMM algorithms and products have been among the major efforts after the TRMM launch. Such efforts are also described in the papers by algorithm developers [Meneghini *et al*. 2000; Iguchi *et al*. 2000; Awaka 2000]. In addition, Ohsaki [2001] and Ohsaki *et al*. [2001] validated the detection of rain area with the TRMM PR, and examined the scan-angle dependence of the mean storm height obtained from the TRMM PR by using ground-based radar data as well as theoretical considerations. Sato and Kishore [1999] made a series of very careful comparisons between radar reflectivities obtained from the TRMM PR and the Middle and Upper atmosphere (MU) radar at Shigaraki, Japan, and found that they agree within about 1 dB, indicating the validity of calibration accuracy of the TRMM PR evaluated in Kozu *et al*. [2001].

As for the basic studies on the dual-frequency radar for the TRMM-follow-on mission and spaceborne cloud radars, comprehensive presentations were made in IHAS and ESTO [1998] and ESTO [2000]. In addition, Sato *et al*. [2001] made a laboratory experiment of a digital-analog pulse compression system with a very low range sidelobe level that is important to improve the sensitivity of spaceborne rain/cloud radar in near future, because a "full" digital pulse compression would be beyond the capability of near-future onboard real-time processing. Their result is encouraging but still needs efforts to compensate the waveform distortion due to the saturation in a high-power radar transmitter.

(T. Kozu and Y. Takaya)

F2.3 Ocean and Ice

Ocean wave direction wad determined by newly proposed split-look processing of the synthetic aperture radar (SAR) from the JERS-1 SAR data [Ouchi, 1999]. Concerning with the analysis, the theory of ocean wave backscattering was proposed [Ouchi, 2000].

Sea ice in the Okhotsk sea were investigated by using spaceborne and airborne SAR and microwave radiometer. Ice type classification were carried out by the X- an L-band polarimetric airborne SAR (Pi-SAR) and resulted that the dual frequency polarimetry is useful to detect the ice characteristics in very thin ice [Matsuoka, 2001]. Also, such polarimetric technique applied for saline lake (Saroma lake) solved the ice thickness [Wakabayashi, 2001]. Methane bubbles in the lake ice were detected by satellite and airborne SAR[Matsuoka, 1999].

(S. Uratsuka)

F2.4 Land, Vegetation and Others

Fully polarimetric and synthetic aperture radar sensing as well as newly developed polarimetric SAR interferometry have been attracting attention [Boerner *et al*., 2000] from theory to data analysis, in various areas including land, vegetation, and others, during these three years.

The basic principle of radar polarimetry is devoted to find optimum polarization states for target enhancement and for retrieving target information [Yang, *et al*., 1999, 2000, 2001]. Compound scattering matrix is examined by Kitayama [2001]

Polarimetric and Interferometric airborne SAR (Pi-SAR) system has demonstrated its potential performance with high resolution (1.5 by 1.5 m at the X-band, 3 by 3 m at the L-band), fully polarimetric (HH, HV, VH, and VV, both in the X- and L-bands) and simultaneous interferometric data acquisition function at the X-band [Kobayashi, *et al*., 2000]. The image acquired with Pi-SAR includes forest, city, mountains, ocean, and volcano activities [Uratsuka, *et al*., 2001], with top-of-the world quality, and it attracted a great reputation among radar experts in the world. This Pi-SAR data will also provide valuable information for ALOS-PALSAR satellite system to be launched in 2004.

There were several implementations of fully polarimetric radar systems. One is a real-time polarimetric FM-CW radar system, developed at Niigata University [Nakamura, 1999]. The radar is especially suited for short range sensing such as snowpack application and subsurface sensing [Moriyama, *et al*, 1999, 2000].The other is a polarimetric borehole radar system for detecting cracks and anomalies within underground structure developed at Tohoku University [Miwa, *et al*., 1999, 2000]. It utilizes circular/conformal array antennas for directional polarimetric scattering matrix measurement. From the scattering matrix information together with super-resolution technique, the detailed ground structure and fracture were retrieved

[Sato, *et al*., 2000; Ebihara, *et al*., 2000].

For obtaining ideal polarimetric data, calibration is mandatory. Using an active calibrator with 30dB isolation together with polarization selective dihedral reflectors developed at CRL, Fujita *et al*. [1988] succeeded in the calibration of SIR-C data and Pi-SAR data.

As far as SAR image analysis is concerned, Kurosu, *et al*. [1999] showed textural feature for land cover classification based on continuous observations with JERS-1 SAR. Polarimetric data are well classified with textural feature [Hoshi, *et al*., 1999], wavelet textural feature [Fukuda, *et al*., 1999], polarimetric index derived from scattering matrix elements [Yoshioda, *et al*., 1999], and scattering mechanisms [Hosokawa, *et al*., 2000].

Polarimetric response of decorative trees is examined in a laboratory by Murase, *et al*., [2000], and analyzed by several polarimetric indices [Yamaguchi, *et al*., 2001].

A super-resolution method applied to polarimetric coherency optimization yielded an accurate estimation of tree height [Yamada, *et al*., 2001]. The novel technique is resulted from a combination of polarimetry and interferometry (Pol InSAR) and locates accurate scattering centers corresponding to ground and canopy. This method is successfully applied to Briatia (Russia) data acquired with SIR-C/X-SAR [Sato, *et al*., 2001] and estimated forest height.

(Y. Yamaguchi)

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