4-9 Long-term Observations Using L-Band Wind Profiler in Asia

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Wind profiler is a Doppler radar that can observe upper winds from the ground by receiving atmospheric turbulence echo. The Communications Research Laboratory (CRL) developed an L-band wind profiler and has been carrying out continuous wind observations at Koganei, Tokyo since 1993. Ministry of Posts and Telecommunications (presently, Ministry of Public Management, Home Affairs, Posts and Telecommunications) and CRL also installed L-band wind profilers at Bangkok, Thailand and Gadanki, India, and has been making wind observations in cooperation with the King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand and the National MST Radar Facility (NMRF), India. Seasonal and diurnal variation of winds and classification of rain type using those wind profiler data are shown in this paper.

Keywords
Wind profiler, Atmospheric boundary layer, Asia monsoon, Diurnal variation of winds, Rain type classification

1 Introduction

A wind profiler is a radar that emits electromagnetic waves upward to measure upper atmospheric winds. This radar has been recently paid attention as a useful instrument for upper air observations due to its higher temporal resolution and its easier automatic operation than those of conventional balloon measurement.

The Communications Research Laboratory (CRL) has developed an L-band wind profiler and has been demonstrating its usefulness since 1991[1]. In 1993, we installed a wind profiler at the King Mongkut's Institute of Technology Ladkrabang (KMITL) in Bangkok, Thailand, and started radar operation in collaboration with the Ministry of Posts and Telecommunications (presently the Ministry of Public Management, Home Affairs, Posts, and Telecommunications) in a joint research/experiment project on the environment monitoring technology in Asia. In 1997, we also installed a wind profiler at the National MST Radar Facility (NMRF) in Gadanki, in southern inland India, and started radar operation under the auspices of the same project (Fig.1).

With rapid urbanization and industrialization now underway in Asia, the issue of air pollution caused by factories and cars is becoming more and more serious. Because pollutants are transported and diffused by wind, it is important to observe and to monitor winds in the atmospheric boundary layer. Wind profilers are suitable for local air environment management as they can continuously observe short-term changes in wind.

In Thailand and India, the influence of the Asia monsoon (the seasonal winds) is significant, because seasonal variation in rainfall in the dry or rain seasons may be accompanied by variations in wind direction. The interannual variation in rainfall is also largely

Fig.1 *Observation sites of L-band wind profilers*

influenced by monsoons. In 1995, the GEWEX Asia Monsoon Experiment (GAME) started under the Global Energy and Water Cycle Experiment (GEWEX), a worldwide program of climate research. In 1998, GAME was conducting intensive observations in Asia. We participated in this project and have provided wind data measured by the wind profilers in Thailand and India to a number of meteorological and climate researchers[2].

In this paper, we will mainly discuss the analysis results of wind and rainfall data using the long-term observations obtained by the L-band wind profilers in Tokyo, Thailand, and India.

2 L-band Wind Profiler System

While precipitation particles such as rain or snow are the main scattering bodies in case of meteorological radar, the atmospheric scattering is used in case of wind profiler. Atmospheric scattering occurs due to variations in the refractivity index caused by turbulence. A variation in refractivity index on the order of one half-wavelength of the electromagnetic wave contributes to such scattering (called Bragg scattering)[3]. A wide range of frequency bands, from the VHF to UHF, is used for observing atmospheric scattering. Because the L-band wind profiler has relatively high frequencies, it can work using a small antenna, with only a few square meters. However, its observation range is limited to less than a few kilometers in altitude, as the scattering intensity in the upper atmosphere is rather small. The scattering intensity varies depending on atmospheric conditions (temperature, humidity, and turbulence). It is usually possible to observe higher altitudes from sites subject to high temperature and high humidity, such as in Thailand and India. It is possible to observe at an altitude ranging from eight to ten kilometers in case of rain, since the scattering intensity from the precipitation particles is high in the L-band.

The wind profiler observes the wind component in the direction of the radar beam by measuring the Doppler frequency shifts of atmospheric echoes. Assuming horizontal homogeneity, it is possible to measure a 3-dimensional wind vector that includes the vertical direction, using observations of more than three beams.

Table 1 lists the specifications of wind profilers operated at CRL in Koganei, KMITL in Bangkok, and NMRF in Gadanki. The transmit frequency is 1357 MHz and the peak transmitted power is 1 kW for all three wind profilers. The wind profilers at CRL and KMITL change their beam directions by mechanically driving the parabolic antenna, while the wind profiler at NMRF can change its beam direction electronically using the phased array antenna. The three beams are directed vertically, eastward, and northward, at all three observation sites. The zenith angle of the beams inclined to the east and north is 8 degrees at the CRL site and 15 degrees at the KMITL and NMRF sites. Normally, the wind profilers operate 24 hours a day, and repeat observations at time intervals of five minutes at CRL and KMITL, and at time intervals of 11 minutes at NMRF, alternating between two pulse widths. Although occasional power failures or mechanical problems interrupted automatic observation, so far we have been operating the wind profilers for tens of thousands of hours, and obtaining massive amounts of data at each of the three observation sites.

Table 1 *Main specifications of L-band wind profilers*

	CRL	KMITL	NMRF
Observation site	Koganei (Tokyo)	Bangkok (Thailand)	Gadanki (India)
Transmit frequency	1357.5 MHz	1357.5 MHz	1357.5 MHz
Peak transmitted power	1 kW	1 kW	1 kW
Pulse width	1 μs	1 μs	1 μs and 2 μs
Antenna type	Parabolic	Parabolic	Phased array
Antenna size	4.2 m ϕ	4 m ϕ	3.8×3.8
Antenna gain	33.5 dBi	32 dBi	29 dBi
Beam control	Mechanically driving	Mechanically driving	Electronic beam scanning
Beam direction (Zenith angle)	Vertical, East (8 degrees), North (8 degrees)	Vertical, East (15 degrees), North (15 degrees)	Vertical, East (15 degrees), North (15 degrees)

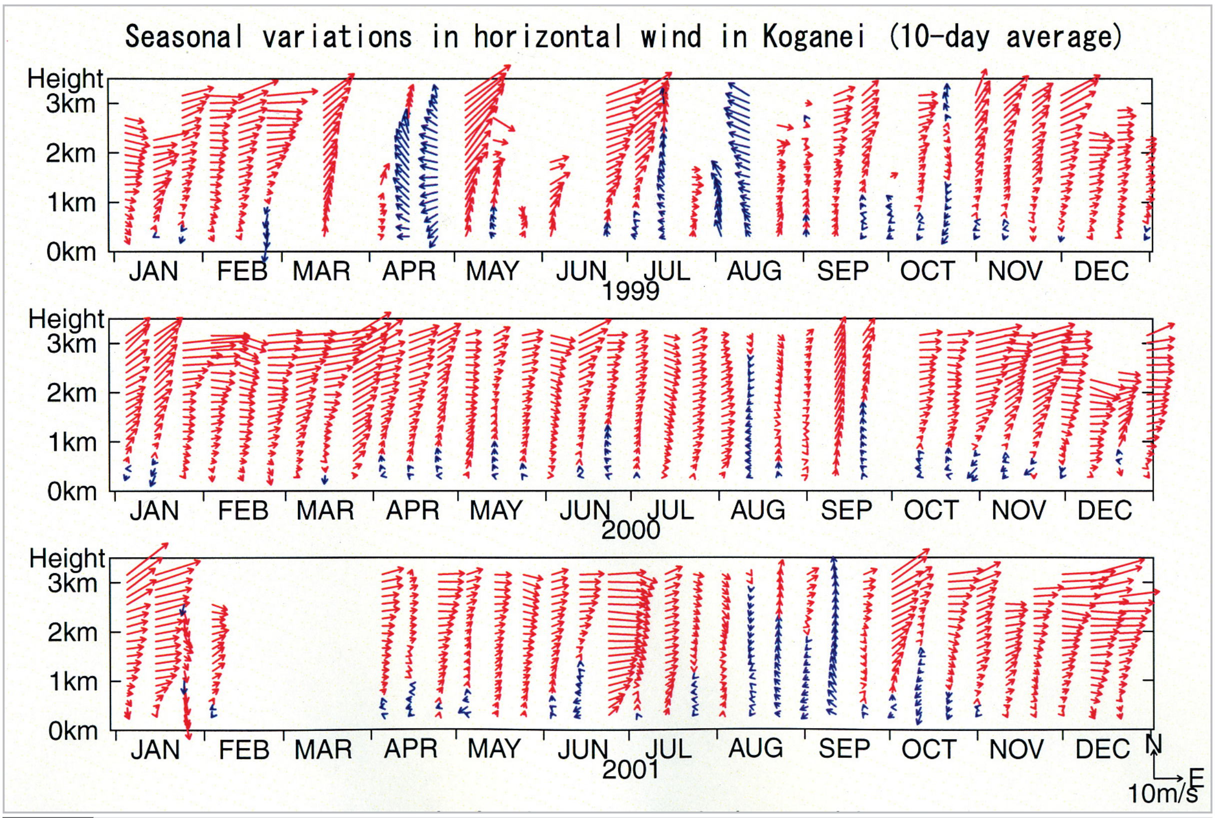

Fig.2 *Seasonal variations in horizontal wind observed by wind profiler in Koganei*

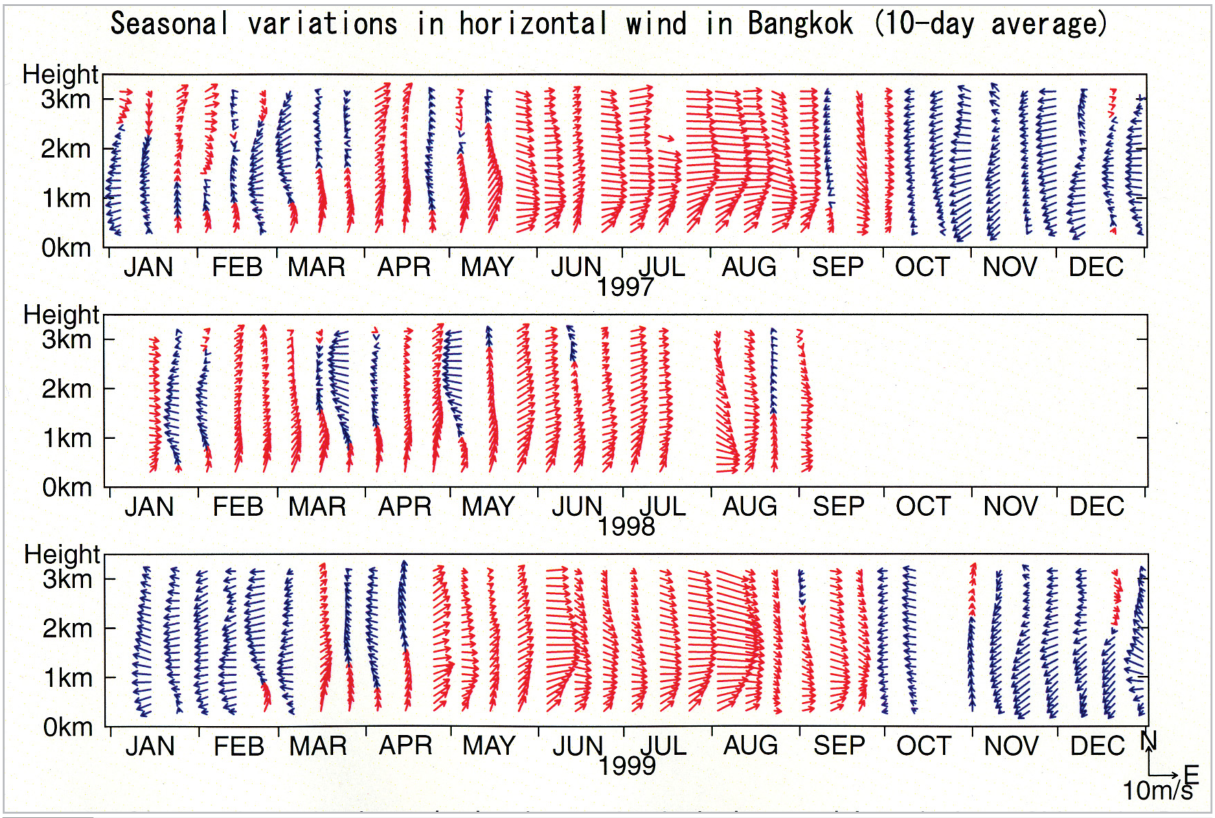

Fig.3 *Seasonal variations in horizontal wind observed by wind profiler in Bangkok*

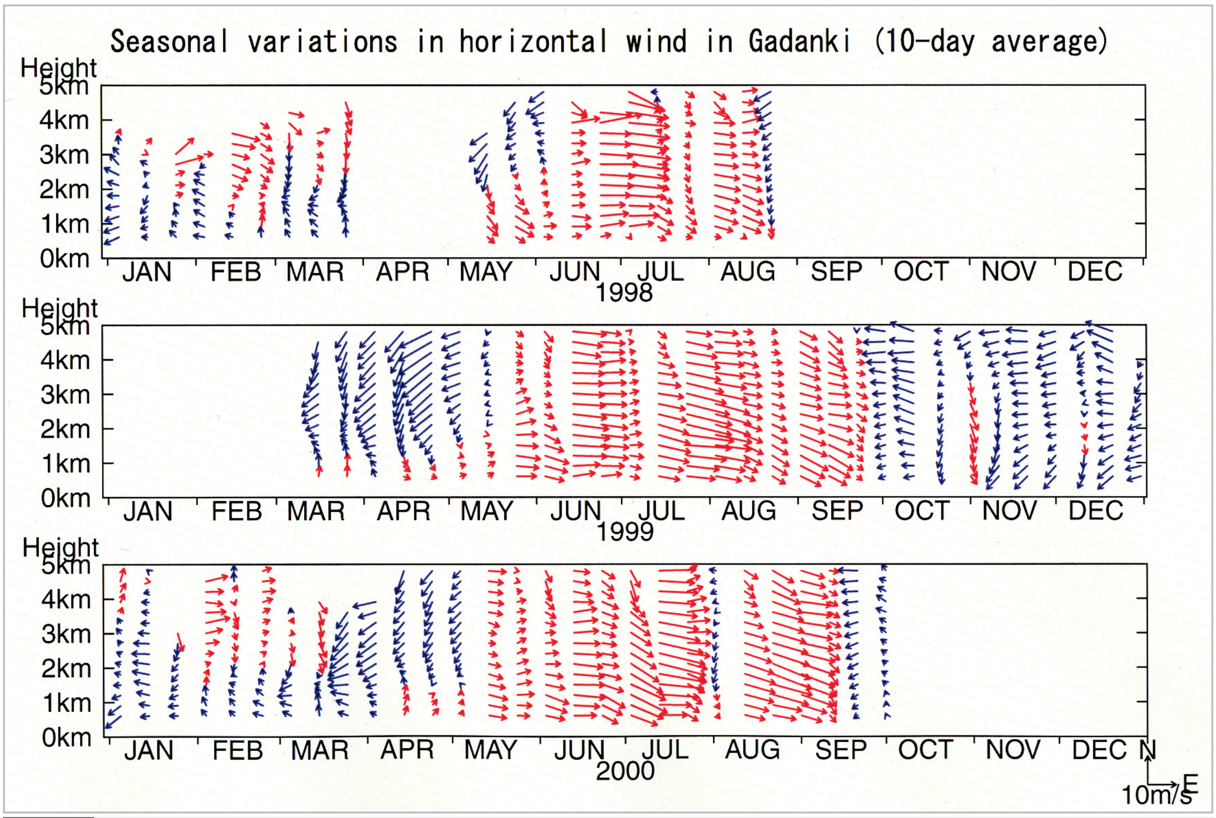

Fig.4 *Seasonal variations in horizontal wind observed by wind profiler in Gadanki*

3 Seasonal and Diurnal Variations in Wind Measured by Wind Profilers

The seasonal and diurnal variations in wind at each observation site are analyzed using the wind profiler's long-term observation data. Figs.2, 3, and 4 show the seasonal variations in horizontal wind at Koganei, Bangkok, and Gadanki, respectively. These results are derived from wind profiler's data obtained over three years of observation, and averaged over each 10-day period. The arrows indicate the direction of wind: arrows pointing upward indicate wind blowing toward the north (i.e., southerly winds); arrows pointing right indicate wind heading the east (i.e., westerly winds). The lengths of arrows are proportional to wind velocities. (See legends at the bottom-right corner.) The coordinates indicate the height from the ground. Wind data are drawn up to 3.5 km at intervals of 150 m for Koganei and Bangkok, and up to 5 km at intervals of 300 m for Gadanki. To make it easier to note the variations in seasonal winds, the westerly winds are indicated in red and easterly winds in blue. In case of failure of the radar, or few effective observations caused by weak atmospheric echoes, no arrows are drawn in these figures.

At Koganei, although the westerly winds are strong in winter and easterly winds occasionally appear from August to September, the seasonal variations are not obvious. Con-

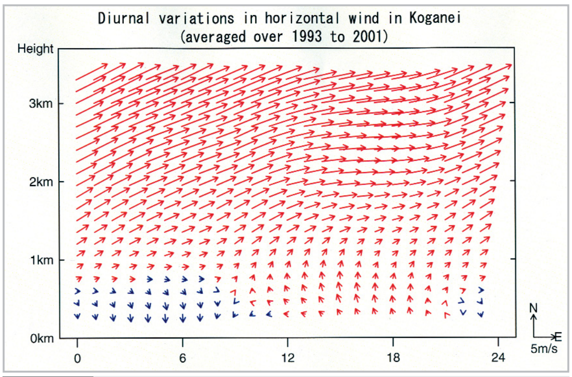

Fig.5 *Average diurnal variation in horizontal wind observed by wind profiler in Koganei*

versely, at Bangkok and Gadanki, distinct seasonal variations can be seen; westerly winds are predominant from May to September, with easterly winds predominant from October to April (with slight variations from year to year). In Thailand and India, westerly winds dominate during the rain season, and easterly winds are prevalent during the dry season. This indicates that both regions are affected by the Asia monsoon.

Making the most of a high temporal resolution of wind profiler, diurnal wind variations are analyzed. Fig.5 shows the diurnal variation in horizontal wind averaged over each hour over the past nine-year period at Koganei. Averaging the data over a long period of time eliminates random factors with time caused by the passage of fronts or low-pressure systems. Then, time-dependent components are extracted by this method. As can be seen in the Fig.5, there are clear diurnal variations below a height of 1 km, in which northerly winds dominate in the morning and southerly winds dominate in the afternoon. This variation comes from land and sea breezes due to the difference in heat capacities between the land and the sea. At night, the sea is warm relative to the land and a land breeze (northerly breeze) thus blows from northern Kanto to Sagami Bay. After sunrise, the land gradually warms up and a sea breeze (southerly breeze) blows from the sea to the land. In the afternoon, the land subsequently cools down and again a breeze blows from the land toward the sea. Although it is unclear in this figure, at altitudes above 1 km there are compensation winds blowing in opposite directions; southerly winds in the morning and northerly winds in the afternoon[4].

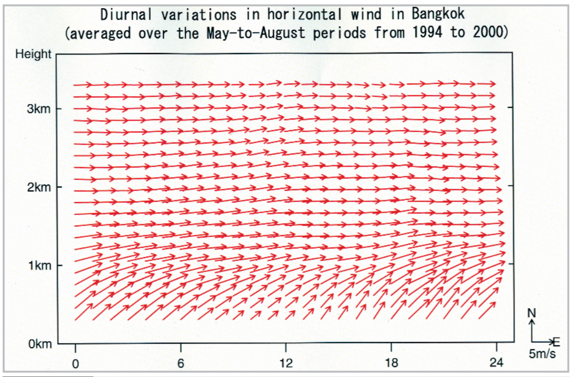

Fig.6 Diurnal variation in horizontal wind during the rain season observed by wind profiler in Bangkok

Fig.6 shows the diurnal variation in horizontal wind obtained by averaging during the rain season in Bangkok using the same method. In this figure, the diurnal variations are not as obvious as in the figure of the Koganei data, but a slight reduction of southwesterly winds in the daytime can be seen below 1 km. Such diurnal variation is not due to the land and sea breezes, but due to the upward development of the atmospheric boundary layer in the daytime, transforming the surface drag to the upper atmosphere; thus weakening winds at altitude around 500 m[5].

While it is difficult to detect diurnal variations through upper wind observation using conventional balloons, observation using the wind profiler enables this type of analysis with its high temporal resolution. Since air pollution due to automobile exhaust is particularly serious around Bangkok, information on the diurnal variation in wind is particularly useful in predicting high pollution area.

4 Rain-Type Classification

The L-band wind profiler can detect precipitation particles such as rain or snow with a high sensitivity as well as atmospheric scattering. Williams et al. classified rain as convective rain and stratiform rain by using the vertical observation of the wind profiler[6]. For stratiform rain, ice and snow fall calmly in the upper atmosphere, melting into rain before reaching the ground. At the melting altitude, where the atmospheric temperature is around 0 degrees, strong scattering echo (called the “bright band”) is observed. Stratiform rain has low variations over time and tends to continue falling for a long time. Conversely, convective rain develops from the collision of precipitation particles in a strong convection. There is no obvious bright band, its rain rate varies over time, and the duration is relatively

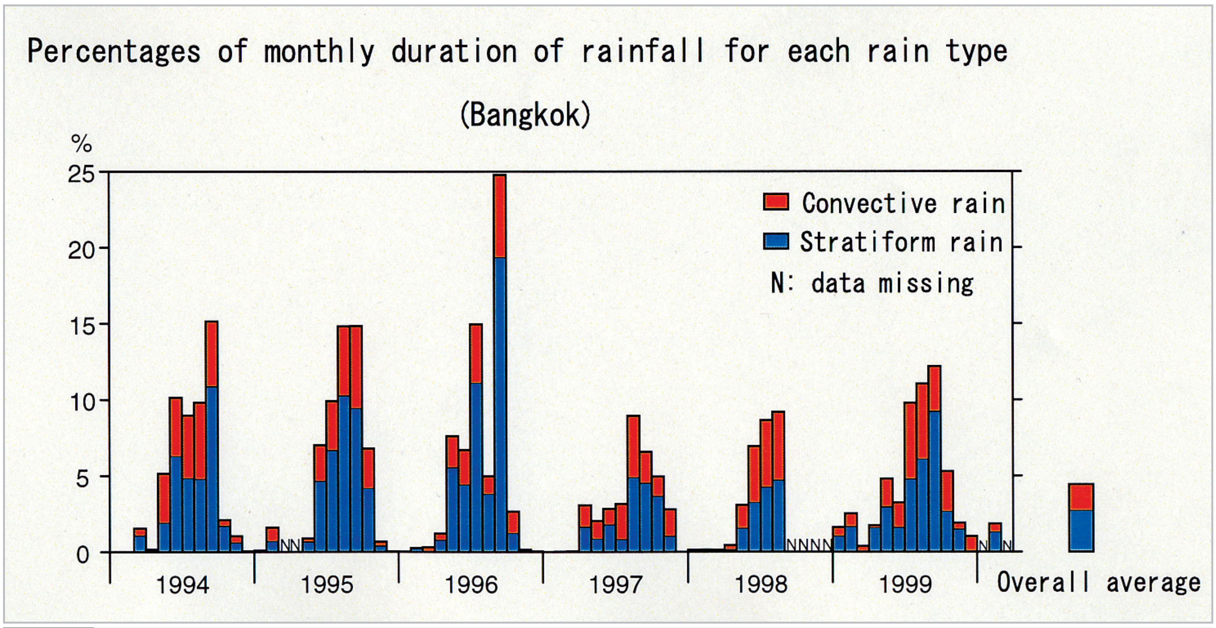

Fig.7 Monthly proportion of each rain type in Bangkok

short. This classification of rain types is not only important for investigating the formation of clouds, but is also significant for rain rate measurements using radars, because it affects differences in drop size distribution.

Following the methods adopted by Williams et al., we have classified rainfall as stratiform or convective, from the wind profiler data in Bangkok, by distinguishing the layers of snow, rain, and the bright band from the scattering intensities and the vertical velocities. Precipitation that have features of the bright band was classified as stratiform, and the rest were classified as convective. At low latitudes, the bright band appears at an altitude between 4 and 5 km. Unfortunately, maximum sampling altitude of the wind profiler in Bangkok is occasionally below the altitude of the bright band, so stratiform rain is somewhat underestimated in this statistic analysis.

Fig.7 shows the monthly statistics for each rain type, expressed as a percentage of the duration of rainfall in the observation time. The lower and upper parts of the bar chart indicate stratiform and convective rain, respectively, where “N” indicates months with little or no data. As described above, Bangkok is affected by the monsoon, and the seasonal variation in rainfall are clear: the percentage of the rainfall is 1 percent or below during the dry season, but increases to about 10 to 15 percent during the rain season. Convective rainfall is slightly less prevalent than stratiform rainfall in the total period: the stratiform rainfall constitutes about 3 percent and the convective rainfall constitutes about 2 percent. From 1997 to 1998, when El Niño occurred, the percentage of the rainfall did not exceed 10 percent even during the rain season, resulting in less rain overall. Stratiform rainfall in particular was less in this period.

Since it is difficult to classify rainfall as convective or stratiform using ground-based instruments such as rain gauges, radar observations such as a wind profiler are thus required. We are planing to make use of this rain type classification results for the ground validation of Precipitation Radar (PR) on board the Tropical Rainfall Measuring Mission (TRMM).

5 Conclusion

In this paper, we have discussed seasonal and diurnal variations in horizontal wind, and the classification of rain type based on data obtained through long-term observations using the L-band wind profilers in Koganei, Bangkok, and Gadanki. Although meteorological observation data is lacking in the Asia monsoon regions due to financial limitations, substantial meteorological observations of all kinds are required to predict availability of water-resource, since this region has large seasonal and inter-annual variations in rainfall. To forecast monsoon behavior, information on winds in the upper atmosphere is vital; it is thus hoped that the wind profiler will become widespread in Asia, and its observation networks are established. To this end, CRL will continue to contribute its accumulated data and experience to the development of remote sensing technologies in the Asia monsoon regions.

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