도플러 레이더를 이용한 해안지역의 대기경계층 분석 연구

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Maritime Atmospheric Boundary Layer Observed By L-band Doppler radar

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요 약

도플러 레이더를 이용하여 적도 해안 지역의 대기 경계층을 분석하였다. 인도네시아의 Serpong 지역(6.4S, 106.7E)에 설치된 L밴드 경계층 레이더(1357.5 MHz) 는 1992년 11월부터 지속적인 관측을 수행하고 있다. 건조(10-12 October 1993)에 경계층 내에서 두 가지 형태의 강한 에코를 확인 하였다. 첫번 째는 오전에 300 m 이하에서 나타나기 시작하여 오후에 3-5 km 까지 이르는 강한 에코로써 그 정부는 혼합층의 고도와 일치를 보였다. 이 적도 지역에서의 혼합고는 중위도 지역에서의 혼합고 보다 높다. 야간에 2-3 km에 나타나는 두 번째 에코는 습도의 변화와 관련이 있는 것으로 보인다. 우기(20-21 February 1994)에 관측된 혼합층의 높이는 건기 보다 낮았다.

Abstract

Atmospheric boundary layer over equatorial maritime continent was analyzed with Doppler radar. An L-band (1357.5 MHz) boundary layer radar (BLR) has been in continuous successful operation in Serpong, Indonesia (6.4S, 106.7E), since November 1992. The performance of the BLR with respect to the observation height range and the wind measurement reliability has been examined on the basis of simultaneous meteorological observations. In the dry season (10-12 October 1993), we have found two types of strong echo structures

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appearing systematically in the equatorial planetary boundary layer with diurnal variations on clear days. The first type is the striking appearance of a strong echo layer ascending from below 300 m (in the morning) to above 3-5 km (in the afternoon), which is identified with a diurnal variation of the top of the mixing planetary boundary layer. As expected, it is higher in the Indonesian equatorial region than in midlatitudes. Another type is a layered echo appearing at 2-3 km heights from nighttime to morning, which seem to be coincident with humidity gaps. In the rainy season (20-21 February 1994), the height of the atmospheric mixing was lower than that in the dry season.

I. Introduction

The Indonesian maritime continent is located in center of the Pacific - Indian Ocean warm water pool region. The world's most active atmospheric convection center exists in this region, which is believed to control the global climate, including large inter-seasonal and interannual variations. It is now widely recognized that the dynamics of the PBL in the Indonesian equatorial region (the maritime continent) are very important to our understanding of global climate control mechanisms associated with the maritime continent surrounded by high sea surface temperature. For example, PBL dynamics govern the generation of convection, and the large year-to-year variations of the cloud convection over the maritime continent are closely related to the behavior of the El Nio southern oscillations (ENSO)[1]. The climatology of the Java Island is characterized by an annual cycle of the rainy and dry seasons, and is affected by both the Pacific Ocean trade wind (easterly) and Indian Ocean monsoon (westerly) circulation.Tall cumulonimbus clouds often penetrate the tropopause and transport various minor constituents in the troposphere deeply into the stratosphere[2]. They also excite various atmospheric waves, such as gravity waves, Kelvin waves, and other long-period oscillations[3, 4, 5]. However, these studies are based on too coarse (or limited numbers of) observations with satellites or radiosondes to clarify essential features of PBL over the maritime continent around Indonesia.

The international cooperative observations was started in order to study the structure and the characteristics the atmospheric boundary using the BLR in November 1992 at PUSPITEK (National Center for Research, Science and Technology) (6.40 S, 106.70 E; 50 m above sea level) in Serpong, West Java, which is located in the southwest suburbs of Jakarta. The observations are conducted by BPPT (Agency for the Assessment and Application of Technology) and LAPAN (National Institute of Aeronautics and Space) on the Indonesian side and by RASC (Radio Atmospheric Science Center) of Kyoto University on the Japanese side. Recent progress in radar profiling techniques has been extended to the planetary layer (PBL) [6, 7, 8]. L-band Doppler radar is transportable system called the boundary layer radar (BRL). The high-resolution (both in time and in height) and the reliability of the three-dimensional wind velocity vector observed with the BLR are expected to improve our knowledge and interpretation of the PBL[9], aircraft, and anemometric towers could not observe the PBL in detail (e.g., [10, 11]).

In this paper we first give a brief description of the BLR system and a description of the performance of the BLR observations in Serpong. Observational evidence concerning the vertical extent and diurnal variations of the PBL is described in the following section. We present the comparison of the atmospheric mixing layer between in the dry season and the rainy.

II. Boundary Layer Radar (BLR)

The basic parameters of the BLR are summarized in Table 1. The BLR is a small and transportable radar operating at a frequency of 1357.5MHZ (L-band) with a peak transmitter power of 1 kW. It is designed to receive backscattered echoes from refractive index fluctuations, which are mainly generated by fluctuations of humidity and atmospheric stability profiles associated with atmospheric turbulence. Three parabolic antennas are pointed into the vertical and two oblique directions aligned to the east and north at a zenith angle of 15. The BLR provides vertical profiles of three components of the wind velocity vector, turbulence parameters (on clear days), and raindrop characteristics (on rainy days) in the lower troposphere, including the PBL, with time and height resolutions of about 1 min. and 100 m, respectively. In addition, temperature profiles can be obtained by means of the RASS (radio acoustic sounding system) technique although they are not described in the paper. The BLR was installed at PUSPIPTEK in Serpong near Jakarta, Indonesia, in October 1992 and has been continuously operating since November 9, 1992. With control by an on-line computer, unmanned operation of the BLR is automatic, except for the exchange of data storage tapes every 4 or 5 days.

In the present study the echoes from each of 64 observed heights (0-6.4km) are integrated coherently for 3.2 ms to form each sampled value, and a 128-point time series of these values is stored. A 128-point (0.4-s average) Doppler spectrum is then calculated for each height by using a fast Fourier transform. Beam direction is instantly changed after taking the Doppler spectrum. Finally 32 Doppler spectra are averaged for each height. We can obtain height profiles for 3 directions in about 50 s, including the data transfer time (~10 s) to the computer.

Table 1. Principal Specifications of the Boundary Layer Radar

Parameter	Value
Operating frequency	1357.5 MHz (L band)
Antenna	Three parabolic antennas
Aperture	$3.1m^2$ (2m in diameter)
Beam width	7.6° (half power)
Beam directions	Fixed into three directions
Transmitter	Three solid state amplifiers
Peak power	1 kW (maximum)
Average power	20 W (duty ratio 2%) (maximum)
Band with	4 MHz
Pulse length	0.67, 1.0, 2.0 μs (variable)
Interpulse period	50, 100, 200 μs (variable)

III. Observations

At the radar site, fundamental meteorological parameters such as surface winds, temperature, humidity, precipitation, and solar and net infrared radiation were also monitored with standard instruments. In addition to routine observations, we carried out two intensive campaigns in the dry (October 8-15, 1993) and rainy (February 15-22, 1994) seasons. In each campaign approximately 50 rawinsondes were launched at 3 - hour intervals at the radar site [12]. In this section we describe the performance of the BLR in Serpong, mainly concerning the observation height range and the wind measurement reliability.

3.1 Height Range of the BLR

The lowest height of BLR observations (throughout this paper the height from the ground is used) is determined to be ~300 m from the delay between signal transmission and reception. However it is significantly affected by both ground clutter and atmospheric echoing properties. In Serpong wind velocities can be obtained from 300 m, which is the system limit of the BLR. This is because the ground clutter level is reduced in Serpong, since we selected the radar site without any surrounding mountains or tall buildings, lowered the antenna height, and constructed a clutter prevention fence around the antennas.

The maximum height of BLR observations depends on echo intensities from the atmosphere. In the clear atmosphere without precipitation, the echo intensity increases with humidity, temperature, and their vertical gradients. It is noted that the highest height in Shigaraki was a little lower than 3 km even under conditions with the highest humidity and temperature in August. For the same reason, the height coverage shows large variations depending on local time. On clear days the height coverage is highest in midafternoon and lowest during the nighttime. The L-band radar is very sensitive to precipitation particles (raindrops or drenched ice crystals), so that the height coverage is greatly increased. Precipitation echo is extended occasionally up to near the tropopause height under conditions of deep convection, although the data are sampled up to only 6.4 km height in routine observations. It is noted, strictly speaking, that since reflectivity weighted fall speed is measured in precipitation, it needs to be subtracted in estimations of horizontal winds.

3.2 Wind Measurement

The BLR detects the mean radial Doppler velocity inside a sampling volume given by the beam width of 7.6 for one beam and the vertical resolution of 100 m. The vertical velocity determined by using one vertical beam corresponds to the mean value for a volume of roughly 130 m wide and 100 m thickness at 1 km height. Since the zonal and meridional velocities are determined by using vertical and 15-oblique beams, these velocity components are the mean values for a volume of about 400 m width and 100 m thickness at 1 km height under an assumption that the wind fields are homogeneous in this volume. The estimated velocities can be regarded as instantaneous values in time taken at the sampling interval (~1 min), although some averaging is required to reliable values.

We have compared wind velocities obtained simultaneously with the BLR and rawinsondes (VAISALA, RS80-15N; launched at the radar site every 3 hours) during the period October 8-15, 1993 and February 15-22 1994. Considering that a rawinsonde took about 15 min to pass through the observation height range of the BLR, we have averaged the BLR data over 15 min after the launch time of the rawinsondes. The BLR detected smaller- scale variations compared with those of the rawinsondes. The inherent accuracy for the BLR wind measurements is better than 1 m s^{-1}. It is noted that the BLR can obtain three-dimensional wind profiles (including vertical velocity only when there is no precipitation) with higher vertical and temporal resolutions than rawinsondes.

In addition, we sometimes observed strong echoes below 1-2 km, in particular in the nighttime. We examined every sample of these echoes and found a discontinuity in height and time in the shape of the Doppler frequency spectrum. We consider that such echoes may be contaminations caused by birds, bats, or insects (e.g., [12, 13, 14]). In order to remove this contamination we fitted a Gaussian function to the data neglecting any peak that was not continuous in height and time.

IV. Structure of the Equatorial Atmospheric Boundary Layer

In this section we demonstrate only the most striking results obtained so far with the BLR in Serpong, Indonesia. These are the observational evidence for the vertical extent and diurnal variations of the equatorial PBL. The equatorial atmospheric boundary layer showed strictly deferent structure between the dry and rainy season.

Figure 1 shows the time-height cross section of echo intensity (equivalent radar reflectivity factor) observed with the BLR in Serpong during the periods October 10-12, 1993 (dry season). Although smaller scale variations were complicated, two types of strong echo regions were found in the dry season. First, every morning at about 0800 LT (Indonesian Western Standard Time equals universal time plus 7 hours), a significant echo layer appeared at the lowest observation height (300 m) and gradually ascended up to 3-5 km height until about 1600 LT. Such a layer structure is smeared in the evening and is identified with the top of the PBL (or the mixing layer) in the following subsections. Secondly, another type of thin layered echo (we named this type "necklace echo") was observed at 2-3 km heights during 2000-1200 LT, descending about 300 m at around 0600 LT every morning. These 3 days were typical clear days (without any precipitation at the ground) in the dry season, and observations on other clear days showed similar diurnal variations of echo power intensity. On cloudy days such features were weak or disappeared. On rainy days strong echoes caused by rainfall appeared, but they are entirely different and distinguished from the typical behavior of clear-air echoes mentioned above.

Figure 2 shows variations of the three components of wind velocity observed with the BLR. We found that the wind direction and speed changed drastically near the type 1 (ascending) echo layer in the daytime and also near the type 2 necklace echo layer in the nighttime. Below the type 1 echo layer (or inside the mixing layer) the horizontal wind was generally weak and the vertical velocity was strong and highly variable. Below the necklace echo layer, both the horizontal and vertical velocities were variable, although the vertical velocity fluctuations were relatively weaker than those below the type 1 echo layer. Above these two types of layers, an easterly wind was dominant throughout the observational period (at least in this season). The downward vertical velocities were observed below 1 km around 1200 LT throughout the observational period. It is possible that this was very light precipitation which cannot be measured by the rain gauge on the ground.

The surface winds (about 10 m above the ground) monitored at the radar site with a standard anemometer (OGASAWARA, WS-A54) are also plotted.

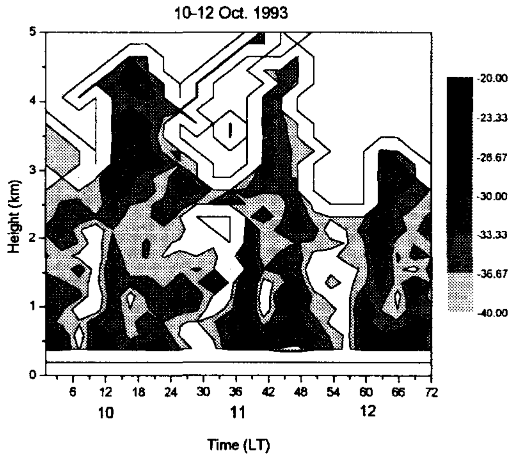


Figure 1. Timeheight cross section of the equivalent radar reflectivity factor observed with the BLR averaged every 1 hour for the eastward beam in Serpong during the period October 10-12, 1993.

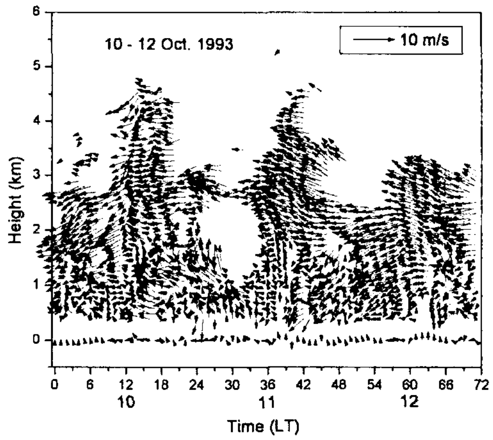


Figure 2. Timeheight cross section of the zonal-meridional winds averaged every 1 hour observed with the BLR in Serpong during the period October 10-12, 1993. The arrows plotted at the bottom are obtained with a standard anemometer at about 10 m above ground at the radar site. The vector direction is upward for a northward wind and rightward for an eastward wind, respectively.

Although variations in the wind were less intense compared with those from the BLR, the wind direction tends to have northerly and southerly directions, in daytime, respectively, throughout the observational period. We consider that these diurnal variations of surface winds correspond to the sea-land breeze circulation, since the observatory is located about 40 km south of the Java coastline, and there are no mountains between observatory and coast. The sea breeze clearly extended to about 1 km height and there was the hint of a return flow aloft. However, the land breeze was not clear in the BLR

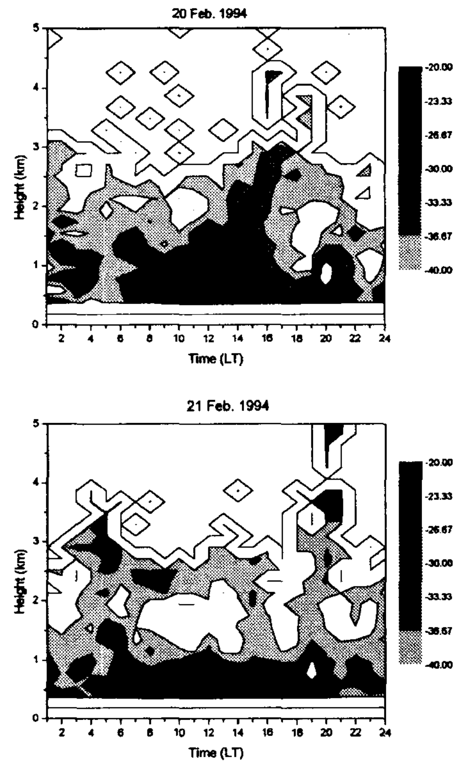
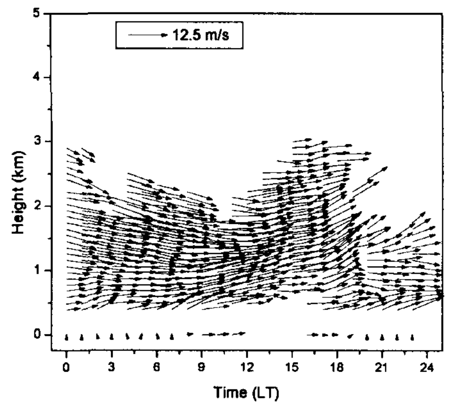


Figure 3. Timeheight cross section of the equivalent radar reflectivity factor observed with the BLR averaged every 1 hour for the eastward beam in Serpong on February 20 (left) and on February 21 (right), 1994.

wind velocities and was, as expected, relatively shallow.

As like the dry season, the structure of the equatorial atmospheric boundary is presented by the vertical profile of the echo power and of the horizontal wind vector for the rainy season. Figure 3 shows the time-height cross section of echo intensity observed with the BLR on February 20 and 21, 1994, respectively. From 0600 LT the mixing layer develops and the height of the mixing layer extends up to 1.5 km at 1500 LT on February 20. This maximum height is lower than the mixing layer height in dry season, which is developed convectively by surface heat fluxes. On February 21, the strong echoes are not appeared above 1 km in daytime. After the sunset another strong echo was observed systematically due to the humidity gaps. According to profiles of the virtual potential temperature observed with rawinsondes launched at the radar site at approximately 3-hour intervals, the echo layer appeared near the top of the mixing layer, defined by an almost constant virtual potential temperature. In considering the echoing mechanisms of the radio waves, we suppose that strong turbulence and vertical velocity fluctuations inside the mixing layer. The striking gap in the vertical distributions of humidity and temperature contributes also to generate the strong echo layer observed with the BLR[15].

In figure 4 winds observed by the BLR in the rainy season, were not affected by a local meteorological system like the seabreeze. The westerly continued during two days is stronger than the winds in the dry season. This rather synoptical wind from the west did not produce a wind shear resulting to the dynamical turbulence, which could develop the atmospheric mixing layer. In consequence, the mixing layer could not profound in the rainy season when heat fluxes were weak without wind shear.



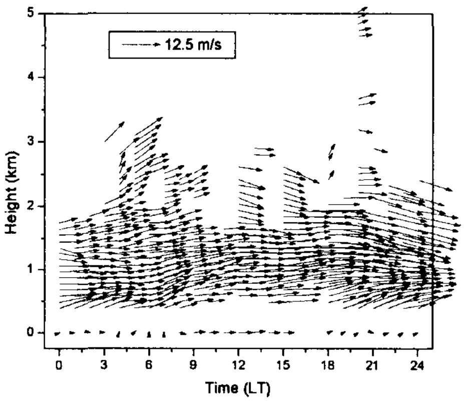


Figure 4. Timeheight cross section of the horizontal winds averaged every 1 hour on February 20 (left) and on February 21 (right), 1994. The arrows plotted at the bottom are obtained with a standard anemometer at about 10 m above ground at the radar site. The vector direction is upward for a northward wind and rightward for an eastward wind, respectively.

V. Conclusions

The atmospheric boundary layer over equatorial maritime continent was analyzed with Doppler radar (L-band). We have been successfully conducting observations with the BLR in Serpong in equatorial Indonesia since November 1992. The good performance of the BLR has been examined by simultaneous meteorological observations. Even in the initial results presented here, the BLR has proved that there exist obvious diurnal variations of the strongly mixing PBL on clear days in the equatorial region, which are partly similar to, but much thicker than, those in midlatitudes in the dry season. In the rainy season the atmospheric mixing did not develop due to the weak heat fluxes and no wind shear. Some features of the equatorial PBL described here have not been found yet in midlatitudes. These prove that the high resolution observations with the BLR must play an important role in various studies of the equatorial lower atmosphere.

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