Quasi 4 Day Mode Observed by a Boundary Layer Radar at Serpong (6°S, 107°E), Indonesia

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Abstract

A spectral analysis of lower tropospheric winds, observed by the Boundary Layer Radar (BLR) at Serpong (6°S, 107°E) in West Java, Indonesia during 1992/93, 1993/94, and 1994/95 rainy seasons reveals a pronounced spectral peak, at a period near 4 days. Filtered analysis of this quasi 4 day mode (Q4DM) shows almost an in-phase structure in the vertical. The GANAL (Global Objective Analysis by Japan Meteorological Agency) data for 1992/93 rainy seasons shows that in general the meridional wind component, at the altitude 700 hPa, has a westward phase propagation.

1. Introduction

Indonesia is a maritime-continent region located between two continents (Australia and Asia), and between two oceans (Pacific and Indian). The climate in its central part (the southern-hemispheric islands of Indonesia such as Jawa) is characterized by the dry (May–August), and rainy (November–February) seasons and that in the equatorial region such as the middle parts of Sumatra and Kaliman-

tan has two rainfall peaks in the equinoctial seasons (March–April and September–October) (Yasunari, 1981). The distributions of rainfall and precipitating clouds are highly inhomogeneous over this region even in a rainy season. The most important factor related to this inhomogeneity may be the complicated distribution of lands and mountains in the maritime-continent region. There is frequently generated a multi-scale, (hierarchical), structure of cloud clusters and super clusters (Nakazawa, 1988). Such a structure often resembles theoretical equatorial waves (Matsuno, 1966).

Yanai and Maruyama (1966) discovered one of the major types of the equatorial waves. It is called mixed Rossby-gravity (MRG) wave, with a period

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Fig. 1. GANAL (solid curve) and BLR (dashed curve) meridional winds for the period of November 1992–February 1993. BLR data are averaged for 12 hours and about 300 m.

of about five days, in the lower stratosphere over the equatorial Pacific. Yanai *et al.* (1968) presented a pioneering study on equatorial waves, with periods around a few days in the troposphere over equatorial Pacific, and Nitta (1970) analyzed a westward propagating wave, with a period around four days and a zonal wavelength of ~ 4000 km in the western side of the dateline over the equatorial Pacific. Liebmann and Hendon (1990), using ECMWF (European Center for Medium-Range Weather Forecasts) data along the equator, detected an abundance of power in the 850 hPa meridional wind with periods near four days, and mostly in the westward propagating component. The longest wavelengths are found over the Pacific Ocean, while the shortest are found over the convectively variable regions of Indonesia, South America, and Africa. Over the central Pacific and Atlantic oceans the disturbances resemble an equatorially trapped MRG wave. Takayabu and Nitta (1993) detected a 3–5 day disturbance from GMS (Geostationary Meteorological Satellite), IR (infrared) equivalent black-body temperature (T_{BB}) data, and ECMWF global analysis data. This 3–5 day disturbance is associated with the MRG wave type in the central Pacific near the dateline and with the tropical depression

(TD) type in the tropical western Pacific. Takayabu (1994a, b) also studied a 2-day mode in similar region, and identified it with westward propagating inertio-gravity waves.

A large number of observational studies are based on regions outside of the Indonesian archipelago. Also, those studies are based on cloud distributions observed by GMS and wind distribution from objective analyses, rather than actual observations. Since November 1992, the RASC (Radio Atmospheric Science Center) of Kyoto University, Japan in collaboration with BPPT (Agency for Assessment and Application of Technology), and LAPAN (National Institute of Aeronautics and Space), Indonesia, has been continuously carrying out three-dimensional wind observations of high-resolution, in altitude and in time (100 m and 1 min) in the lower troposphere (0.3–3.2 km altitude), at Serpong near Jakarta, Indonesia (6.4°S , 106.7°E), using a 1357.5 MHz Boundary Layer Radar (BLR) (Hashiguchi *et al.*, 1995a). Hashiguchi *et al.* (1995b) have shown wind and rainfall disturbances with periods of a few days or longer, and Hashiguchi *et al.* (1997) have done frequency spectral analysis.

The main aim of this paper is to provide an observational evidence of quasi-4-day period disturbances

Fig. 2. Same as Fig. 1 but for zonal winds.

over equatorial Indonesia. In Section 2 we describe data used, and the method of analysis in this study. In Section 3, we describe detailed vertical and temporal structures of this disturbance, based on single BLR observations with fine resolution in time, and in altitude. In Section 4, the horizontal structure is studied by utilizing global objective analysis (GANAL) of JMA. Finally, Section 5 contains the discussion and conclusions.

2. Data and the method of analysis

BLR wind data sets during the rainy seasons (November to February), in 1992/93, 1993/94, and 1994/95 are used in this study. Specification and performance of BLR and an existence of disturbances with periods of a few days, have been reported by Hashiguchi *et al.* (1995a, b, 1997). Mean power spectral densities are calculated every 500 m for 0.4–2.7 km for each rainy season. Existence of a striking peak of quasi 4 day mode (hereafter referred as Q4DM) is confirmed. In order to describe the vertical structures of Q4DM, a band pass filter with the cutoff periods of 3 and 5 days is applied.

As an attempt to study the horizontal structure of this Q4DM, we utilize wind data of JMA GANAL, which are available every 1.850° in latitude, and lon-

gitude for the 1992/93 rainy season period. It must be noted that the GANAL data, over and near Indonesia, are based mainly on pilot balloons, and the cloud movement data observed by GMS (*cf.*, Nitta *et al.*, 1986), because operational radiosonde data are rarely reported during the periods of analysis.¹ In order to examine the reliability of the GANAL data, we compared the GANAL data nearest to the observational site, *i.e.*, GANAL data at (5.6°S, 106.9°E), with the BLR data, averaged for 12 hours and about 300 m around 850 and 700 hPa standard pressure levels. As seen in Figures 1 and 2 the GANAL data agree well with the BLR data, especially for the time scale longer than 2 days. Based on this confirmation, band-pass filter with the same cutoff periods as applied on the BLR data is applied to the GANAL data for 15°N–15°S, and 80°E–130°E at the 850 and 700 hPa standard pressure levels. The horizontal structure of Q4DM is analyzed based on this filtered data.

¹ Our research group is now making strong efforts to collect such un-reported rawinsonde data and to check them very carefully (Okamoto *et al.*, 1999, personal communication to be presented at the 3rd GEWEX Conference). However, the records are still too discontinuous to show a reliable result for Q4DM.

Fig. 3. Frequency spectra of the zonal and meridional wind components observed by BLR at Serpong (6°S , 107°E) at 0.4–0.9, 1.0–1.5, 1.6–2.1, and 2.2–2.7 km altitudes for the 1992/93, 1993/94 and 1994/95 rainy seasons. The results for 2.2–2.7 km altitudes in 1994/95 are not shown because many data are lacked. The results for the altitude regions 1.0–1.5 km, 1.6–2.1 km, and 2.2–2.7 km are multiplied by 10^2 , 10^4 and 10^6 , respectively, to separate each spectra curves. Vertical dashed lines indicate 1 day period, and solid lines indicate 4 day period.

3. Results of BLR data analysis

3.1 Frequency spectra of horizontal winds

Figure 3 shows the mean power spectral densities of meridional and zonal wind velocities computed for four altitude regions with five vertical sampling points, (corresponding to thickness of 500 m), for the three rainy seasons in 1992/93, 1993/94, and

1994/95. Hashiguchi *et al.* (1997) have compared such frequency power spectra between dry, (August–October 1993) and rainy, (December 1993–February 1994) seasons, and have shown that the spectral amplitudes in the rainy season are about two times, or much larger than those in the dry season throughout almost the entire altitude and frequency ranges,

Fig. 4. Time-height cross-sections of the 3–5 day band pass filtered (a) vertical, (b) meridional and (c) zonal wind components for the periods of November 1992–February 1993.

that the diurnal component is dominant in all height ranges, and that the meridional wind component is strongest in the dry season, suggesting a sea-land breeze circulation between the Java Sea, and the northern coast of Java Island. We noted in the present analysis that in the three rainy seasons the diurnal component is dominant, except for the meridional component in the 1992/93 rainy season.

The power spectral density of the 1992/93 rainy season shows clear Q4DM peaks in the meridional wind component for the altitude range of 1.6–2.1 km and 2.2–2.7 km. In the zonal wind component, no clear spectral peaks with the period near 4 days appear. The spectral peak is particularly prominent for the altitude range of 2.2–2.7 km. For periods longer than about 10 days (or frequency lower than 10^{-6} s^{-1}) above the 1.6 km height, continuous spectra are obtained. The power spectra of zonal wind, are in general larger than those of the meridional wind, which suggest Kelvin wave type disturbances. This behavior is consistent with the activity of eastward moving super cloud clusters (Hashiguchi *et al.*, 1995b). Although such a super cluster involves clusters with temporal scales of a few days, they do not have good correlations with the Q4DM wind variations investigated in this paper. The surface rainfall

amounts are also varied with similar scales. They also do not seem to have good correlations with the Q4DM, nor GMS cloud. These imply that cloud and rainfall activities are strongly affected by much smaller-scale local conditions such as orography of the Indonesian Archipelago.

For the 1993/94 rainy season, the Q4DM appears in the meridional wind component as well as in the zonal wind component for the altitude ranges 1.6–2.1 km and 2.2–2.7 km. The spectral peak for the altitude range 2.2–2.7 km is more prominent than for the altitude range 1.6–2.1 km.

Features of Q4DM for the 1994/95 rainy season, are almost similar to those for the 1993/94 rainy season. For the 1994/95 rainy season the power spectral density for the 2.2–2.7 km altitude region cannot be obtained, since many data are missing.

3.2 Vertical structure of Q4DM

Figure 4 shows an example of the time-height cross-sections of the 3–5 day band-passed vertical, meridional and zonal winds, which is based on BLR observations in November 1992–February 1993. We have analyzed all three rainy seasons, and found that a small number of disturbances exhibits downward or upward phase progression. In general the phase structure is an in-phase structure in the vertical.

Fig. 5. Horizontal distributions of 3–5 day band pass filtered GANAL wind data at 850 hPa (left panels) and 700 hPa (right panels) for 12UT on 6, 7, 8 and 9 November 1992. + marks indicate the location of Serpong. The vortex like shape is indicated by solid curve with arrow.

Fig. 6. Time-longitude section of 3–5 day band pass filtered meridional wind component along the equator (a) and along the latitude of Serpong (5.6°S) (b) for the altitude of 700 hPa in November 1992.

The most striking in-phase structure, in the vertical among the three components, is obtained for the vertical wind component. The vertical wind component also seems to change more rapidly at all the altitude regions observed here.

4. Horizontal structure

We have subjectively examined horizontal distributions (over the whole Indonesia region) of horizontal wind corresponding to Q4DM observed by BLR at Serpong for the 1992/93 rainy season period. It is based on horizontal plotting of 3–5 day band pass filtered wind of grid-point GANAL at 850, and 700 hPa altitudes. We have often found a vortex-like shape, which has a westward-moving property. The westward-moving property is prominent for the meridional wind component at the altitude of 700 hPa.

Figure 5 depicts an example of the vortex-like shape which has a westward-moving property of the Q4DM disturbance observed from 6 to 9 November 1992. On 6 November, a clockwise circulation pattern is found both at 850 and 700 hPa levels, of which the center is located near the equator, approximately 1,000 km northeast of the Serpong observatory (the location of Serpong is indicated by + mark). This pattern has a size of about 1,500 km, and moves westward along the equator with a speed of about 500 km/day. An anticlockwise circulation with a similar size is formed clearly after 8 November, and moves westward following the clockwise circulation.

Figure 6(a) and 6(b) show the time-longitude section of 3–5 day band pass filtered meridional wind component along the equator (a), and along the latitude of Serpong (5.6°S) (b) for the altitude of 700 hPa in November 1992. These two figures have almost similar patterns, which imply that the Q4DM observed by BLR at Serpong is not a small scale phenomena, and it can be associated with the Q4DM along the equator of Indonesia. We find that Q4DM show clear westward propagation, especially in the longitudinally eastern and middle part of the Indonesian region. After they pass Serpong (107°E) it seems that they are suppressed.

5. Concluding remarks

Lower tropospheric winds over Indonesia have been analyzed in the data of BLR observations for the 1992/93, 1993/94, and 1994/95 rainy seasons. The Q4DM was found over equatorial Indonesia in every rainy seasons during 1992–1995. The power spectral density of the meridional wind component was not so different from that of the zonal wind component. This feature is clearly different from the longer period components for which the power spectral density of the zonal wind component was much stronger than the meridional wind component. The

vertical structure of the Q4DM is in general in-phase vertically, and the vertical wind component has an almost completely in-phase structure in the vertical.

The Q4DM during the 1992/93 rainy season period has a westward propagation, which is prominent for the meridional wind component at the altitude of 700 hPa. This is clear especially in the eastern and middle part of the Indonesian region. It is suppressed in the more western part of Indonesia.

At present, there are three BLRs in Indonesia: one is at Serpong (6°S, 107°E) used in this study; the others are at Bukittinggi (0°, 100°E) in West Sumatra in collaboration between RASC, BPPT and BMG (Indonesian Meteorological and Geophysical Agency) since August 1998; and, at Biak (1°S, 136°E) in Irian Jaya in collaboration between NOAA (National Oceanic and Atmospheric Administration) of the USA and LAPAN. The next step of our study will involve studying Q4DM and other lower frequency disturbances using high resolution data in time, and altitude from all three BLRs station.

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インドネシア・スルポン (6°S, 107°E) において境界層レーダーにより
観測された準4日周期の風速変動

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1992~95年にインドネシア共和国西ジャワ州・スルポン(6°S, 107°E)で実施された京大境界層レーダー(BLR)観測によるデータを用いて、雨季の対流圏下部(0.4~3.2 km)における風速変動を調べた。まず周波数スペクトル解析から、4日程度の周期性を持つ振動(準4日モード)の卓越が見出された。3~5日のバンドパスフィルターを用いて取り出された準4日モードは鉛直方向にほぼ位相の揃った構造を持っていた。1992/93年雨季の気象庁客観解析データを見ると、700 hPaにおける準4日モードの南北風成分は概ね西向きに位相伝播していることがわかった。