Wind observations around the tropopause over Sumatra, Indonesia by the Equatorial Atmosphere Radar

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Dynamical couplings between the stratosphere and the troposphere are the important factors that control the circulation of the Earth's atmosphere, and the tropics is one of the primary regions that tropospheric air enters into the stratosphere and vice versa. The boundary region between the troposphere and the stratosphere, which is called tropopause, is defined by the temperature lapse rate or temperature minimum. Altitude and temperature variations of the tropopause in the tropics have been studied to understand the mechanism of airmass exchange between the stratosphere and troposphere (stratosphere-troposphere exchange; hereafter STE). While the variations of the tropical tropopause have significant impacts on STE, recent studies have revealed that dynamical, photochemical, and microphysical processes in the region around the tropopause, which is called the tropical tropopause layer (TTL), are also important for clarifying STE. The TTL is generally defined as the layer between the level where cumulus activity generally terminates and the tropopause, and the air gradually changes from the tropospheric one to the stratospheric one with increasing altitude in the TTL.

The Indonesian Maritime Continent is one of the regions where deep cumulus convection occurs most frequently in the tropics. The Indonesian Maritime Continent is composed of five large islands (Sumatra, Borneo, Java, Sulawesi, and New Guinea) and many small islands surrounded by the warm sea. The topographic effects in the region cause the development of deep cumulus convection through local circulation (land-sea and mountain-valley breeze circulation). Though previous studies have pointed out that dynamical, photochemical, and microphysical processes associated with cumulus convection over the Indonesian Maritime Continent affect STE, many of these processes in the TTL remain unsolved due to the scarcity of observations. Observational data derived from a VHF Doppler radar, which is named the Equatorial Atmosphere Radar (hereafter EAR), installed at the Equatorial Atmosphere Observatory, Kototabang (0.20S, 100.32E, 865 m MSL), and has a capability to observe vertical profile of wind and turbulent motions, are used for investigating wind and turbulence features in the TTL over Sumatra.

An enhancement of turbulence by an equatorial Kelvin wave in the tropopause region has been shown using EAR and radiosonde data during November 2001. Significant enhancement of turbulence in the tropopause region (15-17 km) was intermittently observed for about 5 days (19-23 November 2001) in the spectral width of the radar echo power spectrum obtained by the EAR. The turbulence intensity was estimated with the spectral width data to show that the turbulence during the period was a factor of up to about 5 times larger in kinetic energy than that in other periods. Further data analyses using horizontal wind data derived from the EAR and temperature data derived from radiosondes indicated that the enhanced turbulence occurred in the region with weakened static stability and large vertical wind shear produced by tropopause-level Kelvin wave. This study is the first to confirm turbulence generations associated with Kelvin waves in the tropopause region.

Frequent occurrence of Kelvin-Helmholtz instability (KHI) around the tropopause has been shown. In November 2001, continuous strong eastward vertical wind shear (10-50 m/s/km) and westward wind (2-27 m/s) were observed in the region 0-1 km above the tropopause. During the same period, the Richardson number (Ri) calculated with horizontal wind derived from the EAR and temperature data derived from radiosondes was almost continuously less than 0.5 and sometimes less than 0.25, which indicates that KHI frequently occurs in that region. This study is the first observational evidence to show that KHI associated with strong vertical wind shear frequently occurs around the tropical tropopause over Sumatra.

From a case study from 5 to 9 May 2004, vertical motions in the TTL and their relationship to cumulus activity have been investigated using coordinated observation systems operated during the first observation campaign of the Coupling Processes in the Equatorial Atmosphere (CPEA) project (hereafter the first CPEA observation campaign). Before investigating the vertical motions in the TTL, features of wind, cloud, temperature, and humidity in the lower and middle troposphere have been investigated to reveal convective characteristics over the mountainous area of Sumatra. Data observed by the EAR, 1.3-GHz wind profiler, 9.445-GHz weather radar, radiosonde, and lidar installed at or near Kototabang are used. The period of 5-9 May 2004 is an initial phase of westerly wind burst (WWB) period of the first CPEA observation campaign. Convective events during 5-6 May, when precipitating clouds with relatively large radar reflectivity factor (greater than 15 dBZ) were observed at and around Kototabang, have been described. Cumulus activity around Kototabang showed a clear diurnal variability; shallow convective

precipitating clouds were dominantly observed in the early afternoon, and stratiform precipitating clouds were prominent in the nighttime. Raindrop size distribution retrieved by the EAR showed consistent results; smaller median diameter and shape parameter were observed in the early afternoon precipitation events. After 7 May, the 2.5-4.0 km westerly wind at Kototabang became large enough to be identified as WWB. Cumulus activity around Kototabang was suppressed after 7 May, as drier air (lower than 60% relative humidity) was transported from the Indian Ocean by lower-tropospheric westerly. Whereas the convective activity around Kototabang was suppressed, daily-averaged upward motions of 0.07-0.08 m/s were found at 2.5-4.0 km on 7 and 8 May, when strong westerly wind larger than 10 m/s were seen in 2.5-4.0 km. Further, the oscillatory motion of vertical wind with an amplitude of 0.1-0.2 m/s and a timescale of about 12 hours was observed at 2.5-5.5 km. Similar oscillatory motion was found in the 1.5-2.5 km zonal wind. These facts imply that the topography around Kototabang, which has steep mountains to the west, modulates the behaviors of the vertical wind. The vertical wind oscillation was suppressed around an altitude where westerly wind changed to easterly wind; this fact implies that horizontal wind change inhibits upward propagation of vertical wind oscillations. After 7 May, Ri of smaller than 0.25, which suggests an occurrence of KHI, was observed in the upper part of the westerly wind region (3.0-5.5 km). The small Ri was brought about by strong vertical wind shear (larger than 10 m/s/km) and/or weak vertical gradient of potential temperature (smaller than 3 K/km).

Vertical wind features from the middle troposphere to the TTL and their relationship to cumulus convection from 5 to 9 May have been investigated. During 5-6 May, the 3-hourly averaged vertical wind from the middle to upper troposphere (8-14 km) continuously showed upward motions up to 0.09 m/s. The averaged vertical wind during 5-6 May was 0.05 m/s. The upward motions were observed in the vicinity of deep convective events which were continuously seen over Sumatra within a synoptic-scale convectively active envelope, in addition to the diurnal variability of cumulus activity observed around Kototabang. After 7 May, when cumulus activity was suppressed over Sumatra, 3-hourly averaged upward motions of greater than 0.05 m/s almost disappeared. The averaged vertical wind during 7-9 May was 0.01 m/ s. Prominent downward motions in the TTL (above 14 km) were found in the vicinity of enhanced cumulus activity over Sumatra. During 5-6 May, downward motions up to about 0.11 m/s were observed above 14 km. Vertical winds caused by adiabatic processes were estimated using horizontal wind and temperature data derived from the European Center for Medium-Range Weather Forecasts (ECMWF) operational analysis; the estimations have revealed that a major part of the observed downward motions are explained by the leeward (southwestward) wind and leeward downward tilt of isentropes, both of which existed over the western Sumatra. The observed downward motions above 14 km during 5-6 May suggest that downward motions caused by leeward downward tilts of isentropes can be produced in the vicinity of convectively active region, and leeward downward tilts of isentropes suppress an upward transport of airmass into the TTL by producing downward motions in the TTL.

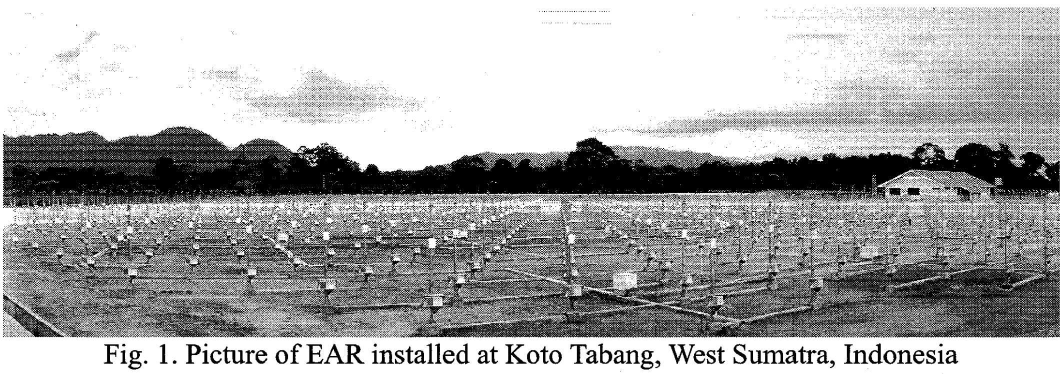

Fig. 1. Picture of EAR installed at Koto Tabang, West Sumatra, Indonesia