Early morning rainfall over the Strait of Malacca

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1. Abstract

Distinct diurnal variation of precipitation around the Strait of Malacca was elucidated using The TRMM rainfall data and non-hydrostatic mesoscale model. The TRMM rainfall data shows the contrast of sea and land surface diurnal rainfall, in the early-morning and evening, respectively. The climatological model study in a typical season suggests the following mechanism of the diurnal precipitation system.

1) During daytime, a deep convections are induced by convergence of the up-slope winds caused by solar radiative heating over the mountains in the both side of the Strait, while divergence is clear above the strait. This convection should produce evening rainfall. 2) In evening, cold air mass caused by evaporation of raindrop begins to blow toward the strait in lower atmosphere. This cold flow transports water vapor to the strait associating with a down-slope wind. 3) In the midnight, these two cold moist air flows converge above the strait, making a precipitation along the strait. The shape of terrain, like a deep basin, should strengthen the convergence in a layer below 900 hPa above the strait.

Thus, this diurnal rainfall is formed by the diurnal convective latent heat flux and the shape of the Strait of Malacca between these two mountainous islands.

2. Introduction

Convections and rainfall in south-eastern Asia have clear diurnal variation, which play an important role to transport of water vapor and energy. These convection and precipitation show various diurnal peaks especially around maritime continents (Nitta and Sekine 1994, Ohsawa et al. 2001).

The Tropical Rainfall Measuring Mission (TRMM) precipitation data detected by Precipitation Radar was used for observational analysis. We averaged 2A25 PR near surface rain data in version 5 from 1998 to 2005, which product averaged to every 0.1 degree grid square. Figure 2 shows the contrast of precipitation of TRMM 2A25 product from 1998 to 2005. There is clear diurnal contrast between evening and early morning precipitation around the Strait of Malacca. Evening precipitation tend to occur along a mountain range. Above the Strait of Malacca, clear precipitation appears in early morning.

These results of TRMM diurnal variation are consistent with a previous result of cloud diurnal variation (Ohsawa et al. 2001, Mori et al. 2004). However, why dose strong precipitation occur above the sea at so early morning? In general, nighttime lower boundary cooling tends to create a thin, stably stratified boundary layer, rather than a deep mixed layer. In addition, mountains around the Strait of Malacca may undergo stronger radiative cooling, resulting as cool-air drainage or katabatic flow. We performed climatological numerical simulation experiment with cloud resolution model for understanding of the diurnal variation.

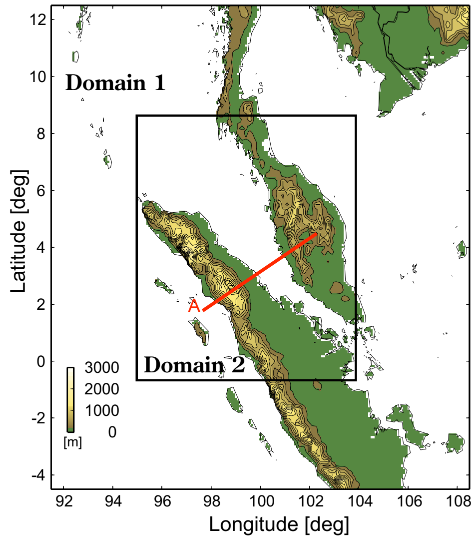

Figure 1: Model domains. Domain 1 and Domain 2 indicate areas of each domain. Color shade indicates the topography.

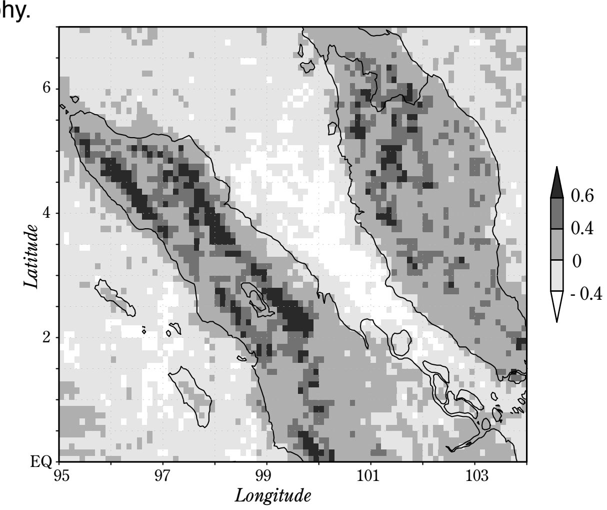

Figure 2: Contrast map of precipitation (evening rain - early morning rain) using 2A25 data in version 5 from 1998 to 2005 which averaged to every 0.1 degree grid square. The negative value indicates rainfall in early morning [mm/hr].

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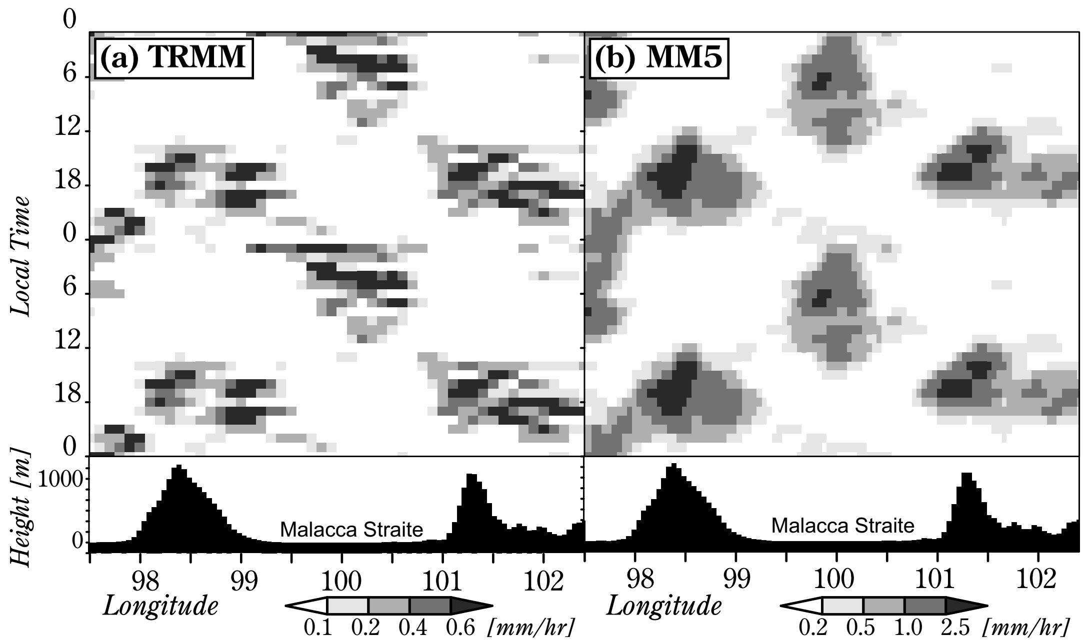

Figure 3: Diurnal time-longitude section of the near surface rain in TRMM PR (a) and MM5 (b) along the bold line in Fig. 1.

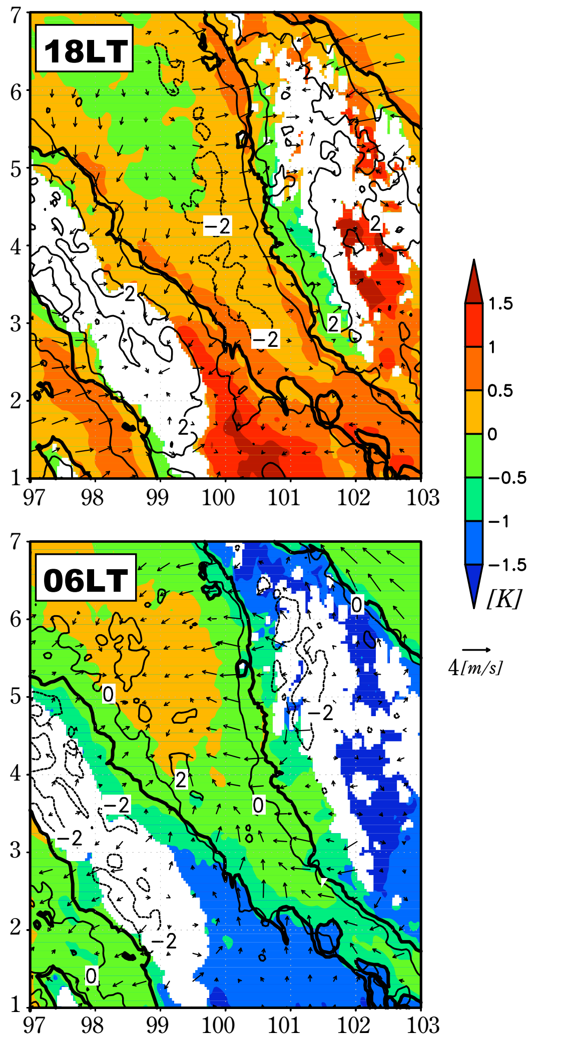

Figure 4: Distribution of precipitable water vapor (contour), potential temperature (color) and surface wind (vector) of control run in evening (upper: 1800 LT) and early morning (lower: 0600 LT), which indicate mean deviation from monthly average.

3. Modeling

Simulation using MM5 numerical model (Dudhia 1993) was performed to study the diurnal precipitation system. NCEP global tropospheric analysis data with 1.0 degree grid square every six hours were used for the initial and boundary conditions. The model domains are shown in Fig. 1. Domain 1 is the mother domain of the horizontal grid increment with 12 km, domain 2 with 4 km is two-way nested in domain 1. The 41 vertical layers range to 10 hPa in the upper layers for two domains. The model were integrated for a period of one month, from 1 to 30 April 2004 when is before onset of monsoons with weak low-level wind. No cumulus parameterization was used for all domains. The Goddard microphysics scheme (Tao and Simpson 1993) was used in two domains. The MRF planetary boundary layer scheme (Hong and Pan 1996) and the Noah Land-Surface Model scheme were selected in this experiment.

4. Results

4.1 Comparison with observational data

Figure 3a shows diurnal time-longitude section of the TRMM PR data along the bold line in Fig. 1. Around mountains at the both sides of the strait (see Fig. 1), the maximum of precipitation occurs in evening. In early morning, clear precipitation was observed above the strait. This morning precipitation keeps strength until sunrise. There is clear contrast of precipitation in evening and early morning, which seems to be separate rainfall system from that in evening.

Simulation using regional numerical model was performed to study the diurnal early morning precipitation system. The numerical experiment successfully simulated averaged diurnal variation. Diurnal time-longitude sections of precipitation are shown in Figure 3b. The simulated precipitation has clear diurnal variation with contrasts between evening and early-morning, which is similar to variation of TRMM. Max precipitations appear around 0600 LT on the striate and 1800 LT on the Sumatra Island and Malay Peninsula.

4.2 Detail structure of convection in early morning / evening

Figure 4 shows a distribution of precipitable water vapor (contour), potential temperature (color) and surface wind (vector) of control run which indicate mean deviation from monthly average. In evening (upper), water vapor converges along mountain rages. Surface air above the land is warmer than that above the sea. Also, clear divergence simulated above the strait. In early morning (lower), surface wind converges above the strait accompanied by precipitation band along the strait. Cold air mass flows toward the strait from eastern coastal line of the Sumatra Island and western coastal line of Malay Peninsula.

Figure 5 shows the simulated longitude-height structure of water vapor, potential temperature and wind. Water vapor was transported to upper layer in daytime, and converges above the mountain slope, which should be induced by up-slope winds caused by solar radiative heating. In evening (upper), water vapor converges around mountain, which unstable atmosphere should produce a precipitation. Above the strait, however, there is clear descending wind as a returning flow of convergence around mountains.

Afternoon/evening maximum convection over the mountainous areas in Sumatra Island is understood as the result of the enhancement of moisture by local circulations and the strong solar heating of surface (Wu et al. 2003).

The terrains around the strait, which is surrounded with two mountain ranges, should be thought to a long deep valley. Kimura and Kuwagata (1995) simulated the thermally induced local circulation over a valley using a two dimensional numerical model. They have shown the daytime transportation of heat from the mountainous region to valley area by anabatic wind and its return flow.

In early-morning, cold air mass above these islands begins to blow toward the strait in lower atmosphere. The slope of mountains should strengthen the cold flows speed. Water vapor in lower atmosphere is carried into the strait by this cold gravity current. Finally, two cold moist air flows converge above the strait (Fig 5, lower). There is clear ascending flow which lifts up water vapor in lower atmosphere. The convergence should make the early morning precipitation zone along the strait. Because atmosphere above the sea is unstable with high sea surface temperature, the convections would keep active until sunrise.

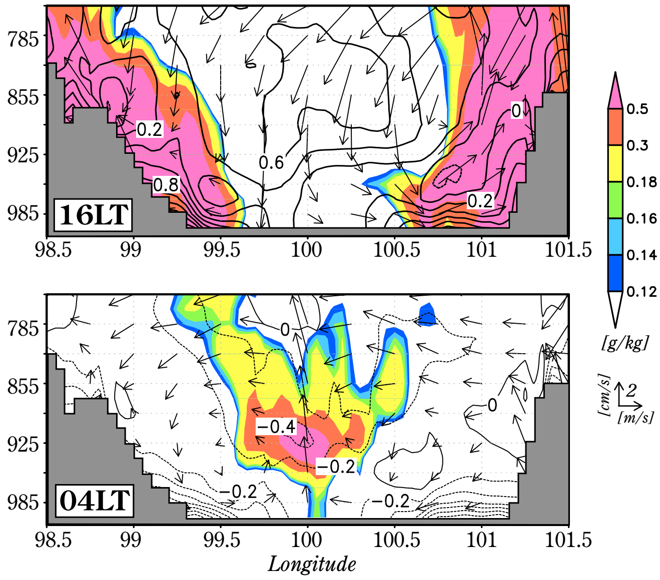

Figure 5: The longitude-height structure of water vapor, potential temperature and wind of control run in evening (upper: 1600 LT) and early morning (lower: 0400 LT), which indicate mean deviation from monthly average.

5. Discussions

After a heavy precipitation, evaporation of raindrop cases cooling in surface atmosphere. We performed a sensitive experiment for early morning convergence in order to distinguish an effect of convection during the daytime over land. The model were integrated for each 30 hours from 1800Z in same period as control run, used a same setting as control run except for using the fake-dry option in MM5.

Figure 6a shows a early morning distribution of dry case. Atmosphere above the land is not taken the heat out. Sea surface air mass is warmer than that in control run. The cold air flows from each land is too weak, which could not make a convergence, causing decrement in column water vapor above the strait.

Figure 6b shows the early morning longitude-height structure in dry case. The convergence above the strait dose not simulated, however, water vapor feebly converges near each coastal lines. The coastal convergences should be a sea-land circulation, which may be strengthen by two mountainous slopes.

Johnson and Bresch (1991) discussed about the diurnal nocturnal downward wind. They speculated that the combined effect of land breeze and evaporation of previous afternoon and evening's precipitating cloud system should makes strong downward motion, cooling, and moistening.

In case of the dry run, the nocturnal convection above the strait was not simulated. These results indicates that previous afternoon and evening land convections make the significant cold moist downward motion, and the cold moist flow travels toward the strait in lower atmosphere. The shape of terrain, like a deep basin, should strengthen the convergence in a layer below 900 hPa along the strait. These convections would keep active until sunrise because sea surface atmosphere above the strait is more unstable than that on land in night time.

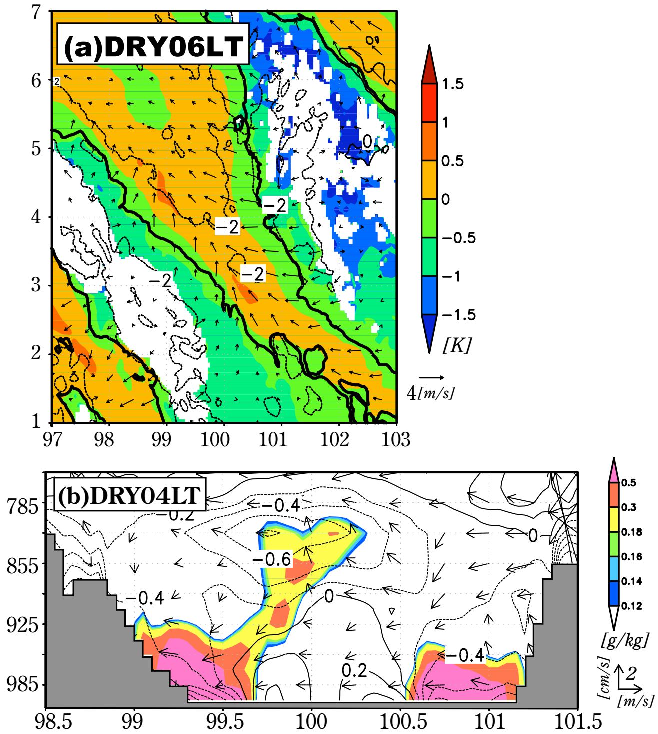

Figure 6: (a) Same distribution as in Fig. 4 except for a dry condition in early morning (0600 LT).
(b) Same distribution as in Fig. 5 except for a dry condition in early morning (0400 LT)

6. Conclusions

We have explained the distinct diurnal variation of precipitation around the Strait of Malacca by the TRMM rainfall data and non-hydrostatic mesoscale model.

The TRMM rainfall data shows the contrast of sea and land surface diurnal rainfall, in early-morning and evening, respectively. The climatological model study in typical season suggests mechanism of the diurnal precipitation system.

During daytime, deep convections are induced by convergence of the up-slope winds caused by solar radiative heating over the mountains in the both side of the strait. This convection should produce evening rainfall. In evening, cold air mass caused by evaporation of raindrop begins to blow toward the strait in lower atmosphere. This cold flow transports water vapor to the strait associating with a down-slope wind. In midnight, two cold moist air flows converge above the strait, making a precipitation along the strait.

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