

Preliminary Study of Nocturnal Rainfall Mechanism over Semi Closed Equatorial Oceans as observed by TRMM-PR

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Abstract. Relation of shape and size of coastal line to coastal rainfall mechanism over Indonesian Maritime Continent (IMC) is not clearly understood. Cendrawasih Bay is a unique coastal line because it is the biggest curvature type in IMC, near equatorial lines and semi-closed oceans. The mechanism of nocturnal rainfall over Cendrawasih Bay has been studied using data from Tropical Rainfall Measuring Mission Precipitation Radar (TRMM-PR) 3B42 product over during 1998–2015. Correlation coefficient of TRMM-PR and observational data from Biak Meteorological Station in 2014 is 0.6. Composite TRMM-PR data showed that nocturnal rainfall over the Cendrawasih Bay began to form at midnight and has peak intensity after midnight. Rain rate intensity over the Cendrawasih Bay is bigger than over inland and adjacent waters with speed of rainfall migration is approximately 5 m/s. Northern monsoon flows and land breeze along curvature coast induced low level convergence over Cendrawasih Bay during late evening until morning.

1. Introduction

Indonesian Maritime Continent (IMC) is the largest archipelago with the greatest convective activity and the longest coastal line in Asia. Convective activity in this area is very complex [1]. Mountainous islands, such as Sumatra, Java, Kalimantan (Borneo), Sulawesi, Papua and many other islands of various sizes are located in the region. The complicated topography induced complex convective activity can significantly affect the formation and distribution of rainfall [2].

Diurnal rainfall over IMC is one of the most significant variations of convection and has close relation to coastal area. Rainfall occurs mostly at boundary of sea land [3]. Many previous studies have described the characteristics and propagation of the diurnal convection over IMC [4]–[8]. Peak of rainfall usually occurs at land on daytime and over oceans during evening until early morning [9]. Peak of rainfall in both Sumatera and Borneo Island show a movement of rainfall from inland to oceans [5], [7].

IMC has a long coastal line with unique shape and size. Relationship of shape and size of coastal line to rainfall mechanism was never discussed on previous studies. This paper specially will discuss about nocturnal rainfall mechanism over the biggest curvature coastal line in IMC, Cendrawasih Bay. There is a very unique location because it is directly facing Pacific Oceans, the biggest curvature coastline and located near equatorial line.



2. Data

The data sets used in the present study are the Tropical Rainfall Measuring Mission Precipitation Radar (TRMM-PR) 3B42 product and National Centers for Environmental Prediction-Final Analysis (NCEP-FNL). Some previous study examined diurnal variation using TRMM-PR 3B42 product at IMC [9]–[13]. To examine diurnal rainfall, we made a composite 3-hourly dataset of rain rate based only on the PR sensor for 18 years (1998–2015) and also calculated total average rain rate for analysis over Cendrawasih bay. Migration of rainfall from inland to oceans was detected by time-spatial slice methods [5]. Correlation coefficient of TRMM-PR and observational data from Biak Meteorological Station in 2014 was 0.6.

Simulation of dynamical atmosphere over Cendrawasih bay was calculated by Weather Research and Forecasting – Advanced Research WRF (WRF-ARW). The initial and boundary conditions were from NCEP-FNL. In these simulations, 5-layer thermal diffusion and Yonsei University scheme boundary layer schemes were employed. The cloud microphysics and radiation schemes used were the WRF Grell-Devenyi (GD) ensemble scheme and RRTMG scheme, respectively. The WRF model was run at 39 vertical levels with the model top at 50 hPa. Parameters of WRF-ARW product used to analyze diurnal cycle were wind to calculate Low Level Convergence Field, Convective Available Potential Energy (CAPE) and lifted condensation level (LCL).

3. Result and Discussion

3.1. Total Mean of Rainfall

Figure 1a below is mean of rain rate base on TRMM-PR 3B42 during 1998-2015. Fig. 1a shows that peak of rainfall over inland and adjacent water has integrated rainfall system. High rainfall intensity over inland will be followed with high rainfall intensity over adjacent oceans. Rainfall intensity over oceans near coastal line is lower than two locations before. Land-sea rainfall system at Sumatera had been examined by Mori [5]. Peak of rainfall seemed to continue from island to oceans. Migration of rainfall from land to oceans about 11.1 m/s. Base on peak of rainfall, land-sea rainfall system over Papua Island seemed to consist of three land-sea rainfall system; Sorong land-sea rainfall system, Nabire land-sea rainfall system and Asmat land-sea rainfall system.

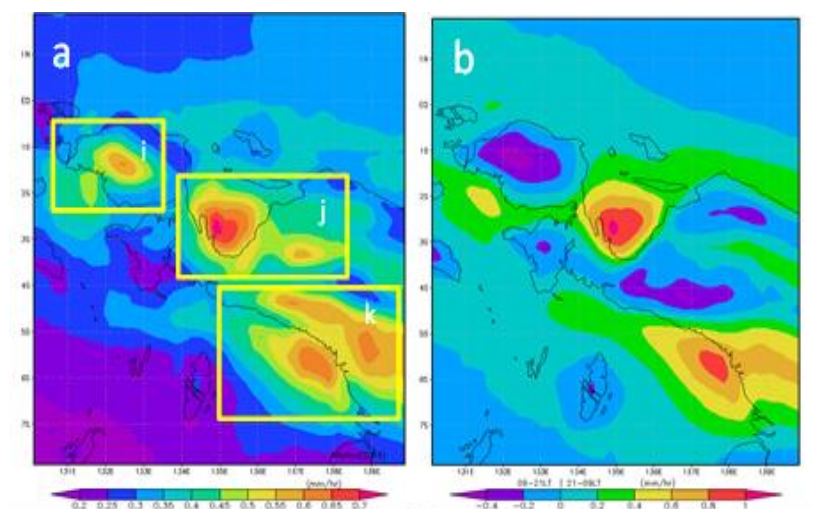


Figure 1(a) Total mean of rain rate during 1998 – 2015, index-*i* is Sorong system, *j* is Nabire system, *k* is Asmat system **(b)** Total mean of daytime and nocturnal rain rate during 1998 – 2015. Minus mean composite of daytime rainfall and plus mean composite of nocturnal rainfall.

Diurnal rainfall divided into two part, nocturnal rainfall is rainfall that occurred from 20.00-08.00LT and daytime rainfall is rainfall that occurred during 08.00-20.00LT [14]. Fig. 1b shows the location of nocturnal and daytime rainfall. Nocturnal rainfall mostly occurred at offshore area (Cendrawasih Bay, Sorong Waters and Asmat waters), and daytime rainfall occurred at inland area (Nabire, Sorong and Asmat). Neumann [15] suggested that land breeze front on curvature coastal line have a significant

effect as a trigger midnight convection at oceans, while daytime rainfall convection over island was triggered by sea breeze front [16] and merger cumulus [2], [9].

Cendrawasih Bay has semi-annual variability of rainfall and have strong influence El Niño–Southern Oscillation (ENSO) during normally dry season [17]. Peak of rainfall over Cendrawasih Bay base on TRMM-PR during 1998–2010 occurred on March, June, and September. Those conditions likely correlated with annual apparent motions of the sun. March 21st and September 23rd are the date on which the annual apparent motion of the sun is located at the equatorial line, while June 21st is the date on which the annual apparent motion of the sun is located at the vernal equinox. Impact of annual apparent motion of the sun is variability of monsoon wind. March and September are month of transition and June is month of peak of dry seasons.

3.2. Distribution and Diurnal of Rainfall over Semi Closed Equatorial Oceans

Diurnal distribution and variation of rainfall that had been detected by the Precipitation Radar (PR) onboard the TRMM satellite for 18-year period from 1998 to 2015 is displayed in Fig. 2. In the early afternoon (1030–1330 LT) most areas of Papua Island and Cendrawasih Bay are nearly rain-free. During the late afternoon and early evening hours (1330–1930 LT), rainfall occurs mostly over the island along the coast and close to the mountainous area of the island. Previous research described that rainfall occurred along coastal line may be triggered by sea breeze front [16], [18], [19]. During these times of the day, rainfall coastal zone continues to grow and spread even across the top of the mountain.

Rainfall on valley began to intense at evening time (1930 – 2230 LT). Local mountain breeze drove rainfall over valley on western of Sarmi. In another part, some of the peak rainfall moved to west and began to intense at oceans.

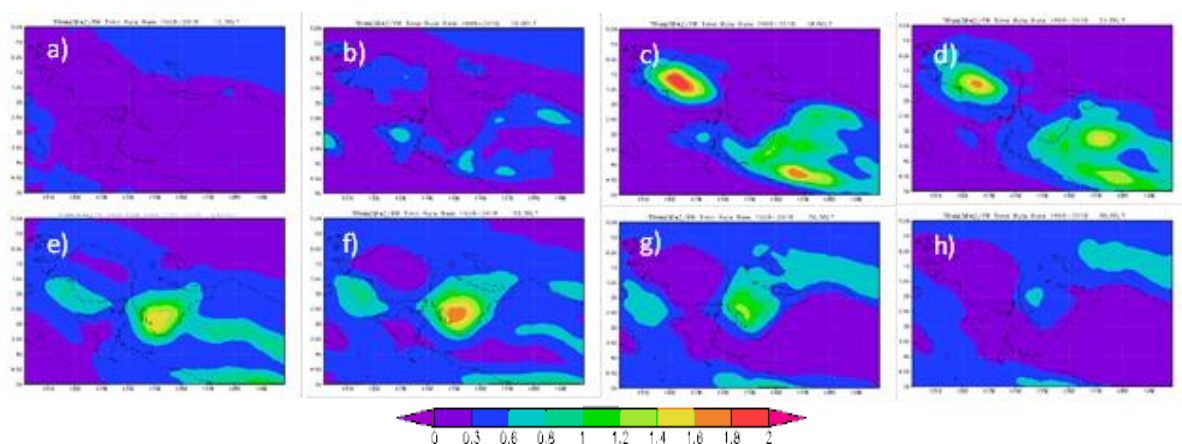


Figure 2 Diurnal rainfall variation composited 3-hourly TRMM-PR 3B42 product during 1998 – 2015 (a) 1030 – 1330 LT (b) 1330 – 1630 LT (c) 1630 – 1930 LT (d) 1930 – 2230 LT (e) 2230 – 0130 LT (f) 0130 – 0430 LT (g) 0430 – 0730 LT (h) 0730 – 1030 LT.

At nighttime until late morning (2230–1030 LT) rain occurred mainly over Cendrawasih Bay. This was main period of nocturnal rainfall. Peak of nocturnal rainfall occurred at after midnight until 0300 LT. Peak rainfall over western ocean of Sumatera [5], [20], western ocean of Borneo [7] and Cendrawasih Bay were almost same time.

Nocturnal rainfall intensity over Cendrawasih Bay was higher than adjacent sea. Nocturnal rainfall intensity at north of Papua was 0.6 mm/hr, meanwhile, rainfall intensity over Cendrawasih Bay was 1.8 mm/hr. Shape of curvature coastline type created effect of cumulus merger. Rainfall from east, south and west migrated together to middle of oceans. Predominant cloud type at north of Cendrawasih Bay (Biak Island) during nocturnal rainfall was stratiform. Nocturnal rainfall over Biak

Island was due to the northward propagation of a cloud system that appeared at midnight in the northern coastal sea region of Papua Island [6].

3.3. Migration of Rainfall

To examine migration of rainfall, we created meridional-time slice and zonal-time slice during diurnal rainfall. Migration of meridional and zonal rainfall to and from around Semi Closed Equatorial Oceans are shown in Fig. 3. Arrow α and β in Figure 3 indicates direction of movements from onshore to inland and land to oceans. From Fig. 3 we can show that there is rainfall migration from land to oceans for all direction, except from open oceans directions.

Analysis of zonal movement (BB') shows that rainfall began to form on coast on the east side of Cendrawasih Bay at afternoon until early evening. Rainfall moved from on coast on the east side to westward with speed 5.2 m/s (β_2). This movement had peak intensity reach 1 mm/hr. During shifting, the peak intensity of rainfall decreased at distance 10-30 km from coastline. Same as with coast on the east side, coast on the west side had movement rainfall to oceans at evening time (β_1). β_1 had the same speed with β_2 but had different direction. β_2 had easterly movement, but β_1 had westerly movement. During shifting, the peak intensity of westerly movement has more decreased than easterly movement. This condition occurred because westerly movement runs through small water between lands.

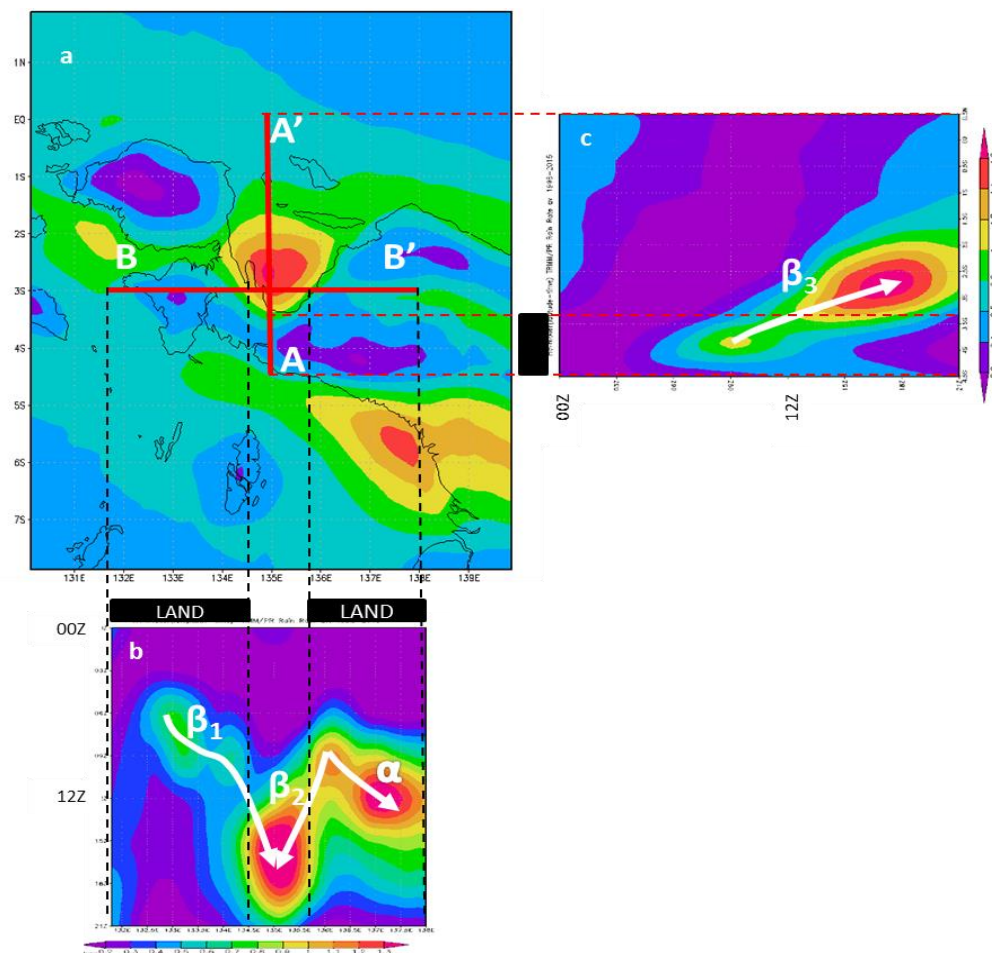


Figure 3 (a) Cross section positions for zonal-time slice and meridional-time slice (b) Zonal-time slice cross section. β_1 and β_2 is westerly and easterly movement rainfall from land to oceans area. α is westerly movement rainfall from onshore to inland area. (c) Meridional-time slice cross section. β_3 is southerly movement rainfall from land to oceans.

Speed movement of α (7.9 m/s) was faster than β_1 and β_2 . Rainfall of α was disappeared at late evening. Characteristic of α rainfall's at this region was the same as with α rainfall at Sumatera, predominant on the deep convective-type peak rain rate [5], [6].

Analysis of meridional movement (AA') showed that rainfall move from south to the middle of the oceans (β_3), but there was no migration rainfall from north. Speed of rainfall β_3 was 4.6 m/s. Rainfall at inland relatively low, but increased after reach the oceans. Average speed of rainfall β for all direction was 5 m/s.

Merger of rainfall system (β_1 , β_2 , β_3) looks occurred in the middle of the oceans. This merger condition was induced by local wind circulation. Different temperature between oceans and inland create wind circulation to convergence in the middle of the oceans at land breeze conditions.

3.4. Diurnal Variations of Low Level Convergence Field, CAPE and LCL

Diurnal variation of rainfall was likely affected by low level convergence (shown in Fig. 2). Low level convergence began to form at 0730 LT near mountainous area. It continued to develop until 1930 LT, but it had peak magnitude at 1200 LT. There was no rainfall over mountain at 0730. Rainfall began to form at late afternoon. Approximately, delayed three hours between peak of low level convergence and rainfall occurred at mountain.

Low level convergence was induced by local circulation. Low level convergence at mountainous area was formed by sea breeze convergence at middle of island. Sea breeze convergence zones related to the shape of coastline and orographic effects. This mechanism at Java island can create merger cumulus [21], but at Papua island cannot create cumulus merger at convergence zone. This condition may be because the size of island is too large [22] and mountainous area is too high [2].

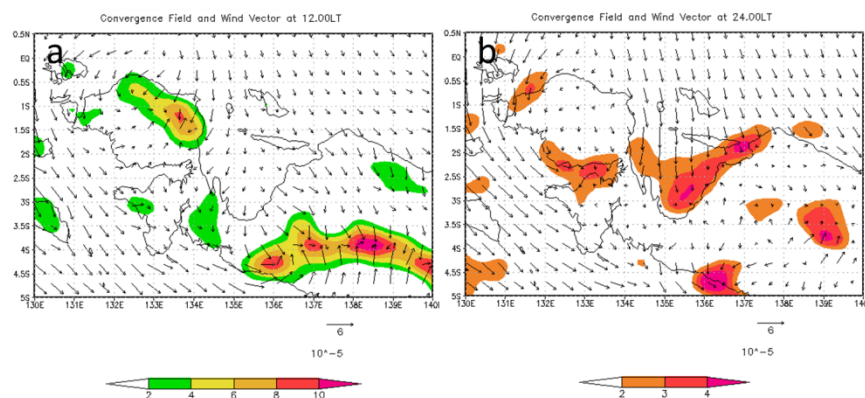


Figure 4 (a) Low level convergence at 1200 LT (b) Low level convergence at 2400 LT.

Different temperature between land and ocean began significantly induced land breeze circulation at 1930 LT. Land breeze not clearly identified by direction of wind because the apparent wind still move to inland. Land breeze can be identified with decreasing wind speed near coastal line and calculation of convergence method at this area. Direction of land breeze began to appear 2230 LT which was marked by change of wind direction 180° . Speed of land breeze was approximately 5 m/s.

Low level convergence at ocean area was induced by low level north monsoon flow and land breeze along curvature coast. This condition was similar with convergence at north of Borneo [7], [23]. Land breeze convergence had peak intensity at 3-hour after midnight. This gradient of temperature made strong land breeze caused increasing intensity of convergence.

Diurnal variations of Convective Available Potential Energy (CAPE) showed that dynamical atmosphere was very unstable at midnight. CAPE is effectively the positive buoyancy of an air parcel and is an indicator of atmospheric instability. The higher value of CAPE means unstable atmospheric condition. CAPE was highest magnitude at 0300 LT (1700 J/kg).

Lifting Condensation Level (LCL) is the height at which the relative humidity (RH) of an air parcel will reach 100% when it is cooled by dry adiabatic. The LCL is a good approximation of the height of the cloud base when air is lifted mechanically from the surface such as convergence area. Fig. 5 shows that base cloud at midnight over Cendrawasih Bay was lower than at daytime. Base cloud at midnight approximately 350 m, while at daytime 500 m. Cloud base was significantly associated with cloud types producing heavy rainfall. Cumulonimbus usually have base cloud approximately 200 – 400 m. Cumulonimbus clouds can produce high winds, heavy rainfall, lightning, gust fronts, waterspouts, funnel clouds, and tornadoes.

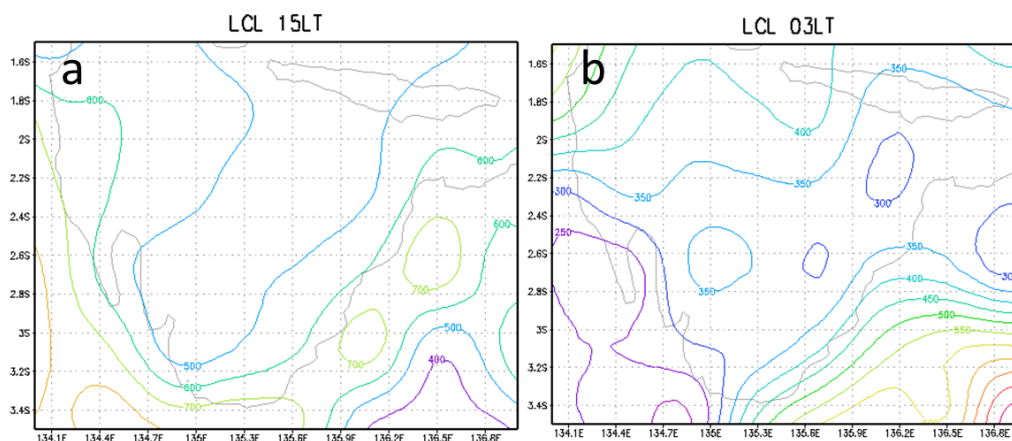


Figure 5 (a) LCL (m) at 1500LT (b) LCL (m) at 0300 LT.

4. Summary and Concluding Remarks

Diurnal rainfall over Cendrawasih Bay has different characteristics with adjacent water and another open sea. Curvature coastal line has significant effect for diurnal variations. Merger rainfall and convergence field over bay induced rainfall has high intensity at nocturnal rainfall. Nocturnal rainfall over the Cendrawasih Bay begins to form at midnight and has peak intensity after midnight (0300LT).

There is migration of nocturnal rainfall from all direction except open sea. Different temperature land and oceans induce land breeze that affects migration of rainfall. Speed of rainfall movement at nocturnal system is 5 m/s.

Northern monsoon flow and land breeze along curvature coastal line induce low level convergence at evening over oceans. Atmosphere is unstable which marked by high magnitude of CAPE. Cumulonimbus is very easily formed due to lower LCL.

This paper just focuses on TRMM data and simple parameter for analysis. More work is needed to examine more clearly the relationship of size of curvature of coastal line and mechanism of nocturnal rainfall. More intense observation is also needed because meteorological station observation over Nabire is just 12-hr operational.

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