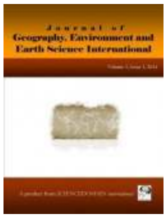

Journal of Geography, Environment and Earth Science International

11(3): 1-10, 2017; Article no.JGEESI.35612
ISSN: 2454-7352

Variability of Total Latent Heating Rate over Three Climatic Zones in West Africa

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/35612
Editor(s):
(1) Anthony R. Lupo, Department of Soil, Environmental, and Atmospheric Science, University of Missouri, Columbia, USA.
Reviewers:
(1) Gustavo Zen de Figueiredo Neves, University of São Paulo, Brazil.
(2) Moses O. Nwagbara, Michael Okpara University of Agriculture, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/20670

Original Research Article

Received 21st July 2017
Accepted 16th August 2017
Published 25th August 2017

ABSTRACT

A study of variability of latent heating rate over West Africa has been done. Results were divided into three categories: mean latent heating rate profiles, monthly time series of mean latent heating rate at four different vertical layers in the atmosphere, and the latitudinal cross section of the mean 4 – 11 km diurnal latent heat distribution.

The data was analysed using seventeen (17) years Tropical Rainfall measurement mission (TRMM) Precipitation Radar (PR) data, of total (convective + stratiform) latent heating, over West Africa.

Strong latent heating rate was observed in the Savannah zone than Guinea and Sahel zones during MAM season, whereas in the JJAS season, latent heating rate was much weaker when compared to MAM season. In JJAS season, the Sahel zone indicated stronger latent heating rate than the other two zones. Sahel had the weakest latent heating rate in MAM, whereas Guinea had the weakest latent heating rate in JJAS.

The first vertical layer (0.5 – 3 km) indicated that latent heating rate dropped sharply in April and August, and there are also bi – modal peak in June and September. With altitude, the bi – modal distribution is sustained in the Savannah zone, but Guinea and Sahel zones gradually change to one – mode. At higher layers, results indicated that Guinea and Sahel are always showing contrasting modes, especially around August.

The 4- 11 km diurnal pattern showed that, during MAM, peak occurrence of latent heating rate is

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mostly observed during 16 – 23 hours, that is, late in the evening hours. In the case of JJAS, these observed strong latent heating rate are now located above latitude 8^0N, but occurrence of peak values are sustained at evening hours.

Keywords: Latent heating rate; bi – modal; diurnal.

1. INTRODUCTION

Cloud and precipitation in the tropics occur in a variety of processes, which affects regional and seasonal profiles of latent heating (LH) in the atmosphere, as documented in [1]. Around the same year, [2] have shown that LH profiles from two precipitation types (convective and stratiform) have well defined vertical structures due to the different microphysical processes occurring in these systems. Varying degrees or sizes of precipitation systems, resulting from convective and stratiform microphysical processes, and hence, latent heating, have been shown to play important roles on controlling large-scale circulation [3,4,5] thus, signifying the need for crucial study of latent heating in atmospheric research globally.

History had shown it place in the study of diurnal variations of clouds and precipitation [6,7,8,9]. In general, clouds and precipitation have a stronger diurnal variation over land with a strong peak in the late afternoon and a weaker diurnal variation over ocean with a slight peak in the early morning. The diurnal change of clouds and precipitation is directly related to precipitation systems of different types and life cycles. Not only would the total LH (combination of stratiform and convective latent heating) change with the total precipitation diurnally, but the vertical distribution of latent heat would shift diurnally because some types of precipitation systems tend to occur or be at certain stage of life cycles during specific local times over different regions. This has been confirmed from field campaign observations [10].

Diurnal variation of unconditional latent heat over tropical land and ocean from 15 years of Spectral Latent Heating (SLH) retrievals were analysed by [11]. They showed that the diurnal variation of the latent heat, which is consistent with the diurnal variation of precipitation, is much stronger in the later afternoon between 1300 and 1800 LT over land and is slightly stronger in the early morning between 0200 and 0700 LT over ocean. They also observed that there are some interesting details in the variations of latent heating vertical distributions. Over land, there is a tilted structure of latent heating in the late afternoon with relatively shallower latent heating at 4–6 km in the early afternoon and deeper latent heating at 5–7 km in the late afternoon. In the early afternoon, convective systems tend to be at an early developing stage and mainly consist of convective precipitation. Convective latent heating even dominates the latent heating at high altitudes at this stage. Therefore, the latent heating is relatively shallow due to the bottom-heavy structure of convective latent heating. In the late afternoon and early evening, some convective systems develop and become MCSs with a large volume of stratiform precipitation.

Due to the wider coverage of TRMM within the Hadley circulation domain (rising motion near the equator and sinking motion near 30^0 latitude), it is possible to investigate the vertical latent heating profiles that are associated with the rainfall within this large-scale Hadley circulation. [12] displayed the average vertical profiles of total latent heating associated with the Hadley Cell and the seasonal evolution over January - December periods averaged between 1998 and 2010 from both the TRAIN and SLH algorithms. The showed an apparent deep layer of total heating between 1 km and 10 km concentrated close to the equator in the TRAIN heating profiles, which is not as deep in the SLH heating profiles, which showed maximum heating between 5 km and 10 km. Also observed were differences in the location of the maximum average total latent heating during January – February and July - September in both algorithms, which according to [12] illustrated the seasonal migration of the intertropical convergence zone (ITCZ) northward during July and August and southward during January and February.

Mean monthly latent heating at three different altitudes (2, 5 and 8 km) over the entire tropics from the convective stratiform heating (CSH) algorithm were analysed by [13]. Their result showed resemblance of the horizontal pattern of the CSH estimated latent heating structures to the pattern of the surface rainfall, especially at the 5km and 8km altitudes. They also observed that stronger latent heat released, in the range of 10 K/day or greater, in these two altitudes are always linked with heavier surface precipitation.

Previous studies had analysed retrievals, validation, and intercomparison of latent heating profiles based on different algorithms ([14,15,16]) without adequate focus on the spatial and temporal distribution of latent heating profiles. Other studies on atmospheric latent heating profile estimates have been on regional scales and have used ground-based soundings and especially field campaigns (e.g. [17,18]).

The West African Guinea, Savannah, and Sahel zones are three distinct climate zones with different climatic characteristics that require separate observational studies. Most research works, on a different topic, have considered each of these zones separately, but on the field of heat budget and especially latent heat released from cloud and precipitation systems, there is rarely any that have separated these zones. Also most researches have not considered the separate contributions of latent heating, from each of Guinea, Savannah, and Sahel zones of West Africa, to the global heat budget, and the intercomparison of latent heating among these zones. A better understanding of the diurnal variability of the vertical profile of total latent heating will enhance our knowledge of latent heat contribution to global atmospheric heat budget, especially from the three (3) climatic zones being considered in this study.

2. DATA, METHODS, STUDY AREA

Seventeen (17) years (1998-2014) Tropical Rainfall Measuring Mission (TRMM) satellite ([19,20]) level 2 (irregularly spaced) monthly data of total latent heating (Convective + Stratiform) are analysed in this study. The total latent heating data, obtained from the TRMM's Radar Precipitation Features (RPFs), contained nineteen (19) height levels as follows; 0.5 km, 1 km, 2 km, 3 km, 4 km, 5 km, 6 km, 7 km, 8 km, 9 km, 10 km, 11 km, 12 km, 13 km, 14 km, 15 km, 16 km, 17 km, 18 km. The domain of interest was extracted which is West Africa covering latitude 4^0N – 20^0N and longitude -17^0W - 20^0E, and the separate zones of Guinea, Savannah, and Sahel. The data were sorted and further separated into four (4) diurnal time periods covering night (0 – 5.99 am), morning (6 – 11.99 am), daytime (12 – 17.99 pm), evening (18 – 23.99 pm).

The level 2 irregularly spaced data were averaged for each of the nineteen (19) levels for each month, for March – May (MAM), and June – September (JJAS) in each of the zones under investigation. Profiles of latent heating were plotted for each month and at each of the diurnals. The monthly variability at each level were also plotted to investigate and compare the heating/cooling pattern in each of the zone.

The study area showing the three zones is shown below:

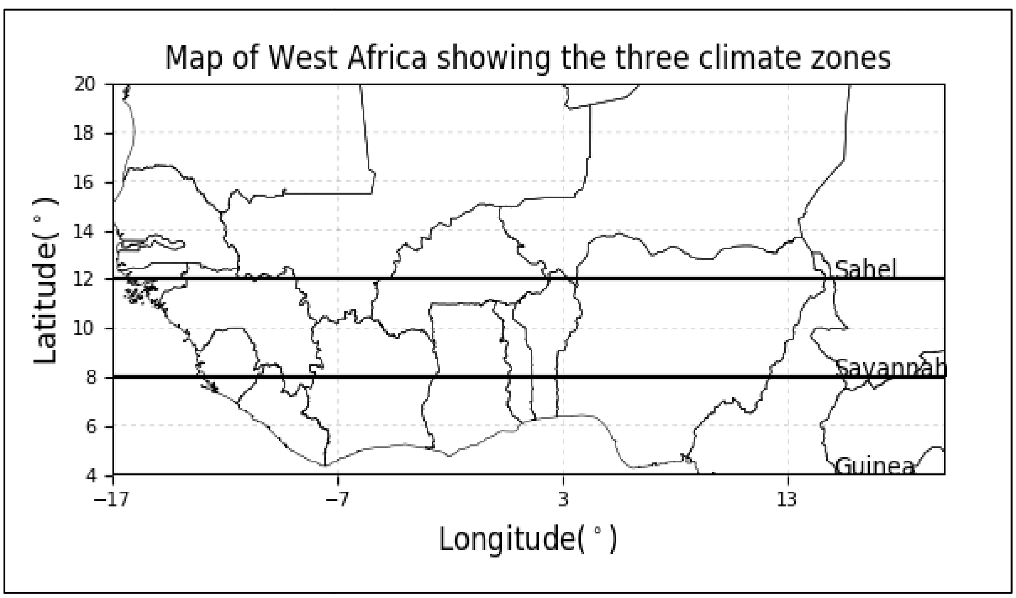

Fig. 1. Study area

3. RESULTS AND DISCUSSION

The latent heating profiles in the atmosphere during MAM, as shown in Fig. 2, clearly indicated that Savannah zone had the strongest latent heating rate in the atmosphere with a peak value of about 6.5K/day near 6km altitude. The Guinea zone had the second strongest atmospheric latent heating rate in West Africa during MAM, with a peak value of about 5K/day, whereas the Sahel Zone indicated the least atmospheric latent heating rate in the atmosphere during MAM, with a peak value of around 2.5 K/day. The presence of strong latent heating in Savannah zone could be due to contributions from convection systems over land in Savannah, which has more land cover, as against the guinea zone with significant presence of ocean, which agrees with [11].

In JJAS, as shown in Fig. 3, Sahel indicated the strongest atmospheric latent heating rate, especially at mid-altitude where the profile began to decrease. The profile indicated that at altitude just before 2km to around 3km, the three zones followed the same trend in atmospheric latent heating rate. The level (altitude) of peak or maximum atmospheric latent heating rate for the Guinea zone during JJAS is slightly lower compared to the other two (2) zones (Savannah and Sahel) and Guinea is observed to be the zone with the least atmospheric latent heating rate during JJAS, especially at higher altitude. The atmospheric latent heating rate for the three (3) zones decreases with increasing altitude from its peak value to close to 14 km altitude in the atmosphere. The maximum observed atmospheric latent heat rate for Sahel is 6 K/day, for Savannah, it is close to 5.5 K/day, whereas for Guinea, it is 3.5 K/day, at their respective altitude in the atmosphere. During JJAS, Monsoon system has commenced in the Sahel zone, as a result of the migration of the Intertropical Discontinuity (ITD), thus convective activities are contributing to high latent heating rate in the zone.

The monthly atmospheric latent heating rate for the first atmospheric layer (Fig. 4), computed by taking the average over the four levels, indicated an overall positive (heating) environment in all the zones, with the Guinea zone dominating West Africa with stronger atmospheric latent heating, followed by Savannah and Sahel. All the

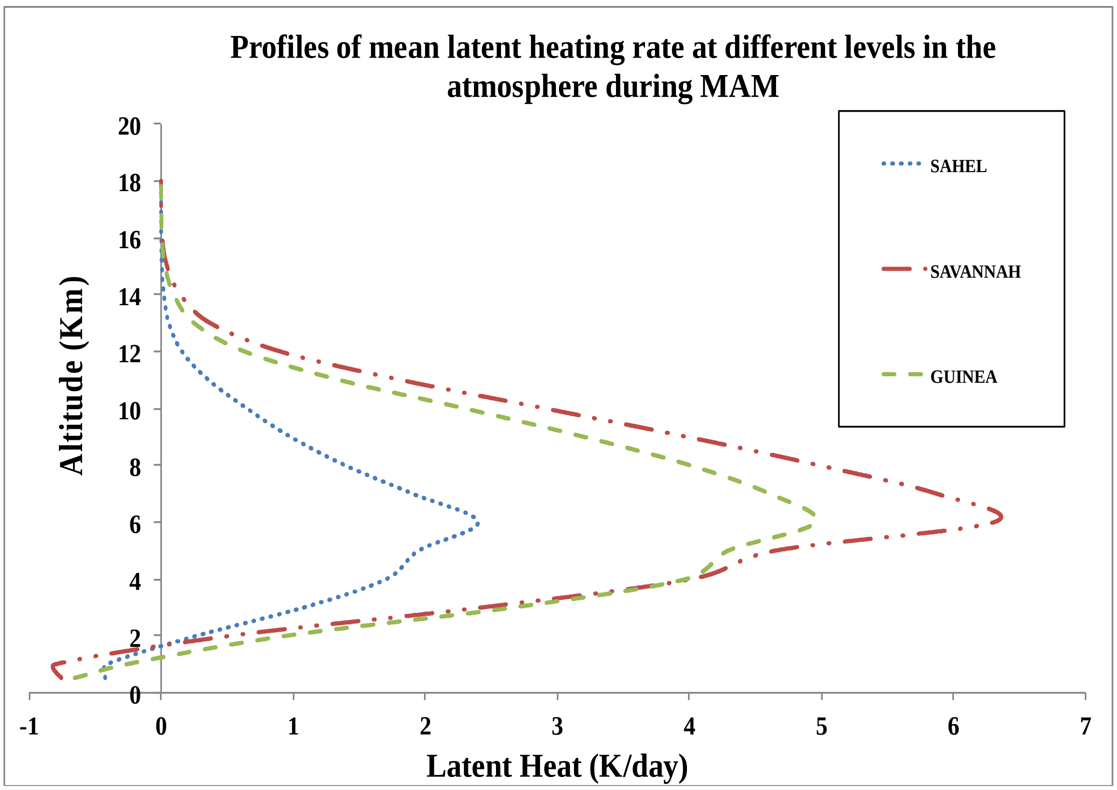

Fig. 2. Profiles of latent heat released from cloud systems in the atmosphere during MAM

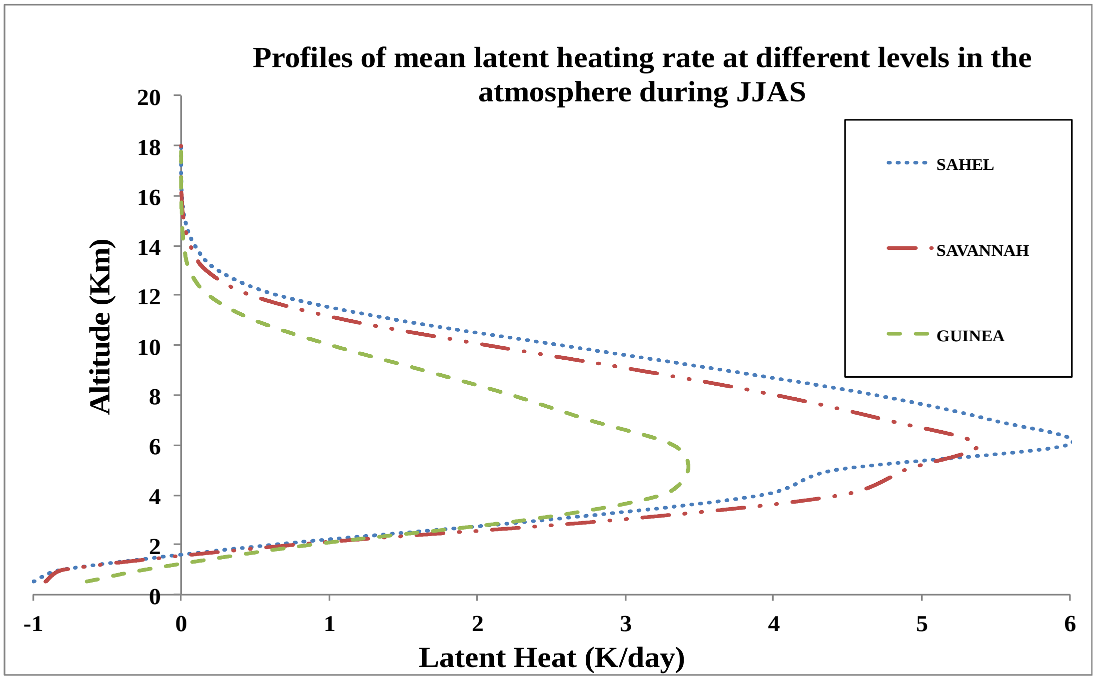

Fig. 3. Profiles of Latent Heat released from cloud systems in the atmosphere during JJAS

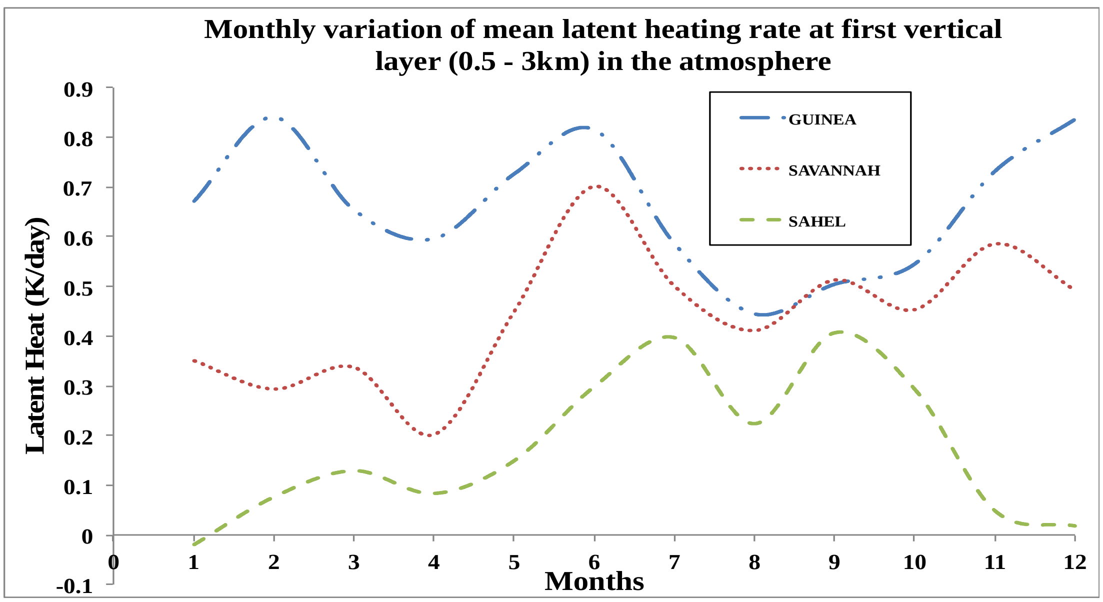

Fig. 4. Monthly series of Latent Heat released from cloud systems for levels 1 – 4 (0.5 – 3 km averaged) in the atmosphere

zones have bi – modal minimum periods of atmospheric latent heating in April and August, whereas, the zones showed maximum atmospheric latent heating in June, for Guinea and Savannah, and bi – modal (July and September) for Sahel.

The second atmospheric layer as shown in Fig. 5, representing the average of levels 5 – 8 (4 km – 7 km altitude) in the atmosphere, showed that the Sahel zone constituted the least latent heating rate in this layer of the atmosphere between 4 km – 7 km, especially before June, but appreciated above Guinea and Savannah between June and October, and thereafter falls below Guinea and Savannah after October. Savannah still have a very strong primary peak in June but a weak secondary peak in September when considering the second layer as shown in Fig. 5. The two (2) zones of Guinea and Savannah indicated one (1) singular drop or fall in atmospheric latent heating during the month of August. In August, the Guinea zone indicated the least atmospheric latent heating rate while the Sahel zone indicated the strongest atmospheric latent heating rate.

The third vertical layer in the atmosphere considered in this work, is shown in Fig. 6. Clearly, the Sahel indicated one (single) peak atmospheric latent heating rate, which is between July and August, but Guinea and Savannah showed sharp drop in atmospheric latent heating, during this same period. The Guinea and Savannah zones still maintained bi – modal latent heating distribution in the atmosphere at this layer. The plot showed that there is very small amount of latent heat released at higher altitude (this layer) in the atmosphere in the Sahel zone during the dry months of November – March but Guinea and Savannah had substantial amount of atmospheric latent heating rate in this third layer during the dry months.

The fourth vertical layer is as shown in Fig. 7 above. On the average, the peak observed atmospheric latent heating rate, which is in the Savannah zone, is about 0.45 K/day in the month of May. The fourth layer also showed that Guinea and Savannah still had bi – modal latent heating distribution in the atmosphere. Sahel indicated one (single) peak, as was the case in the previous layer, in the month of August, and this single latent heating maximum is occurring in the same month of August when the Guinea and Savannah had drops in their latent heating distributions. The Guinea zone had maintained its bi – modal latent heat distribution in the months of April and October, as were observed in the previous layer in the atmosphere, while the Savannah zone had its bi – modal distribution in the months of May and between September and October in the fourth layer. In this fourth layer, it was observed that the Guinea and the Savannah had latent heating rate below 0.1 K/day in the dry months.

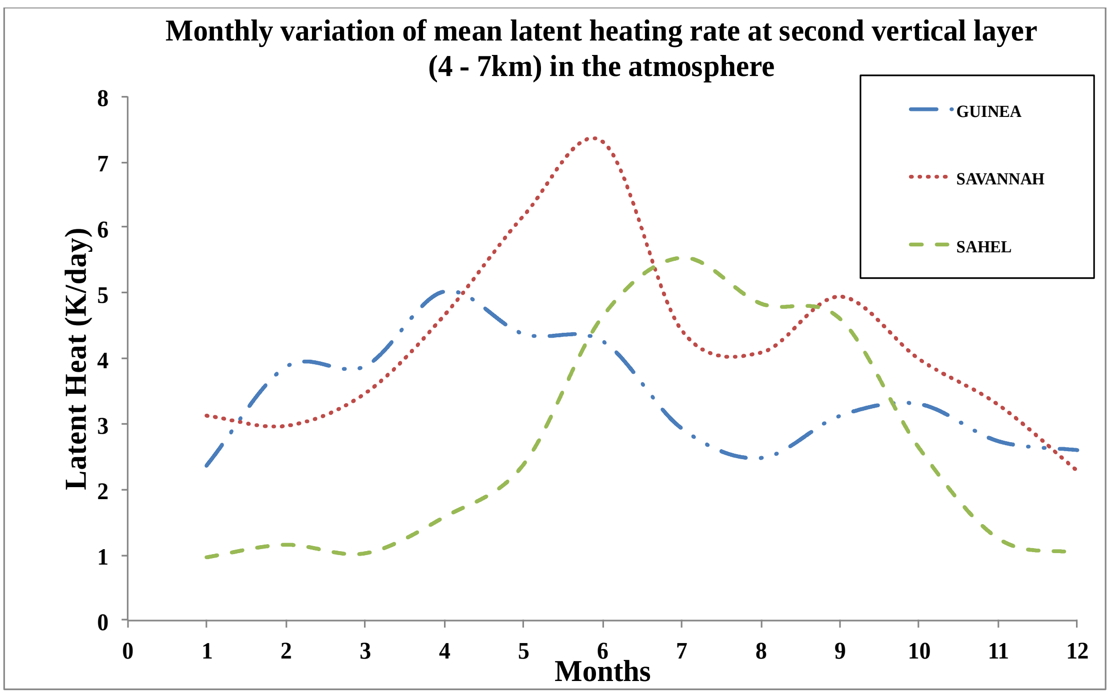

Fig. 5. Monthly series of latent heat released from cloud systems for levels 5 – 8 (4 – 7 km averaged) in the atmosphere

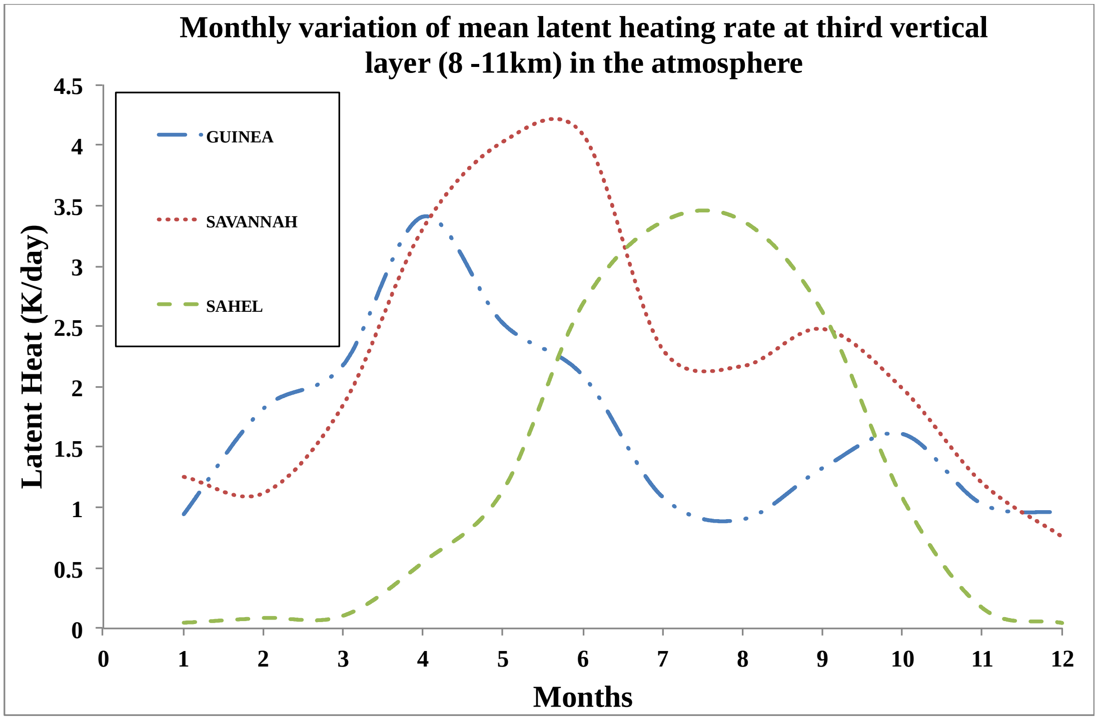

Fig. 6. Monthly series of Latent Heat released from cloud systems for levels 9 – 12 (8 – 11 km averaged) in the atmosphere

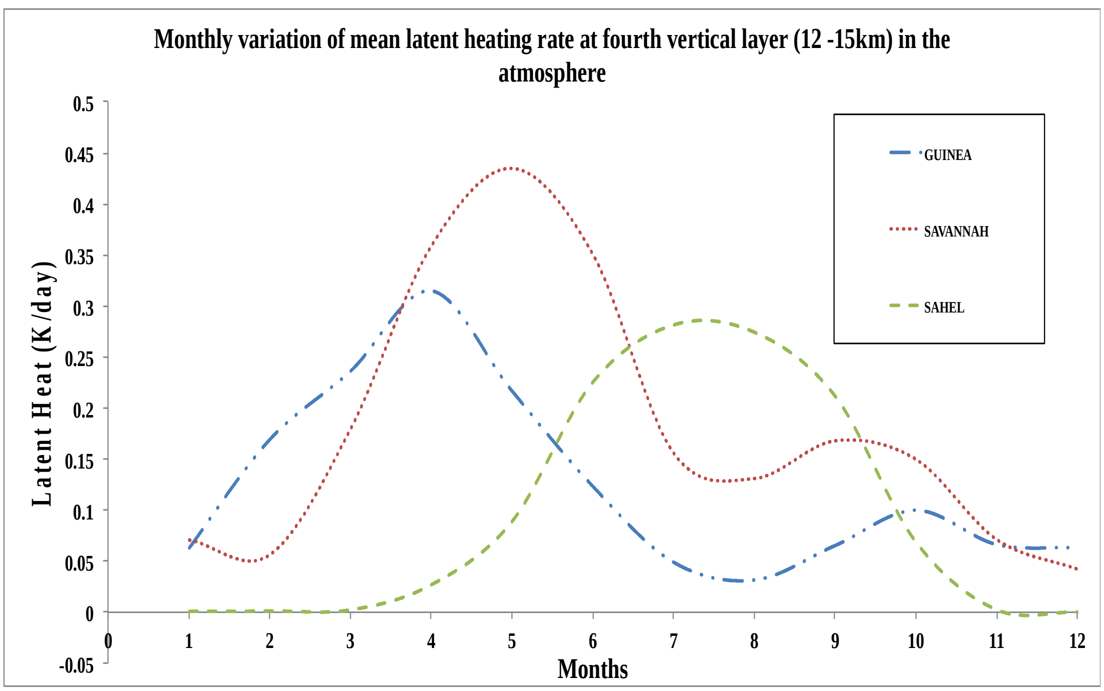

Fig. 7. Monthly series of Latent Heat released from cloud systems for levels 13 – 16 (12 – 15 km averaged) in the atmosphere

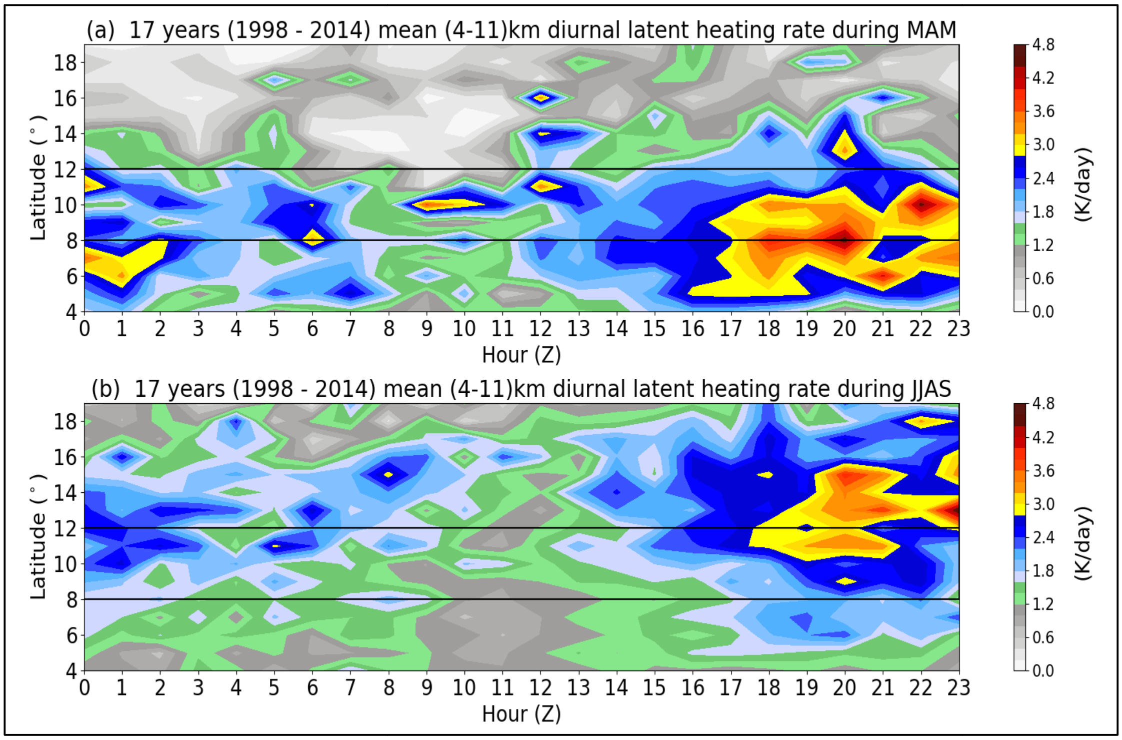

Fig. 8. Latitude – Time cross section of latent heating rate over West Africa

Latitude – time cross section, in Fig. 8, showed that strongest latent heating rate were observed during the evening (late) hours of the day. During MAM, as shown in Fig. 8a, these strongest latent heating rates are located below the Sahel zone, that is, in the Guinea and Savannah zones, whereas, during JJAS, as shown in Fig. 8b, the zone of strongest latent heating had migrated northward, and are located above the Guinea zone, that is, Savannah and Sahel zones. The morning hours, between 8 – 13 hours, generally indicated weaker latent heating rates, in all the zones, particularly during JJAS. During MAM, stronger latent heating rates are consistent in the Guinea and Savannah zones, but weaker in the Sahel zone, whereas, during JJAS, stronger latent heating rates are now consistent in the Savannah and Sahel zones, with weaker latent heating rates in the Guinea zone.

4. CONCLUSIONS

The results showed that, in West Africa, latent heating profiles in the atmosphere initially increases with altitude from the surface to about 5 – 6 km, depending on the zone of observation, where most of the peak values were observed, and decreases thereafter with altitude to values close to zero (0K/hr) in the upper atmosphere. The profiles also indicated that evaporative cooling (negative latent heating) was observed in both MAM and JJAS at the boundary layers. Further observation showed that the Sahel zone had the least atmospheric latent heat rate, during MAM, but during the JJAS season, the Sahel zone had the highest atmospheric latent heating rate. The Savannah zone indicated most of the dominance in MAM, as indicated by the profiles.

The monthly variations showed that peak values of atmospheric latent heating were observed in the month of June for the first 7 km in the atmosphere, especially for the Savannah zone, which encompasses the first and second vertical layers. From about 2 km altitude to 5 km altitude, there are sharp drop in the atmospheric latent heating in the month of August, in all the zones. These persisted or continued in Guinea and Savannah, except for Sahel, throughout the atmosphere (the remaining altitudes under investigation). The Sahel zone did not indicate this sharp drop, in August, after the 5 km altitude. Obviously, this sharp drop is a result of the little dry season mostly observed during this month in most parts of Guinea and Savannah, when there is little or no cloud development necessary for the release of atmospheric latent heat. After this 5 km altitude, observations indicated that the Sahel zone had only one peak for the rest of the atmosphere, in contrast to the bi – modal latent heating distributions indicated by the Guinea and Savannah zones throughout all the other layers (altitudes) in the atmosphere.

Latitude – time cross section showed that strongest latent heating rate were observed during the evening (late) hours of the day. During MAM, these strongest latent heating rates are located below the Sahel zone, that is, in the Guinea and Savannah zones, whereas, during JJAS, the zone of strongest latent heating are located above the Guinea zone, that is, Savannah and Sahel zones.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/20670