Synoptic and Mesoscale Background of the Disastrous Heavy Rainfall in Sri Lanka Caused by a Low Pressure System

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Abstract

Sri Lanka is having tropical and monsoonal climatology and southwest monsoon is the longest monsoon season (May to September) which brings about 30% of the total annual rainfall of the country. Average onset of southwest monsoon is 25th May (+- 5 days) over southern part of Sri Lanka. Low level disturbances associated with the Inter Tropical Convergence Zone (ITCZ) develop over or in the vicinity of Sri Lanka affect the weather of the country during pre-monsoon season.

In mid May 2016, atmosphere around Sri Lanka was very unstable. Extremely heavy rainfall, exceeding more than 200 mm in a day, was received in many parts of the island leading to flood and landslide on 15th May 2016. It caused massive damages to human lives as well as the economy of Sri Lanka. Total financial damage was estimated at 250–280 billion rupees (US$1.7–2 billion) and caused nearly 200 casualties.

This study is focused to analyse the synoptic situation during the said period. Synoptic observation, JRA 55 Reanalysis data are used to generate synoptic charts. Behavior of wind patterns at different levels of the atmosphere, change of atmospheric pressure were analysed. Satellite data also analysed and analysis clearly showed that this extreme rainfall was associated with a low pressure area developed in the Bay of Bengal closer to Sri Lankan eastern coast and it was initial stage of Cyclone “ROANU”.

Key Words : Monsoon, synoptic, low pressure area, extreme rainfall

1.Introduction

Extreme rainfall events today pose a serious threat to many populated and urbanized areas worldwide. An accurate estimate of frequency and distribution of these events can significantly aid in policy planning and observation system design (Goswami, 2007). Extreme rainfall with flood and landslides is more frequent in the world today due to change in weather pattern and improper land use changes. Many parts of Sri Lanka are vulnerable to extreme events leading to flood and drought (Arunasalam et.al, 2019). In Asia, floods are by far the most frequent and devastating natural disasters (Dushmanta, 2004). Compared to the decade ending in 1983, the number of disasters caused by natural hazards has increased by 22 times during the last decade mainly due to increased hydro-meteorological disasters. In terms of the frequency of disasters affecting the people and economy, flood is the highest [1](56%) followed by drought (18%), high winds (10%) and landslides (16%) (Impacts of Disastes in Sri Lanka 2016-Ministry of Disaster Mangemnet, Sri Lanka and Asia Pacific Alliance for Disaster Management, Sri Lanka). Therefore, an understanding of the characteristics of extreme rainfall events is important, as these events cause extensive damages to the ecology, infrastructure, agriculture, economy, environment, human settlements, etc. (Coates, 1996).

Most recent heavy rainfall events in Sri Lanka during the month of May occurred in 2016, 2017 and 2018. In May 2016, tropical storm ROANU caused flooding and landslides in 22 out of 25 districts. According to the preliminary post-disaster needs assessment done by Global Facility for Disaster Risk Reduction (DFDRR), damages and losses exceeded $570 million.

Heavy rainfall over Sri Lanka on 15 May 2016

Sri Lanka (5°-10° N and 80°-83° E) is an island situated at the interface of two sea areas with the Bay of Bengal to the East and Arabian Sea to the west. Sri Lanka has 2 major monsoons, southwest and northeast associated with the southwesterly and northeasterly regional wind patterns respectively. Within these monsoons there are two inter-monsoon seasons when convective activities are dominant. The central part of the southern half of the island is mountainous with heights more than 2.5 km. The core regions of the central highlands contain complex topographical features such as peaks, hills, basins, and valleys. The rest of the island is basically flat except for several small hills in the lowlands. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season.

Formation of Tropical depressions and storms in the Bay of Bengal usually occur in pre-monsoon and at the onset of southwest monsoon period (from latter part of April to June). The onset of southwest Monsoon normally occurs either with the gradual setting of winds of moderate strength, or with a burst by a formation of depression in the Southwest Bay of Bengal. On the other hand if such a system is formed in the Arabian sea during the mid-May or first week of June the onset will be late or weak. However, this tropical depression is likely to produce greater impacts when it is formed close to Sri Lanka or having a projected path along or close to the Eastern coast of Sri Lanka. The areas that usually receive the heaviest rainfall are the South and West of the country, including the major cities of Galle, Mathara, Kalutara, Ratnapura, and Colombo.

Onset of southwest monsoon of 2016 was induced by a low-pressure system which was at the initial stage of the tropical cyclone ’ROANU’’ in the Bay of Bengal (Track and the number of people affected due to heavy rain are shown in the Figure 1). It has caused massive damage to human lives and the economy of Sri Lanka with flooding and landslides in the western Sri Lanka, during the third week of May 2016 although it did not make a landfall in Sri Lanka. Very heavy rainfall exceeding 200 mm (highest was 373.2 mm at Kilinochchi in the Northern part of Sri Lanka) within 24hrs was received in the western and northern parts of Sri Lanka on 15 May 2016(Figure 2b). There were around 93 casualties and still 113people were missing. In all, 619 houses were destroyed, and 4294 were partly damaged, affecting a total of 472775 families (Figure 1a) due to floods and land Slides. (Report on 2016 Sri Lanka flood, Disaster Management Center, Sri Lanka/International Water Management Institute)

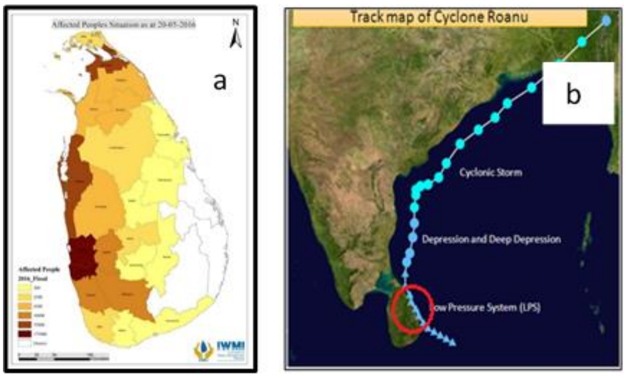

Figure1. (a) The affected number of people (Source IWMI) and (b) The track of the tropical cyclone ROANU (source-Indian Meteorological Department) (during 14-16 red circle)

Initially the "'ROANU" cyclone was developed as a low level disturbance associated with the ITCZ on 10th of May, to the South of Sri Lanka and remained at the same intensity around Sri Lanka until 14 May 2016. It developed into a low-pressure area over southwest Bay of Bengal (BoB) to the Southeast of Sri Lanka on 14th May 2016. It moved northeastwards along the east coast of Sri Lanka while intensifying into a well-marked low pressure area in the morning of 15May 2016. It further moved northwestwards and lying over Trincomalee coast of Sri Lanka and Southwest Bay of Bengal in the morning of 16 May 2016. Thereafter, moving north-northwestwards, it concentrated into a depression and lay centered over southwest Bay of Bengal off Tamil Nadu coast on 17th near 11.00N and 81.00E. It further moved, and intensified into a deep depression, on 18th. It further intensified into a cyclonic storm and continued to move northeastwards along the East coast of India during 19-20 May 2016. It crossed Bangladesh coast on 21st as a Cyclonic Storm. Cyclone ROANU followed a unique track (Figure 1b), moving very close to Sri Lanka and East coast of India. It recurved northeastwards and crossed Bangladesh coast to the north of Chittagong (Figure 1, source-Indian Meteorological Department).

Under the influence of the system rainy condition over the country started on early morning of the 15th and highest daily rainfall of 373.2 mm was observed in the Killinochchi district ,Northern province (Fig 2b). Sabaragamuwa province which connected to the Kelani River (Figu.2a-in black circle) basin in the western slopes of the central hills also received considerable amount of rainfall. Due to heavy rainfall in both lower and upper catchment of Kelani river basin, river flooding was experienced over downstream of the Kelani river basin, especially in the Colombo Metropolitan region and caused massive landslides along the western slopes of the central hilly areas in the Kegalle district of Sabaragamuwa province.

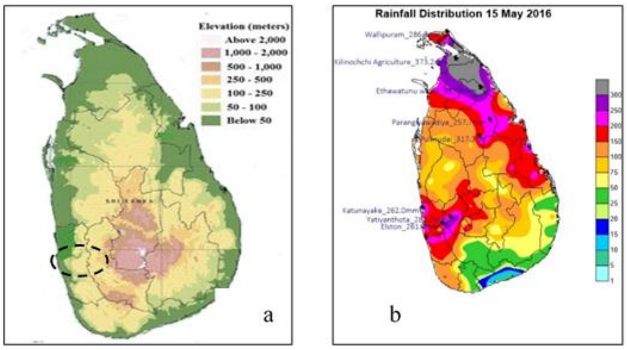

Figure 2(a) Topography and provincial boundaries of Sri Lanka (source- Galgamuwa et al 2018) and (b) Spatial daily rainfall distribution over Sri Lanka on 15th May 2016.

The objective of this study is to identify and document the possible synoptic and environmental characteristics of the heavy rainfall events on the 15th May 2016 over western and Northern parts of Sri Lanka.

2. Data and Methodology

- The largescale atmospheric pattern associated with the cyclone “ROANU” was reconstructed using JRA 55 and NCEP Reanalysis data. Spatial resolution of the data of JRA55 and NCEP was (2.5^{o}x2.5^{o}) and (1^{o}x 1^{o}) respectively,
- Interactive Tool Analysis of Climate Systems (ITACS) software was used to study the data. (ITACS is developed by Japan Meteorological Agency (JMA).
- Atmospheric condition to develop the cyclone “ROANU” was carried out using the gridded data from NCEP and JRA55.
- Rainfall analysis during the heavy rainfall event was done using more than 250 daily observation data and Arc GIS was used to develop the spatial rainfall distribution map.
- GrADS (Grid Analysis &Display System) was used to analyse the horizontal and vertical profile of the atmosphere.

- Diagrams displaying amounts of precipitation were plotted by using ArcGIS software.

3. Results and Discussion

The data has been used to explore the possible causes and mechanisms behind the occurence of the heavy rainfall event over Sri Lanka on 15th May 2016 (during onset of southwest summer monsoon season). Figs.3 to 10 contain the analyses of various synoptic maps of the flow variables on 15 May 2016. The results are described in the following section in details.

3.1 Synoptic situation

(a) Mean sea level pressure and wind

The daily average mean sea level pressure (hPa) values during 13-16th May 2016 are shown in Fig. 4. It is found that a well-marked low pressure area was formed over Southwest Bay of Bengal (BoB) to the southeast of Sri Lanka on 15th May 2016.

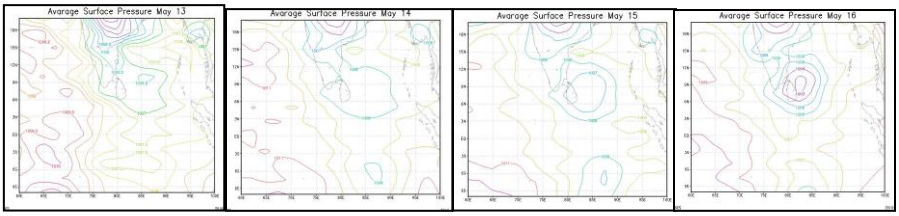

Figure-03 Daily Average surface pressure distribution from 13-16 May 2016 (NCEP Reanalysis)

The daily average mean sea level pressure (hPa) during 13-16th May 2016 is shown in Fig. 3. It is found that a well-marked low pressure area formed over Southwest Bay of Bengal (BoB) to the southeast of Sri Lanka on 15th May 2016.

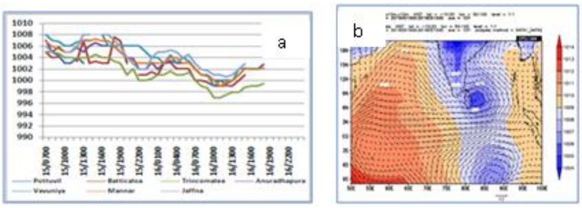

Figure-04. (a) Hourly pressure distribution during 15/0700UTC to 16/2200UTC recorded at Department Meteorological stations in the Northern and Eastern parts of the country and (b) daily average mean sea level pressure (shaded) and surface wind (arrow) on 15th May 2016.

Figure 4 (a) shows the hourly pressure distribution at Department of Meteorology meteorological stations in Eastern and Northern parts of the country from 0700hrs on 15th to 2200 hrs on 16th May 2016. Observed pressures at stations along the east coast of the country were lower than that of inland stations. The minimum pressure was recorded at Trincomlee on 16th Morning, suggesting that the system was moving along the east coast of the country.

Figure 4(b) shows the daily average mean sea level pressure and surface wind pattern on 15 May 2016. The isobars which are indicted by colours over the Southwest Bay of Bengal have east west run while over South East Arabian sea has almost west east run which enhanced the moisture feeding into country. It is found from the surface wind field that the westerly to northwesterly low level flow are moving towards the western coastal region and Northeasterly flow towards the Northern part of Sri Lanka where heavy rainfall was observed. This low level flow from the large area of Bay of Bengal and the Arabian sea moves towards the country and converges over a narrow belt of the western and Northern part of the country where heavy rainfall was reported.

(b) Middle level (500 hPa) and upper level(200hpa) wind

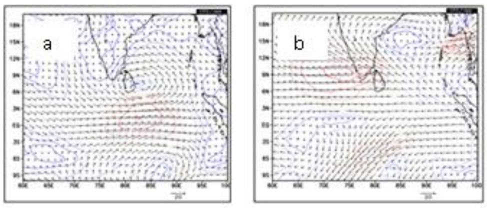

Figure 5. The daily average (a) middle level wind distribution at 500 hPa and (b) upper level wind at 200 hPa on 15 May 2016

The daily average middle level at 500 hPa and upper level wind at 200 hPa wind distribution on 15 May 2016 are shown in Fig. 5(a- b). It is found that a cyclonic circulation, a low pressure area, observed in low level wind (Fig. 4b) is continuing up to the mid-level (500 hPa) of the troposphere. The out flow from a high pressure cell in central bay of Bengal is observed in 200 hpa level (Fig. 5(b)) with diverge pattern of wind over the region of Sri Lanka.

(c) Low level relative vorticity (1/s) and pressure vertical velocity (Pa/s)

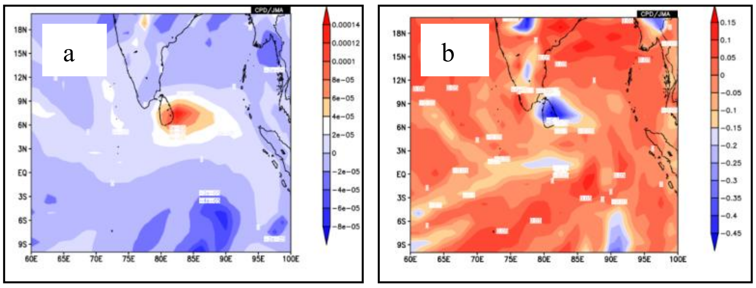

Figure 6. Daily average low level relative vorticity (1/s) field (a) and pressure vertical velocity (Pa/s) (b) on 15 May 2016

Daily average low level relative vorticity field and pressure vertical velocity on 15 May 2016 are shown in Fig.6 (a) and 6(b) respectively. Both relative vorticity field as well as pressure vertical velocity fields show a very favorable condition for vertical development of clouds over the country and the vicinity.

(d) Low level convergence and upper level divergence

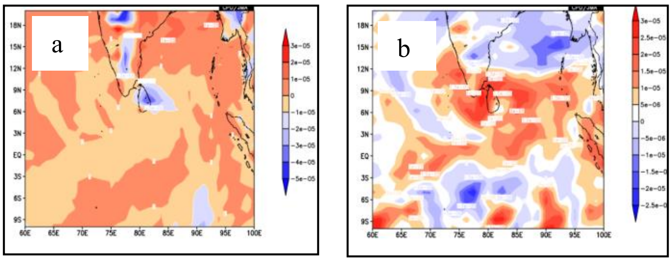

Figure 7. The daily average low level-950hpa (a) and Upper level-(200hpa) divergence (b) on 15 May 2016.

The daily average low level and upper level divergence on 15 May 2016 are given in Fig.7 (a) and (b) respectively. It is found that a distinct area of low-level convergence (negative divergence) extends from Bay of Bengal to Eastern part of the country with a maximum over the Eastern part of Sri Lanka (Fig. 7(a)). A well-defined area of the upper level divergence is evident in the divergence field (Fig.7 (b)) which is associated with the divergent flow of the upper level wind (Fig.5(b)).

(e) Outgoing Longwave Radiation (OLR) and MJO

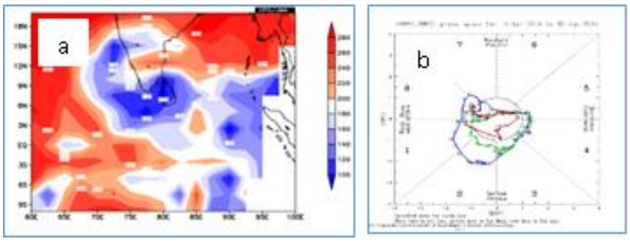

Figure 8. (a) The outgoing longwave radiation (OLR) W/m^2 on 15 May 2016 and (b) Track of Madden Julian Oscillation (MJO) during April to June 2016

The Outgoing Longwave Radiation (OLR/W/m^2) on 15 May 2016 is shown in the Figure 8 (a). It was found that the region of Sri Lanka is covered by low OLR of the order around 100 W/m^2. It is evident that the dense clouds are characterized over the Northern and Western parts of Sri Lanka. Figure 9(b) shows the track and amplitude of Madden–Julian Oscillation (MJO) index, which is a eastward propagating intra-seasonal oscillation with a low frequency on 30-60 day scale, during April to June 2016. It was found that the MJO is in middle of the phase 2 and 3 with amplitude of more than 1 during 7-18 May 2016 with maximum on 15 May 2016. Accordingly, MJO also contributed to enhance the convective activity over the Bay of Bengal on 15 May 2016.

(f) Horizontal and vertical profile of dew point depression (T-Td) and wind

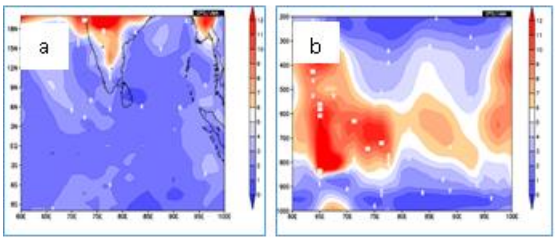

Fig. 9. (a) The dew point depression (T-Td)(K) analysis at 925 hPa level and (b) Vertical profile of dew point depression within latitudes 7°-10°N on 15 May 2016

Dew point depression (T-Td) is a useful indicator of how moist the air is. Fig. (9a) contains the analyzed dew point depression field at 925hpa level and it indicates that heavy incursion of moisture into the country. A leading tongue of high moisture, about 90-100%, extending from the Southwest Bay of Bengal into northern part and from Arabian sea into western part of Sri Lanka is an exceptional feature of this map (Fig.9 (b)). A narrow zone of high moisture content, like a moisture river is seen over and in the vicinity of Sri Lanka within 1000-900hpa levels (b). In contrast, low amount of moisture in the middle level (700- 500 hPa) of the troposphere is evident.

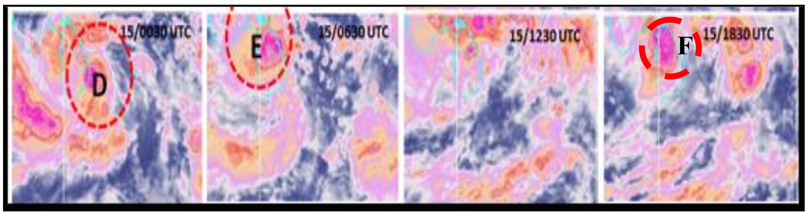

Figure.10. The Chinese FY 2D satellite imageries on 15May 2016

The FY 2D satellite imageries are presented in Figure 10. Deep convective clouds are observed over Northern (E), Western and Northwestern parts (F) of Sri Lanka and the vicinity, which are supported by the outgoing longwave radiation fields (Fig. 9a).

4. Conclusions

Based on this study, the following conclusions can be drawn.

A cyclonic circulation persisted at the mean sea level just to the East of Sri Lanka and adjoining Southwest Bay of Bengal. The low level wind field indicates that there were Easterly to northeasterly flow from the Bay of Bengal towards the northern part of Sri Lanka and Westerly to northwesterly flow from Arabian sea towards the Western part of Sri Lanka, which converged over the North and West region of Sri Lanka. The low level easterly flow and westerly flow helped to transport a high amount of moisture from the Bay of Bengal towards the Northern and from Arabian sea towards the Western regions of Sri Lanka and vicinities respectively. Orographic effect also triggered to enhance the rainfall over western slopes of the central hills.

The strong low level convergence helped to carry moisture up to 700hPa level and accordingly high relative humidity extended up to this level. However mid-level drier condition was another triggering factor for the enhanced rain. The high relative vorticity, low level convergence, upper level divergence, favorable pressure vertical velocity over Sri Lanka preceded the development of heavy rainfall.

There was low OLR over North and western part of the country and presence of MJO in phase 2/3 with higher amplitude was favorable for enhancement of activity in the Bay of Bengal.

Further study is required to understand more about such cases. High resolution data are needed to identify localized effects.

Acknowledgments

The JRA-55 reanalysis dataset was provided by the JMA and is available at http://jra.kishou.go.jp/JRA-55/index_en.html. Preliminary analysis in the present study used the ITACS system developed by the JMA.

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