Case Study of Flash Flood Event on 14th November 2014 in Colombo due to Short Period High Intense Rainfall

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ABSTRACT

Flash flood in Colombo is becominga frequent eventwith heavy and intense rainfall event, due to the land use change with rapid urbanization. Collapsed with the natural drain system with illegal constructions and less infiltration due to concrete and tar are some of the reasons which trigged flash flood event. Many articles clearly explain the flash flood situation in many countries with the rapid urbanization.

Flash flood occurred in Colombo on 14th November 2014 at about 1630Sri Lanka Standard Time (SLST) due to heavy and intense rainfall. Many areas in the southwestern part of Sri Lanka received high intense rainfall and experienced flood situation. Not only intense rainfall, strong winds also accompanied with showers.

Department of Meteorology, Colombo reported 56 mm rainfall within 20 minutes. Past flash floods in Colombo also associated with heavy rainfall, but this event is not a common one due to less amount of rainfall. Analysis of pluviograph clearly evident the intense rainy condition.

The aim of this study is to identify the cause of sudden changes of atmospheric phenomena during high intense precipitation on 14th November 2014. Observation meteorological data and reanalysis data from NOAA NCEP was used for the analysis. Weather Research Forecast (WRF) model (Version 3.7.1) with 3DVAR data assimilation has done. In addition satellite pictures and atmospheric water content also analyzed. 1.0 degree NCEP data were downscale for 5 km grid to proper identification of local circulations.

Analysis clearly showed that the change of local atmosphere with the reaching of middle level dry air mass combined with the moist atmosphere over Sri Lankan area. Recent heavy rainy condition in Sri Lanka was associated with the meeting of dry winds with moist winds (dry line). Therefore the findings of this study can be used for such events in future for early warnings.

Key Words:Flash Flood, Weather Research Forecast, NOAA NCEP, 3DVAR

Introduction

Sri Lanka is an island located in the tropics between 05N to 10 N and 80E to 83E to the south of India. Sri Lanka is regulated by two (2) major monsoons as southwest (May – September) and Northeast (December to February) with the prevailing southwesterly and northeasterly winds respectively. There is another two monsoons named as first inter-monsoon (March to April) and second inter-monsoon (October to November) in between two major monsoons. 60 % of annual rainfall in the country received from southwest and second inter-monsoon periods (Climatology available at the Department of Meteorology). 30% of annual rainfall received during the second inter-monsoon and this is the highest rainfall intense period, because it received within 2 months period and generally the rainfall fairly distributed over the country. Heavy rainfall events within this period usually associated with local thunderstorms as well as low pressure area developed in the Bay of Bengal.

Flash flood occurred in Colombo on 14th November 2014 at about 1630 SLST due to fairly heavy and intense rainfall. Newspapers mentioned that, Gangarama, Armour Street and Norris Canal Road in Colombo impacted for flash flood condition (Figure 1). Not only high intense rainfall, strong winds also accompanied with showers. Similar condition was experienced even Minuwangoda and Mattegoda area according to the newspapers.

Figure 1 : Flash Flood in Colombo with fallen some trees on 14th November 2014 (Courtesy of Lankadeepa News Paper)

Rainfall observation at the Department of Meteorology, Colombo reported 56 mm rainfall within 20 minutes (Figure 2). Past flash floods in Colombo also associated with heavy rainfall, but this event is not a common one due to less amount of rainfall within a short duration. Analysis of pluviograph clearly evident the high intense rainy condition.

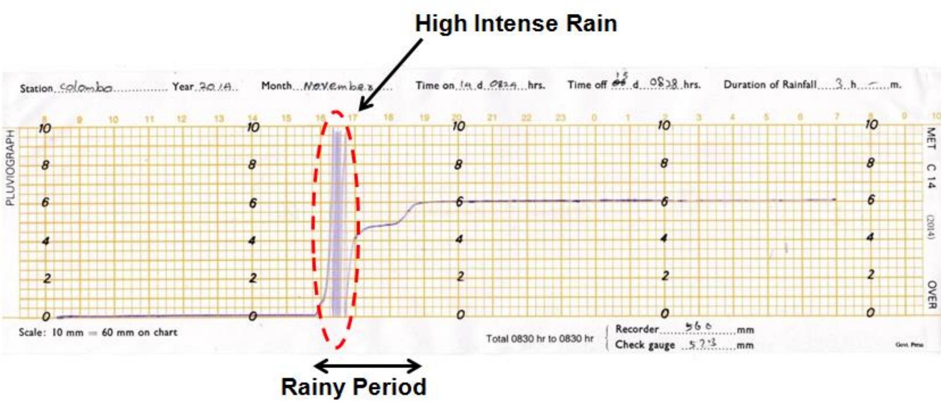


Figure 2: Pluviograph at CBO on 14th Nov 2014

Onset of southwest monsoon (end of May or beginning of June) associated with monsoon trough, meso scale phenomena (thunderstorm) during inter-monsoon periods (March – April and October – November) and indirect impact of cyclones and low pressure systems develop in the Bay of Bengal, are some of the main reasons for heavy and intense precipitation in Sri Lanka. In addition, heavy rainfall can be associated with the Inter Tropical Convergence Zone (ITCZ), which is at the vicinity of Sri Lanka. Month of November belongs to the second inter-monsoon. Thunderstorm with heavy rainfall accompanied with strong winds can be expected during the second inter-monsoon. Even this is a general feature during inter-monsoon seasons, it can be triggered due to local changes of the atmosphere. There are many heavy rainfall cases in Sri Lanka, associated with mesoscale systems. Heavy rainfall and strong winds on 01st June 2014 is a good example and 443.8 mm rainfall with heavy thunder activity with strong winds were received (Premalal et.al, 2015). Moore et al. 2003; Schumacher and Johnson 2005, 2006 mentioned that, a large percentage of extreme rainfall events result from particular organizations of deep convection in mesoscale convective systems (MCSs) that result in slow or repetitive storm motion over a particular geographic area. Even though the intense rainfall on 14th November 2014 associated with a thunderstorm, atmospheric phenomenon did not follow the usual pattern which favorable for local thunderstorms, because it was found that dry mid tropospheric winds reached towards the western coast of Sri Lanka during the event.

It is well known that frontal systems generally associates strong convective meso- scale systems along subtropical region. Many studies have been conducted on heavy rainfall associated with frontal systems. Some of the examples are onset of the summer southwesterly monsoon over China region. It is generally occurred in the middle of May as the mei-yu front established its quasi-stationary position over southern China, Taiwan, and the western North Pacific (Tao and Chen 1987; Chen 1988, 1994; Chang and Chen 1995).11 July 2007 indicates that a meso-alpha-scale low developed over a mei-yufrontnear 408N, 1348E at 0000 UTC (Biao, 2014) Themei-yufront extended from the East China Sea and sweptacross regions from western to eastern Japan. Deepconvection evolved over western Japan well ahead ofthemei-yu front. Not only these two events, there are many heavy and intense events can be found over the sub-tropical region associated to warm and cold fronts.

There are no frontal systems develop over the tropical region, but similar condition can be observed over the tropical region associated with the front line of meeting of midlevel dry and moist air. According to the past observation similar condition happened in Sri Lanka, which gave about 700 mm within 12 hours. But no written document available due to no or less studies on heavy rainfall associated with the collapsed of dry air and moist air along tropical region.

The aim of this study is to identify the synoptic situation associated with the heavy rainfall . Observation meteorological data and reanalysis data from NOAA NCEP was used for the analysis. Weather Research Forecast (WRF) model (Version 3.7.1) with 3DVAR data assimilation was used to downscale 1.0 degree NCEP data for 5 km grid to proper identification of local circulations. Satellite pictures and other atmospheric products also used to identify the clear reason for the intense rainy event on 14^{th} November 2014.

Data and methodology

NCEP reanalysis data has been widely used for diagnostic studies as, they usually capture the meteorological patterns synoptic scale. In addition, the sub synoptic scale mechanisms responsible for the heavy rains were investigated by means of numerical simulations with a mesoscale model, Weather Research and Forecasting (WRF) model. The WRF Model is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It can generate atmospheric simulations using real data (observations, analyses) or idealized conditions. It features two dynamical cores, a data assimilation system, and a software architecture facilitating parallel computation and system extensibility. (Source -WRF home page). The WRF model version 3.7.1 was included in the study as a tool to understand the physical processes that cause the high intensity rains.The model offers advantage compared to re–analyses because it allows description of the dynamical processes with higher horizontal and vertical resolutions. The WRF model was configured with 3DVAR data assimilation with resolution of 15km for regional scale analysis and 05km for localscale horizontal grid size and 35 vertical layers. The numerical integration was carried out for 12hrs starting at 0000 UTC on 14November 2014, using NCEP reanalyzes as initial and lateral boundary conditions. For the WRF model boundary conditions of topography are downloaded from the USGS website .Wyoming University sounding profiles were obtained to identify thermodynamic variables over the study region. Dundee satellite images were also downloaded for the study period to describe the sub-synoptic system.
In this study, the Runge-Kutta 3rd order time integration with 90 seconds time step were used in the WRF Model. WRF Single-Moment (WSM) 3-class and 6-class has been used as micro physics in the model and Kain-Fritsch (new Eta) scheme is being used as cumulas parameterization.

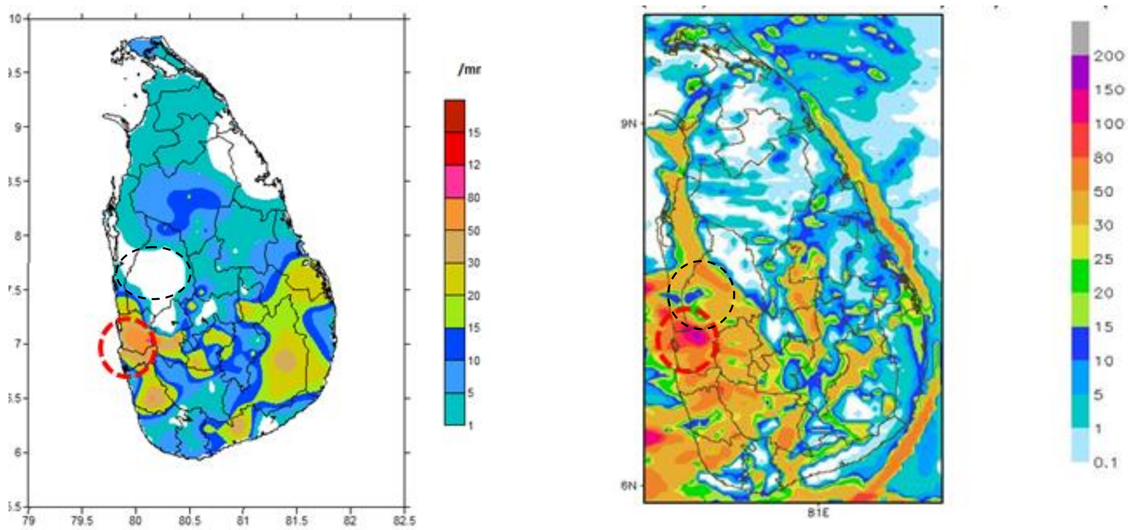
Model Configuration

Model Feature	configuration
Horizontal spatial resolution	15km (Regional) and 5km (Local)
Grid points	100X80
Vertical Levels	35
Topography	USGS 30 sec
Dynamics	
Time Integration	Runge-Kutta 3rd order
Time steps	90 seconds
Physics	
Micro physic	WRF Single-Moment (WSM) 3-class and 6-class
Cumulus physic	Kain-Fritsch (new Eta) scheme
PBL	YSU scheme
Surface layer	Monin-Obukhov Similarity scheme
Radiation	LW- RRTM scheme, SW- Dudhia scheme
Land Surface Process	Noah Land Surface Model

The Grid Analysis and Display System (GrADS) software was used to visualize the relevant data such as Winds, Relative Humidity (RH) at the levels, surface, 850 hpa, 700 hpa, 500 hpa and 300 hpa. Wind shear, CAPE, Vorticity and vertical winds also visualized for better analysis to identify the reason. Mechanism for uplift low level moisture is one of the important factors to develop cloud. Favorable wind shear will be enhancing the uplift until to develop cumulonimbus cloud. Generally, low level wind shear is considered as one of the factors, to develop cumulonimbus cloud as Chaudhari et al. 2010, explained. Chaudhari et al. found that the favorable condition to develop longevity and strengthen thunderstorms in the tropical region is wind shear between 0.003 S^{-1} and 0.005 s^{-1}.

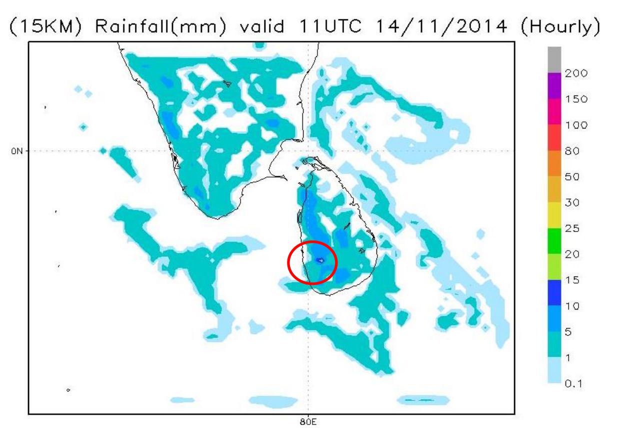
Results

To verify the model performance, rainfall on 14^{th} was compared with the observational values. Figure 3shows the WRF(5kmX5km) model output and the observed rainfall and Figure 4 shows the model simulation with 15kmX15km resolution. Red dashed circle shows the rainfall over Colombo area and the condition is mostly similar. Therefore the model with both simulations were able to capture the inland rainfall to some extent, except some places.Although the both simulations able to capture the isolated fairly heavy fall,there were over estimation around black circled area in figure 3(b) .

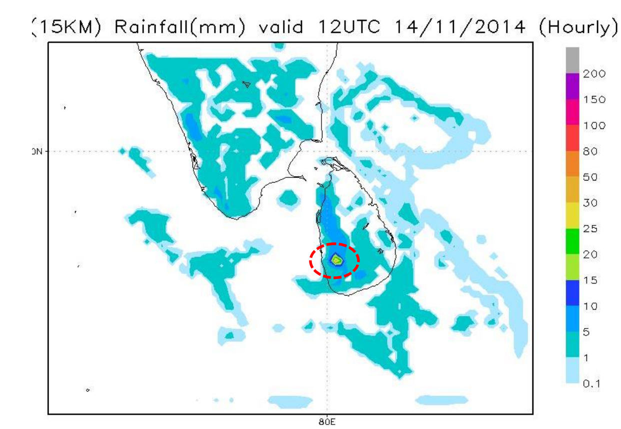


(a) Observation on 14th November 2014 **(b) WRF model simulation**

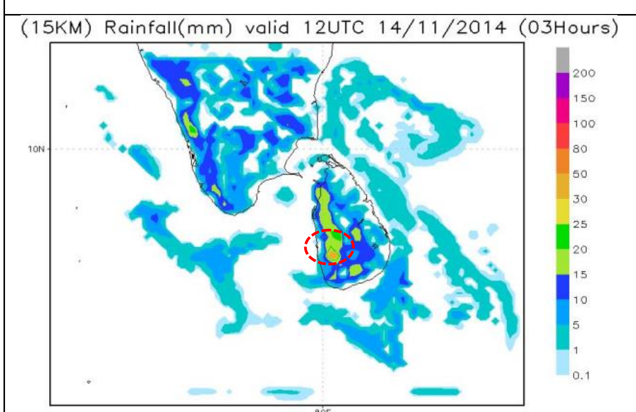
Figure 3 : observational rainfall data (a) and WRF simulated rainfall data on 14th November 2014



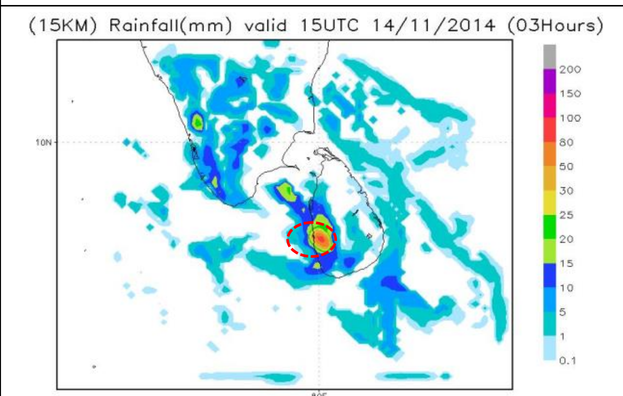
4a.hourly accumulated rainfall during 1530-1630hrs



4b .hourly accumulated rainfall during 1630-1730hrs



4c. 3.hourly accumulated rainfall during 1430-1730hrs



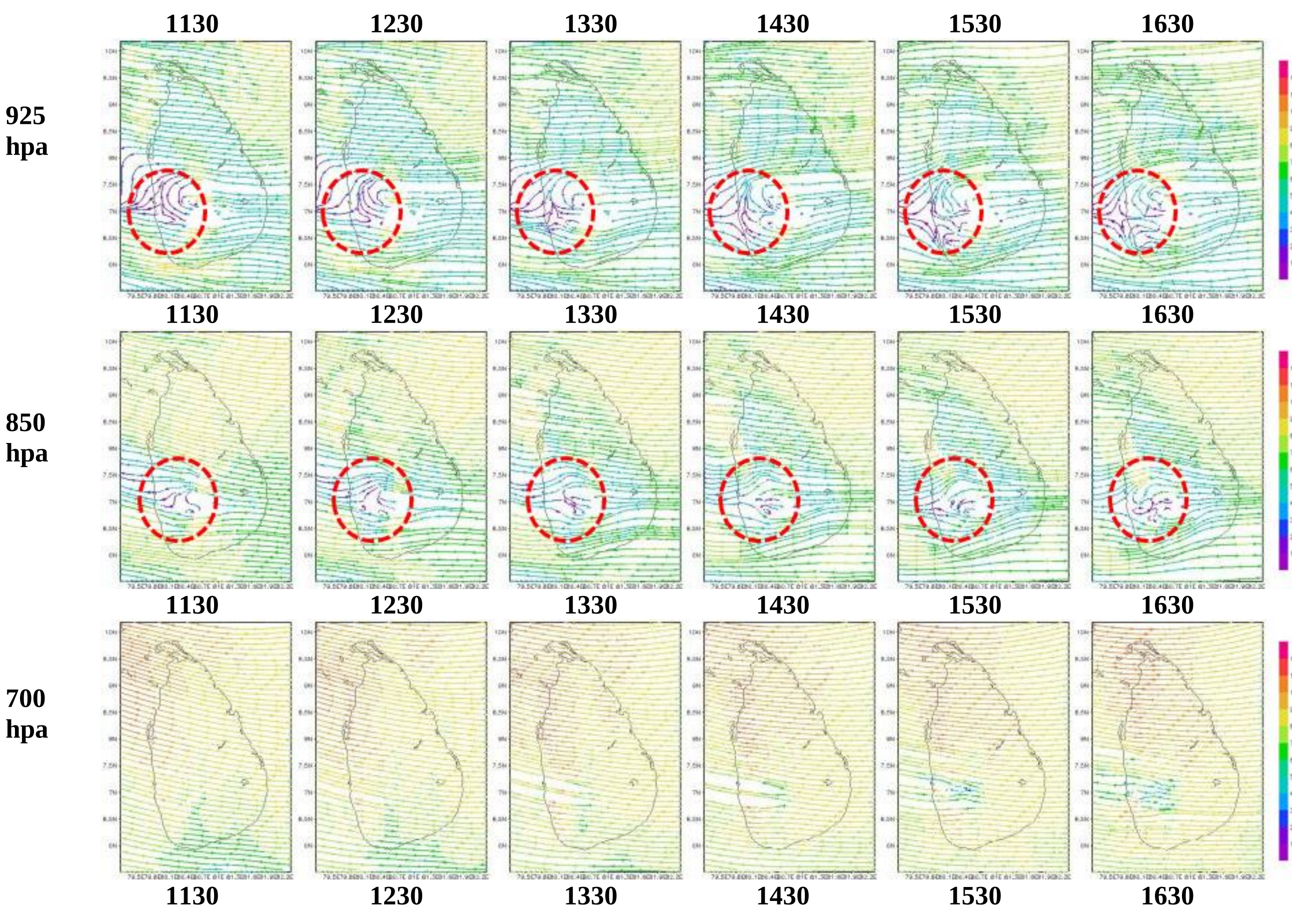
4d.3hourly accumulated rainfall during 1730-2030hrs

Figure.4Hourly and 3hourly accumulated rainfall (in mm) distribution with WRFDA(15kmx15km) model (with data assimilation) simulated on 14th November 2014.

Figure 5 shows the hourly wind pattern at 925hpa to 500 hpa level from 1130 SLST on 14th November 2014. Only low level, upto 850hpa, shows the development of localized wind disturbance over the southwestern part(red circled) of Sri Lanka, but the condition was gradually decreasing towards upper atmosphere. Therefore it clearly indicated the sudden change of lower atmosphere. Wind disturbance generally localized and it extended up to only 850hpa level. Therefore it is clear that the intense rainfall is associated with a meso-scale phenomena. It is essential to have moisture rich condition in the atmosphere todevelop severe thunderstorm. Analysis of relative humidity indicated the dry atmospheric condition reaching towards the western coast at the middle level. Figure 6A shows the RH at 925 hpa (near surface) and 850 hpa at 1130 and 1730 SLST. There was no moisture deficit at the surface, but it can be seen that gradual reaching of dry air mass towards the western coast of Sri Lanka at the level 700 and 500 hpa (Figure 6B). Figure 8 shows the Infrared(IR) and water vapour images at 1130SLST and 1730SLST. The water vapour images at 1130 SLST and 1730 SLST illustrate a clear boundary of dry and moist areas and IR images show the development of cloud along the boundary of dry and moist air (Figure 8). As the moist air is less dense than the dry air, more-densedry air mass overtakes the less-dense moist air mass. This phenomena is most likely behavior of a cold front. This sudden uplift helps to lifted up moist air from the low (850hpa) level.

Similar condition happened even in the past and heavy rainfall occurred due to the meeting of dry air and moist air. Therefore, the sudden change of local atmospheric and it upward motion was the reason of the meeting of dry and moist air.

Wind shear was calculated for further clarification and it also indicated the sudden buildup of favorable wind shear (between 0.003 and 0.005 s-1) for development of thunderstorm (Figure 9).



500 hpa

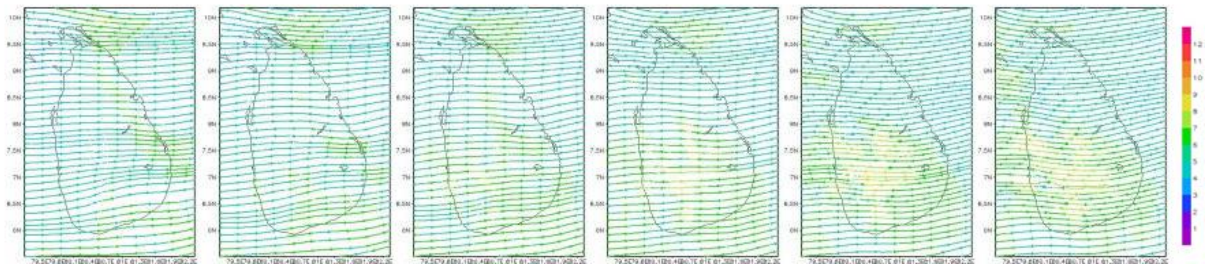
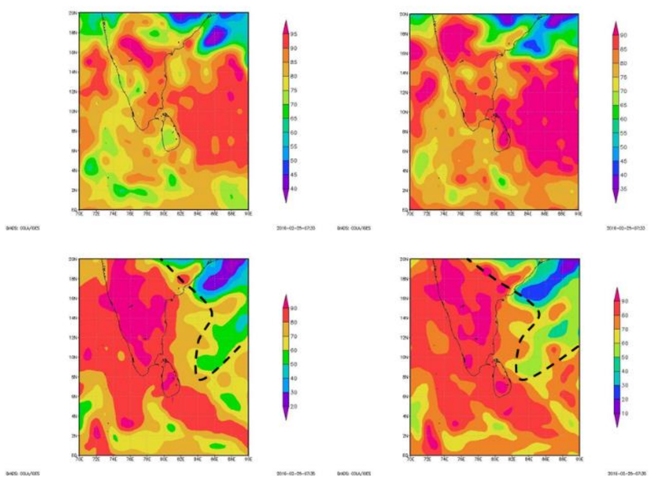


Figure 5 :change of local winds at 925 (near surface), 850, 700 and 500 hpa levels

(a) RH at 1130 (925 hpa) on 14/11/2014

(b) RH at 1730 (925 hpa) on 14/11/2014



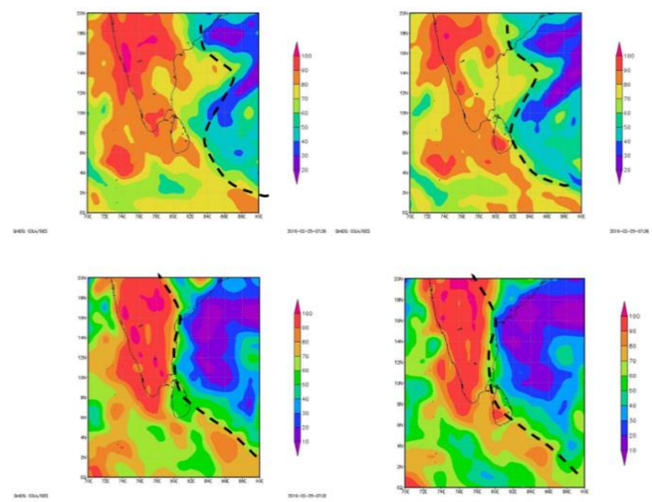
(c) RH at 1130 (850 hpa) on 14/11/2014

(d) RH at 1730 (850 hpa) on 14/11/2014

Figure 6A: Relative Humidity at 925 and 850hpa

(a)RH at 1130 (700 hpa) on 14/11/2014

(b)RH at 1730 (700 hpa) on 14/11/2014



(c)RH at 1130 (500 hpa) on 14/11/2014

(d)RH at 1730 (500 hpa) on 14/11/2014

Figure 6B: Relative Humidity at 700 and 500 hpa

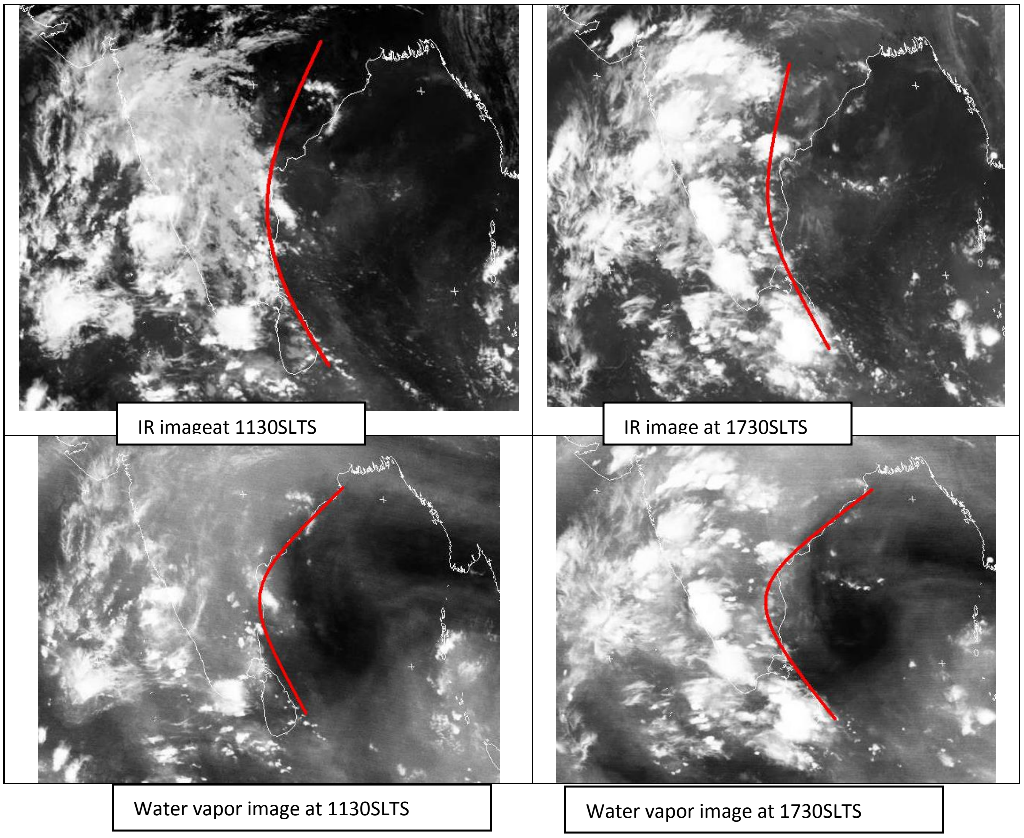


Figure8: Dundee Satelliteimages at (a) 1130 SLST and (b) 1730 SLST on 14.11.204

Figure 7a shows the observed tephigram at Colombo at 1130 SLST (0600 UTC) on 14th November 2014 and 7b shows the model simulation of CAPE during 11.30-1530 SLSTon 14th November 2014. Model simulation is well matched with the observation at 1130SLST and shows the gradual increased of CAPE around Colombo area(Black circled) during 1430-1530SLST . At 0600UTC both show low CAPE (748.5), but Lifted index supported to develop thunderstorms (LI = -2.65). Wind shear is 0.007 and it is not supported to develop thunderstorm.

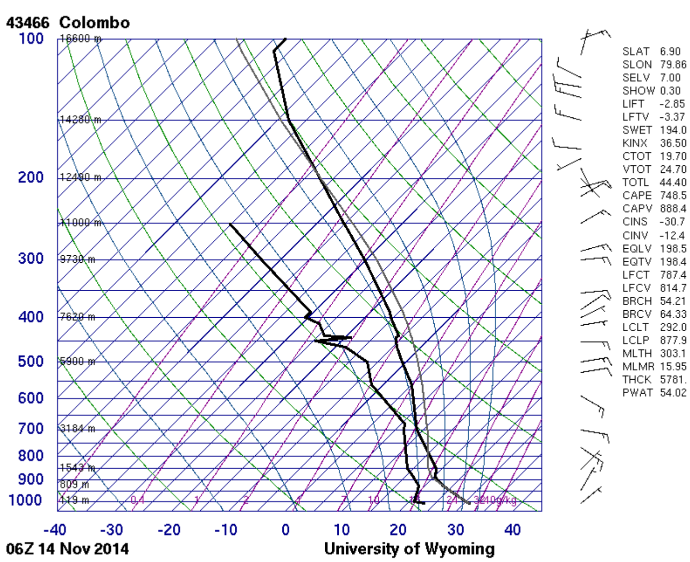


Figure 7a:SkewT diagram at Colombo at 0600UTC on 14th November 2016

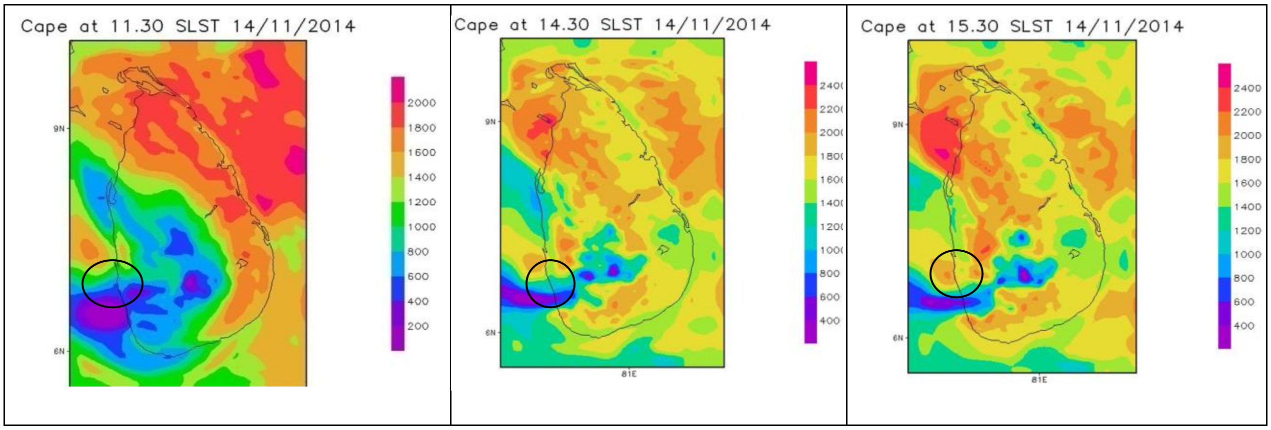


Figure 7b.Model simulation of CAPE during 1130-1530 SLST

Conclusion

It is cleared that the event is triggered with middle level dry air mass combined with the moist atmosphere over Sri Lankan area. Recent heavy rainy condition in Sri Lanka was associated with the meeting of dry winds with moist winds (dry line). Therefore the findings of this study can be used for such events in future for early warnings.

It can happen with the surface convergence, confluence etc at the surface level, but no convergence or confluence can be seen over the vicinity of Sri Lanka according to the wind analysis at different atmospheric levels shown in the figure 4. Analysis of relative humidity clearly evident that dry air mass reaching towards Sri Lankan area at 700 hpa and 500 hpa levels (Figure 5 and 6). Dotted line indicate the demarcation of dry and moist air masses at the levels 850 hpa to 500 hpa. It is much clear that the movement of dry air towards Sri Lanka.

Convective Available Potential Energy and Wind Shear were analyzed for the period 0000 – 1800 UTC on 14th November 2014. Upper air observation (Radiosonde) taken by Colombo meteorological station also analysed to identify the possibility of development of thunderstorm.

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