Synoptic Analysis of Catastrophe Heavy Rain and Strong winds over Sri Lanka on 01st June 2014

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ABSTRACT

Climatological onset of southwest monsoon in Sri Lanka is on 25th May ±5 and the month of June belongs to the southwest monsoons was delayed in 2014 and catastrophe heavy thunderstorm occurred in the western part s of Sri Lanka on 01st June 2014 evening. Nearly 110,743 people were affected and 6 people were killed from floods, landslides and strong winds. On the particular day some places reported more than 300 mm within 6 hours. This condition was continued for next two days too. This paper carried out a synoptic study in order to find reasons for such heavy rainy situation by analyzing Global Forecasting System (GFS) data based on 31st May 2014.

1 Introduction

This study focuses to find the possibility of issuing a severe weather warning on 01st June 2014, in advance by the National Meteorological Centre (NMC) in the Department of Meteorology, Sri Lanka. Severe thunderstorm with strong windy conditions was occurred in the western part of Sri Lanka on 01st evening (just after 1700 SLST) resulting huge disaster and huge economical losses. According to the Asian Disaster Reduction Centre (ADRC) Japan, nearly 110,743 people were affected from the flash flood in the western parts of Sri Lanka and death toll was six (6). Fully damaged and partially damaged houses due to strong winds and floods were about 294 and 1,850 respectively. Department of Meteorology was not able to predict such severe situation with the available weather charts and the other supplements. This condition was continued for next two days too. This paper carried out a synoptic study in order to find reasons for such heavy rainy situation by analyzing Global Forecasting System (GFS) data based on 31st May 2014

2 Synoptic Situation and Forecast

Climatologically, month of June belongs to the southwest monsoon season and heavy rainy spells can be expected during the month of June, particularly during the first two weeks over the southwestern region. Climatologically, onset date of monsoon in Sri Lanka is 25thMay with a ±5 days uncertainty, which is the monsoon onset date in central Arabian ocean (Fieux and Stommel, 1977). Even though, climatological onset date of monsoon is 25th May, it was not established even on 01st of June across Sri Lankan region. Steep (Pressure difference higher than 2.5 hpa between Colombo and Trincomalee at 0830 SLST) southwesterly pressure gradient, strong southwesterly wind flow over Sri Lankan region up to 6000 m (500 hpa), equatorial easterly jet about 40 knots at 200 hpa level over Singapore region are some of the essential criteria to establish southwest monsoon along Sri Lankan region. These criteria were not satisfied until 31stMay and even after. Wind anomaly charts (Earth System Research Laboratory) at the level 925 hpa, 850 hpa, 700 hpa and 500 hpa indicated the northeasterly or easterly anomaly over Sri Lankan region on 31st May 2014 (Figure 1 (b) to (d)) at all the three levels 850hpa, 700hpa and 500 hpa except at 925hpa (Figure 1(a)) where it was light westerly over there. Therefore, it is clear that monsoon was suppressed on 31st May and no chance to established across Sri Lankan region.

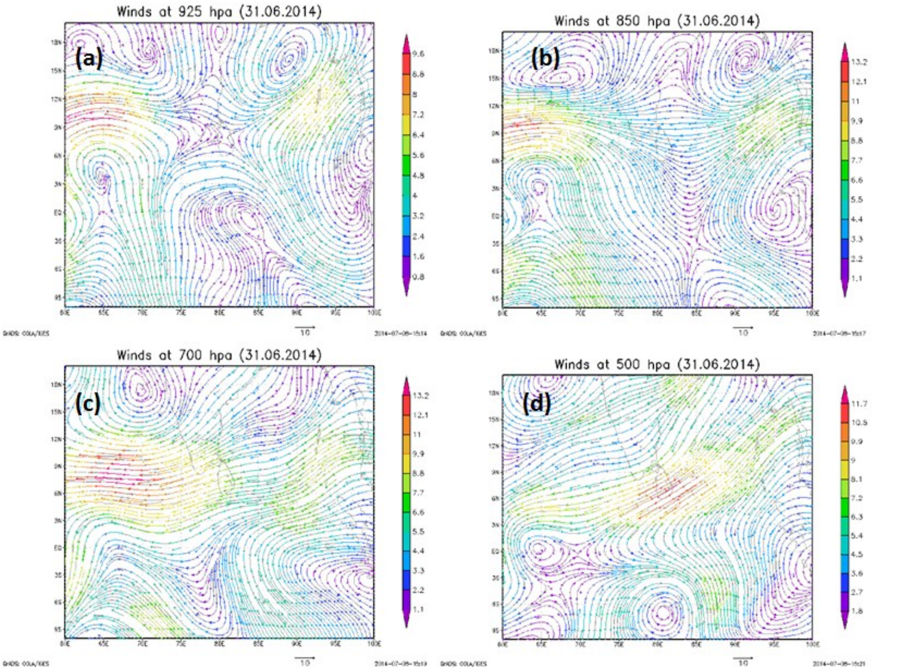


Figure 1: Charts of Wind anomaly vectors (Base period 1981-2010) at (a) 925 hpa (b) 850 hpa (c) 700 hpa (d) 500 hpa

Even though monsoon was not established over Sri Lanka, showers and possibility of having windy condition were included in general weather forecast on 31st May 2014 evening after analysis of surface data, upper air data and supporting numerical weather prediction charts and satellite imageries. The forecast issued by Department of Meteorology on 31st May 2014 for the next 24 hours is shown below.

"Showers will occur at times in the Central, Sabaragamuwa, Western and Southern provinces and several spells of showers will occur in the Western province particularly in the morning. Thundershowers will develop at several places in the Uva and Eastern provinces during the afternoon or evening.
Fairly strong winds can be expected along the western slopes of the Central hills at times.There may be temporary localized strong winds during thundershowers. General public is kindly requested to take adequate precautions to minimize the damages caused by lightning activities."

This forecast was continued until the next day evening, because there were no significant changes according to the regional charts and local synoptic charts. Rough analysis of numerical weather charts also did not show significant changes of the wind flow across the island and the vicinity. Therefore the issued forecast for the next 36 hours on 01st June 2014 at 1600 SLST was also the same forecast as above. After issuing the forecast on 01st June evening, satellite imagery at 1300 UTC (1830 SLST) indicated the development of cumulonimbus cloud along the western part of Sri Lanka (Figure 8). Hence unexpected heavy rainy situation with severe thunder activity, especially in the western parts of Sri Lanka was observed after 1300UTC on 01st of June 2014. Rain started in the evening on 01st of June and highest rainfall reported from Agalawatta, Kalutara district in the Western province, and the amount was 443.8 mm until 0300UTC on 02nd June 2014. The distribution of rainfall over the island on 01st of June is shown in the figure 2.

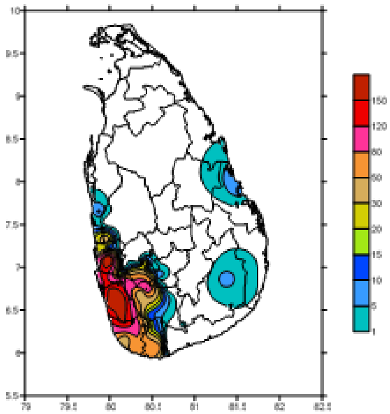


Figure 2: Daily Rainfall amount on 01st June 2014

Therefore it can be suspected that the situation was localized and not associated with the monsoonal flow across Sri Lanka. Hence analysis for this study was more concentrated to the Sri Lankan region.

3 Methodology

Comprehensive analysis has been carried out to find out the possible chances to issue the accurate forecast to some extent using the Global Forecasting System (GFS) data. Forecast data for the next 24 hours was used based on the initial data at 1200 UTC for this analysis. The resolution of the initial data is $1^0 x 1^0$ and the data downloaded from NOAA NCEP for 6 hour period. 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, CINE, Vorticity derived from the basic meteorological data were 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. Chaudhari et al. 2010, considered low level and upper level wind shear to identify the favorable condition to develop thunderstorms in tropical region. For the experiment they used 162 thunderstorm cases.The formula they used to compute wind shear was,

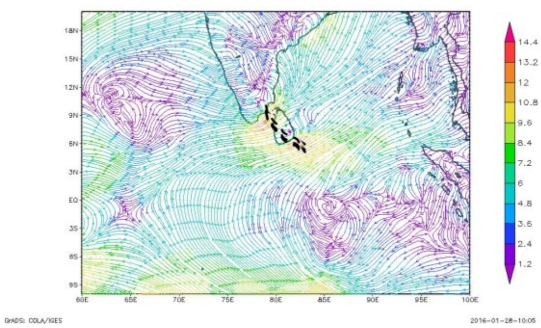
$$\mathrm{VWS}_{2-1} = \frac{\sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2}}{z_2 - z_1} \mathrm{s}^{-1}$$

Where VWS_{2-1} is vertical wind shear between lower level (1) and upper level (2); u_2, u_1 indicate zonal component of wind at level (2) and level (1) respectively; v_2, v_1 indicate meridional component of wind at level (2) and level (1) respectively; z_2, z_1 indicate height of (2) and (1) respectively. They computed Low Level Wind Shear (LLWS) between surface and 700 and Upper Level Wind Shear (ULWS) between 500 and 200 hpa. Then average wind shear was taken as the average of LLWS and ULWS. If the value is $<0.003S^{-1}$ it considered as low wind shear and Moderate wind shear for the value between $0.003S^{-1}$ and$0.005S^{-1}$ and high wind shear for the value $>0.005\ s^{-1}$. 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 $0.005\ s^{-1}$.

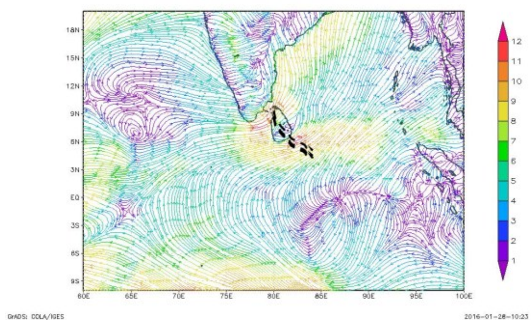
Other important variable for development of thunderstorm is higher Convective Available Potential Energy (CAPE) and low Convective Inhibition Energy (CINE). CAPE is the vertical integral of the buoyancy force exerted on an air parcel lifted from the surface to the level of neutral buoyancy and CINE is the contribution to this integral from the surface up to the level of free convection for suppressing convestion (Seol Eun Shin et. al., 2005). According to the study done by Chaudhari for 162 tropical thunderstorm, he found that CAPE values show more than 1000 J kg^{-1} for majority of thunderstorms and also CINE values were >-20 J kg^{-1}.

4 Results

Analysis and forecast of 1200UTC on 31st May data for next 24 hour period indicated low level trough over Sri Lanka (Figure 3(a) to (f)). Gradually it becomes little deepened, over the eastern coast of Sri Lanka by 1200 UTC on 01st June and wind discontinuity line was visible over the eastern part of Sri Lanka (Figure 3(e)) at 01st evening around 1200 UTC. It was a local phenomenon and it would help to increase the convergence at the surface level. Generally Relative Humidity (RH) at surface level is high on particular day.



(a) 2014.05.31 (1200 UTC)



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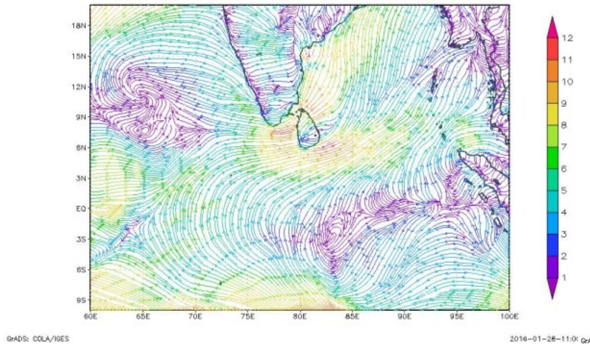
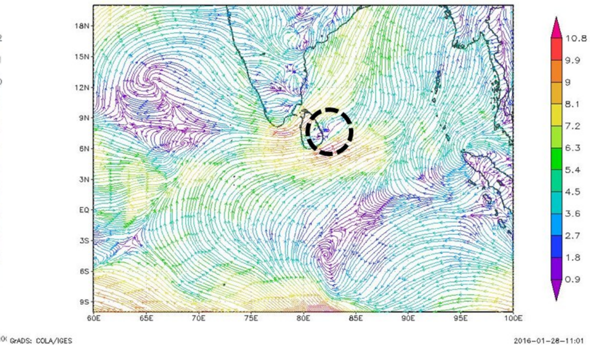
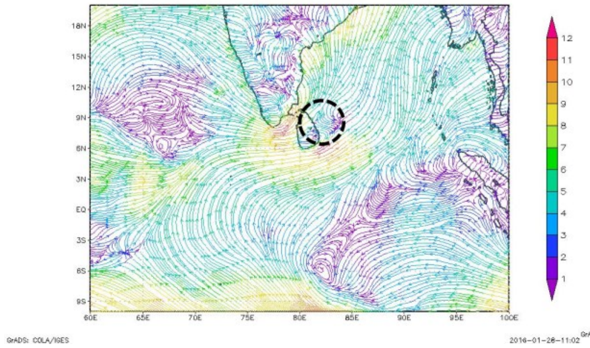
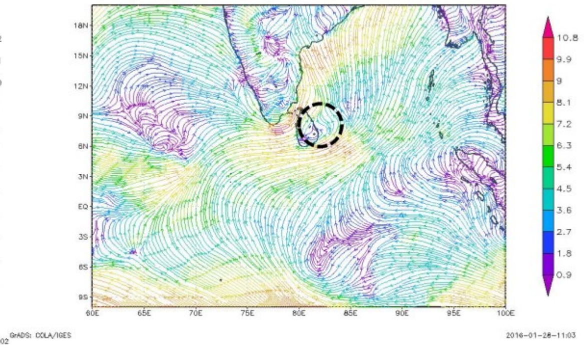




(c) 2014.06.01 (0000 UTC) (d) 2014.06.01 (0600 UTC)

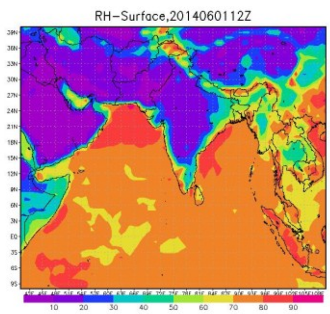


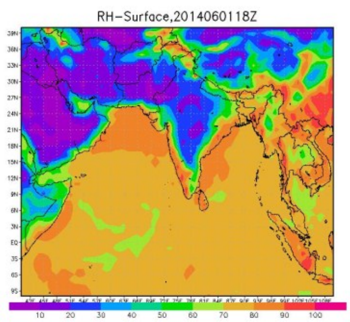


(e) 2014.06.01 (1200 UTC) (f) 2014.06.01 (1800 UTC)

Figure 3 (a) to (f): Wind charts at 925 hpa analysed using the GFS data at 1200 UTC

Figure 4 (a) and (b) show the surface RH at 1200 UTC and 1800 UTC on 01st June 2014 and it shows higher RH value as 70 – 80 % over Sri Lankan area and the vicinity. These features could help to uplift the moisture towards the upper atmosphere.

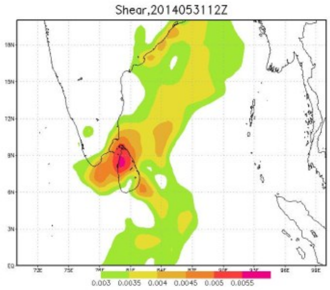




(a) 2014.06.01 (1200 UTC) (b) 2014.06.01 (1800 UTC)

Figure 4: Surface RH at (a) 01/1200UTC (b) 01/1800UTC

As described in chapter 3, wind shear has calculated. According to the figure 5 it is clear that the wind shear along Sri Lankan region is favorable for develop longevity and strengthen thunderstorms over Sri Lankan region on 01st June 2014.



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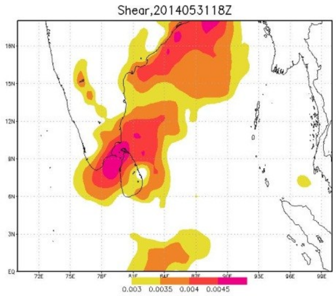

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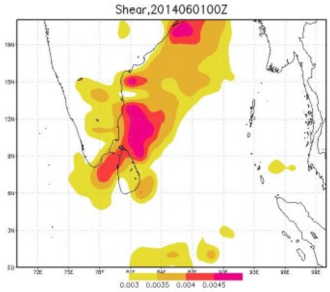

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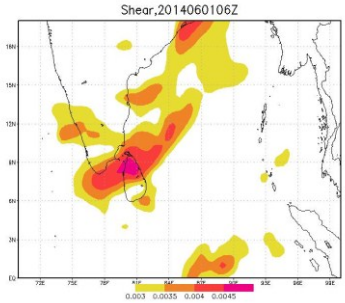

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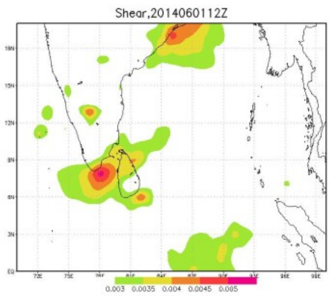
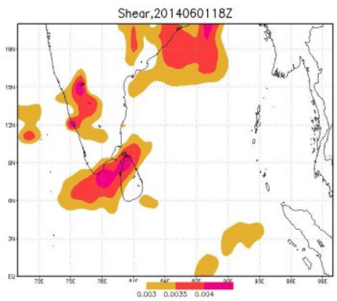


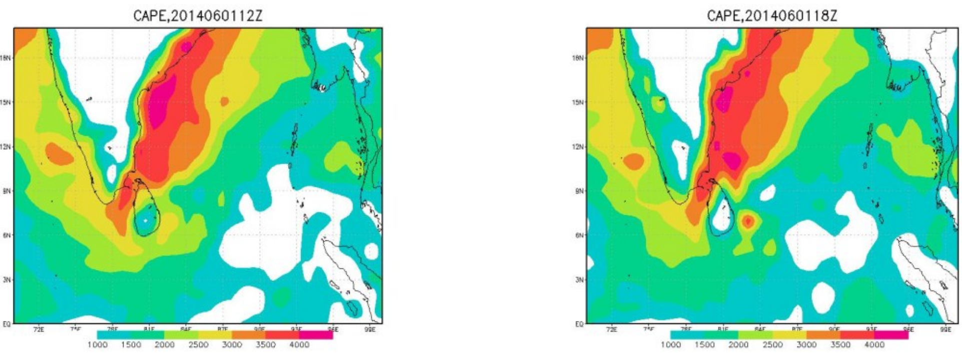
(e) 2014.06.01 (1200 UTC)



(f) 2014.06.01 (1800 UTC)

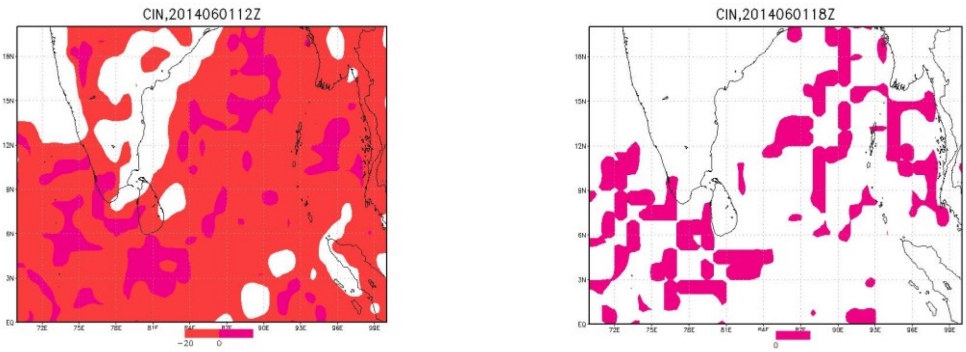
Figure 5 (a) to (f): Average wind shear at upper and low levels (after Chaudhari et al.) 6 hour interval

Favorable wind shear is not the only criteria to develop thunderstorms, CAPE also one of the important factors to develop thunderstorms. Seol Eun Shin et. al., (2005) explained CINE is the other important factor to develop thunderstorm. Figure 6 and 7 shows CAPE and CIN values on 01st June 2014. It also indicates the favorable condition (wind shear around Sri Lanka is ~ 0.004 s^{-1}) to develop thunderstorm over Sri Lankan region on particular day.



(a) 2014.06.01 (1200 UTC) (b) 2014.06.01 (1800 UTC)

Figure 6: CAPE for 01st June 2014



(a) 2014.06.01 (1200 UTC) (b) 2014.06.01 (1800 UTC)

Figure 7: CINE for 01st June 2014

5 Discussion

5.1 Convective Instability

Surface analysis and the wind shear indicates the possibility of development of thunderstorm. CAPE and CINE also indicates the stability to develop thunderstorms in the upper atmosphere. Further analysis such as vertical winds, localized vorticity by running a mesoscale model with data assimilation, has to be done to find out the reasons for severe weather condition on 01st June 2014, because satellite imageries indicate the rapid and stationary development of cumulonimbus cloud mass over western coast over Sri Lanka. Figure 8 shows the 60 minutes interval satellite imageries and it indicates a possibility of super-cell type development over western part.

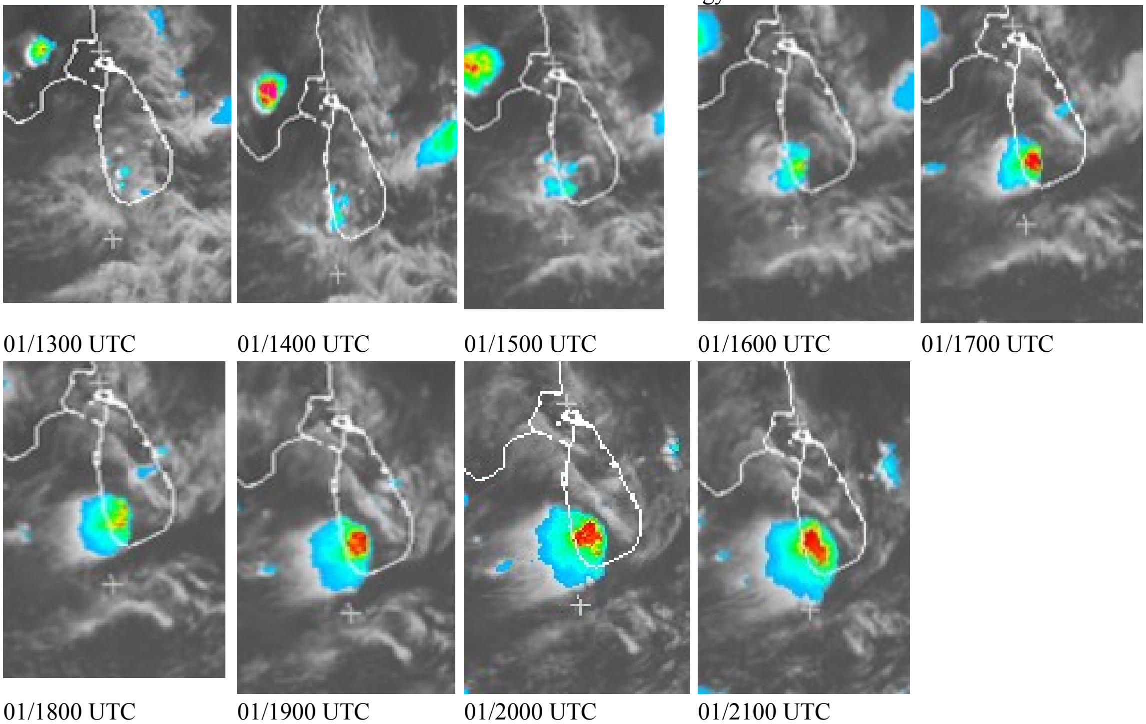
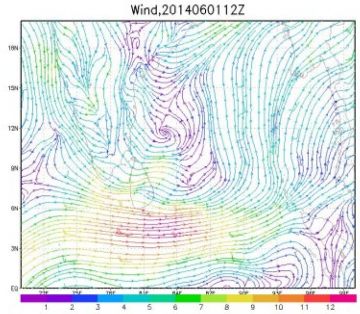


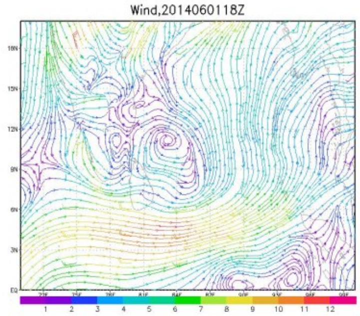
Figure 8: Hourly Satellite Imageries on 01st June 2014

Generally a super-cell storm are developed as a single core convective cloud, which have a deep persistent and rotating updraft. They are often accompanied by strong winds, tornedos, heavy rainfall with hail and high intense lightning flash (Honda et.al.). According to the meteorological observations done in Sri Lanka, high intense lightning flashes were recorded from the meteorological observation stations at Colombo, Ratmalana and Katunayake in the western part in Sri Lanka. Hail was not reported, but reported rainfall intensity was very high and the highest amount is 443.8 mm within about 16 hours. Strong winds were not reported according to three hourly observation data taken by the meteorological stations, but strong winds were reported through the media and the Disaster Management Centre (DMC).

A Supercell cannot be identified without monitoring the system continuously. To find the possibility to develop the system on particular day, analysis have to be extended to the other important atmospheric layers such as 850 hpa, 700 hpa, 500 hpa and 300 hpa. Figure 9 shows the Winds and RH on 01st June 1200 and 1800 UTC at 850 hpa. It does not indicate proper synoptic feature for convergence except associated trough to the circulation over the Bay of Bengal (BOB), but 01/1800 UTC indicates convergence or north to south trough line over western coast of Sri Lanka. RH charts shows the favorable moist condition to develop clouds.



(a) 2014.06.01 (1200 UTC)



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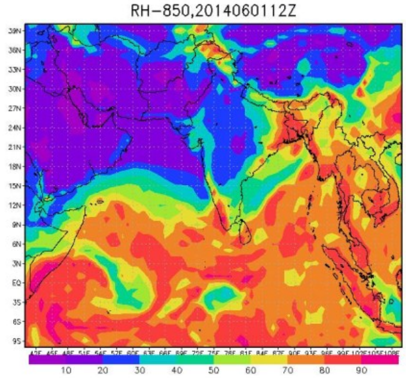

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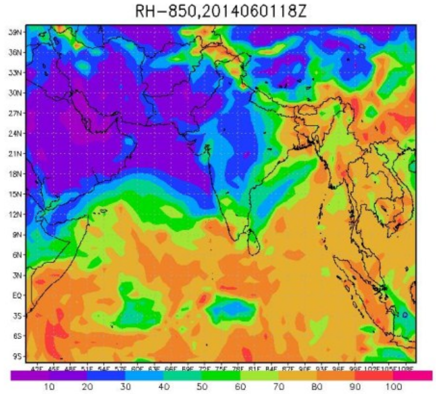
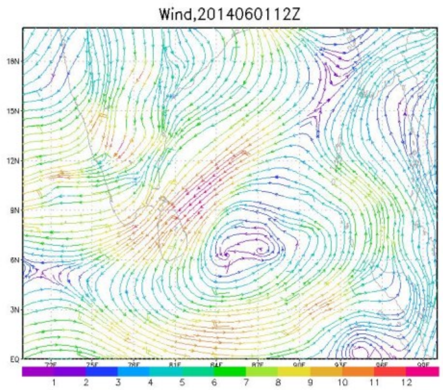


(d) 2014.06.01 (1800 UTC)

Figure 9: (a) and (b) winds at1200 and 1800 UTC on 01st, (c) and (d) RH at 1200 and 1800 UTC on 01st

Figure 10 shows the Winds and RH on 01st June 1200 and 1800 UTC at 700 hpa. It also does not indicate proper synoptic feature for convergence. But a trough line associated with the cyclonic circulation towards the south east of Sri Lanka could be supported for regional convergence. RH charts also shows the favorable moist condition to develop clouds.



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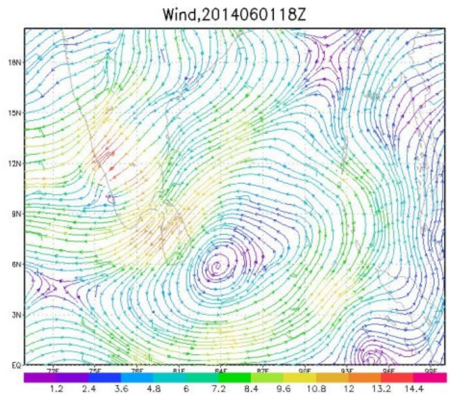

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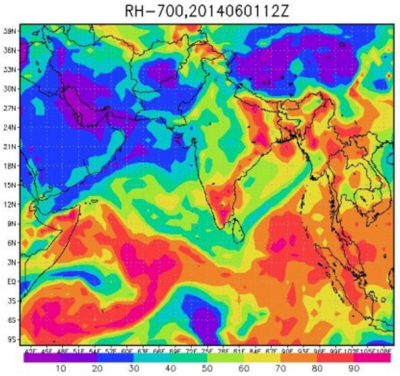

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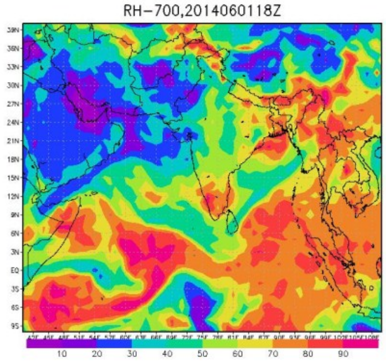


(d) 2014.06.01 (1800 UTC)

Figure 10 :(a) and (b) winds at1200 and 1800 UTC on 01st, (c) and (d) RH at 1200 and 1800 UTC on 01st

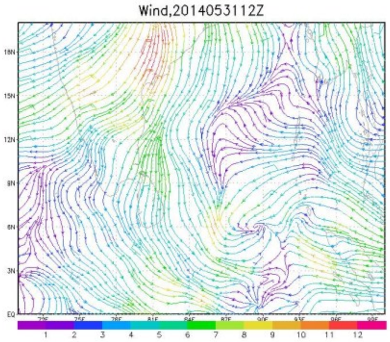
Deepened near surface trough at the 925 hpa level (Figure 3) and the wind discontinuity line over the eastern part of Sri Lanka associated trough at 850 hpa to the cyclonic circulation over BOB, west to east trough associated to the cyclonic circulation to the southeast of Sri Lanka at 700 hpa at 1200 UTC on 01st June 2014 indicated some regional convergence and unstable condition along Sri Lankan region. Not only that favorable wind shear, CAPE and CINE also indicated the favorable conditions to develop thunderstorm over Sri Lankan region.

Analysis of 500 hpa level shows the dry condition and winds are blowing from dry Indian land (Figure 11). Hence the analysis of relative humidity indicates the gradual decreases of humidify over Sri Lankan region (Figure 12). Matthew et. al. 1998, pointed out that the possibility for develop thunderstorm or meso-cyclone within the storm area even for dry mid tropospheric condition.

Convective instability occurs when dry mid-level air advects over warm and moist air in the lower Planetary Boundary Layer (PBL) (http://www.theweatherprediction.com/habyhints/214/). This instability caused by the release of latent heat in convection. Due to the more moisture over the PBL, the cooling rate of the air parcel with height is decreased (perhaps only 4 C/km).

Sri Lanka experienced heavy thunderstorm on 17th June 2003 and some places received more than 700 mm within 12 hours. Analysis of 500 hpa shows dry atmospheric conditions on the particular day and northerly winds blew from the Indian land. Weather condition on the particular day is almost similar as the atmosphere on 01st June 2014, because both systems are mesoscale systems. Therefore dry at mid troposphere show positive condition to develop severe thunderstorm.

Dryness is not the only reason, 500 hpa chart indicated the gradual development of circulation over the eastern coast of Sri Lanka and it might be one of the reason of enhance the convergence capacity on 01st June 2014 (Figure 11).



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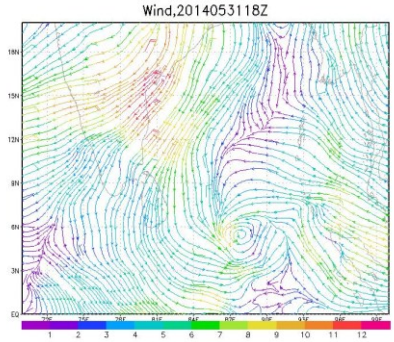

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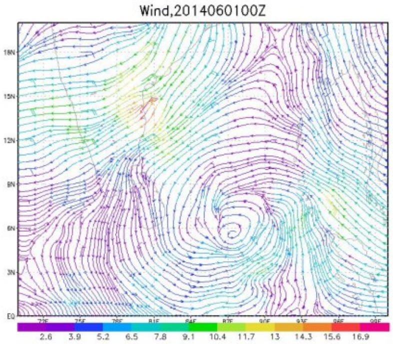

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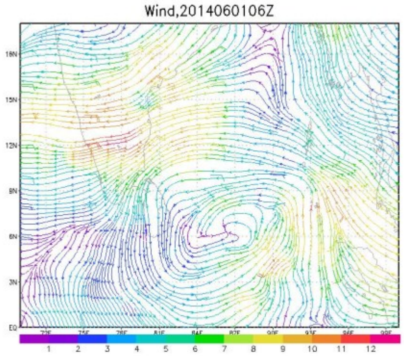

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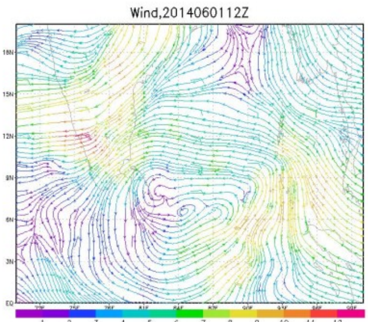

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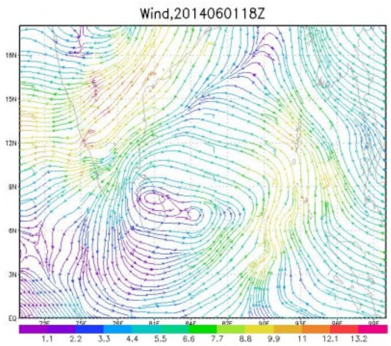
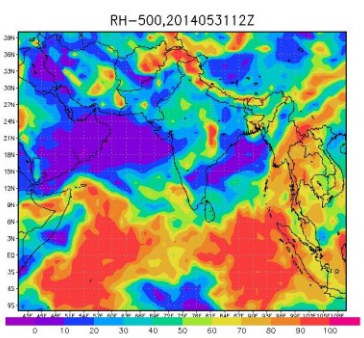


(f) 2014.06.01 (1800 UTC)

Figure 11 : Wind charts at 500 hpa analysed using the GFS data at 1200 UTC



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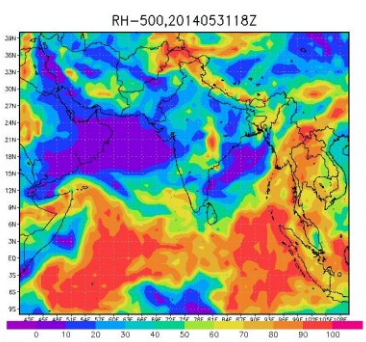

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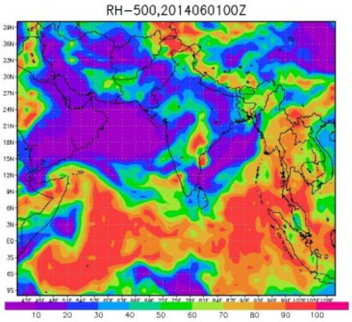

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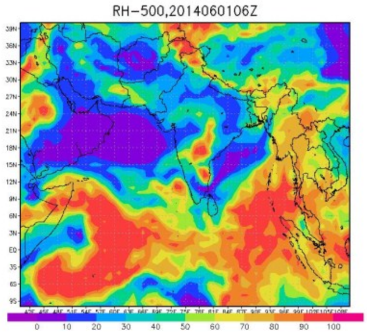

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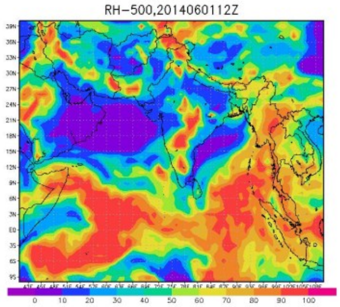

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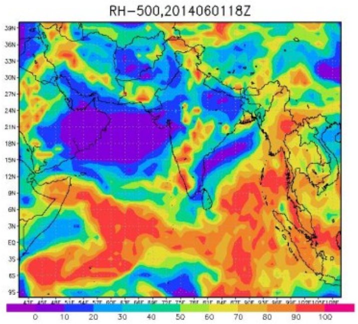


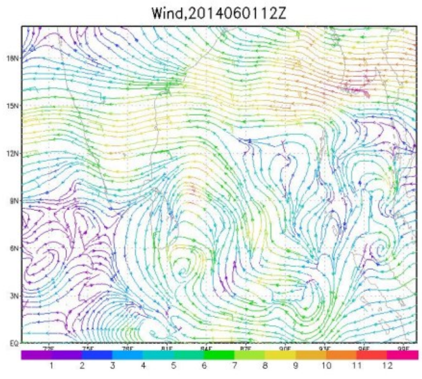
(f) 2014.06.01 (1800 UTC)

Figure 12 : RH at 500 hpa

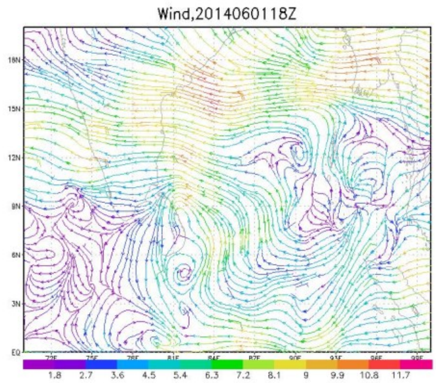
Other significant feature to develop severe thunder storm is Tropical Upper Tropospheric Trough (TUTT) Upper air analysis has been carried out for the layer 300 hpa and it indicates the convergence existed in the area over the northern part of Sri Lanka.

Ferreira and Schubert, 1999 explained in their study about the role of TUTT for tropical cyclone genesis. They also mentioned in their papers about other authors findings. Accordingly, a TUTT cell can cause a decrease in intensity or inhibition of genesis by increasing the vertical wind shear in which the tropical cyclone is embedded (e.g., Gray 1968). On the other hand, when the vertical wind shear does not exceed a certain threshold, TUTT cells may aid in the genesis and intensification of tropical cyclones (e.g., Pfeffer and Challa 1992; Montgomery and Farrell 1993; Molinari et al. 1995). Hence it is clear that TUTT plays an important role for uplifting the air parcel by enhancing the wind shear, when it is not at threshold level to develop cyclones.

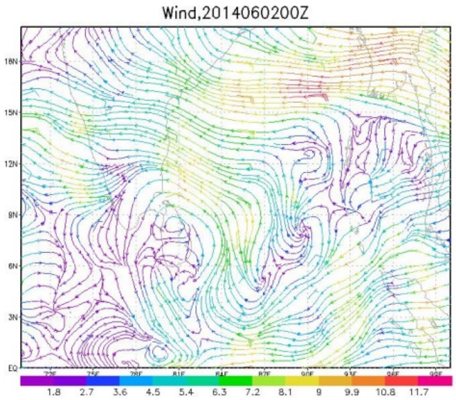
Vertical wind shear is one of the important factor to develop thunderstorm in the tropical region. Therefore TUTT can play a vital role to decrease the inhibition energy as well as increase the vertical wind shear. Analysis of 300 hpa wind charts (figure 13) on 01st June 2014 indicates gradual development of circulation and the associated trough over north of Sri Lanka. Therefore in-cooperated the condition at 300 hpa with the other layers it is possible to develop meso scale convective activity over Sri Lanka on 01st June 2014.



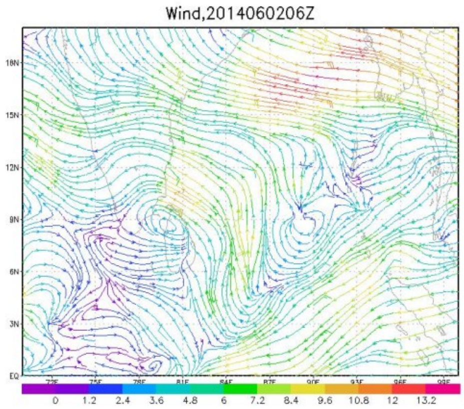
(a) 2014.06.01 (1200 UTC)



(b) 2014.06.01 (1800 UTC)



(c) 2014.06.02 (0000 UTC)



(d) 2014.06.02 (0600 UTC)

Figure 13: Winds at 300 hpa

Conclusion

It is noticed that 500 hpa and 300 hpa layers contributed more to developed such condition on 01st June 2014. Generally this is very rare case and no or less case studies have been conducted for this type of severe weather situation, therefore it is not easy to find out an exact reason to develop strong meso scale thunderstorms. Especially no or less research have been conducted to find out the relationship between TUTT at 300 hpa and the thunderstorm development , but more research are still going on the relationship on TUTT at 300 hpa and cyclogenesis on Atlantic ocean. In this paper that feature is adopted to develop severe thunderstorm. Therefore more research has to be conducted to identify the relationship between the severe thunderstorm and the TUTT.

Other important level is the 500 hpa. Low level higher instability is much important to over shoot the air parcel at 500 hpa even if it is dry. Therefore more attention have to be paid for these two levels to identify the possibility to develop severe thunderstorms.

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REFERANCES

Chaudhari et.al. 2010, Thunderstorms over a tropical Indian Station, Minicoy: Role of Vertical Wind Shear, Journal of Earth System Science, 119, No.5, pp, 603-615.

Ferreira and Schubert, 1998, The Role of Tropical Cyclones in the Formation of Tropical Upper-Tropospheric Troughs, Journal of Atmospheric Science, 56, 2891-2907

Fieux, M., and H. Stommel, 1977: Onset of the southwest monsoon over the Arabian Sea from marine reports of surface winds: Structure and variability. Mon. Wea. Rev., 105, 231–236.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. Mon. Wea. Rev., 96, 669–700.

athew S. Gilmore and Louis J. Wicker, 1998, The Influence of Midtropospheric Dryness on Supercell Morphology and Evolution, Mon. Wea. Rev.,126, 943-958

Molinari, J., S. Skubis, and D. Vollaro, 1995: External influences on hurricane intensity. Part III: Potential vorticity structure. J. Atmos. Sci., 52, 3593–3606

Montgomery, M. T., and B. F. Farrell, 1993: Tropical cyclone formation. J. Atmos. Sci., 50, 285–310.

Pfeffer, R. L., and M. Challa, 1992: The role of environmental asymmetries in Atlantic hurricane formation. J. Atmos. Sci., 49, 1051– 1059.

Seol Eun Shin et. al., 2005 , Severe thunderstorms over northeastern Queensland on 19 January2001: the influence of an upper-level trough on the convective destabilisation of the atmosphere,, Aust. Met. Mag. 54, 333-346

Takumi Honda et.al. Effects of Mid-Tropospheric Dry Air on Evolution of Supercell Storms, Kyushu University, Fukuoka, Japan

URL
http://www.theweatherprediction.com