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The Effect of Atlantic Nino on the Summer Monsoon Rainfall Anomalies in Sri Lanka

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Abstract

Sri Lankan climate is influenced by temperature patterns in the Indian Ocean as well as the Pacific Ocean. El-Nino Southern Oscillation (ENSO) is one of the global scale climate phenomena that have significant influence on the year to year variability of the monsoon over South-Asia. There have been numerous studies which explores the connection between the Indian Summer Monsoon (ISM) rainfall and the Atlantic Niño. However, the teleconnections of the Atlantic Ocean with the rainfall of Sri Lanka are not extensively studied. Considering the rainfall over Sri Lanka, Atlantic Niño and the South-west monsoon (summer monsoon) peaks during the June-July-August (JJA) period. Therefore, in this study the connections of the Atlantic Ocean, specifically the Atlantic Niño with regards to the ATL3 region rainfall during June-July-August (JJA) periods were considered. It was found that the JJA rainfall anomaly had significant correlations with the SSTA of ATL3 region (Atlantic Niño/Niña). In this study it was revealed that the Atlantic Niño has a significant positive correlation with rainfall over Sri Lanka with the Niño (positive phase) resulting in increasing JJA seasonal rainfalls over Sri Lanka while the Niña (negative phase) reduces the rainfall. Then the potential mechanisms of how the Atlantic Niño/Niña is linked to the seasonal rainfall JJA were studied. In doing so, Relative Humidity (RH) at lower levels of the atmosphere, Outgoing Long-wave Radiation (OLR), divergence at different levels, zonal and meridional wind components at different levels of the atmosphere, moisture flux and moisture flux divergence, streamline analysis were extensively studied. In this analysis, it was revealed that low pressure areas associated with the SSTA anomaly over the tropical Atlantic Ocean during the Niño phase has drawn the zonal winds at lower-levels of the atmosphere towards the Atlantic Ocean which has strengthened the latter part of the cross-equatorial flow prevalent during the south-west monsoon period. Cross-equatorial flow plays a vital role during the south-west monsoon period. In addition to that, the extra water vapor that is evaporated during the Niño phase is then transported over the North African continent to the Indian Ocean by the strong westerly zonal wind anomaly prevalent over the Atlantic Ocean. This moisture is then fed to the westerly flowing upper part of the cross-equatorial flow which will further enhance the rainfall over south-western part of Sri Lanka. This wind formation also has resulted in keeping the Inter Tropical Convergence Zone (ITCZ) or the Monsoon Trough (MT) over Sri Lanka for an extended period.

***Keywords:** Rainfall; Sri Lanka; South-West monsoon; Atlantic Nino; Teleconnection; SST*

Introduction

Rainfall over Sri Lanka has been affected by various factors such as ENSO, IOD and MJO. Early studies have shown that the rainfall over Sri Lanka has significantly increased with the rainfall over Sri Lanka during the South-West monsoon making the most significant increase. Previous studies have found that there exists a relationship of rainfall and SST of the Indian Ocean. This relationship was found to be independent of ENSO which was later identified as the IOD and characterized by the Indian Ocean Dipole Mode Index (IODMI). ENSO which originates in the Pacific Ocean also has significant impact on the rainfall over Sri Lanka. According to previous studies it has been found that ENSO is responsible for significant annual rainfall variability over Sri Lanka and the South-Indian peninsular. This can be attributed to the SST variability of the Indian Ocean with El-Nino and IOD accounting for 30% and 12% of the SST variability respectively. Statistical analysis has shown that the correlation of

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the Southern Oscillation Index (SOI) is positive with the South-West monsoon rainfall over Sri Lanka. MJO which originates in the Indian Ocean also has significant impact on rainfall over Sri Lanka, especially on the strengthening of the monsoons. A study which examined rainfall during 1981-2010 over Sri Lanka has shown that the MJO has a greater impact on the rainfalls during the South-West monsoon period [1-3].

Atlantic Nino is generally identified as the Sea Surface Temperature (SST) anomaly in the equatorial region between 0^o and 30^oW. Atlantic Nino is a basin wide anomaly compared to the El-Nino of the Pacific where the SST anomalies switch from east to west. This SST anomaly is related to change in the climatological trade winds. According to the study of Zebiak in 1993, the Atlantic Nino or the ATL3 index is defined as the SST anomaly in the tropical Atlantic Ocean between 3^oN-3^oS and 0^o-30^oW. Valles-Casanova and his group in their study in 2020 has defined the Atlantic Nino (Nina) as the three month averaged SST anomalies exceeding 0.5°C (-0.5°C) in the ATL3 region for at least two consecutive seasons. According to their study, the Atlantic Nino develops in the boreal spring which is the March to May (MAM) period and peaks in boreal summer which is the June to August (JJA) period and disintegrates in fall [4-7].

Considering the rainfall over Sri Lanka, Atlantic Nino and the South-west monsoon (summer monsoon) peaks during the June-July-August (JJA) period. There have been numerous studies which explores the connection between the Indian Summer Monsoon (ISM) rainfall and the Atlantic Nino. It is stated that the ISM rainfall which peaks during the boreal summer has an inverse relationship with Atlantic Nino. This has been attributed to the intensification of the Inter Tropical Convergence Zone (ITCZ) as a result of the enlargement of the upper tropospheric divergence. This intensification results in an upper tropospheric divergence which entices a series of geopotential height anomalies. This binds the relationship of Atlantic Nino and Indian summer monsoon [8-12]. This combined with the Pacific-Japan type pattern which hinders the cross-equatorial flow, enhances the moisture transport towards Indian regions and strengthens the monsoon rainfall. It has also been stated that South equatorial Tropical Atlantic (STA) modulates the rainfall of the Indian monsoon by a Gill-Matsuno mechanism which was tested through Coupled General Circulation Models (CGCMs) revealed that a teleconnection exists between STA and Indian region. Atlantic Nino also seem to intensify the meridional stationary wave that affects the anomaly of pressure over northwest Europe which triggers the Eurasian Rossby wave along the mid latitude upper troposphere high pressure anomaly which then affects the northern India. However, the effect on rainfall in this region from this phenomenon has not been studied. In another study it has been found that Atlantic Nino warms the western Indian Ocean and weakens the ISM rainfall by an atmospheric Kelvin wave propagating eastward which is produced by the easterly wind anomalies in the tropical western Indian Ocean. Studies have found that in the recent decades, the connection between the Atlantic Nino and the Pacific Ninas of the following winter through the strengthening of the Walker circulation has enhanced. However, the modulation (or the lack thereof) between the South-west monsoon, which is a subset of the ISM has not been studied. The increasing number of studies linking ENSO and IOD with Atlantic Nino warrants the need to further investigate the relationship between climate of Sri Lanka and Atlantic Ocean [13-16].

Sri Lanka is a country that is affected by an array of weather related hazards such as floods, flash floods, heavy rainfall, strong winds, thunder and lightning strikes, droughts etc. With the recent changes in climate, the extreme events have increased and the severity of these hazards has increased considerably throughout the world. For instance, Sri Lanka has encountered floods, flash floods and heavy rains with thunder and lightning during the last quarter of the year 2019 damaging crops and livelihoods of countrymen all around the island with considerable number of casualties. Floods are the most common type of natural disaster in Sri Lanka with the flood risk profile rising due to the frequency of hydro meteorological hazards. High majority of these flash floods and floods occur in the South-West monsoon period. The annual monsoons and related floods and landslides are the most dangerous in terms of human casualties and economic impact (UNDRR, 2019). Sri Lanka was one of the top 3 countries that were affected with weather related loss events estimates in 2017 and ranked second in the climate risk index which is used to measure the economic losses resulting from extreme weather. Floods and other hydro meteorological hazards combined with droughts have a considerable impact on the healthcare sector of the country with the burden of these events on healthcare was estimated to be 52.8 million USD annually.

Sri Lanka depends heavily on agriculture and agriculture forms the backbone of rural livelihoods. The amount of rainfall received has decreased and conventional rainfall patterns have changed which has affected the distribution of rainfall various parts of the country. Drought conditions have caused delays in planting seasons and have adversely affected the planting seasons while floods destroy mature crops which are to be harvested. 82% of Sri Lanka’s populations are rural and agriculture is the one of the main contributors to their livelihoods. 80% of the country’s low-income people represent the rural sector and 50% of poor rural people are small-scale farmers. Considering the contribution to economy, agriculture sector contributes 8.36% of Gross Domestic Product (GDP) in the year 2020 which is in an upward trend (The World Bank, n.d.). Tea and rubber which are two of the three major agricultural exports in Sri Lanka contributes to a staggering 55.67% of the agricultural export earnings in Sri Lanka. Tea smallholders contribute 70% of Sri Lanka's total tea production, while smallholder rubber growers cultivate 62% of the land under rubber cultivation who have mostly depended on rain water for their farming activity. However, excessive rainfall can also damage the crops and bring destruction to the day to day lives of the people. In this background, better climate predictions in the long term will assist policy makers, Irrigation engineers and farmers to better prepare for impending situations and accurate short-term predictions would be beneficial for mitigation of adverse impacts of any approaching weather-related hazards. Therefore, studying extreme events that affect Sri Lanka would be highly beneficial for reduce adverse impacts of impending situations. In this regard, ocean-atmospheric coupled teleconnections such as El-Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Madden-Julian Oscillation (MJO) have played a major role in climate predictions.

Sri Lankan climate is influenced by temperature patterns in the Indian Ocean as well as the Pacific Ocean. El-Niño Southern Oscillation (ENSO) is one of the global scale climate phenomena that have significant influence on the year-to-year variability of the monsoon over South-Asia. However, the teleconnections of the Atlantic Ocean with the rainfall of Sri Lanka are not extensively studied. Therefore, in this study the connections of the Atlantic Ocean, specifically the Atlantic Niño to the rainfall in the South-West monsoon period over Sri Lanka are looked into.

Materials and Methods

Main features of the South-West monsoon

The period from end of May to September is generally referred to as the 'Southwest monsoon' period. The Southwest monsoon period is the main rainy season for the whole of Indian subcontinent. Indian Summer monsoon will be affected by many factors. In recent years there is much scientific research on the factors influencing the Indian summer monsoon The onset of the south-west monsoon is a highly anticipated event in the region and the main circulation features that have been identified by previous studies are as follows;

- Formation and northward movement of a cyclonic circulation which is al referred to as onset vortex in the south-east Arabian Sea
- Strengthening and deepening of westerlies in the lower troposphere and strengthening of easterlies in the upper troposphere over the Indian sub-continent
- Lower-level Jetstream
- Persistent cloudiness over south-east Arabian Sea.

There are few major features that are identified with the south-west monsoon and following is a brief description of some of them.

Monsoon onset vortex: The vortex, a low-pressure system that originates on the front end of the monsoon current over the East-Central Arabian Sea (ECAS), provides monsoon flow and establishes the monsoon over Indian region. Sometime, this intensifies into a cyclonic storm, leading in the formation of a convergence zone over the south-east Arabian Sea, followed by the strengthening of monsoon westerlies. These synoptic systems (lows/depressions) that occur in the monsoon flow, as well as the semi-permanent systems that form as convective features, play a vital role in the commencement and progression of the monsoon and the associated rainfall.

Arabian Sea Mini Warm Pool (ASMWP): The ASMWP was first discovered in 1979 data from the Monsoon Experiment (MONEX), which revealed that a tiny warm pool (SST > 30.5°C) existed in the SEAS east of 65°E a week before the onset of the Indian summer monsoon's onset vortex. The SST within this warm pool typically exceeds 29°C in the months leading up to the summer monsoon. The warmest SSTs in the Indian Ocean are found in three places: the western equatorial Indian Ocean, the Southeastern Arabian Sea (SEAS), and the eastern Bay of Bengal. The Arabian Sea Mini Warm Pool is a location in the SEAS where temperatures reach 29°C from February to May. The majority of the time, the origin of monsoon onset vortices occurs over this mini-warm pool region, according to historical data on the genesis of monsoon onset vortices.

Cross-equatorial flow and low-level jet stream: The Indian summer monsoon is assumed to be caused by the southern hemispheric trade winds, which are diverted at the equator and approach India's west coast from the southwest. According to earlier studies, a considerable mass of air crosses the equator during the monsoon, especially over the extreme western region of the north Indian Ocean and nearby Somalia (between 38E and 45E). Estimates of cross-equatorial water vapor transfer were made for the same season. During the monsoon, massive amounts of air and water vapor are surely transported from the southern hemisphere over the equator. This is in addition to the Find Later Jet (FLJ), sometimes known as the Somali jet, which plays a significant part in the monsoon's commencement and progression. The intensity of FLJ increases during the arrival of monsoon in Kerala and is linked to rainfall across the Indian subcontinent. This is also in charge of transferring moisture from the surrounding oceans to the Indian continent.

During the boreal summer monsoon season, June–September, a strong cross-equatorial Low Level Jet stream (LLJ) with a core at 850 hPa exists over the Indian Ocean and south Asia. There is a split depending on whether it is a break or an active monsoon. This was first proposed by Find later and has subsequently gained widespread support as evidenced by the literature. The conclusions of Find later were based on a study of monthly mean winds. The LLJ of active and break monsoons are expected to occur simultaneously in such an analysis, implying a split.

This in combination with the Find later jet or Somali jet, which plays an important role on the monsoon onset and progress of the monsoon. In general, the intensity of FLJ increases after the onset of monsoon over Kerala region and related with rainfall over Indian sub-continent. This is also responsible in transporting moisture from the surrounding Oceans to Indian land mass.

Data and Methodology

Data

Monthly rainfall station data over Sri Lanka: DoM maintains a gauge rainfall network of over 400 direct and indirect rainfall stations. Some of these rainfall stations record on a daily basis, while others offer monthly rainfall data. The rainfall stations that are directly under the DoM strictly follow the World Meteorological Organization (WMO) guidelines in measuring rainfall data, whereas the rainfall stations that are maintained indirectly are provided with technical assistance in the form of equipment and training in measuring rainfall according to the WMO guidelines.

CHIRPS data: The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) dataset uses novel interpolation techniques with high resolution precipitation estimates which runs for a long period which are based on infrared Cold Cloud Duration (CCD) observations. The algorithm is developed around a 0.05° climatology that includes satellite data to represent areas which does not have a lot of gauge data. Monthly CCD based precipitation estimates of resolution 0.05° from 1981 present merges station data to generate an initial product and uses a modern interpolating process which incorporates the spatial correlation structure of CCD estimates to assign interpolation weights. In this study, monthly rainfall data spanning from 1981 to 2019 of resolution 0.05° is used.

GPCC data: Global Precipitation Climatology Centre (GPCC) was established in 1989 on the request made by World Meteorological Organization (WMO) based on the increased interest and high demand for long-term precipitation data by national and international level organizations. This program was established by the Deutscher Wetterdienst (National Meteorological Service of Germany) as a contribution by Germany to the World Climate Research Program. GPCC monthly rainfall station data-base is considered to be the largest monthly precipitation station database of the world with data from more than 84,800 different stations with data available in 2.5° × 2.5°, 1.0° × 1.0°, 0.5° × 0.5°, and 0.25° × 0.25° resolutions. Data used in this study is GPCC V.2020 of resolution 0.5° × 0.5°, and 0.25° × 0.25° based on data from 1,23,000 stations which spans from 1981 to 2019.

ERA5 data: ERA5 data is based on the Integrated Forecasting System (IFS) Cy41r2 which came to operational level in 2016. ERA5 has benefitted from developments in model physics, core dynamics and data assimilation. Horizontal resolution of ERA5 data is 31 km and this improved temporal and spatial resolution makes way for a comprehensive progression of weather systems. The global-mean correlation with monthly-mean GPCP precipitation data has increased from 67% to 77% compared to the previous version of ERA reanalysis data. In this study, monthly rainfall data from 1981 to 2019 of resolution 0.25° × 0.25° has been used.

Sea Surface Temperature (SST) data

COBE SST2 data: COBE SST2 dataset contains monthly mean data from 1850 to 2019 in 1° × 1° spatial resolution covering an area from 89.5N - 89.5S, 0.5E - 359.5E. In this dataset, an improved equation is introduced to represent the ice-SST relationship, which is used to produce SST data from observed sea ice concentrations. Satellite observations are introduced in the rebuilding of SST variability over regions where data are sparsely available.

Relative humidity data: lERA5 Relative Humidity data contains the water vapor pressure as a percentage of the value at which the air will become saturated. Depending on the phase of water, the saturation over water or ice is considered. Reanalysis monthly mean data from 1981-2019 of a resolution of 0.25° × 0.25° for 1000 hPa level and 850 hPa level is used in this study.

Outgoing Long-wave Radiation (OLR) data: OLR data from NCAR spans from 1974 to present with a spatial coverage of 2.5° × 2.5° on a global grid. These gridded monthly OLR data are temporally interpolated. Data used in this study spans from 1981-2019 and the units are W/m^2.

Divergence data: Divergence parameter used in this study is used to measure the horizontal divergence of velocity and the unit of this parameter is s^{-1}. This gives a measure of in which rate the air is spread horizontally from a point per a square meter. Divergence is positive for air that is spreading out (diverging) and it is negative for the air that is concentrating (converging) or commonly known as convergence. ERA-5 monthly reanalysis divergence data is used in this study is of 2.5° × 2.5° resolution and data of 850 hPa, 700 hPa, 500 hPa and 200 hPa levels are considered in this study.

Wind data: In this study Zonal (U) and Meridional (V) components are used in considering the wind fields at 850 hPa, 500 hPa and 200 hPa levels. Zonal (U) component wind flowing in an eastward direction is considered positive while westward moving winds are identified as negative. Meridional (V) component wind is positive when it is moving towards the north and negative when it is moving to the south. These two components can be combined to give the direction and speed of the horizontal wind. The units for both the components are in ms^{-1}. Horizontal resolution of ERA-5 data considered in this study is 2.5° × 2.5°.

Velocity potential data: In this study NCEP/NCAR reanalysis monthly anomaly data of velocity potential data for 250 hPa level of resolution 2.5° × 2.5° was used. The base period used for anomaly was 1991-2020 and data for the period of 1981-2019 was used. The units were m^2s^{-1}. Data was downloaded through the website of Columbia climate school international research institute for climate and society.

Methodology

- Collect and arrange station rainfall data of Sri Lanka issued by the department of meteorology, Sri Lanka and download gridded rainfall data of multiple origins.
- Compare gridded rainfall data with observed rainfall to verify model precipitation data.
- Download SST data to identify the Atlantic Nino pattern in the Atlantic Ocean.
- Calculate SST anomalies to identify Atlantic Nino pattern for tropical regions of the Atlantic Ocean.
- Study effect of Atlantic Ocean on the rainfall over Sri Lanka. Correlation analysis is used to understand the influence of the Atlantic Ocean over the rainfall of Sri Lanka.
- Conduct composite analysis of relative humidity (1000 hPa and 850 hPa), Outgoing Longwave Radiation (OLR) and divergence to check the associated atmospheric circulation anomalies.

Results and Discussion

Model precipitation data verification

Using observation data in an analysis has several drawbacks. The quality of data available is problematic and the gaps in availability of data in both temporal and spatial scales hinder a meaningful analysis to be carried out. The reasons stated above and the lack of homogenous observational data warrants the use of gridded data. In line with that, data evaluation and comparison are essential since gridded rainfall data is used in this study. Therefore, multiple sources of gridded rainfall data need to be compared with the synoptic rainfall data for Sri Lanka and the following are the specifics of the data used in this study.

- Department of Meteorology (DoM) observational monthly rainfall data for the period of 1981-2019.
- Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) monthly precipitation data for the period of 1981-2019 of spatial resolution of 0.05 × 0.05 degrees.
- Global Precipitation Climatology Centre (GPCC) monthly precipitation data for the period of 1981-2019 of spatial resolutions 0.5 × 0.5 and 0.25 × 0.25 degrees.
- European Centre for Medium Range Weather Forecast (ECMWF) ERA-5 reanalysis monthly total precipitation data for the period of 1981-2019 of spatial 0072esolution 0.25 × 0.25 degrees.

According to a previous study conducted by the author for the same region, it has been concluded that, considering the wet-zone of Sri Lanka, GPCC (0.25° × 0.25°) has the rainfall estimates that better represents the actual rainfall observations recorded by the Department of Meteorology, Sri Lanka compared to the other rainfall sources considered in this study. Therefore, GPCC (0.25 × 0.25) was selected for further analysis in this study.

SST and Rainfall Correlation Analysis

ATL3 Region

The spatial pattern of SST over ATL3 region: Considering the JJA period, the SSTA of JJA is negative in 1981-1983, 1985-1986, 1990, 1992-1994, 1997, 2000-2001, 2004-2005, 2009, and 2011-2015 and SSTA is positive in 1984, 1987-1989, 1991, 1995-1996, 1998-1999, 2002-2003, 2006-2008, 2010, 2016-2019 (Figure 1). According to previous studies, three-month averaged SSTA exceeding 0.5°C (-0.5°C) in the ATL3 region during this JJA period is considered an Atlantic Niño (Niña). Accordingly, 1988, 1995-1996, 1998-1999, 2008 and 2016 are identified as Atlantic Niño years while 1982-1983, 1992, 1997 and 2005 are considered as Atlantic Niña years.

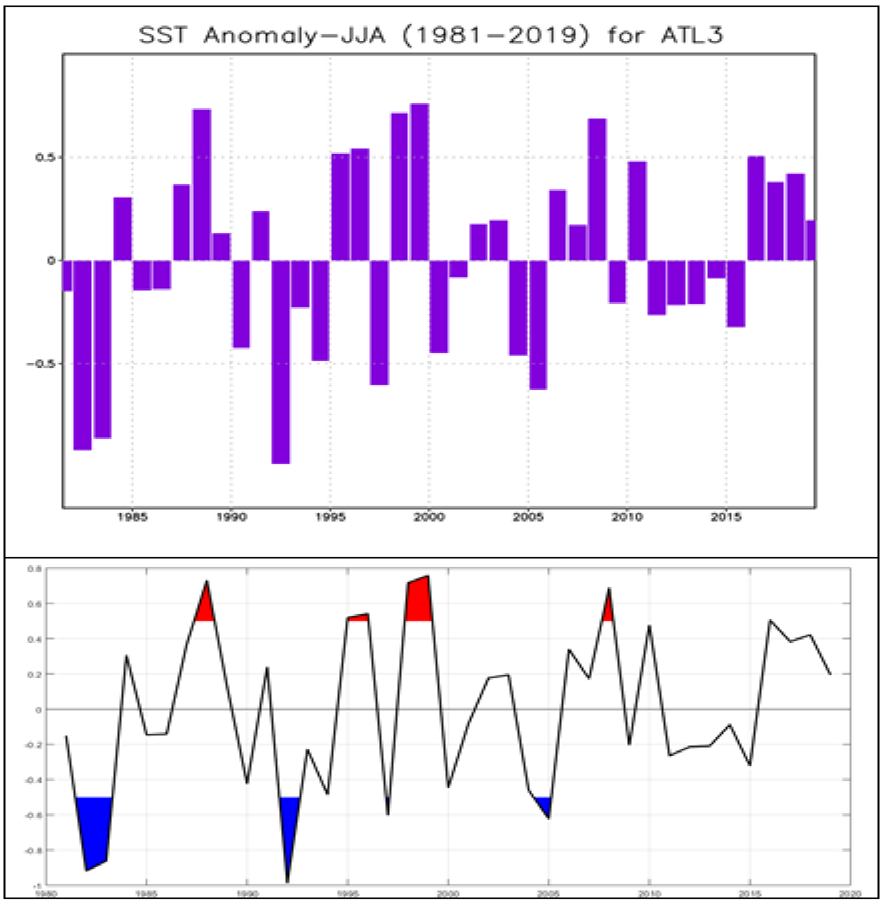

FIG.1**. (a) SST Anomalies of the ATL3 region for the period June-July-August during the years 1981-2019 in Co (bar graph) (b) represents the same in a line graph. Years that exceed 0.5 Co (-0.5Co) is identified as Atlantic Niño (Niña).**

The relationship between ATL3 region and abnormal rainfall over Sri Lanka: The CC of SSTA of JJA and GPCC (0.25 × 0.25) rainfall anomaly for JJA period shows a positive correlation with correlations significant at 90% threshold in the western to north-western parts and northern parts of the island and correlations significant at 95% threshold in the same areas but less spread than in 90% significance (Figure 2).

Since a significant correlation with a greater degree of spatial spread with the JJA abnormal rainfall was found to be with the SSTA of ATL3 region, further analysis was done based on Atlantic Niño and Niña years identified based on the ATL3 region.

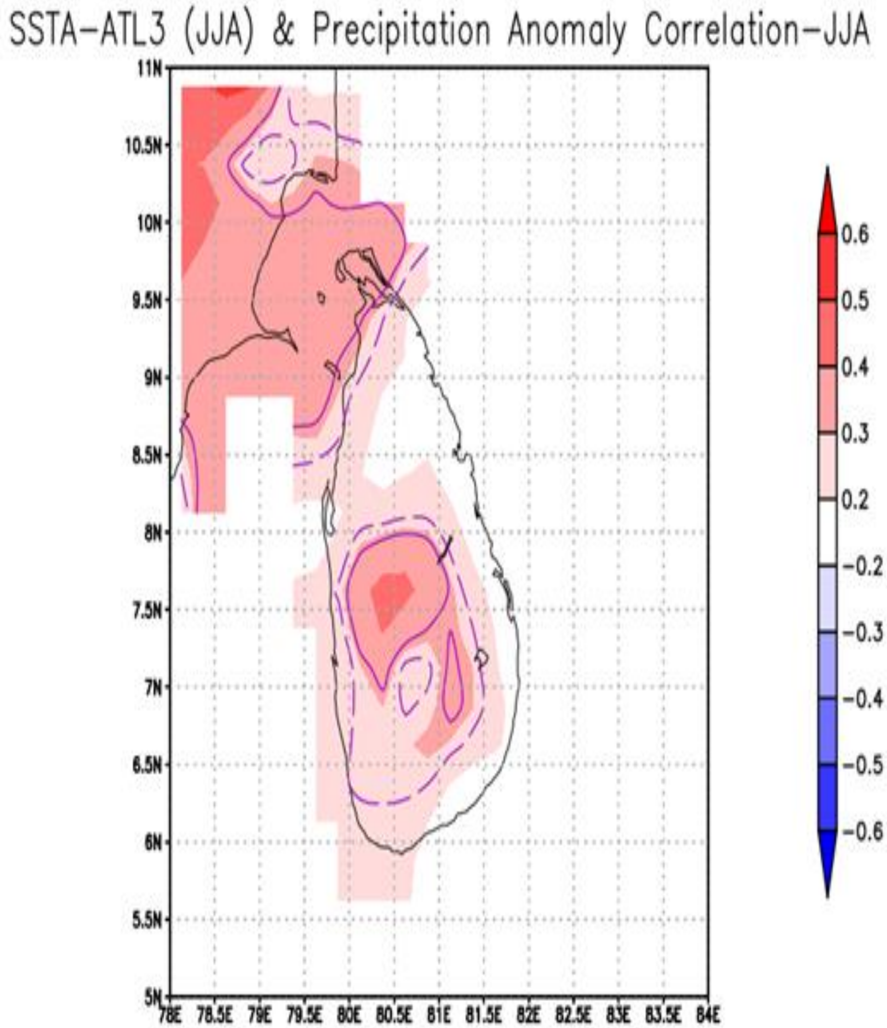

FIG.2. **CC of SSTA for JJA and GPCC (0.25 × 0.25) monthly rainfall anomaly over Sri Lanka for JJA period. The dashed purple line shows the significance of CC at 90% and the solid purple line shows the significance of CC at 95%.**

Outgoing Longwave Radiation (OLR) anomalies during Atlantic Niño (Niña) years: OLR is a critical component when considering the earth's energy budget and it is also used as an alternative measure of convection in tropical regions. This is due to the fact that the cloud top temperatures are an indication of the height of the cloud. These OLR values are also used in MJO diagnostics as well. In this study OLR is used as a measure of convection during this period and positive OLR values show less clouds and in turn less rainfall and negative OLR is an indication of more clouds and in turn more rainfall.

The composite of the anomaly of Outgoing Longwave Radiation (OLR) for the area 50W-100E and 20S-20N shows that for Atlantic Niño (positive) years, the OLR anomaly was positive for the TA region and the whole Indian Ocean including the majority of Arabian Sea and the Southern Indian Ocean.

The same for the negative phase years are positive in the TA region while it is slightly positive around Sri Lanka (Figure 3). This is further evident on the Figure 32 where contrast in OLR anomaly for the difference phases are shown with clear negative anomalies over Sri Lanka and clear positive anomalies over Sri Lanka in the negative phase. The composite of the anomaly of Outgoing Longwave Radiation (OLR) shows that for Atlantic Niño (positive) years, the OLR anomaly was negative throughout the whole island with higher negative anomaly towards the south-eastern part of the country. The composite of OLR anomaly for Atlantic Niña (negative) years are positive throughout the island (Figure 4).

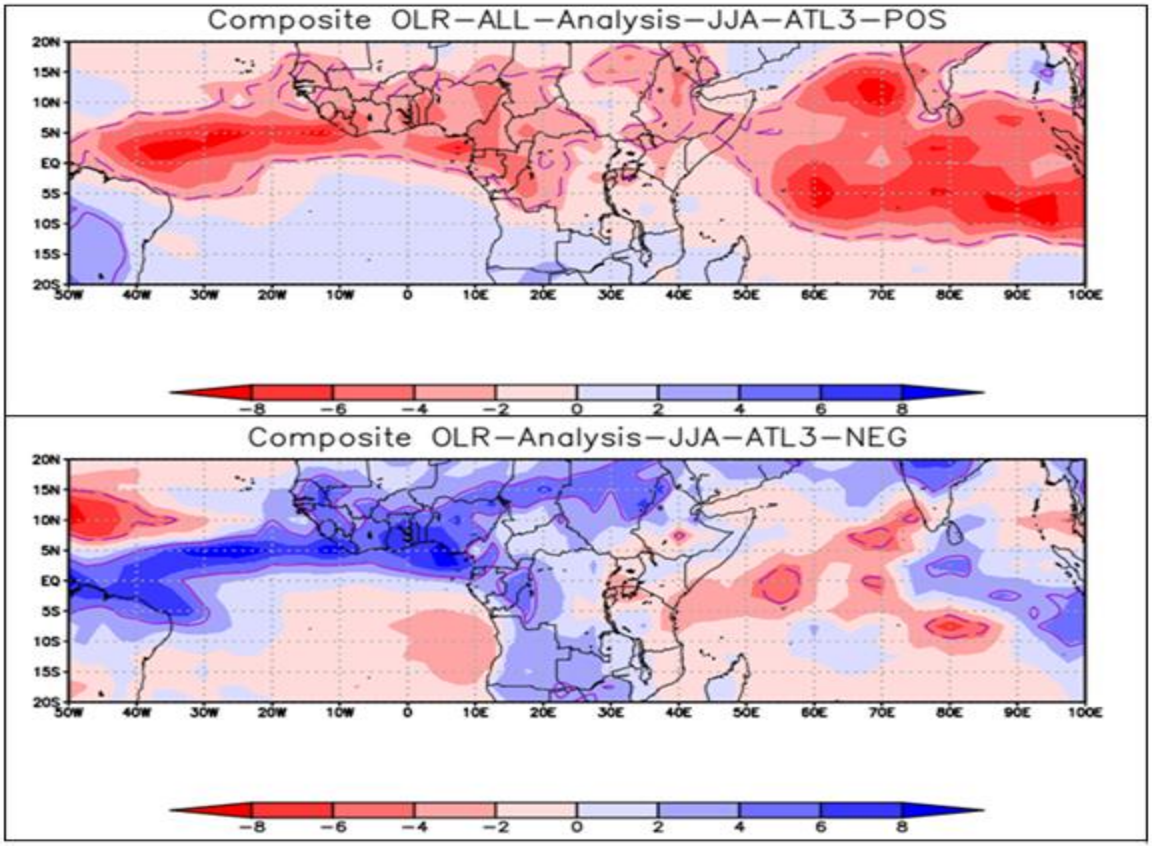

FIG.3. **Composite seasonal OLR anomalies during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within the study period of 1981-2019 in W/m^2. Purple line shows 95% significance level.**

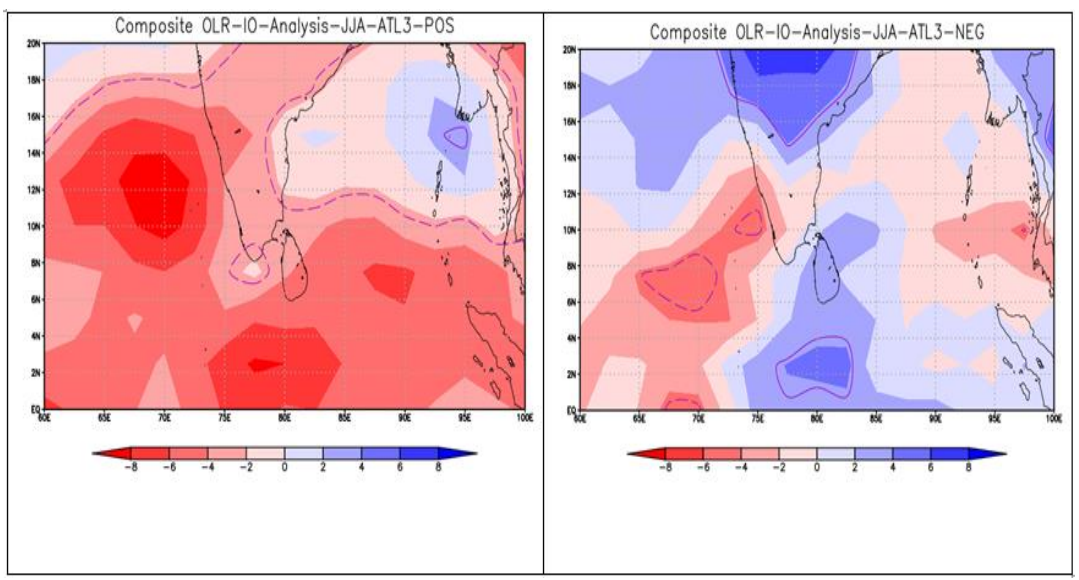

FIG.4. **Composite seasonal OLR anomalies during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period for the Indian Ocean region for 1981-2019 period in W/m^2. Purple line shows 95% significance level.**

Divergence anomalies during Atlantic Niño (Niña) years: In any given circumstance or condition, it could be stipulated that, low-level convergence and high level divergence is a fundamental feature in the occurrence of precipitation in any region of the world. With this in mind, the study looked at how the lower and higher levels of the atmosphere behaved in during the Nino and Nina years [20-25].

Higher level divergence: The composite of the anomaly of Divergence for the area 50 W-100 E and 20 S-20 N shows that for Atlantic Niño (positive) years, the divergence anomaly at 200 hPa level was positive for the TA region and over Sri Lanka and the surrounding areas. For the negative phase year's divergence is negative in the TA region and Sri Lanka and its surrounding areas (Figure 5).

A further closer look at the Indian Ocean region shows that the 200 hPa level divergence is positive over Sri Lanka during the positive phase which indicates that the higher levels of the atmosphere is supportive of the occurrence of precipitation while the negative phase clearly indicates the opposite (Figure 6).

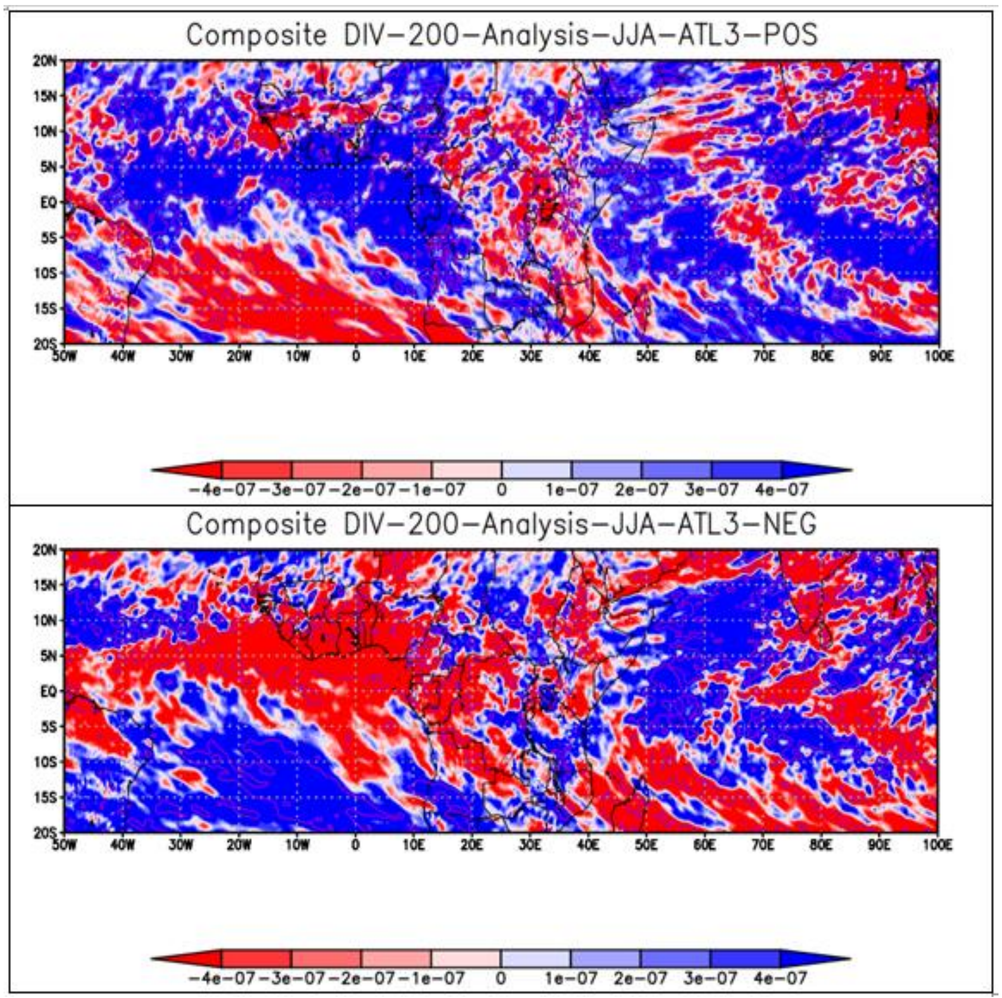

FIG.5. **Composite seasonal Divergence anomalies at 200 hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within the study period of 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

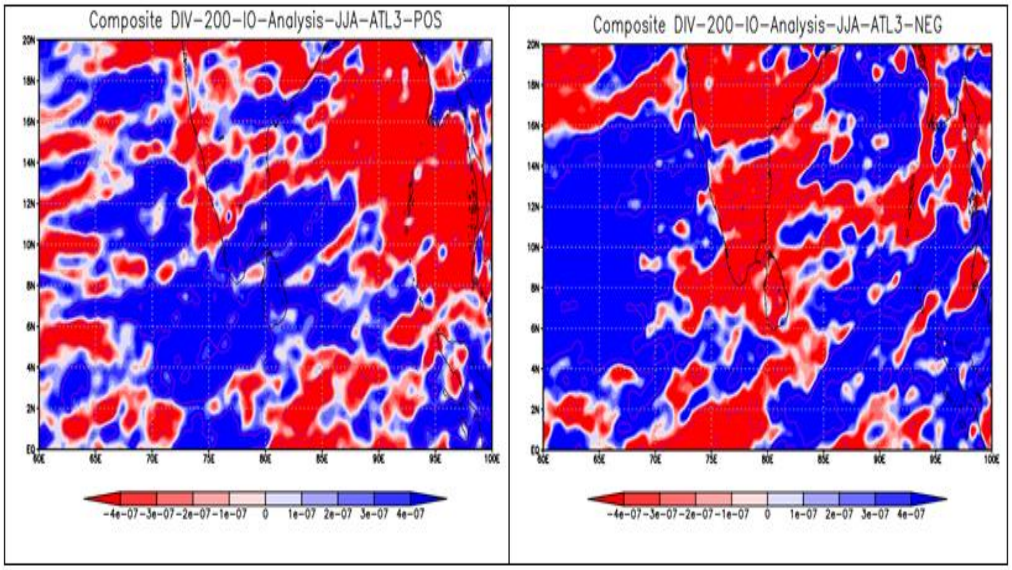

FIG.6. **Composite seasonal Divergence anomalies at 200 hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within Indian Ocean during 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

Considering the region of Sri Lanka and its close surrounding, it could be stated that the composite of the anomaly of divergence at 200 hPa level shows that for Atlantic Niño (positive) years, the divergence anomaly was positive throughout the whole island and the divergence anomaly is negative in almost all over the island barring small isolated regions for Atlantic Niña (negative) years [26-30].

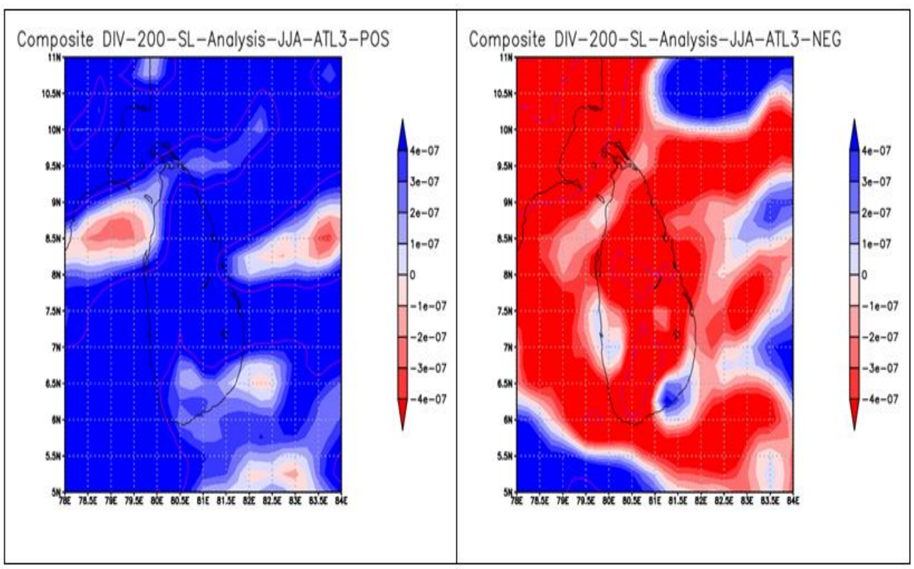

FIG.7. **Composite seasonal Divergence anomalies at 200 hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period around Sri Lanka during 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

Therefore, a positive anomaly in the Atlantic Niño phase shows a tendency in enhanced rainfall during the JJA period and negative anomaly in the Atlantic Niña phase shows a slightly less subdued rainfall comparatively. To further understand this behavior the study now looks at zonal wind fields at 200 hPa level.

Considering the Zonal (U) wind component at 200 hPa level for the whole JJA season, the anomalies for the negative phase years show a strong positive anomaly with regards to the wind speed with westerly winds and over the TA region and the surrounding areas of Sri Lanka. The anomalies of the positive phase years show a strong negative anomaly with easterly directed winds in the TA region with the surrounding areas of Sri Lanka showing slightly negative anomalies (Figures 8 and 9).

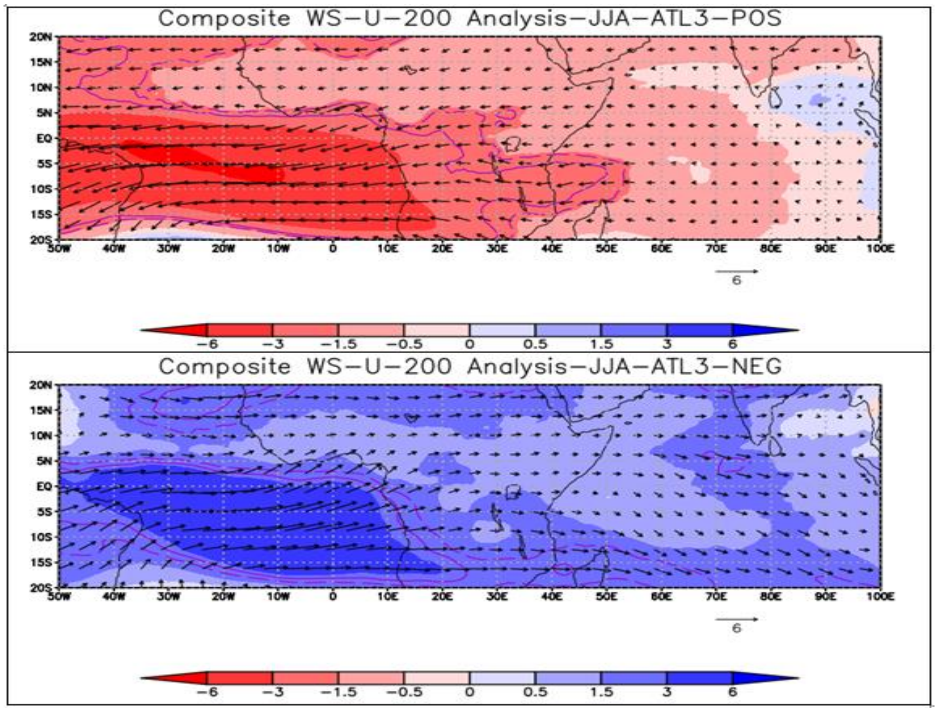

FIG.8.**The composite of the anomaly of U (Zonal) wind component at 200 hPa over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}. Purple lines show 95% level of significance.**

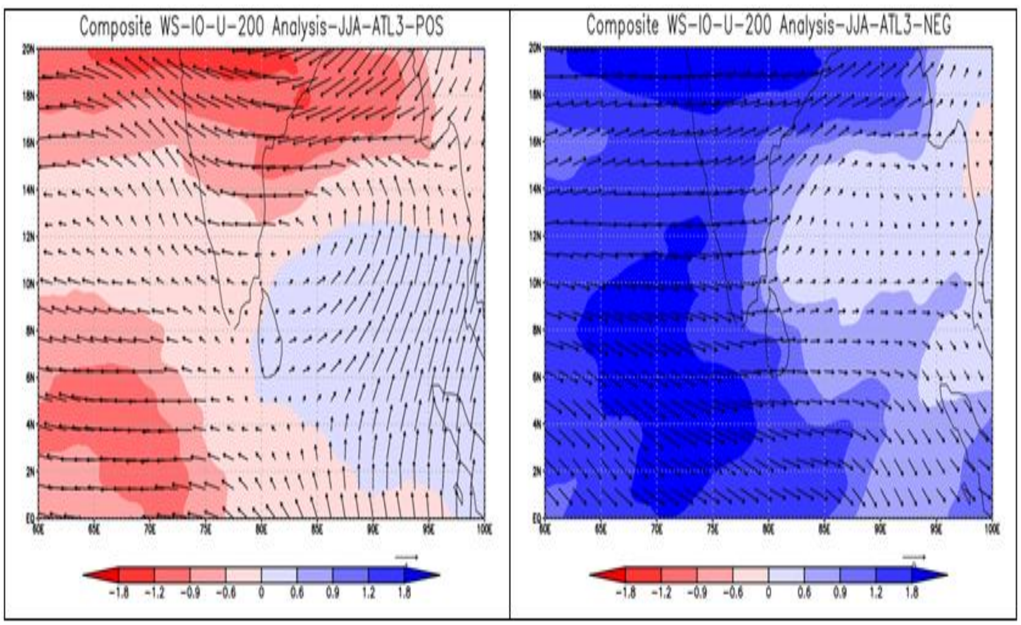

FIG.9. **The composite of the anomaly of U (Zonal) wind component at 200 hPa over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}.**

Then we take look at the lower levels of the atmosphere and in this study, the 850 hPa level has been looked at with regards to this.

Lower-level convergence: In the 850 hPa level, the composite of anomalies of Atlantic Niño and Atlantic Niña years does not show a prominent difference as the whole JJA season (Figure 10). However, a closer look at the Indian Ocean region and the region around Sri Lanka, it can be seen that in the Atlantic Niño years, the windward side during the south-west monsoon period always illustrates a negative anomaly and the leeward side depicts a positive anomaly for the JJA period (Figures 11 and 12). A negative divergence in this instance indicates convergence at 850 hPa level and convergence at 850 hPa level during this period indicates enhanced rainfall.

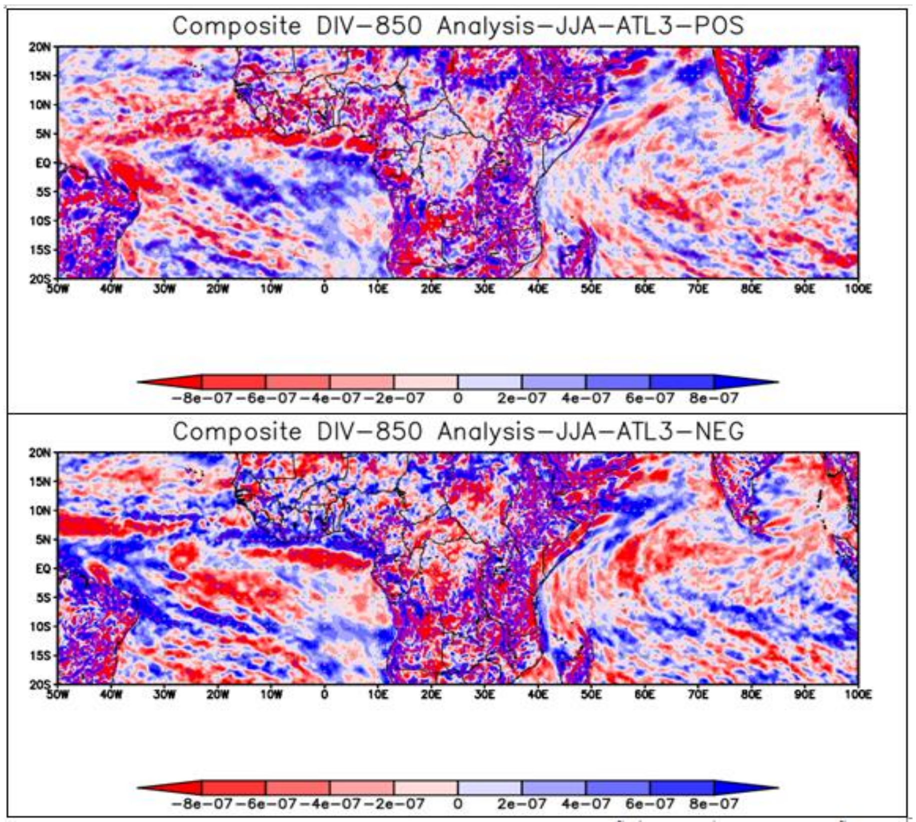

FIG.10. **Composite seasonal Divergence anomalies at 850 hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within the study period of 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

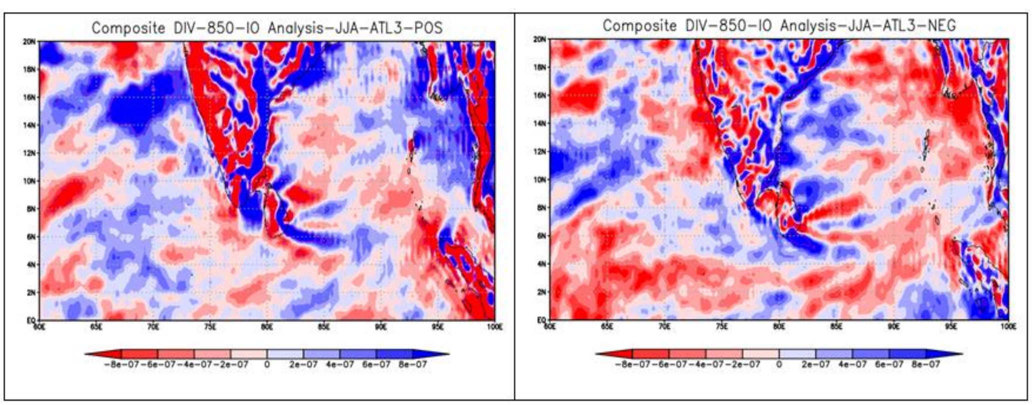

FIG.11. **Composite seasonal Divergence anomalies at 850hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within Indian Ocean region during 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

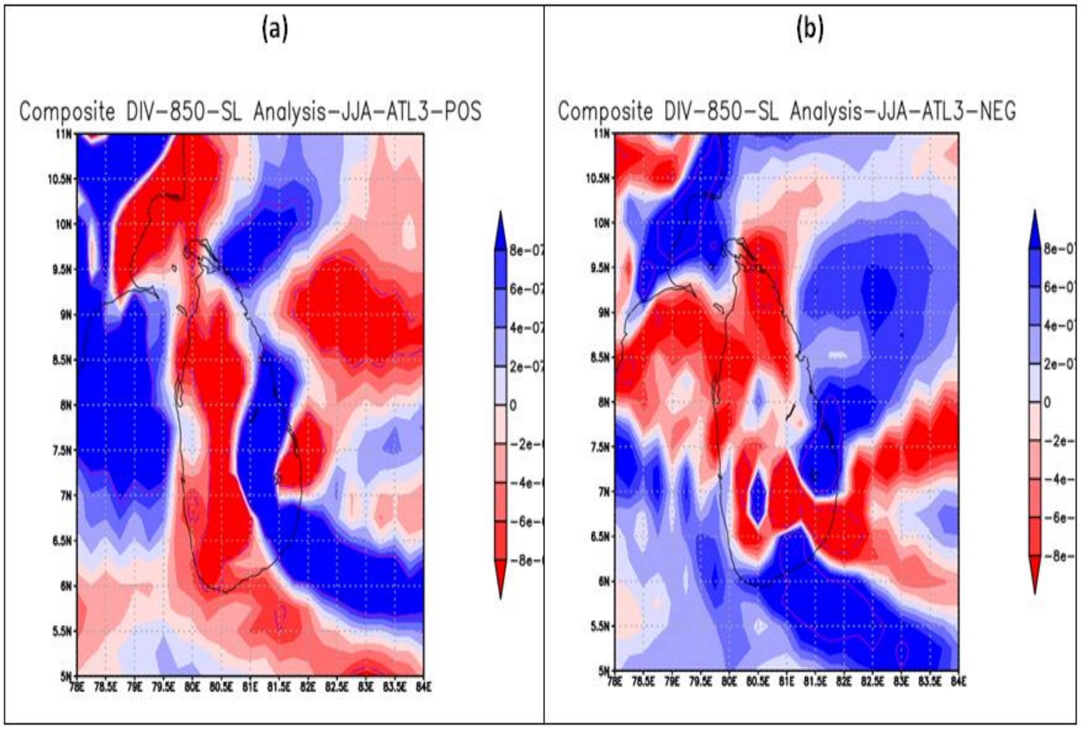

FIG.12. **Composite seasonal Divergence anomalies at 850 hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period around Sri Lanka during 1981-2019 in s^{-1}. Purple lines show 95% significance level.**

Low level convergence is a condition favorable for enhanced rainfall and the seasonal anomalies for the JJA season does not show an island wide contrast in the two phases considered. However, there is a clear difference in the anomalies in the central region of the country where a negative anomaly is shown to the west of center and positive anomaly towards the east of the center during the positive phase years and this is reversed in the negative phase years. Topologically speaking the two contrasting areas are on the either side of the central highlands. The west of center is the windward side during the JJA period and the east of center is the leeward side. The windward side, which incidentally receives more rainfall during this period is having negative anomaly in horizontal divergence which means low-level convergence is present.

Cross-equatorial flow during the South-West monsoon: During the south-west monsoon period, the low-level cross-equatorial flow in the western Indian Ocean, which is the world's strongest low-level jet, is a prominent feature of the monsoon. The monsoon flows start south of the equator, according to early studies of the south-west Indian monsoon.

In the western monsoon region, the low-level monsoon airflow is arranged into a relatively narrow high-speed trans-equatorial current. This cross-equatorial flow, which is also known as the 'Find later Jet' or 'Somalia Jet', is a vital ingredient of the South-West monsoon. It transports moisture from the southern Indian Ocean to south Asia, connects the Mascarene High and Indian monsoon trough, and completes the lower branch of the Hadley cell of the south-west monsoon.

Sea Surface Temperature (SST) and Mean Sea Level Pressure (MSLP) anomalies during Atlantic Niño (Niña) years: During the composite of the Niño phase, the SST anomaly in the TA region is strongly positive and a strong negative MSLP anomaly is also expected with the increase of temperature paving way for low pressure in the region.

Conversely, during the Niña phase the opposite of this occurs. SST anomaly during the Niña phase is strongly negative over the TA region which is also reflected in MSLP with a higher than usual pressure over the region (Figure 13 and 14).

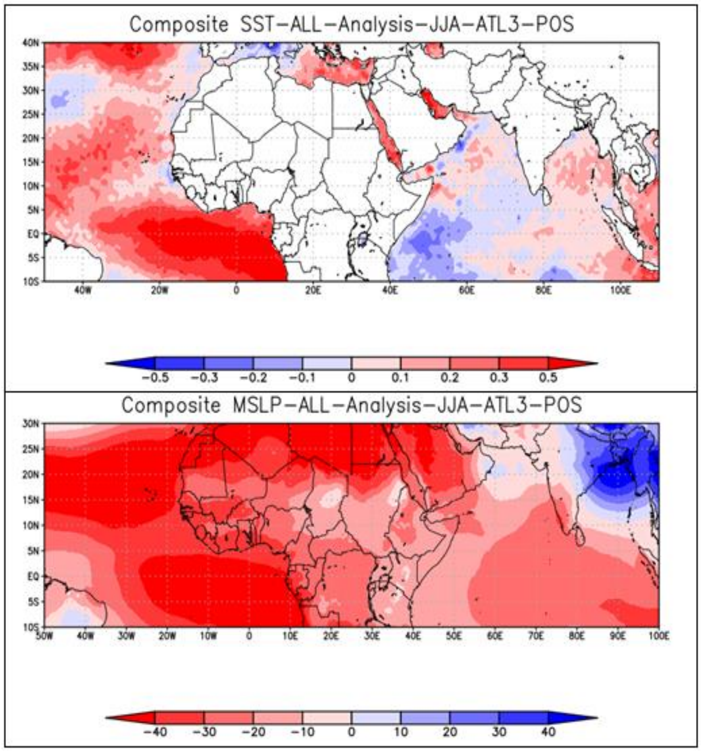

FIG.13. **The composite of the anomaly of SST (in C, a) and MSLP (in Pa, b) over study area during the JJA period for Atlantic Niño (positive) phase.**

During the Niño phase, the low pressure that originates in the TA will result in the lower-level winds from either side of it to move towards it. In this regard, the easterly winds in the Southern Indian Ocean will be drawn towards to the TA region while during the Niña phase the winds will be drawn away.

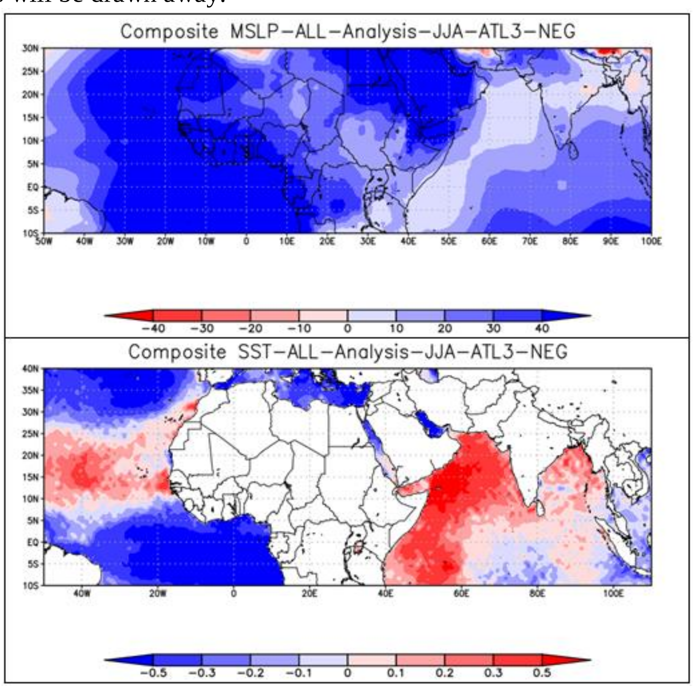

FIG.14. **The composite of the anomaly of SST (in C, a) and MSLP (in Pa, b) over study area during the JJA period for Atlantic Niña (negative) phase.**

This jet stream also responsible for driving a strong seasonal cross-equatorial ocean current which is known as the Somali current. Due to the Eckman Effect, winds along the shores of the African continent resulting from this jet induces an intense upwelling farther up the coast which results in SST drop of around 3-4°C in the western Arabian Sea. This feature is further enhanced during the Niño phase while during the Niña phase the temperature is above the normal in this region which is also a good indicator for the strengthening of the cross-equatorial flow (Figure 15).

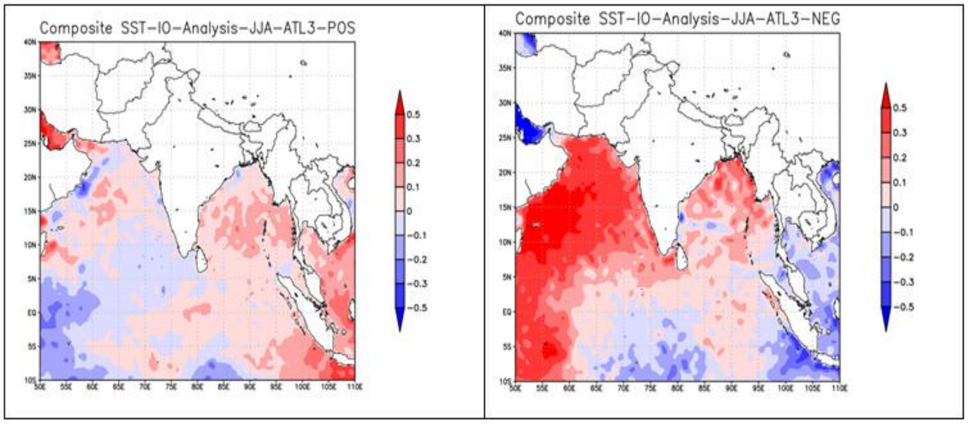

FIG.15. **The composite of the anomaly of SST over Sri Lanka during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in C.**

Zonal Wind (U Component) and Meridional Wind (V Component) anomalies during Atlantic Niño (Niña) years: When the zonal wind component at 850 hPa level for the JJA season is looked at, it shows that there exists a westerly wind anomaly with a strong positive anomaly over TA region in the positive phase which has extended its effect to the Indian Ocean as well. The opposite effect happens in the negative phase where there is a strong negative anomaly with an easterly direction over the TA region which again extends to the Indian Ocean as well. This has resulted in strengthening of the cross-equatorial wind flow prevalent during the south-west monsoon period in the Niño phase. The strong easterly winds during the Niña phase on the other hand have the opposite effect which hinders the cross-equatorial flow across Sri Lanka (Figure 16). Since this flow plays a major role in the monsoon strength over Sri Lanka, this explains the reduction of rainfall during the Niña phase.

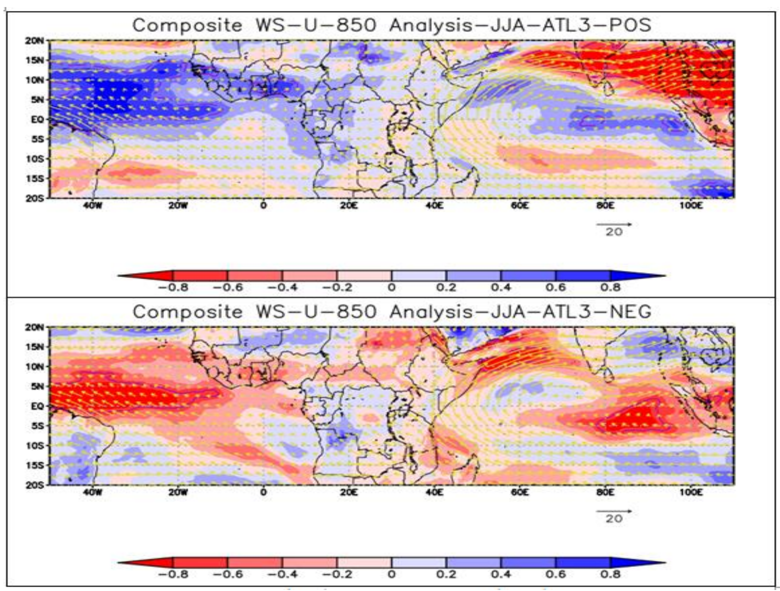

Fig.16. **The composite of the anomaly of U (Zonal) wind component at 850 hPa (shaded) and the climatological wind in vector arrows over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}. Purple lines show 95% level of significance.**

Meridional wind component at 850 hPa level for the JJA season shows that there exists a strong positive anomaly over TA region in the positive phase while the negative phase shows a negative anomaly over TA region (Figure 17). Generally, the Monsoon Trough (MT) or the Inter Tropical Convergence Zone (ITCZ) is associated with the south-west monsoon rainfall with such association during the monsoon period will enhance the south-west monsoon rainfall. When a closer look at the Indian Ocean region is made on the anomaly of the meridional winds it is evident that during the Niño phase, there is an alternating positive and negative wind anomaly over the Indian Ocean surrounding Sri Lanka. This tendency of strong negative (southward) meridional wind to the east of Sri Lanka and west of Sri Lanka will draw the MT or ITCZ towards Sri Lanka which will result in enhanced rainfall during that period. This feature has shifted the west in the Niña phase and also lost its strength (Figure 18).

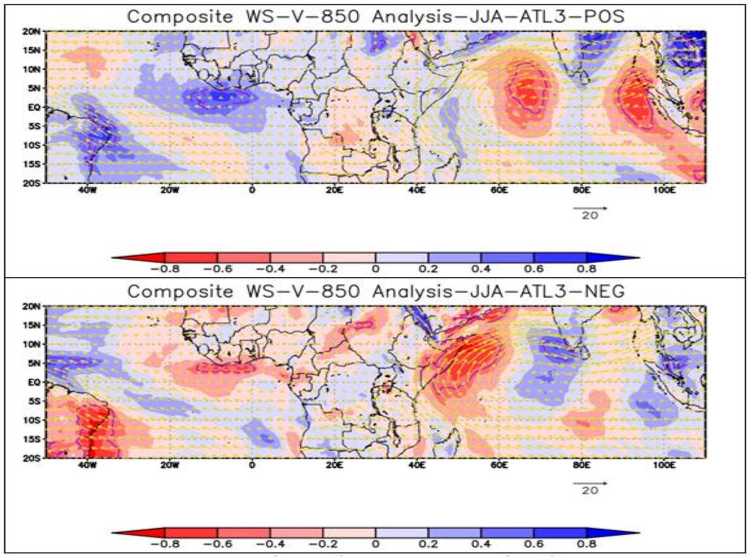

FIG.17. **The composite of the anomaly of V (Meridional) wind component at 850 hPa (shaded) and the climatological winds in vector arrows over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}. Purple lines show 95% level of significance.**

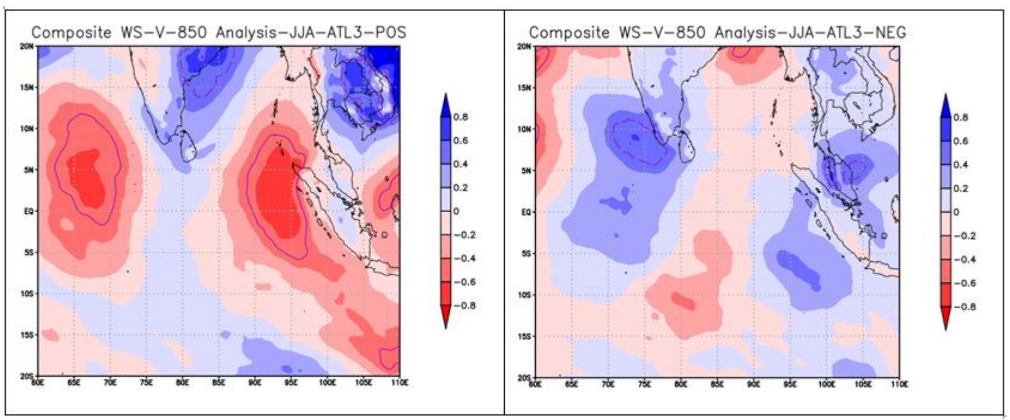

FIG.18. **The composite of the anomaly of V (Meridional) wind component at 850 hPa (shaded) over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}. Purple lines show 95% level of significance.**

Further to the above, a closer look at the streamline analysis of the Niño and Niña years indicates that during the positive phase years, Sri Lanka is under the influence of a cyclonic circulation (anticlockwise) which generally increases the potential for higher rainfalls over Sri Lanka. This feature of a cyclonic circulation is further away in the negative phase years (Figure 19).

This streamline analysis also shows that the cyclonic circulation in the vicinity of Sri Lanka is also part of an Equatorial Rossby wave pattern and during the Niño phase it appears to be closer to Sri Lanka whereas during the Niña phase it's further away from Sri Lanka, minimizing the impact of it.

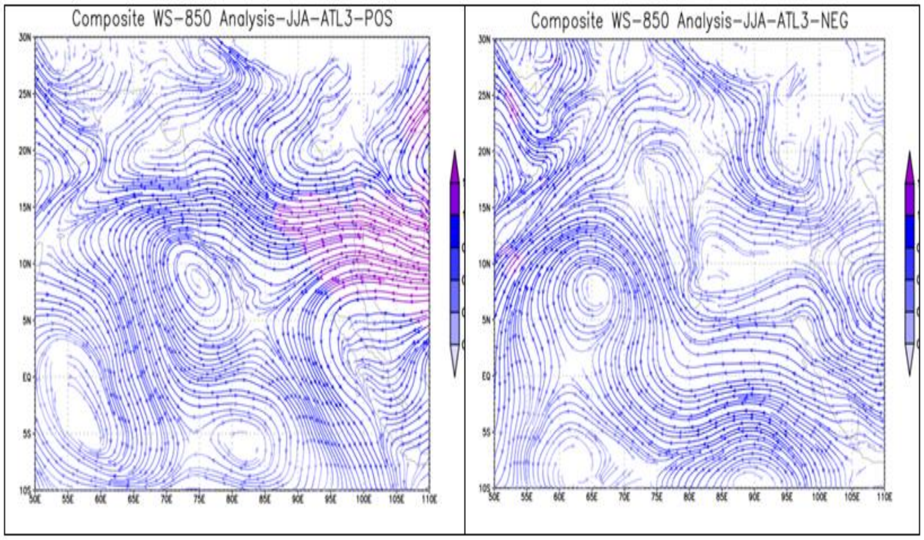

FIG.19. **Composite anomalies of rotational streamlines at 850 hPa over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in ms^{-1}**.

Moreover, a closer look at the MSLP over the Indian Ocean, during the Niño phase, there exists a pressure gradient in a north westerly direction from the Western Arabian Sea towards the southern Indian Ocean. This pressure gradient will result in pushing the cross-equatorial flow further southwards resulting in it hovering over Sri Lanka for an extended period. This feature is reversed in the Niña phase where the pressure gradient is now towards the western Arabian Sea (Figure 20).

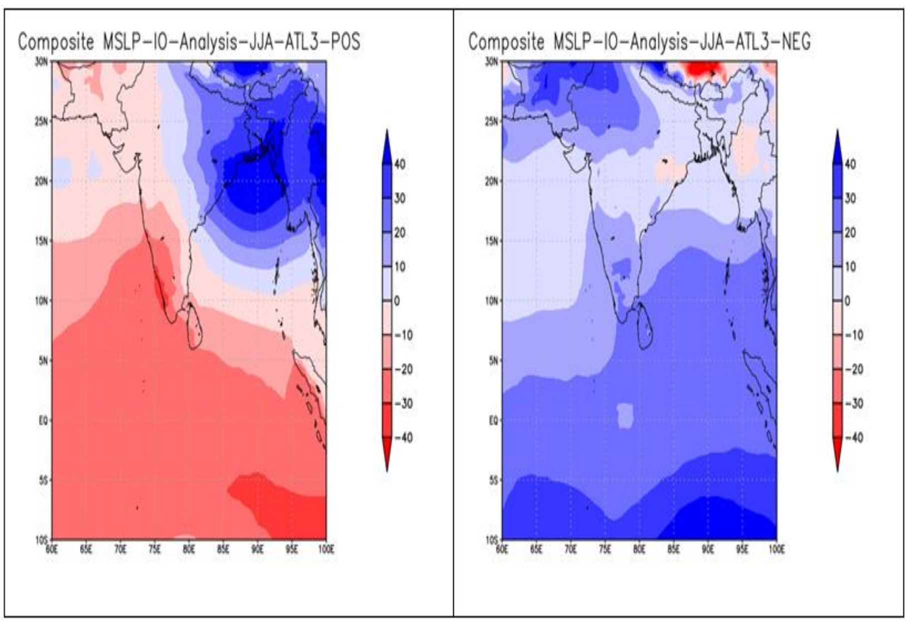

FIG.20. **The composite of the anomaly of MSLP over Sri Lanka during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in Pa.**

One of the clearest indicators of the ITCZ or the MT is the precipitation. The seasonal rainfall for the JJA period for the Niño and Niña phases were analyzed and it is evident that there is a slight shift to the north in the precipitation line in the Niña phase compared to the Niño phase towards the western part of the Pacific Ocean which also extends to the Indian Ocean (Figure 21). This confirms the previous claim of the shift of the ITCZ or MT.

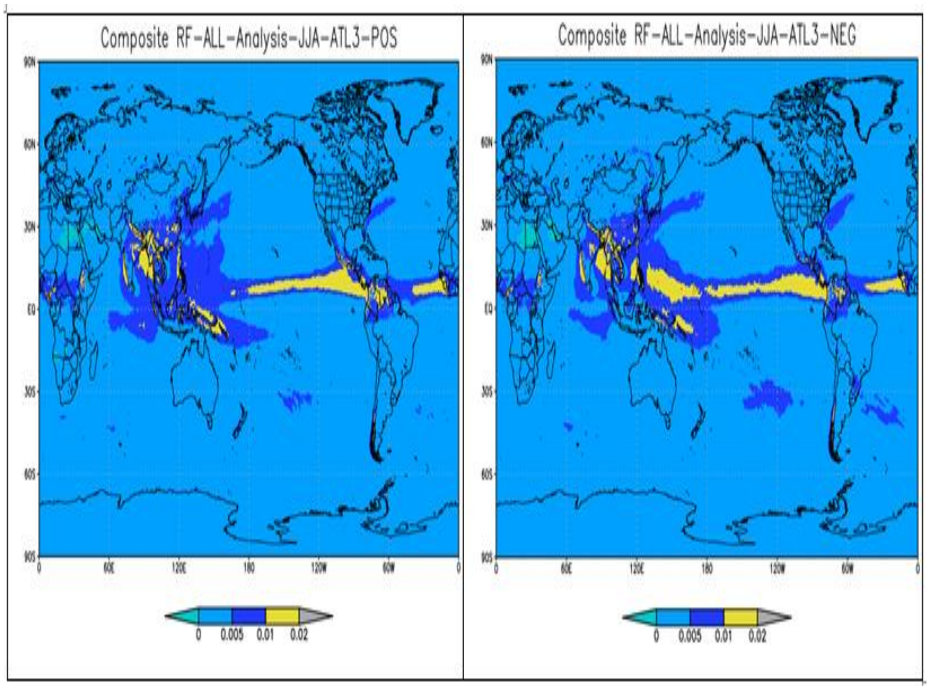

FIG.21. **Composite for seasonal rainfall during the JJA period for Niño (positive, a) and Niña (negative, b) phases.**

Velocity potential: The velocity potential at the 250 hPa level contains information concerning the overall intensity of the tropical circulations of Hadley, Walker and monsoon. These tropical circulations are driven by different dynamical causes. In the framework of general circulation, meridional differential heating drives Hadley circulation. Because it exists even on the hypothetical aqua-planet, the essential structure can be termed axisymmetric. The Walker circulation, on the other hand, is driven by the equatorial tropics' varying SST. The Walker circulation could be caused by a zonal imbalance of the SST caused by the continental obstruction of large oceanic circulations. The heat contrast caused by land sea distributions is primarily what drives the monsoon circulation. As a result, the annual cycle with the seasonal reversal in circulation direction between summer and winter may be an important aspect of the monsoon's description. In this regard, 250 hPa velocity potential, could be used a good substitute for the "Walker circulation". The peaks in the following zonal means of velocity potential anomaly for respective phases indicate the location of the ITCZ or MT. The difference in the position ITCZ or MT in the Nino and Nina phases is evident here as in the Nina phase there is one peak whereas in the Nino phase there are several peaks and the peak positions are also different (Figure 22 and Figure 22a).

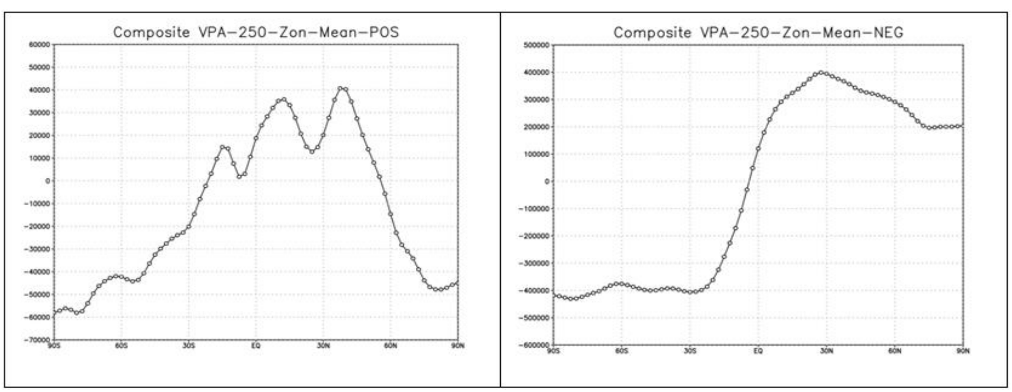

FIG.22. **The composite of the anomaly of velocity potential anomaly over Sri Lanka during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in m^1s^{-1}. Purple lines show 95% level of significance.**

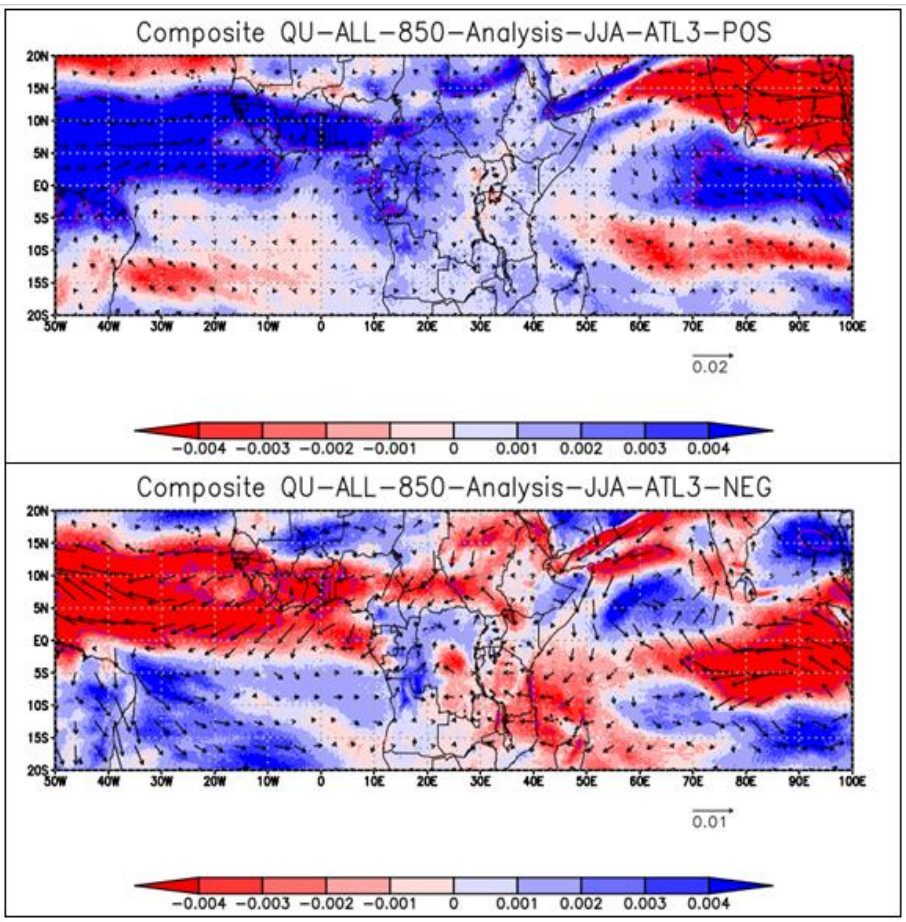

FIG.22a. **The composite of the anomaly of zonal moisture flux at 850 hPa over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

Moisture flux anomalies at lower-levels during Atlantic Niño (Niña) years

850 hPa: Moisture flux anomalies at 850 hPa level of the zonal wind component indicate that there exists a strong positive anomaly over the TA region with westerly winds in the positive phase. This extends to the Indian Ocean which surrounds Sri Lanka as well. However, the winds over Sri Lanka appear to be slightly less positive compared to the TA region. Wind direction and the anomaly changes to the opposite of the positive phase with TA region having strong negative anomalies with north-easterly to easterly winds (Figure 22). Moreover, when the Indian Ocean is considered, BoB area has negative anomalies with easterly winds during positive phase while the BoB area has positive anomalies with north-westerly winds.

This feature is clear in the (Figure 23). Further, it is evident that during the positive phase the strong positive moisture flux in the westerly direction in the tropical Atlantic Ocean transports moisture from the Atlantic Ocean through the North African region towards the Arabian Sea and then to the Indian Ocean south of Sri Lanka which has slightly enhanced the moisture flux in the south-wester part of the country. This moisture coupled with the cyclonic circulation in the vicinity of Sri Lanka has enhanced rainfall over Sri Lanka during the Niño phase.

On the negative phase the strong negative moisture flux in the easterly direction over the Atlantic Ocean has disrupted the moisture supply to the Indian Ocean which in turn has resulted in reducing the rainfall over Sri Lanka. The cross equatorial plays a major role in the south-west monsoon season over Sri Lanka and this moisture flux is feeding moisture to the cross-equatorial flow during the Niña years while the reverse is happening during the Niño years.

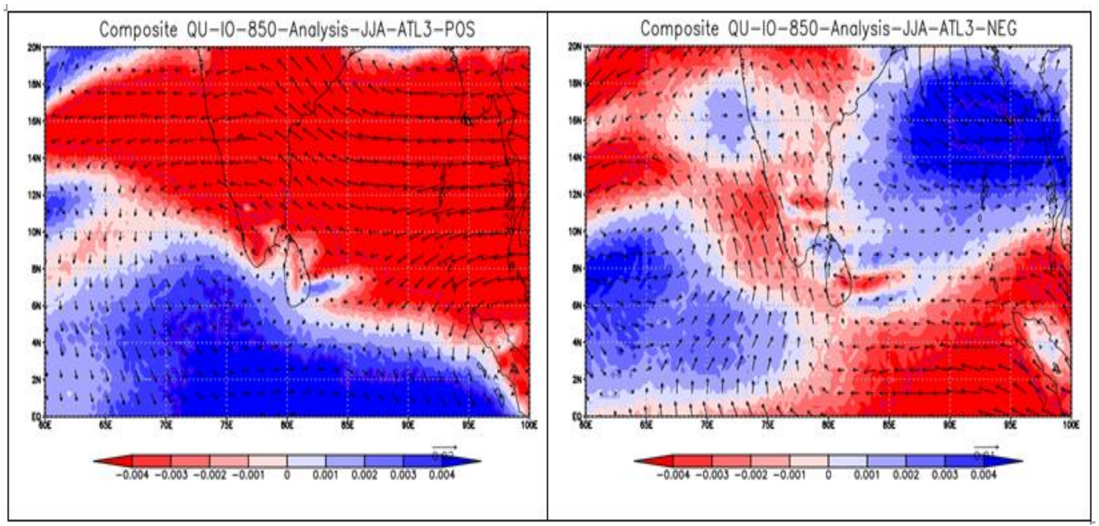

FIG.23. **The composite of the anomaly of zonal moisture flux at 850hPa over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

Meridional moisture flux at 850 hPa level behavior is quite similar to the behavior of zonal moisture flux with positive anomalies over the TA region in the positive phase and negative anomalies over the negative phase. However, it appears as if the alternating negative, positive and negative anomaly patches over the Indian Ocean region have shifted in an easterly direction in the negative phase years when compared with the positive phase years (Figure 24). This shift in the spatial pattern is further evident in (Figure 25).

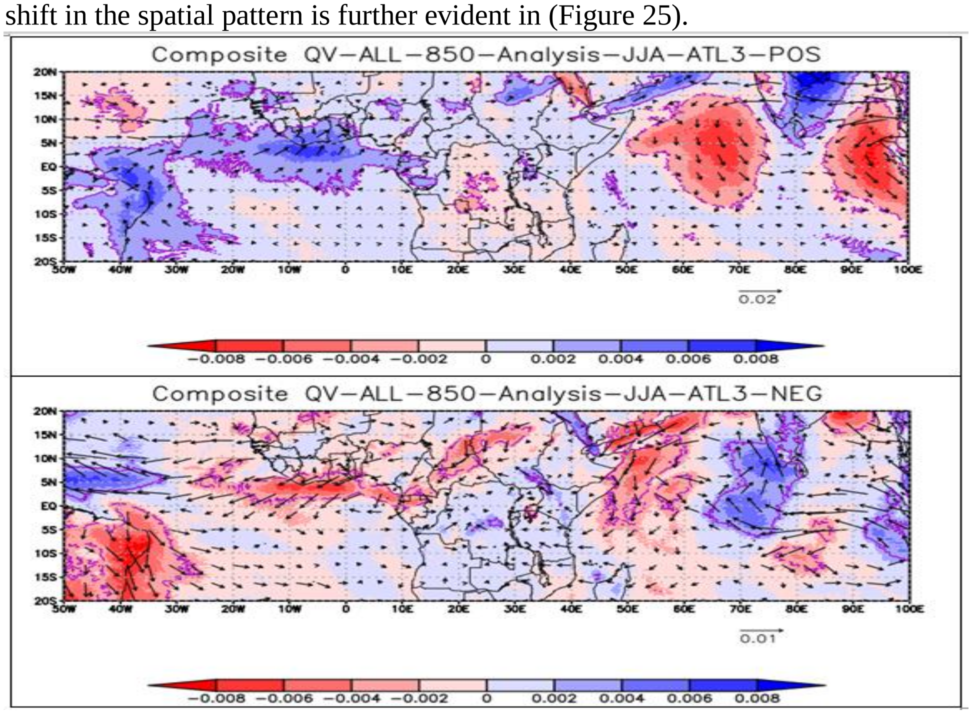

FIG.24. **The composite of the anomaly of zonal moisture flux at 850 hPa over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

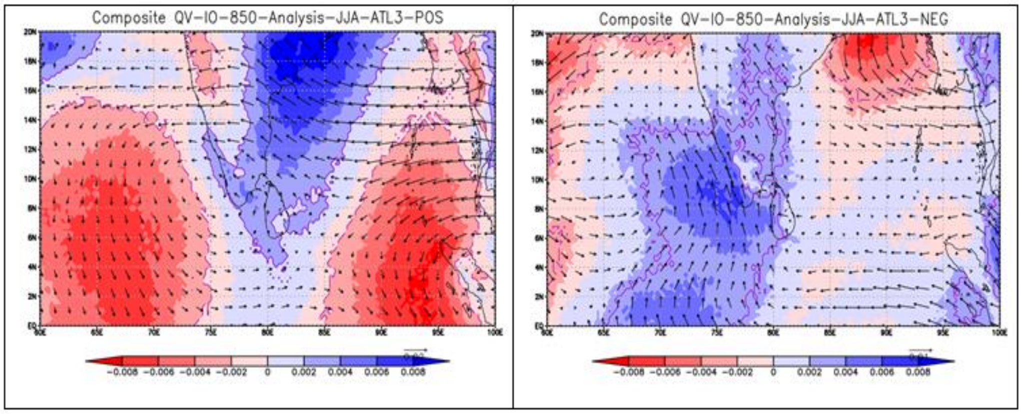

FIG.25. **The composite of the anomaly of zonal moisture flux at 850 hPa over study area during the JJA period for Atlantic Niño (positive, a) & Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

925 hPa: The moisture flux at 925 hPa level for the zonal wind component is also similar to the 850 hPa level. This also shows a positive anomaly with westerly winds over TA in the positive phase and shows a negative anomaly with easterly-south easterly winds during the negative phase (Figure 26). This also further strengthens the idea of moisture flux movement from the tropical Atlantic towards the Indian Ocean over North Africa to the Arabian Sea. Although over Sri Lanka, the anomaly for moisture flux remained slightly negative to negative with easterly winds and in the negative phase wind direction has changed to southerly to south-westerly with patches of positive anomalies over the northern and eastern parts of Sri Lanka (Figure 27). However, on closer inspection it is evident that even at 925 hPa level, moisture flux is higher in comparison during the Niño phase to Niña phase and the cyclonic circulation anomaly is also existent in the 925 hPa level as in the 850 hPa level. This cyclonic circulation is not to be seen in the negative phase year's anomaly.

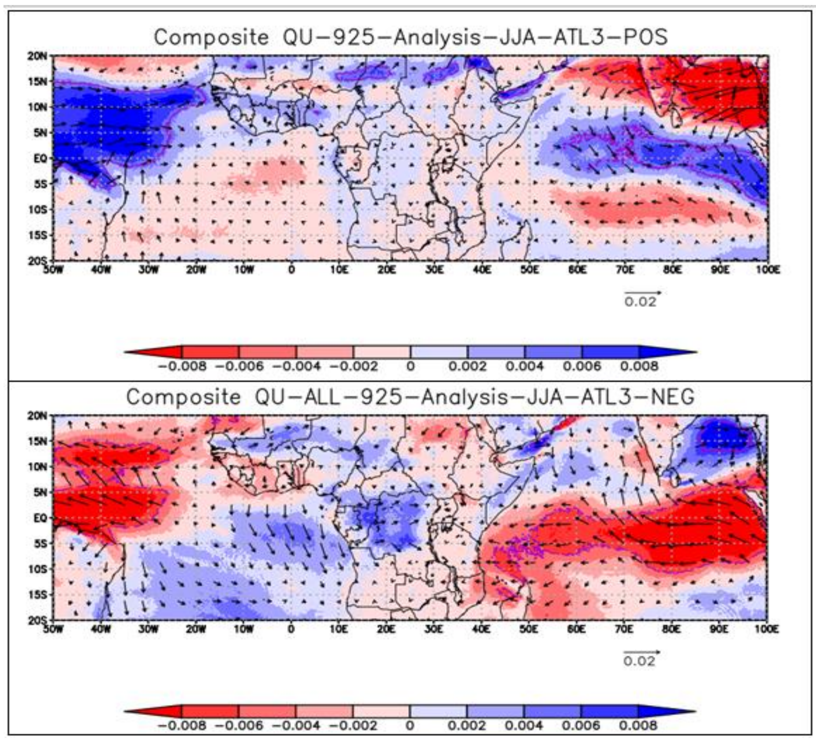

FIG.26. **The composite of the anomaly of zonal moisture flux at 925 hPa over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

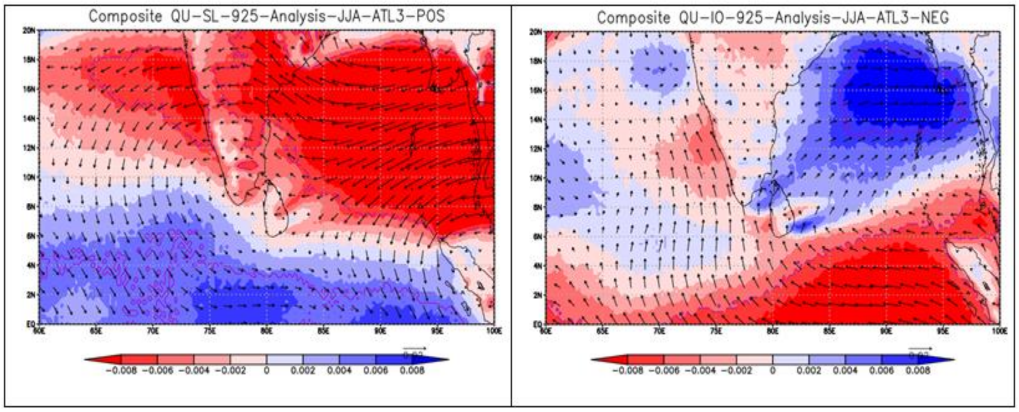

FIG.27. **The composite of the anomaly of zonal moisture flux at 925 hPa over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

The meridional component of the moisture flux at 925 hPa levels is also similar to 850 hPa levels when the Indian Ocean region is compared. Moreover, over Sri Lanka, at the 925 hPa level the moisture flux for the meridional component shows negative anomalies over most parts of the country with easterly flux direction in the positive phase and southerly to south-westerly flux direction in the negative phase (Figure 28). However, over the TA region although the flux direction has remained the same in both the levels, the strong positive anomaly is reduced in the 925 hPa level (Figure 29).

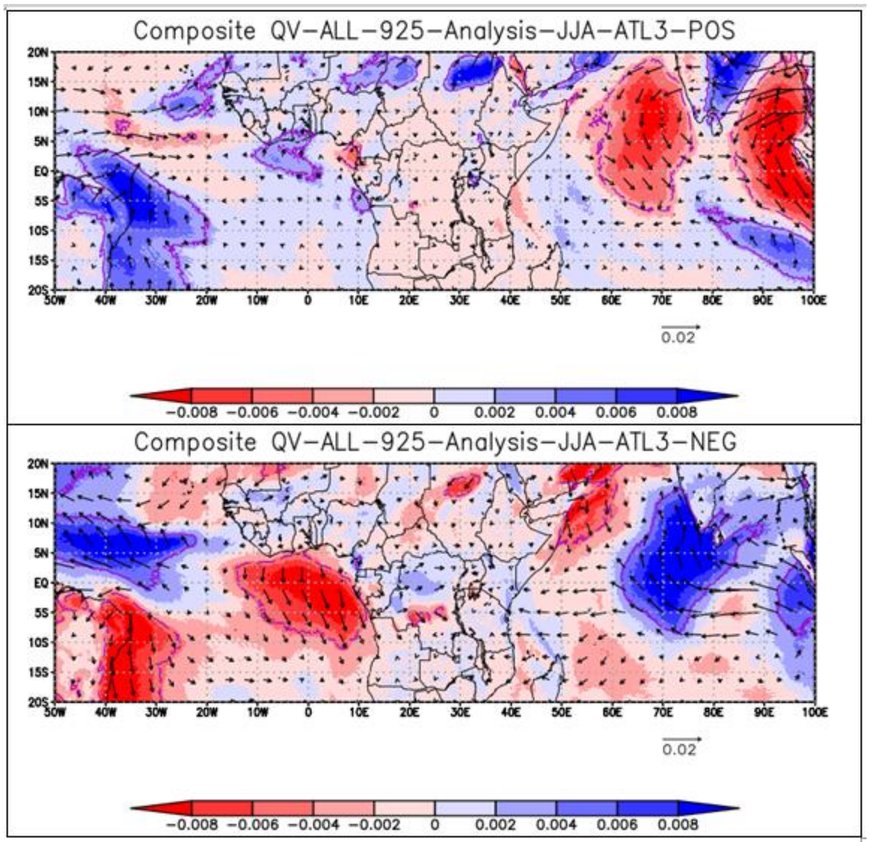

FIG.28. **The composite of the anomaly of meridional moisture flux at 925 hPa over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

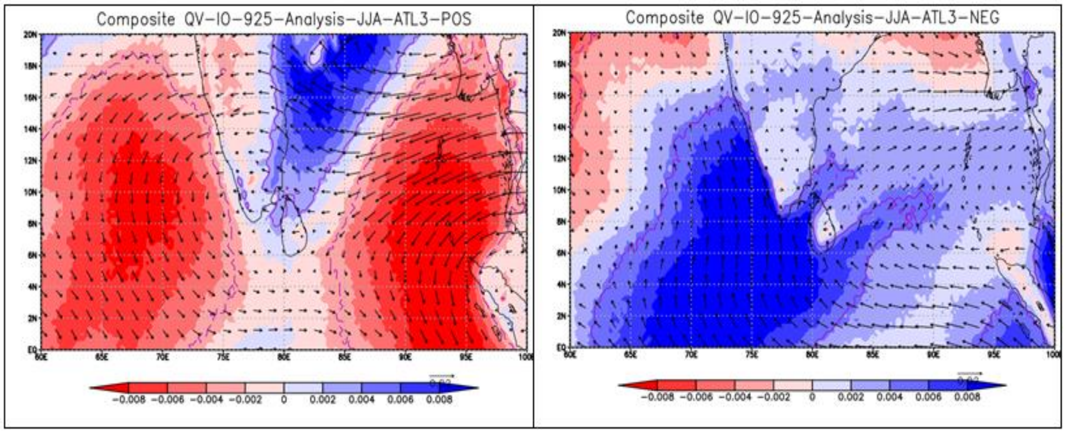

FIG. 29. **The composite of the anomaly of meridional moisture flux at 925 hPa over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

Vertically Integrated Moisture Flux Divergence (VIMFD) anomalies during Atlantic Niño (Niña) years: For a column of air running from the Earth's surface to the top of the atmosphere, the vertical integral of the moisture flux is the horizontal rate of moisture flow over the flow. The pace at which moisture spreads outward from a point is measured by its horizontal divergence. This value is positive for moisture that is dispersing or diverging, and negative for moisture that is converging or concentrating (convergence). This parameter determines whether atmospheric motions cause the vertical integral of moisture to drop (for divergence) or increase (for convergence) over time. Precipitation intensification can be linked to high negative values of this parameter (*i.e.* substantial moisture convergence) [31-36].

VIMFD indicates that during Niño years, it is strongly negative in the TA region and around Sri Lanka which implies strong convergence in the mentioned regions. This has reversed during the Niña phase years and with strong positive anomalies indicating divergence in those regions (Figure 30). A closer look at the Indian Ocean and the vicinity of Sri Lanka, it could be stated that there is strong negative VIMFD values over the south-western part of Sri Lanka which points to strong convergence in the region which will enhance the rainfall over the region. In the Niña years, it shows that the central part of the country having strong positive values indicating strong divergence while the south-western part shows reduced negative values compared to the Niño years which indicates that convergence has significantly reduced during this phase (Figure 31 and 32).

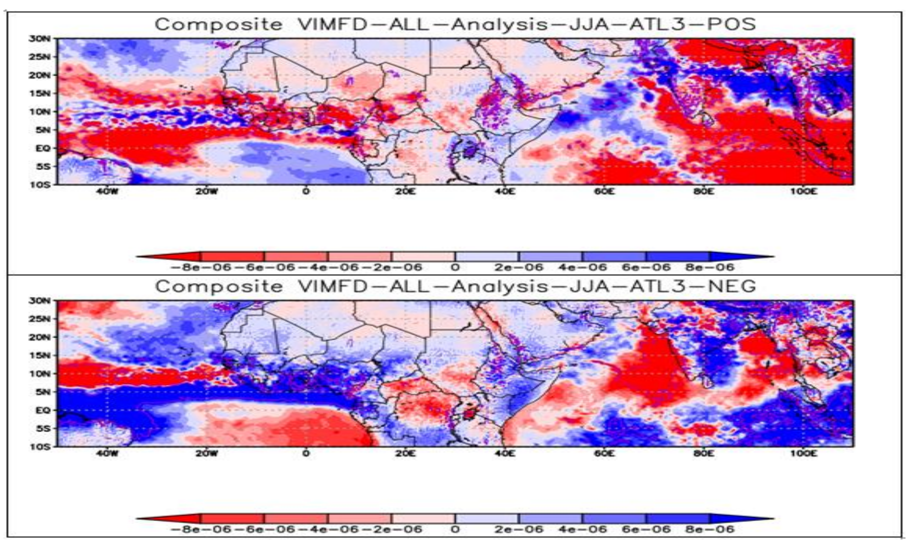

FIG.30. **The composite of the anomaly of VIMFD over study area during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

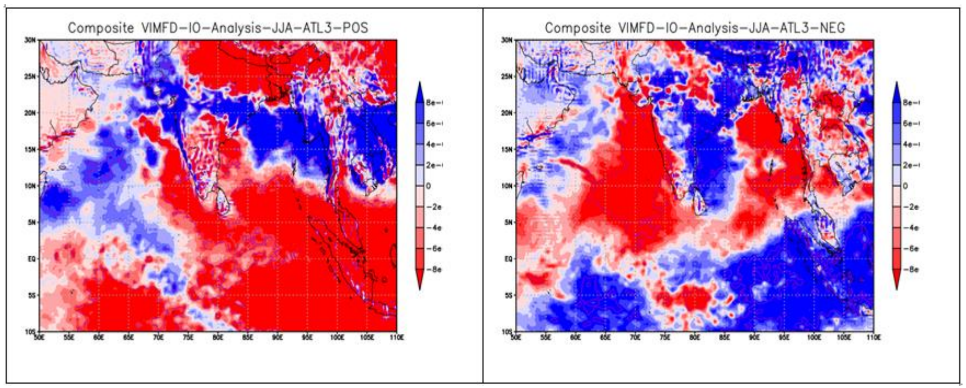

FIG.31. **The composite of the anomaly of VIMFD over Indian Ocean during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

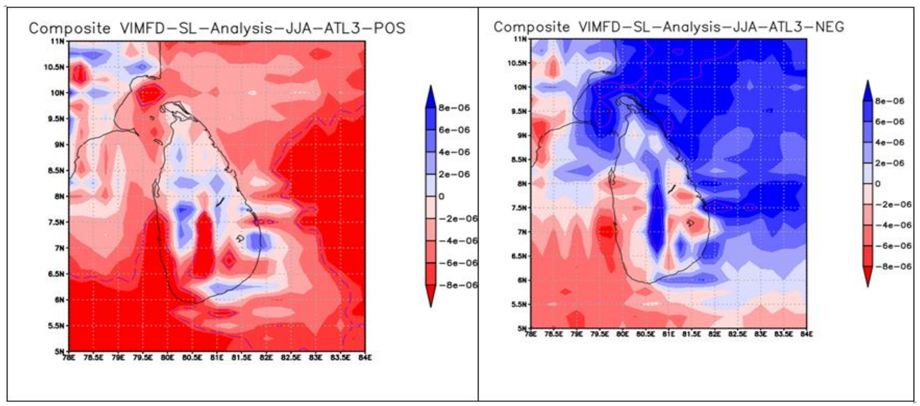

FIG.32. **The composite of the anomaly of VIMFD over Sri Lanka during the JJA period for Atlantic Niño (positive, a) and Atlantic Niña (negative, b) in kgm^{-1}s^{-1}. Purple lines show 95% level of significance.**

Conclusion

Relationship between SSTA of Atlantic Ocean and JJA rainfall over Sri Lanka: The aim of this study is to find the relationship between the Atlantic Ocean and rainfall of Sri Lanka during the South-West monsoon period. In this regard, initially the SSTA of the ATL3 region of the Atlantic Ocean were looked at which were used in previous studies. The ATL3 region (20°W–0°, 3°N–3°S) of the Atlantic Ocean was considered which is the widely accepted region used in identifying Atlantic Niño and Atlantic Niña years. Previous studies conducted have identified Atlantic Niño (Niña) years as the years which the three-month averaged SSTA exceeds 0.5^{oC} (-0.5^{oC}). Accordingly, 1988, 1995-1996, 1998-1999, 2008 and 2016 (7 years) are identified as Atlantic Niño years while 1982-1983, 1992, 1997 and 2005 (5 years) are identified as Atlantic Niña years. Then the correlation of the rainfall anomaly for JJA period with SSTA of ATL3 was considered for JJA period. The correlation for JJA period SSTA with rainfall of JJA was considerably higher. Therefore, for further studies the JJA period SSTA was selected, and the identified Atlantic Niño and Atlantic Niña years were used to conduct a composite analysis on various elements deemed necessary to understand the behavior of the atmosphere during the Atlantic Niño (positive phase) and Atlantic Niña (negative phase).

Influence on rainfall and its proxies: a significant positive correlation was found between SSTA of ATL3 and rainfall over Sri Lanka during the JJA period, it warranted a further look at how the rainfall varied during Niño and Niña phases. In doing so, a composite of rainfall anomalies for both Niño and Niña phases were looked at and it was found that there is a significant positive anomaly of rainfall during the Niño phase especially in the south-western part of the country which is affected most by the south-west monsoon during JJA. OLR acts as a proxy for precipitation and the OLR anomalies during the Niño phase are strongly negative over TA and Sri Lanka which confirms the earlier observation of a positive rainfall anomaly during the Niño phase. OLR anomaly is positive during the Niña phase which indicates that during this phase it was less cloudy than usual.

Availability of low-level moisture: Initially, the study looked at the lower-level moisture which plays a vital role in the occurrence of rainfall and both 1000 hPa and 850 hPa level moisture was deemed supportive during Niño phase compared to Niña phase showing positive anomalies in relative humidity and negative anomalies in the Niña phase. This shows that moisture was available at the lower levels during the Niño phase compared to the Niña phase. However, this does not indicate how the water vapor at the lower levels became favorable during the Niño phase. For this, the study looked at a few parameters that are associated with the transport of moisture at the lower levels. One such parameter was moisture flux and moisture flux was looked at for both 925 hPa and 850 hPa levels and for both zonal and meridional components. Accordingly, it was evident that the Niño phase which created a strong positive anomaly in SST over TA would create a westerly anomaly of zonal winds at 850 hPa and 925 hPa over the TA which will eventually spread to the Indian Ocean as well over the west and North West of the African Continent. This would transport the extra moisture that has evaporated over the TA due to the excess heat to the Indian Ocean. The impact of this flux of water vapor is the source of the increased relative humidity over Sri Lanka during the Niño phase.

Influence on the lower-level and upper-levels of atmosphere: When it comes to precipitation, upper-level divergence and lower-level convergence plays a major role in assisting water vapor to be transported from the surface up to the higher levels to be condensed and form clouds. During the Niño phase, the divergence anomaly at 200 hPa level was significantly positive over TA and Sri Lanka alike. This indicates that the upper-level atmosphere was favorable for precipitation during the Niño phase compared to the Niña phase where the divergence at 200 hPa level was strongly negative. This stems from the fact that highly divergent winds over the TA have created a strong easterly zonal wind anomaly over TA which has spread to the Indian Ocean as well. Conversely, during the Niña phase, there is a strong westerly wind anomaly at 200 hPa level which will eventually reduce the divergence over the Sri Lanka. From the outset, looking at the lower-level convergence, convergence at 850 hPa level does not show any significant difference during the two phases. However, on a closer view over Sri Lanka, it is evident that the divergence values over the western half is significantly negative (indicates convergence) which is the area usually affected during the south-west monsoon period.

Influence on cross-equatorial flow: Considering the strong SSTA positive anomaly, a low-pressure area is created over the TA and this will drive the surrounding winds towards the low-pressure area. This is apparent in the SSTA and MSLP anomalies over TA with negative pressure anomalies over the TA. The importance of the cross-equatorial flow during the south-west monsoon was emphasized in the previous section. Although, the MSLP over the south-Indian Ocean is negative during the Niña phase, considering the pressure gradient, it has created relatively higher-pressure area over the southern Indian Ocean during the Niño phase which has resulted in a flow towards the TA. This is also apparent in the 850 hPa level zonal wind anomaly, where there is a negative anomaly (eastward) in the southern Indian Ocean during the Niño phase. This will in turn result in strengthening the cross-equatorial flow and the Somali Jet. The moisture flux during the Niño phase also demonstrates that additional water vapor will be fed to the cross-equatorial flow as well. As mentioned in the previous section, the strength of this low-level jet stream drives the Somali Current, which is a seasonal cross-equatorial ocean current. Due to the effect of this jet stream on the current, a drop of the SST occurs in the western Arabian Ocean and this drop is further enhanced in the Niño phase which is further evidence that the jet stream has strengthened during the Niño phase. Moreover, the VIMFD, which is an indicator of the horizontal moisture flux from top to the bottom of the atmosphere indicates that the moisture is converging over the south-western part of the country during the Niña phase while the magnitude of convergence has reduced during the Niña phase in the south-western part and it is diverging over the central hills of the country. In addition to that, the streamline analysis of the 850 hPa level suggests that Sri Lanka is under the influence of a cyclonic circulation during the Niño phase. A cyclonic circulation is also part of Rossby wave like formation across the equator. This cyclonic circulation anomaly is further away from Sri Lanka during the Niña phase. During the south-west monsoon period, the prevalence of such formations enhances rainfall over Sri Lanka.

Influence on Inter Tropical Convergence Zone or Monsoon Trough: The ITCZ or the MT enhances rain during the south-west monsoon and the movement of this dictates the rainy condition. If the ITCZ or MT hovers over Sri Lanka for an extended period, it will also result in enhancement of rainfall over the country. When considering the meridional wind anomalies, it is demonstrating a negative anomaly on both east and west sides of Sri Lanka at 850 hPa and 925 hPa levels. This will result in the ITCZ or MT being pushed southwards which will extend the time period Sri Lanka is under the influence of it. The rainfall anomaly pattern for both Niño and Niña phases demonstrates that the ITCZ or MT is pushed northward away from Sri Lanka during the Niña phase while during the Niño phase it has extended its stay over Sri Lanka. The 250 hPa level velocity data anomaly for the respective periods also points to the fact that there exists a shift of the ITCZ or MT.

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