Characterization of the Sri Lanka Monsoon period with weather type approach

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Executive summary
The weather type of 5 weather stations in Sri Lanka was investigated. The May to September monsoon or South-west is characterized by the dominance of South-east and East wind weather type while the December to February or South West Monsoon is indicated by North-East wind weather type. Easterly wind are presents during both periods. Furthermore, the intermediary period between monsoon presents high occurrence of cyclones and North East pure wind direction in agreement with the main mosoon wind direction.

Both % of the volume contribution of total yearly rainfall and the % of volume contribution of total yearly rainfall per rainfall events were computed and plotted. Results indicated that 5 main weathers type are generating the rainfall volume in Sri-Lanka: Cyclone, Hybrid, East, North-east and South-East. Further investigation regarding event volume indicates that weather type present strong seasonal variability and the volume of rainfall.

Those results will provide ground base knowledge for the implementation of a real time optimize regional weather forecast.

Plan
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1. Introduction
1.1. Regional rainfall pattern

The climatic period of Sri Lanka presents two monsoons period that presents variability both in space and time. The first period occurs mainly in the South-West from May to September and in the North-East from December the February. The Figure 1 illustrates the synoptic station in Sri Lanka while the Figure 2 shows the elevation map of the country. The south-central mountain play a major role in the climate of the country.

Figure 1 Meteorological synoptic station of Sri Lanka (Source: Sri Lanka Meteorological Agency).

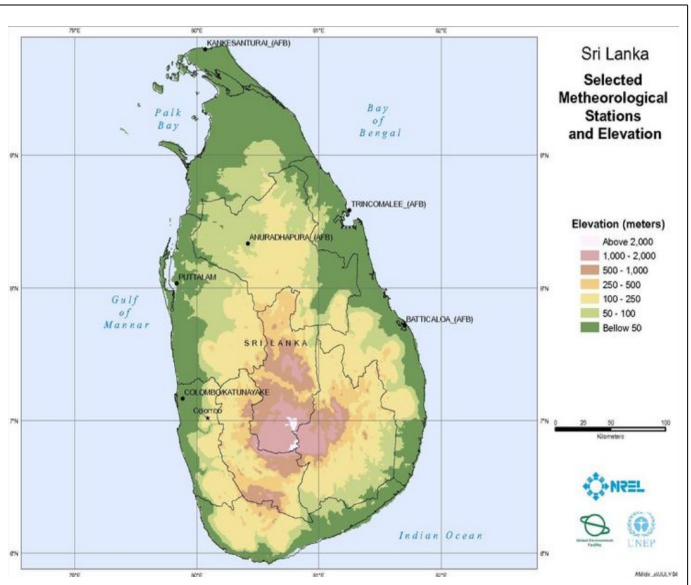

Figure 2 Altitude map of Sri Lanka (Source: Sri Lanka Meteorological Agency).

The Figure 3 and 4 indicates the distribution of the rainfall maximum during monsoon period for the south-east and North-east region.

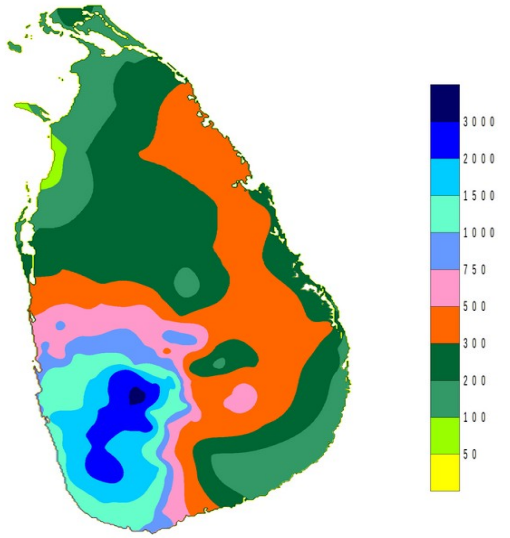

Figure 3 South-West monsoon Season: May-September (Source: Sri Lanka Meteorological Agency).

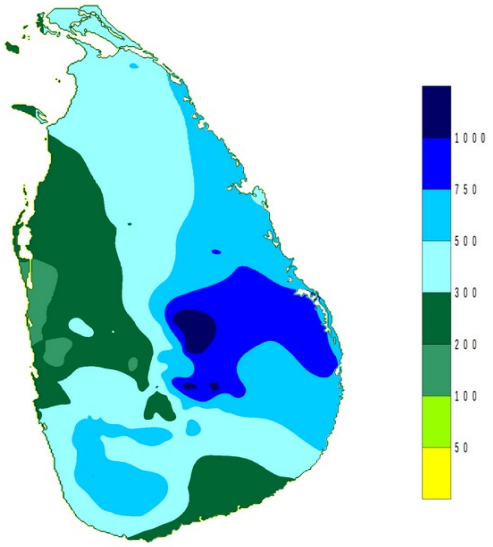

Figure 4 North-East monsoon Season: December-February. (Source: Sri Lanka Meteorological Agency).

The Figure 5 and 6 illustrates the number of rainy days at Colombo and Anuradhapura for each month. Maximum of rainy days are indicated for May/June and Nov/Dec for the south-west and north location respectively. The monsoon influence on the South East and northern part can be clearly noticed.

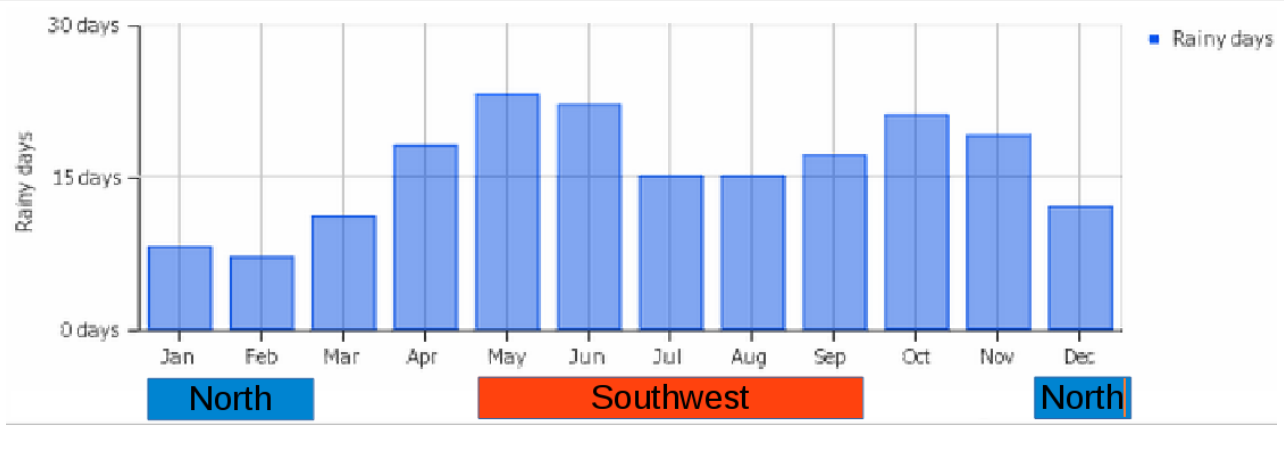

Figure 5 Colombo station monthly average.(Source: Sri Lanka Meteorological Agency).The monsoon periods are indicated by South-west and North labels.

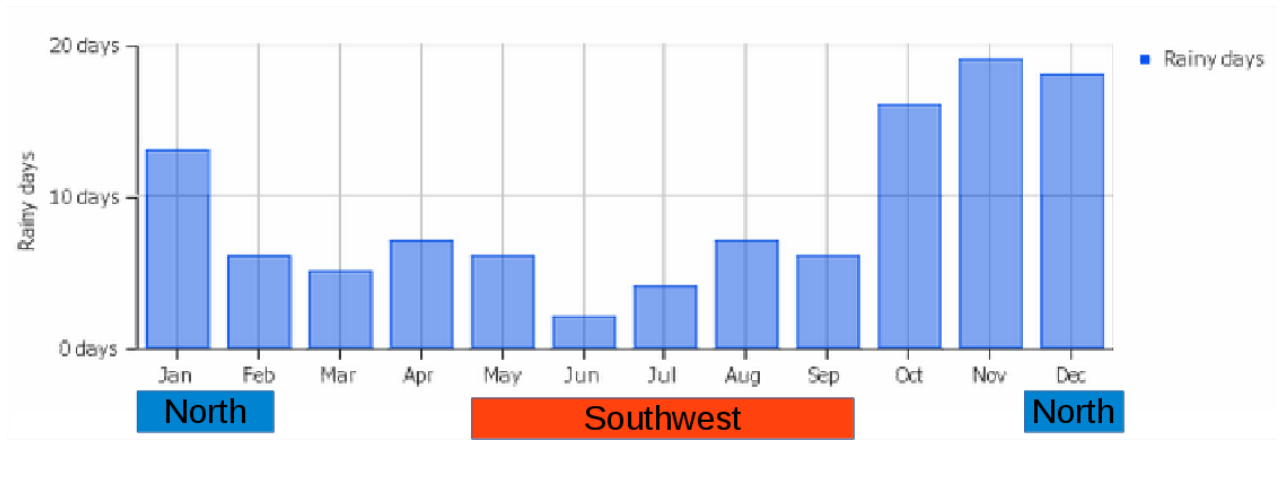

Figure 6 Anuradhapura station monthly average. (Source: Sri Lanka Meteorological Agency). The monsoon periods are indicated by South-west and North labels.

1.2. Monsoon and inter-monsoon system

Sri Lanka presents two monsoon periods which are characterized by main wind direction pattern. In addition, inter-monsoon periods carries important rainfall water volume. It also exhibits a regional wind direction pattern. The Figure 7 illustrates the wind direction associated with the monsoons and inter-monsoons period. Only the North-east monsoon presents a spreading of rainfall associated all over the country. The South-west monsoon and the two inter-monsoon periods present local pattern.

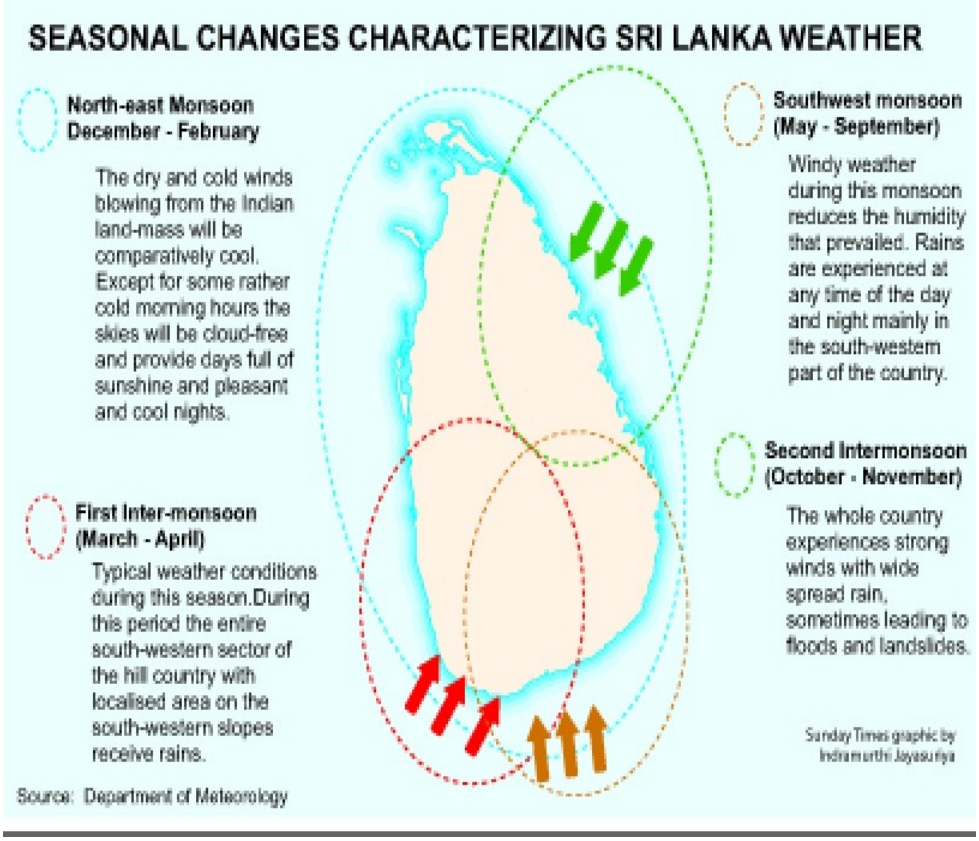

Figure 7 Seasonal changes characterizing the Sri Lanka weather. (Source: Department of Meteorology).

2. Data

Two datasets were used to compute the weather types associated with rainfall event higher than 10mm/day:

- The Persiann satellite data from 2005 to 2015
- The Reanalysis ERA ECMWF data from 1979 to 2015

3.Methods

We used several grid systems to compute weather type at 5 locations (Table 1). This method allowed the capture of the signature of the monsoon effects on weather type for each location. Anuradhapura and Tricomalee are located north-east and exhibits monsoon from December to February while Galle and Colombo in the south-west of the country present a monsoon from May to December. Finally, Kurunegala presents an intermediary location with both monsoon systems.

Table 1 Stations used in the study with their location and monsoon regime.

Station name	Latitude	Longitude	Monsoon regime
Anuradhapura	8.18	80.24	North-east monsoon Season (December-February)
Colombo	6.92	79.86	South-west monsoon Season (May-September)
Kurunegala	7.48	80.36	Mix – both system
Gallee	6.05	80.2	South-west monsoon Season (May-September)

Tricomalee	8.34	81.14	North-east monsoon Season (December-February)

The weather type computation using a simple classification between vorticity (cyclonic and anticyclonic) and purely wind direction was used. The determination of weather types is performed by different methods, both subjective and automatic weather patterns. We used a Mean Sea Level Pressure (MSLP) based methods and the popular Gross Weather Type defined by the German Weather agency and based on Lamb weather types themselves defined by Lamb's work (1972). It is done by calculating 6 different weather parameters that allow the computation of the wind flow direction and the Anticyclonic/Cyclonic character of perturbation. Then 11 types can be defined which 8 are purely directional and 2 based on vorticity. Then, the last one is labelled 'hybrid cyclonic' or 'hybrid anticyclonic' or simply 'unclassified'.

The six parameters are defined as Southern Flow (SF), Westerly Flow (WF), westerly shear vorticity (ZW), southerly shear vorticity (ZS), the Resultant Flow (RF) and the total shear vorticity (Z), are computed through the following formula developed by (Trigo and DaCamara, 2000):

First, a grid of daily pressure point was defined which have 5 degree resolution between (132E-147E and 25-45 N) during the period 1979-2014 was computed based on the ERA-Interim data.

Then, the direction of a WT (S, SE, E, NE, N, NW, W and SW) is defined as:

$$SF = 1.35\left[\frac{1}{4}\left(p_5 + 2\times p_9 + p_{13}\right) - \frac{1}{4}\left(p_4 + 2\times p_8 + p_{12}\right)\right] \quad \text{(Equation 1)}$$

$$WF = \left[\frac{1}{2}\left(p_{12} + p_{13}\right) - \frac{1}{2}\left(p_4 + p_5\right)\right] \quad \text{(Equation 2)}$$

$$ZW = 1.12\left[\frac{1}{2}\left(p_{15} + p_{16}\right) - 0.5\times\left(p_8 + p_9\right)\right] - 0.91\left[\frac{1}{2}\left(p_8 + p_9\right) - \frac{1}{2}\left(p_1 + p_2\right)\right] \quad \text{(Equation 3)}$$

$$ZS = 0.85\left[\frac{1}{4}\left(p_6 + 2\times p_{10} + p_{14}\right) - \frac{1}{4}\left(p_5 + 2\times p_9 + p_{13}\right)\right] \quad \text{(Equation 4)}$$

$$RF = \left(WF^2 + SF^2\right)^{0.5} \quad \text{(Equation 5)}$$

$$Z = ZS + ZW \quad \text{(Equation 6)}$$

Finally, the classification criteria are defined by the Flow Strength (F), vorticity (Z) and Mean Direction (D). Jenkinson AF, Collison FP. 1977 found that simple relationships between F and Z determined whether the weather was pure Lamb Directional Flow (S, SE, E, NE, N, NW, W and SW), hybrid or synoptic structure (Anticyclonic or Cyclonic) then:

- if Abs(Z) < F, the magnitude of the total shear is less that the resulting flow, then the Weather type is purely directional. The direction of a CT is defined by the Dir= tan-1(WF/SF) adding 180 degrees to the value if WF was positive. 45 degree segment is allocated for each direction.
- if Abs(Z) > 2F the n type was whether Anticyclonic or Cyclonic.
- if Abs(F) was between Abs(Z) and F the type was a synoptic hybrid type.
- if F < Mean year F annual and Abs(Z) < Mean Z annual, the type was hybrid.

Table 2: Summary of classification of WT: Purely directional, Cyclonic, Anticyclonic and hybrid

Purely directional (SE, E, NE, N, NW, W, SW, S)	$\|Z\| < F$
Cyclonic	$\|Z\| > 2F, Z > 0$
Anticyclonic	$\|Z\| > 2F, Z < 0$
Hybrid cyclonic and hybrid anti cyclonic	$F < \|Z\| < 2F$

4. Results

We computed the seasonal distribution of weather type for each month for the five stations considered. The Figure 8 Figure 9 illustrates the seasonal weather type distribution in Colombo and Anuradhapura respectively. Colombo presents a large volume of rainfall generated by South-east wind system.

The south-west monsoon being characterised by the dominance of South-East and East purely wind weather type that carries most of the rainfall from May to September. The North-East Monsoon is characterised by purely North East and east wind as well as cyclone and hybrid systems.

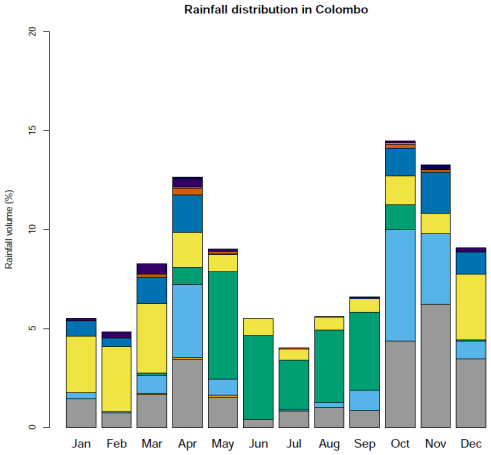

Figure 8 Seasonal weather type distribution in Colombo per volume of rainfall using satellite data observation.

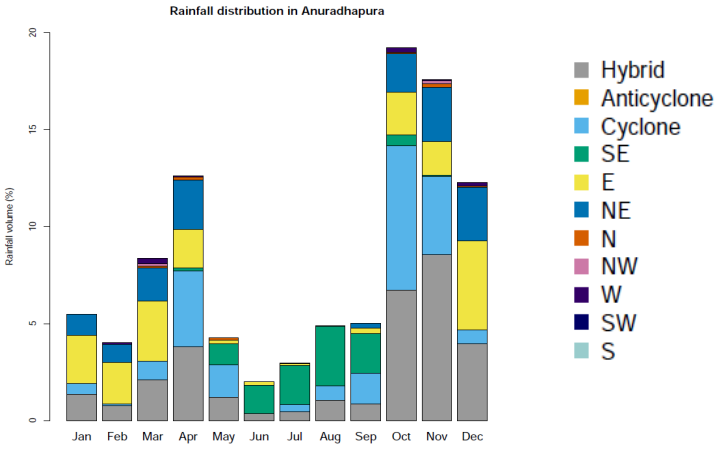

Figure 9 Seasonal weather type distribution in Anuradhapura per volume of rainfall using satellite data observation.

The Figure 10 and Figure 11 indicated the % of rainfall generated per events for Colombo and Anuradhapura respectively.

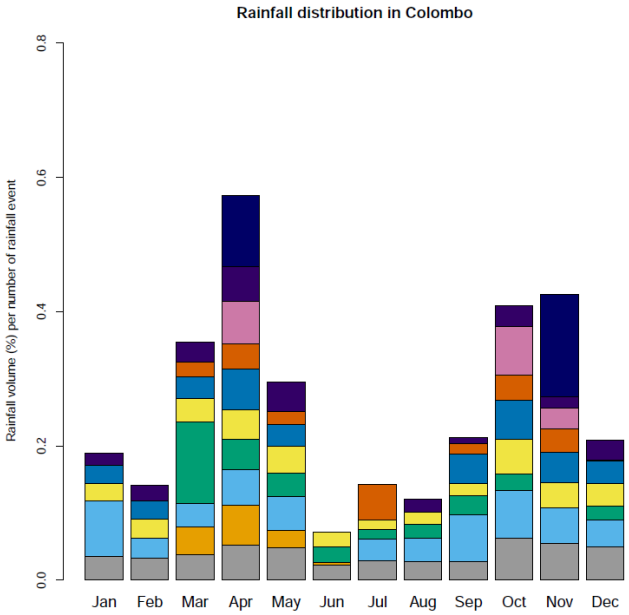

Figure 10 Seasonal weather type distribution in Colombo per volume event of rainfall using satellite data observation.

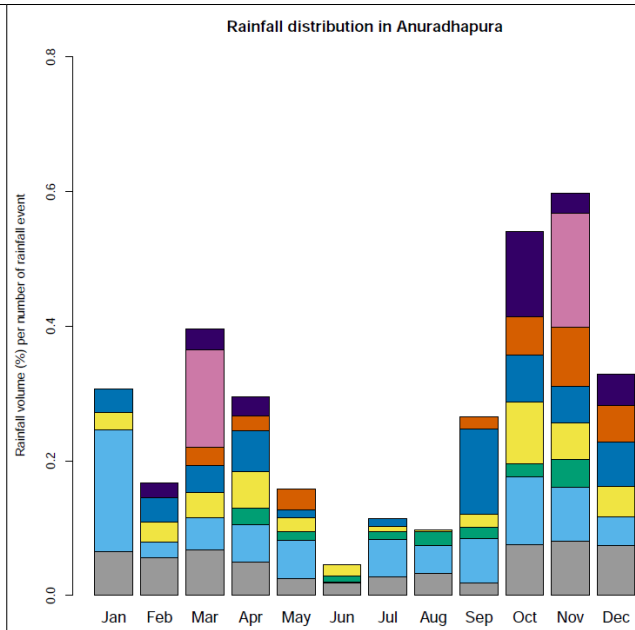

Figure 11 Seasonal weather type distribution in Anuradhapura per volume event of rainfall using satellite data observation.

The Figure 12 highlights the distribution of the rainfall volume in % associated with weather types over Sri Lanka in five locations with their respective seasonal pattern. The South East weather type characterizes the Northwest monsoon with East and South East wind pattern stronger for the station of Colombo and Galle.

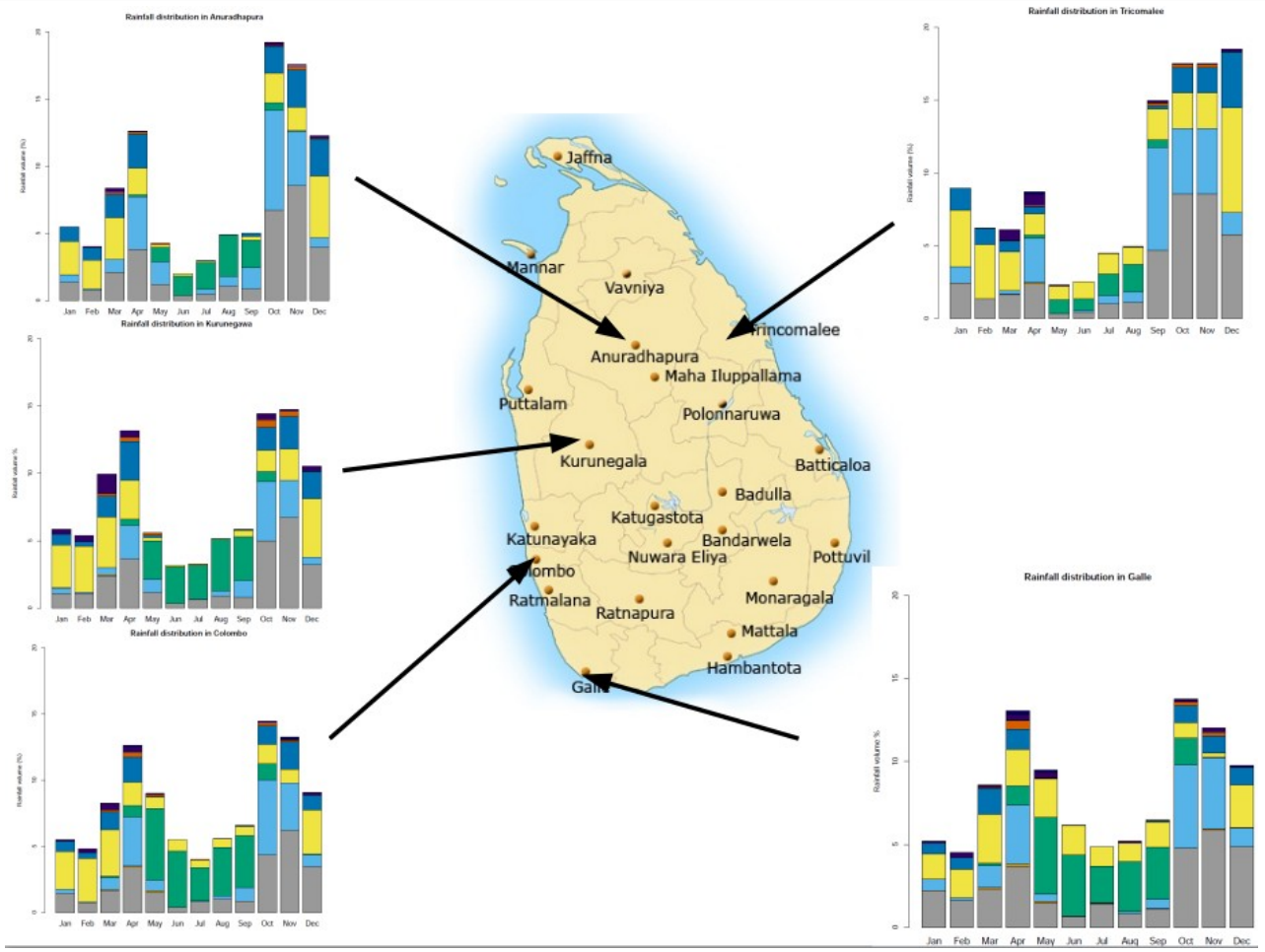

Figure 12 Map of the distribution of seasonal rainfall event >10mm/day per weather type for the Anuradhapura, Colombo, Galle, Kurunegala and Tricomalee.

5. Conclusions

During this study, we computed the seasonal % rainfall volume and % rainfall volume per rainfall events associated with weather types for Sri Lanka in 5 different locations. The locations were chosen for their representatively of both the North-east (Anuradhapura and Trincomalee), South-west (Colombo and Galle) and intermediary location (Kurunegala).

The Hybrid, Cyclone, South-east, East and North-east wind direction are the main rainfall contributors of the region. However, seasonal and location variability can be observed. The May to September monsoon or South West is characterized by the dominance of North-West purely wind weather type while the December to February or South West Monsoon is indicated by purely North and North-East purely wind weather types. Furthermore, an intermediary period is indicated by the occurrence of cyclones and north-east winds. The pattern can be match with the current understanding of weather in Sri-Lanka.

Furthermore, the results of this study can be used as the background to optimize the WRF schemes by focusing on the dominant weather type per month and location and potentially improve the WRF rainfall prediction.

5. Annexes

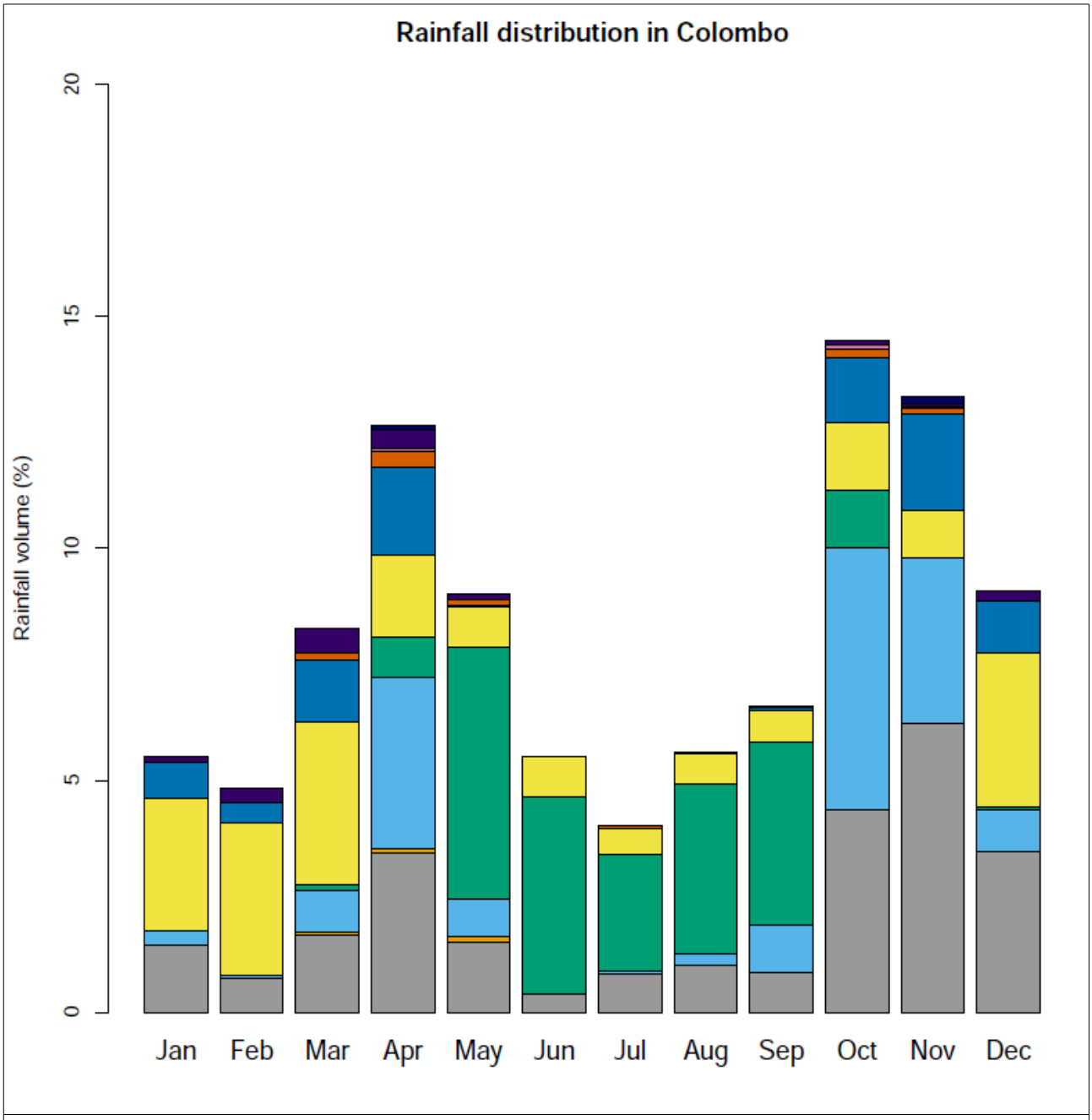

Figure 13 Seasonal weather type distribution in Colombo.

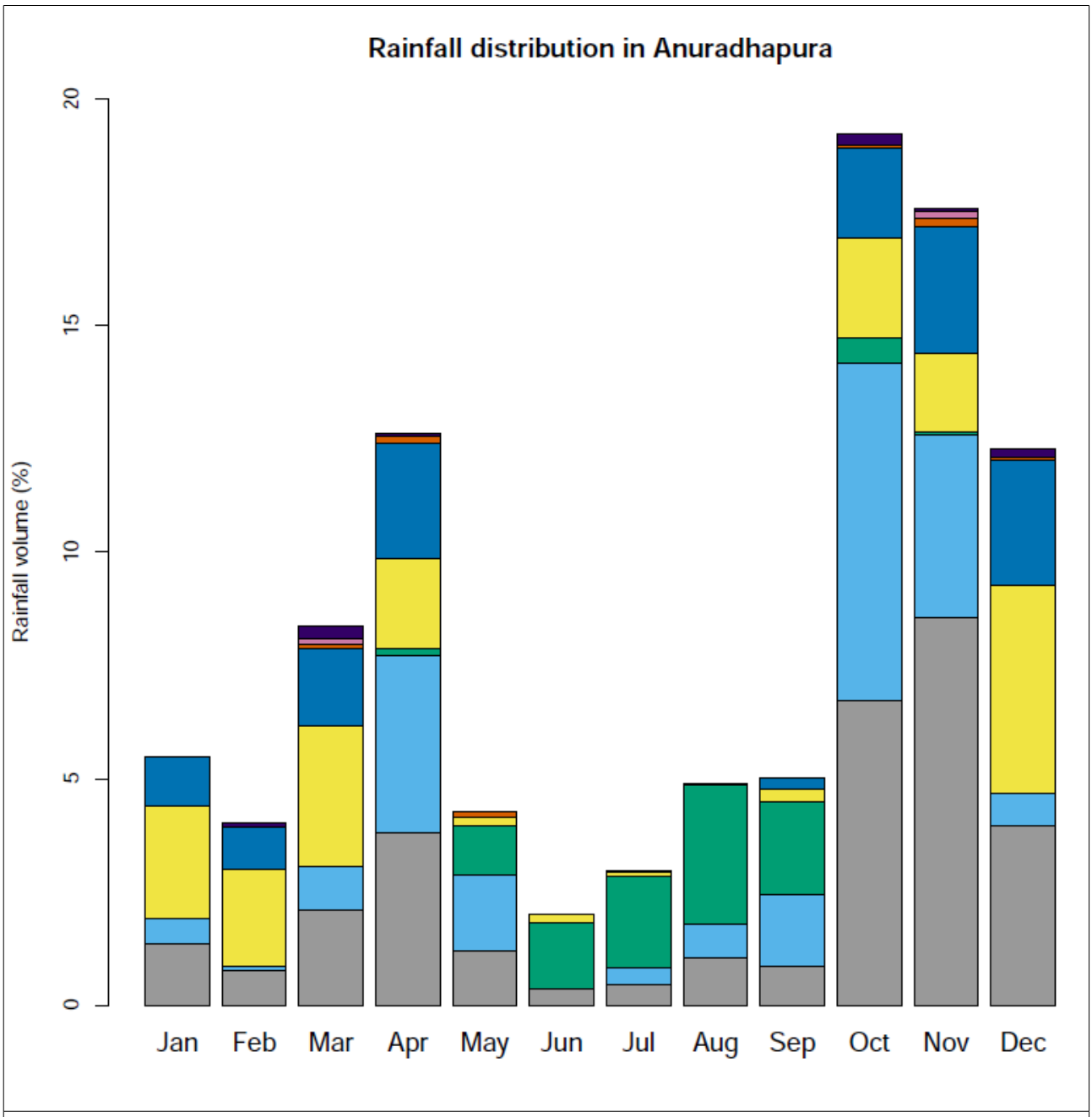

Figure 14 Seasonal weather type distribution in Anuradhapura.

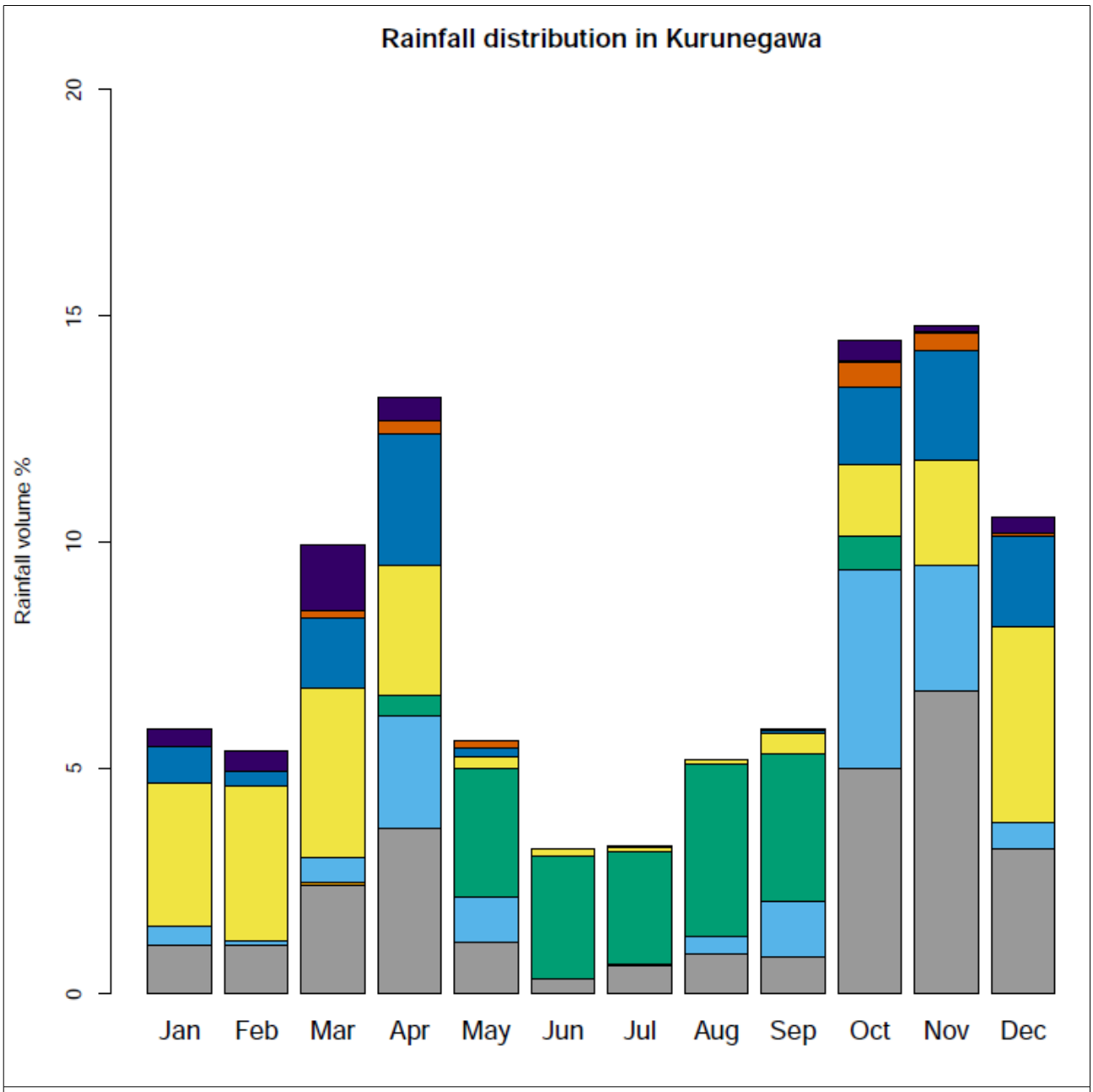

Figure 15 Seasonal weather type distribution in Kurunegala.

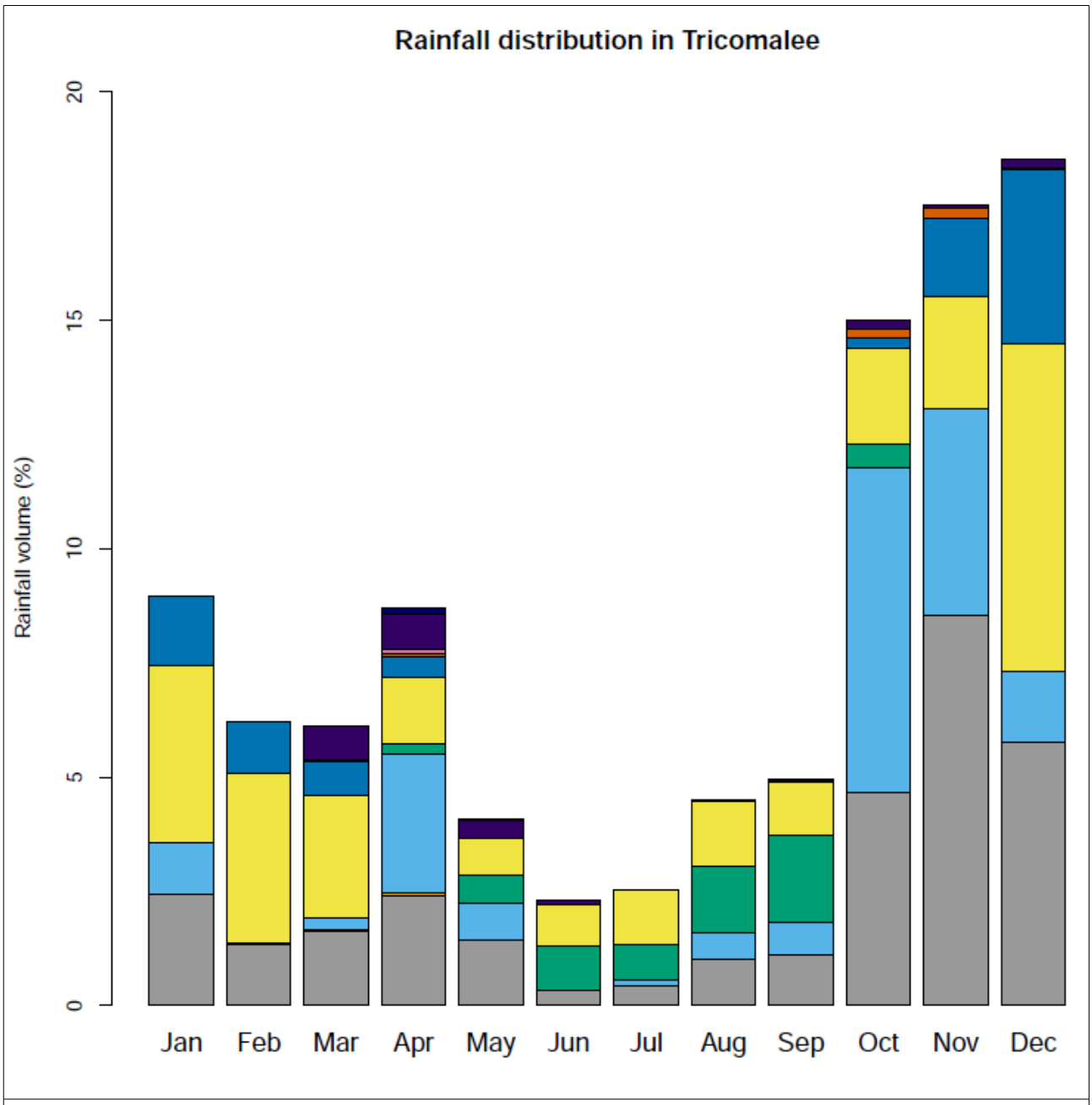

Figure 16 Seasonal weather type distribution in Tricomalee

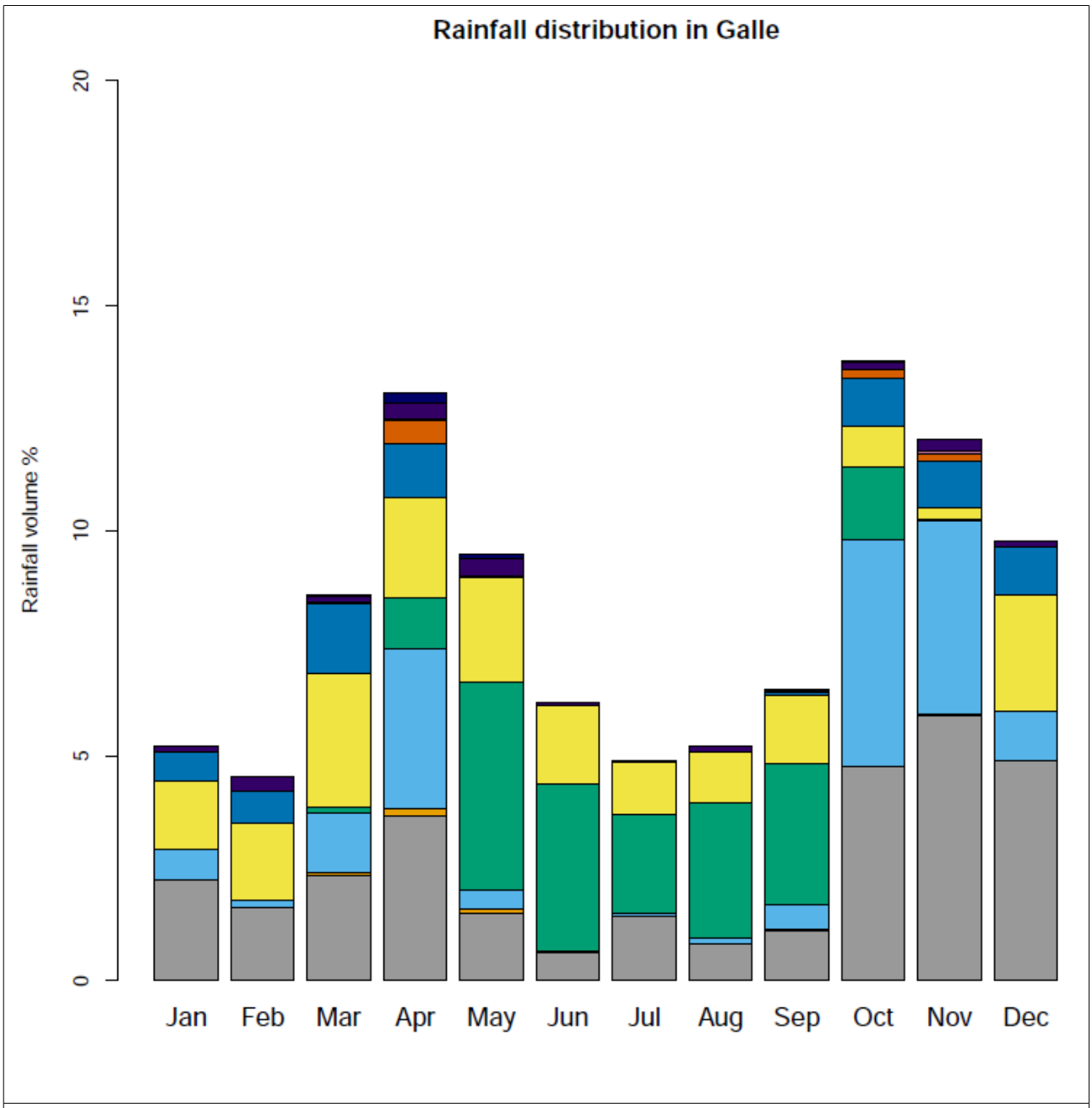

Figure 17 Seasonal weather type distribution in Galle