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Spatial variability of north east monsoon rainfall over Peninsular India during strong, weak and normal NEMR years

E K Simon[*,a], R Sajeev[a] & Basil Mathew[b]

[a]Department of Physical Oceanography, Cochin University of Science & Technology, Cochin – 682 016, India

[b]Kerala University of Fisheries and Ocean studies (KUFOS), Cochin – 682 506, India

*[E-mail: simonambat@gmail.com]

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North East Monsoon Rainfall (NEMR) is classified as strong, weak and normal depending on the strength of the NEM rainfall using Peninsular India (PI) monthly rainfall data and its behavior is examined during contrasting NEMR years. The sub divisions Kerala, Tamil Nadu and Coastal Andhra Pradesh contribute maximum rainfall to the cumulative PI NEMR and South Interior Karnataka and Rayalseema contribute the least, whether it is a strong or weak NEM. Analysis shows that the rainfall pattern is substantially different in all six sub divisions between strong and weak NEMR years and the difference is statistically significant as confirmed by the Wilcoxon Mann-Whitney rank sum test. Composite analysis shows that more rainfall is received in all the six sub divisions in comparison to the Long Period Average (LPA) during years of strong NEMR, and vice-versa during years of weak NEMR. Correlation analysis between PI NEMR and the sub divisional NEMR indicates that the sub divisions Tamil Nadu (TLN), Rayalseema (RLS), South Interior Karnataka (SIK) and Coastal Andhra Pradesh (CAP) have strong positive correlation whereas Kerala (KER) and Coastal Karnataka (COK) rainfall shows moderate correlation.

[**Keywords:** NEM rainfall, North East Monsoon, OND rainfall, Peninsular India, Spatial variability, Wilcoxon Mann-Whitney rank sum test]

Introduction

The northeast monsoon (NEM) season during the months of October, November and December (OND) is a very important season for Peninsular India (PI) during which it receives a fair amount of rainfall. It is a monsoon of smaller scale compared to the south west monsoon (SWM) affecting the PI which consists of the meteorological subdivisions viz., coastal Andhra Pradesh (CAP), Rayalseema (RLS), south interior Kamataka (SIK), coastal Kamataka (COK), Tamil Nadu (TLN), and Kerala (KER)[1].

NEM is associated with the seasonal reversal of surface winds from south westerlies to north easterlies which sets in over Indian region in October[2] and is caused due to radiative cooling of land in the northern region and the resultant flow of cold air from north to the south[3]. This season is also known as the "winter monsoon"[4], "retreating (southwest) monsoon season" or "post-monsoon season"[5]. During the NEM season, India receives about 11 % of its annual rainfall and PI receives 29.3 % of its annual rainfall, whereas the subdivisions of PI receive 17-49 % of their annual rainfall[6]. For Tamil Nadu, NEM is the main rainy season compared to other sub divisions and accounts for about 48 % of the annual rainfall.

The North East monsoon, which affects the Indian South Peninsula is comparatively less studied and penetrated compared to the South West monsoon. It plays an important role in the agricultural and hydrological sustenance of southeast peninsular India and it has been observed that a below normal decrease of NEM rainfall seriously affects agricultural production in the southeastern parts[7]. Inbanathan[8], studied the behavior of Tamil Nadu rainfall and the study shows that there is a randomness or non-linearity in the quantity of Northeast Monsoon of Tamil Nadu indicating that NEM is chaotic. In the present study we try to examine how the OND rainfall or NEMR (OND rainfall, NEM rainfall and NEMR are synonymously used in this paper) behave in the sub divisions of PI during strong, weak and normal NEMR years. This study may give more insight into the spatial variability of Northeast monsoon during contrasting rainfall conditions of PI.

It may be noted that the study does not aim to investigate into the atmospheric or oceanic mechanisms causing the strong or weak NEM rainfall but try to look into the NEM rainfall data in order to understand the spatial variability of PI sub divisional NEM rainfall during contrasting NEMR years. The paper is systematically arranged in standard sections and sub sections. The rainfall data and the various methods adopted in this study are given in detail in data and methodology. The sub divisional rainfall distribution during strong, weak and normal NEMR years along with the composites is presented in the subsequent section. Next, the changes in rainfall in the six subdivisions of PI during strong and weak NEMR years is analysed and attempted to find the strength of association between PI NEMR and the changes of sub divisional OND rainfall and the results are discussed in detail. Then we proceed with, Wilcoxon Mann-Whitney rank sum test, an objective statistical significance testing of the spatial differences in PI sub divisional rainfall between contrasting NEMRs (strong/ weak). Finally, we conclude by summarising the findings in summary and discussion section.

Materials and Methods

Data and methodology

The dataset used in this study is the IITM monthly rainfall dataset for the period 1871-2016 for PI and its six subdivisions. The monthly and seasonal rainfall for PI and the six sub divisions is extracted from this dataset. The dataset in text tabular format is imported to R software and the required sub divisions and seasons are extracted. Means and standard deviations are computed for each sub division and seasons for PI. Some of the methodologies described by Yangxing *et al.*[9], are adopted in the present study.

Peninsular India subdivisions

As defined by IMD, Peninsular India consists of 6 sub divisions, two on the eastern side [Coastal AP (CAP) and Tamil Nadu (TLN)], two on the Western side [Coastal Karnataka (COK) and Kerala (KER)] and two in the interior middle [Rayalseema (RLS) and South Interior Karnataka (SIK)] (Fig. 1). PI experiences floods and droughts in various seasons and in different subdivisions. We give special focus to the spatial distribution of OND rainfall during diverse rainfall conditions – strong, weak and normal NEM rainfall.

Strong, weak and normal NEMR

For the purpose of this study, we define strong, weak and normal NEMR year depending on the strength of the NEM Rainfall compared to the long period average (LPA) of NEMR. The criteria used in this study are taken from Parthasarathy *et al.*[10].

A strong NEMR year is defined as a year in which the total PI rainfall of NEM season (OND) is more than one standard deviation (SD) of the mean OND rainfall, 331.9 mm. It is the LPA of the OND rainfall over the years 1871-2016. (OND rainfall > LPA + 1 SD). A weak NEMR year is a year in which the total PI rainfall of NEM season (OND) is less than one Standard Deviation of the LPA of the OND (OND rainfall < LPA -1 SD) and a normal NEMR year is defined as a year where the total OND rainfall is within 1 SD of the LPA (OND rainfall >= LPA – 1SD and OND rainfall <= LPA + 1SD)

The distribution of the PI OND rainfall for the years 1871-2016 is graphically presented in Figure 2. Strong, weak and normal NEMR years are marked blue, red and grey, respectively, according to the defined criteria. There are 25 strong, 21 weak and 100 normal NEMR years during the years 1871-2016.

Extreme strong and extreme weak NEMR years

From the 25 strong NEMR years, four extreme strong years are identified in descending order (1946, 2010, 1930, 1993). Similarly, from the weak NEMR

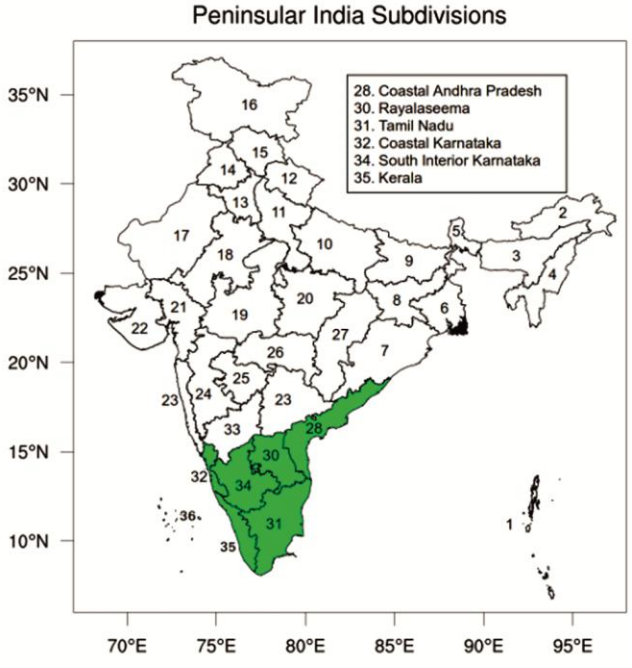

Fig. 1 — Peninsular India sub-divisions – green shaded region (Courtesy: Indian Institute of Tropical Meteorology web site).

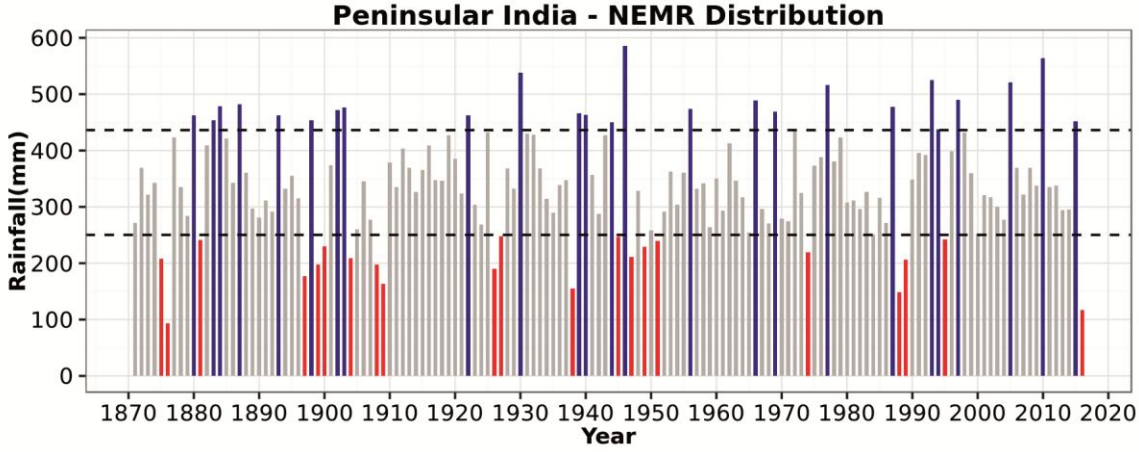

Fig. 2 — Distribution of Peninsular India NE Monsoon Rainfall for the period 1871-2016. Strong NEMR (blue), weak NEMR (red) and normal (grey). Upper dashed line indicates mean + 1 SD and lower dashed line indicates mean -1 SD

years, four extreme weak years are identified in ascending order (1876, 2016, 1988, 1938). Composites of sub division wise OND rainfall distribution during Strong/ Weak/ Normal years are also prepared.

OND rainfall ratios

OND rainfall ratios of PI rainfall and sub divisional rainfall during NEM season is computed as percentage:

Sub division wise Rainfall Ratio = (Sub divisional OND Rainfall/ LPA OND rainfall)*100

From these rainfall percentage values, composites during strong, weak and normal years are also taken. Anomalies are also computed for these composites.

Correlation of sub division wise OND rainfall to PI OND rainfall

Correlation coefficients of sub divisional OND rainfall to PI NEM rainfall is computed and graphs are plotted to evaluate the coherence between the rainfall patterns of peninsular India and its six sub divisions.

Wilcoxon Mann-Whitney rank sum test

Wilcoxon Mann-Whitney rank sum test[11] is used to compare the means of two groups - one for rainfall during strong NE monsoons and another for rainfall during weak NE monsoons. It is a nonparametric test and the data sets need not follow a normal distribution and is quite useful for the present study. Statistical Significance Test on PI sub divisional NEM rainfall to PI NEM rainfall between strong and weak NEMR is done.

Table 1 — General statistical parameters of rainfall of peninsular India sub-divisions during the period 1871 - 2016

Sub Division	Mean (mm)	Min (mm)	Max (mm)	SD (mm)	CV (%)
CAP	376.4	87.9	700.1	144.6	38.4
TLN	457.8	163.6	858.7	143.9	31.4
RLS	207.7	11.9	455.3	87.2	42.0
SIK	214.9	23.2	444.2	85.0	39.6
COK	244.1	18.7	705.1	121.6	49.8

Results and Discussion

In order to understand the Spatial Variability of North East Monsoon Rainfall over PI during Strong, Weak and Normal NEMR years, we undertook the following studies over PI and its sub divisions.

Sub-divisional OND rainfall distribution during strong, weak and normal NEMR years

The general statistics of the PI sub division rainfall of NEM is presented in Table 1. Kerala has the highest mean NEM rainfall, followed by Tamil Nadu and then coastal Andhra Pradesh and all three of them are coastal sub divisions. Rayalseema has the lowest mean rainfall and the next is south interior Karnataka and both of them are interior sub divisions. The CV shows that Kerala followed by Tamil Nadu has the lowest variability and coastal Karnataka has the highest variability of NEM rainfall. The minimum, maximum and standard deviation of NEMR of the six sub divisions are also given in Table 1.

To study the spatial variability of NEMR, it is worthwhile to study how the OND rainfall is distributed in PI across the six sub divisions during

strong and weak NEMR years. During the strongest NEMR years it is seen from Figure 3 that either Tamil Nadu (TLN) or Kerala (KER) records the highest rainfall with Coastal Andhra Pradesh (CAP) coming third. South Interior Karnataka (SIK) or Rayalseema (RLS) shows the lowest rainfall except in 1930 when Coastal Karnataka (COK) records the lowest rainfall. It is also noted that COK rainfall fluctuates more during the various extreme years. During the weakest years, it is seen that either KER or TLN or CAP displays the highest rainfall with SIK or RLS showing the lowest rainfall. Among the weakest NEMR years, COK records the lowest rainfall of 18.7 mm in 1876.

To examine the average picture of OND rainfall in the six sub divisions, the OND rainfall in these sub divisions are averaged over 25 strong years, 21 weak years, 100 normal years and LPA for 146 years (Fig. 4). The LPA (Fig. 4d) shows the ranking of OND rainfall in the sequential order KER, TLN, CAP, COK, SIK, RLS with Kerala receiving highest average NEM rainfall and Rayalseema receiving the lowest. In NEMR weak composites (Fig. 4b), the

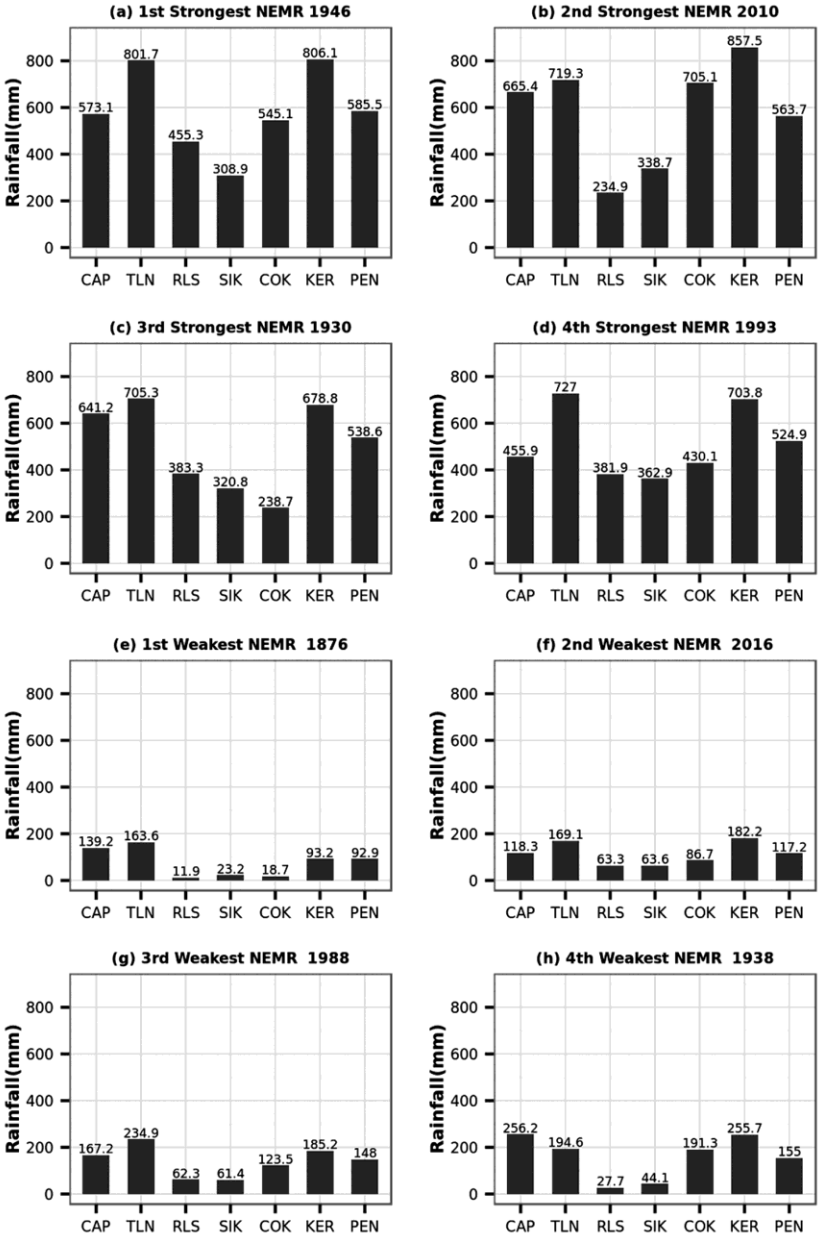

Fig. 3 — Peninsular India rainfall distribution of sub-divisions during the four strongest NEMR years (a) to (d), and the four weakest years (e) to (f)

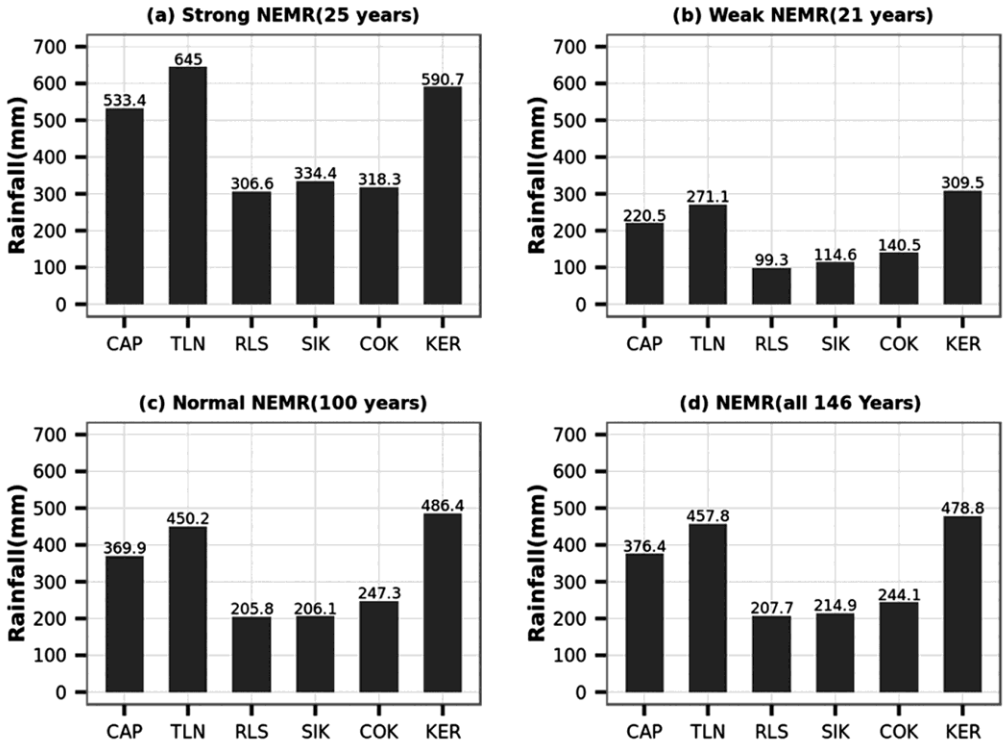

Fig. 4 — Composites of peninsular India sub divisional rainfall distribution based on (a) 25 strong years, (b) 21 weak years, (c) 100 normal years, and (d) full NEMR period 146 years

same ranking order as that of LPA is maintained. During strong NEMR years (Fig. 4a), highest rainfall is received in TLN, then KER and CAP. Lowest rainfall is received in RLS. Changes in rainfall from NEMR weak years to strong years are very high; it is almost more than double in most of the sub divisions. Table 2 tabulates the difference of sub divisional rainfall between strong NEMR years and weak NEMR years. The difference is highest for Tamil Nadu (373.9 mm) and lowest for Coastal Karnataka (177.9 mm).

Table 2 — Mean OND rainfall of peninsular India sub divisions during strong, weak and normal NEMR. Column 6 gives the difference of rainfall between strong and weak NEMR years.

Sub Division	Strong NEMR (25 Yrs) (mm)	Weak NEMR (21 Yrs) (mm)	Normal NEMR (100 Yrs) (mm)	All NEMR (146 Yrs) (mm)	(Strong – Weak) (mm)
CAP	533.4	220.5	369.9	376.4	312.9
TLN	645.0	271.1	450.2	457.8	373.9
RLS	306.6	99.3	205.8	207.7	207.3
SIK	334.4	114.6	206.1	214.9	219.8
COK	318.3	140.5	247.3	244.1	177.9

Change in sub-divisional OND rainfall

First, we examined the sub divisional rainfall for weak and strong NEMR years and their composites. In this section, we try to find out the changes in rainfall with respect to the long period average in the six subdivisions of PI during strong and weak NEMR years.

Changes in rainfall of PI subdivisions are computed by the ratios of OND rainfall of each sub division to the corresponding sub divisional LPA (expressed as percentage) following the method described in data and methodology. Changes of OND rainfall over the six sub divisions (CAP, TLN, RLS, SIK, COK, KER) relative to the OND LPA in the corresponding sub divisions are worked out and a composite graph of strong (25), weak (21) and normal (100) is presented in Figure 5. During the strong NEMR years, rainfall in all the six subdivisions is more than the rainfall during the weak NEMR years and the respective LPA. Similarly, rainfall in all the six subdivisions is less than the corresponding LPA during the weak NEMR years. SIK rainfall followed by RLS rainfall shows the largest increase relative to the corresponding LPA during strong NEMR years and RLS followed by SIK shows largest decrease of rainfall relative to the corresponding LPA during weak NEMR years. Kerala rainfall is least sensitive to the strength of the NEMR. It has the smallest increase

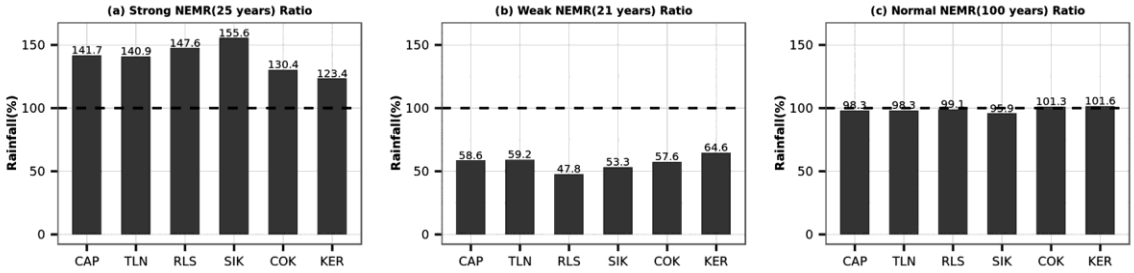

Fig. 5 — Ratios in % of sub divisional OND rainfall based on (a) 25 strong years, (b) 21 weak years, (c) 100 normal NEMR years to the corresponding monthly long period average. The horizontal dashed line represents the value of 100%

during strong years and smallest decrease during weak years. It is also notable that the ratio in normal NEMR years is comparable to the LPA values.

The overall changes of sub divisional OND rainfall in the six subdivisions (during NEM season) for 25 strong, 21 weak and 100 normal OND rainfall years depicted as ratios in percentage to the PI OND rainfall LPA is presented in Table 3. The difference in rainfall percentage from strong to weak NEMR years is highest for SIK (102.3 %), followed by RLS (99.8 %). The lowest percentage change is observed for KER (58.8 %) followed by COK (72.8 %). Change in rainfall percentage of TLN and CAP remains in between. The percentage of maximum, minimum and range of OND rainfall of six sub divisions of peninsular India relative to the corresponding LPA OND rainfall is given in Table 4. The percentage range of OND rainfall shows that the highest variability is for COK and the lowest for TLN.

Table 3 — Ratios (in %) of peninsular India sub divisional rainfall to the corresponding LPA computed over the period 1871-2016 for 25 strong, 21 weak and 100 normal NEMRs. Column 5 gives the difference of rainfall % between strong and weak NEMR years.

Sub Division	Strong NEMR (25 Yrs) %	Weak NEMR (21 Yrs) %	Normal NEMR (100 Yrs) %	(Strong – Weak) %
CAP	141.7	58.6	98.3	83.1
TLN	140.9	59.2	98.3	81.7
RLS	147.6	47.8	99.1	99.8
SIK	155.6	53.3	95.9	102.3
COK	130.4	57.6	101.3	72.8
KER	123.4	64.6	101.6	58.8

Table 4 — Mean percentage (Max, Min and Range) of OND rainfall of six sub divisions of peninsular India relative to the corresponding LPA OND rainfall

Sub Division	OND max %	OND min %	% Range
CAP	186.0	23.4	162.6
TLN	187.6	35.7	151.9
RLS	219.2	5.7	213.5
SIK	206.7	10.8	195.9
COK	288.8	7.7	281.1
KER	179.1	19.5	159.6

Association of sub divisional OND rainfall with NEMR over Peninsular India

In the previous section, we tried to find the strength of association between PI NEMR and the changes of sub divisional OND rainfall. In this section, we further investigate the relationship between sub divisional OND rainfall and the PI NEMR.

Figure 6 depicts the scatter plot of sub divisional OND rainfall against the PI NEMR over the period 1871-2016. The linear correlation is computed for OND rainfall of each sub division and printed on the left upper part of each graph. A line of best fit is also drawn and its slope is printed below the correlation in each graph. Scatter plot of the PI NEMR vs the sub divisional OND rainfall gives a clear picture of the relationship between them. OND rainfall of the four subdivisions (TLN, RLS, SIK and CAP) has strong linear positive correlation with PI NEMR rainfall. KER and COK NEM rainfall shows only a moderate relationship with the PI NEMR rainfall. The steepness of the relationship, denoted by the slope, is higher for TLN, CAP and KER OND rainfall. This indicates that for a unit change in these three sub divisions, the effect is more (compared to other three sub divisions) on PI NEMR. RLS and SIK OND rainfall has a lower slope and COK OND rainfall has the least slope, indicating a comparatively less effect on the PI NEMR rainfall.

Statistical significance test on Peninsular India sub divisional rainfall between weak and strong NEMR years.

First, we try to find out how much variation occurs in rainfall in the six subdivisions during strong and

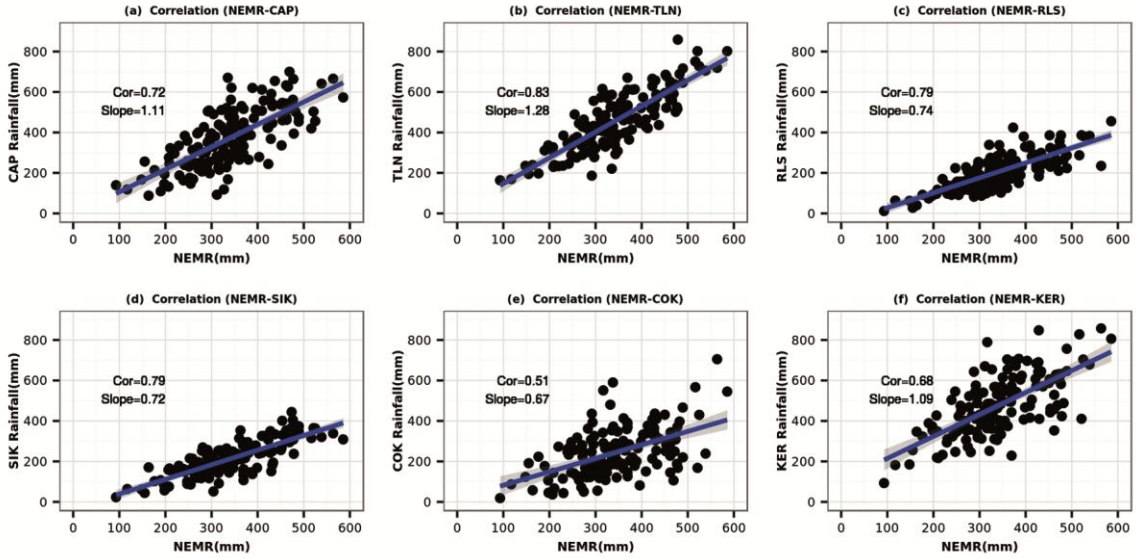

Fig. 6 — Scatter plot and best fit line of OND rainfall of peninsular India sub divisions (CAP, TLN, RLS, SIK, COK & KER) vs NEMR for the period 1871-2016 of peninsular India. The correlation coefficient and slope of the best fit line is printed in the left top part of each graph.

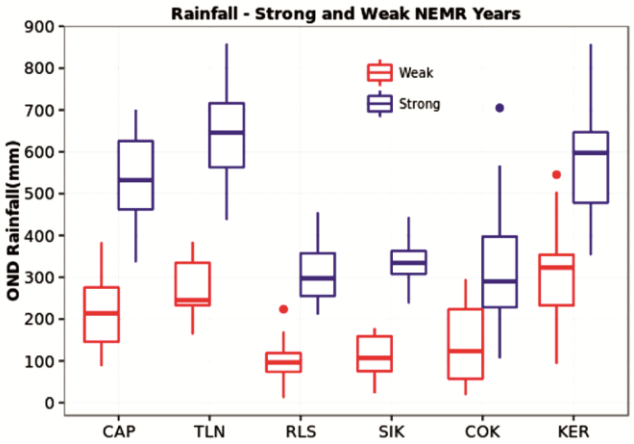

Fig. 7 — Boxplot of OND rainfall in the six sub divisions of peninsular India during strong and weak NEMR years. Red box indicates weak NEMR and blue box indicates strong NEMR

weak NEMR using box plots. Visual inspection of the box plot in Figure 7 shows that the rainfall pattern is substantially different in all the six sub divisions between strong and weak NEMR years. Now, we examine whether the differences observed in the features of sub divisional rainfall between strong and weak PI NEMR is statistically significant. For the significance test, we make use of a non-parametric test, Wilcoxon Mann-Whitney rank sum test[11] to compare the means of two groups; one for rainfall during years of strong NE monsoon and another for rainfall during years of weak NE monsoon.

The null hypothesis in the hypothesis testing is that the rainfall pattern during years of both weak and strong NEMR are identical and the alternate hypothesis is that the sub divisional rainfall received during years of strong NEMR are significantly greater than that received during years of weak NEMR with reference to a defined confidence level. We make use of R function named 'wilcox.test' for the hypothesis testing. Table 5 shows the results of the test at 95 % and 99 % confidence level for each of the six sub divisions. The p-values generated from the test signifies that NEM rainfall in the six sub divisions of PI during 25 strong NEMR years are significantly greater than those NEM rainfall in the corresponding sub divisions during 21 weak NEMR years.

Table 5 — The Wilcoxon-Mann-Whitney rank sum test regarding whether sub-divisional peninsular India rainfall during 25 strong NEMRs are significantly greater than those during 21 weak NEMRs at 95 % & 99 % confidence level

Sub Division	P-value	Significant at 95 % ?	Significant at 99 % ?
CAP	9.21E-009	p-val < .05, yes	p-val < .01, yes
TLN	7.08E-009	p-val < .05, yes	p-val < .01, yes
RLS	9.12E-009	p-val < .05, yes	p-val < .01, yes
SIK	7.09E-009	p-val < .05, yes	p-val < .01, yes
COK	2.53E-005	p-val < .05, yes	p-val < .01, yes
KER	2.80E-008	p-val < .05, yes	p-val < .01, yes

Summary and Conclusion

In this study, the spatial variability of seasonal and sub divisional rainfall in the PI during the NEM season is examined using the seasonal mean rainfall

for the PI sub divisions prepared by IITM over the period 1871-2016.

The sub divisional seasonal rainfall analysis shows that the sub divisions KER, TLN and CAP contributes the maximum rainfall to the cumulative PI NEMR and the sub divisions SIK and RLS contribute the least amount of rainfall towards PI NEM whether it is a strong or weak NEM. It is also observed that during years of strong NEMR, rainfall received in all the six sub divisions are larger than that received during weak NEMR years (Fig. 3) and that the change is statistically significant at 99 % confidence level (Table 4).

Composite analysis of years of weak and strong NEM rainfall shows that the NEM rainfall in all of the six sub divisions of PI is larger than the corresponding LPA (upto 55.6 % increase for SIK) during years of strong NEM rainfall and smaller than the corresponding LPA during years of weak NEM rainfall [(upto 52.2 % decrease for RLS), Fig. 5]. Correlation analysis, which displays the strength of association between PI NEMR and sub divisional OND rainfall, indicates that OND rainfall of the four subdivisions (TLN, RLS, SIK and CAP) have strong linear positive correlation and two sub divisions (KER and COK) show only a moderate relationship with PI NEMR rainfall. The steepness of the relationship, denoted by the slope, is higher for TLN, CAP and KER NEMR compared to RLS, SIK and COK which have a lower slope and COK OND rainfall has the least slope, indicating a comparatively less effect on the PI NEMR rainfall.

The average sub divisional rainfall during strong NEMR years is highest for TLN and lowest for RLS and the highest average rainfall during weak NEMR years is for KER and lowest for RLS indicating that TLN is more benefited during strong NEMR years and KER is more benefited during weak NEMR years. The highest difference of mean between weak and strong NEMR years is seen for TLN and the lowest is for COK. It is noted that, even though Kerala gets the highest LPA of OND rainfall, Tamil Nadu gets the highest mean rainfall during strong NEMR years whereas Kerala gets the highest mean OND rainfall during weak NEMR years.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

Conceptualization and design of the work: EKS, RS and BM; Data collection, analysis and interpretation, Software and Writing - original draft: EKS; and Supervision and Writing - review, editing and final approval: RS and BM.

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