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Study on Rainfall Variability and Atmospheric Teleconnections Associated With El NiãO Southern Oscillation

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Abstract

Rainfall variability at interannual and longer time scales is a crucial area of study with many practical implications for the way we manage our water resources. This variability, which is often linked to both internally and externally forced fluctuations in the global Sea surface Temperature (SST) field can often affect the weather patterns of entire continents via a group of large-scale pressure and circulation anomalies referred to as teleconnections that transmit these anomalies across large distances. The El Niño (warm phase) and La Niña (cold phase) are two opposite phases of the ENSO cycle. The annual and seasonal increasing or decreasing trend of precipitation in the southern states of peninsular India have teleconnections with ENSO warm (El Niño) and cool (La Niña) phases and has been the considered as the significant area of this study. The anomaly rainfall patterns of the 4 seasons namely Summer, Monsoon, Post Monsoon and Winter over the Southern States of India during the 30-year period (1991-2020) corresponding to the El Niño-Southern Oscillation have been studied. Spatially coherent increasing and decreasing trends in seasonal and annual rainfall are found in the southern states of India and the ENSO–Indian Rainfall has been found to have an inverse relationship. During the study period, 9 drought years were observed in southern parts of India, among which three were in non-El Niño years, and specifically the year of 2012 and 2017 were reported to be La Nina years. Likewise, 12 heavy rainfall years were received in the southern states of India, out of which four were in non-La Nina years, and of these 3 years namely 1997, 2015 and 2019 were actually in El Niño years including the well-known Chennai (Tamil Nadu) Floods (2015). The ENSO–Indian Rainfall relationship stands contrary to popular beliefs, stating not all La Niña years does guarantee better-than-normal rains and similarly an El Niño year does not always translate into below-normal rains. Overall, the findings provide a better understanding of the rainfall variability in the southern states of our country, and this information is of potential use for mitigating and managing disaster risks.

Keywords: Anomalies; ENSO; El niño; La niña; Indian rainfall; Sea surface temperature; Teleconnections

Introduction

Over the course of years, numerous research works have been carried out to study the inter-annual Variation of Rainfall and its relation with Climate Change. But with the distribution of excess heat in the ocean being not uniform, with the greatest ocean warming occurring in the Southern Hemisphere and majorly contributing to the subsurface melting of ice shelves, it is imperative to carry out extensive studies on large scale climate drivers influencing globally, such as El Niño and Southern Oscillation Index (SOI), together known as ENSO.

Typically, Asia experiences two monsoons. The Southwest monsoon or the Indian Summer Monsoon which begin by early or mid-June and fade away by the end of September while the Indian Meteorological Department refers to October to December period as the Northeast Monsoon [1] but this season also is referred to as the Winter Monsoon [2]. While the Southwest monsoon is responsible for a major portion of the Annual Precipitation over the Indian Sub-continent, rainfall received during the Northeast monsoon is also important, especially for South India and neighboring countries like Sri Lanka. During the withdrawal phase of the summer monsoon, lower level winds over south Asia reverse their direction from south- west to Northeast which causes the Onset of Northeastern rains [3]. Even though the Northeast monsoon is dry, stable and has less vertical extent compared to the Southwest monsoon, this season is typical during which the country receives about 11% of its annual rainfall, while many districts over the south peninsular region receive about 30-60% of their annual rainfall [4] and thereby migrating to the southern India and onwards to Sri Lanka and the neighbouring sea.

The Inter-annual variability of the Northeast Monsoon Rainfall (the NEMR) influences a wide range of food production activities and effective precipitation serves as the primary source for surface water and as well as the groundwater storage over the south of the peninsula [5]. Approaches to studying the change of precipitation have been attempted considerably, ranging from analyses of the spatio-temporal characteristics of heavy rainfall [6] to changes in rainfall intensity [7] globally. But studies on the possible effects of the El Niño-Southern Oscillation (ENSO) and its impacts on the Peninsular India has been very limited.

But with the continuous changes in the Sea Surface Temperature, it is important to study extensively about the El Niño-Southern Oscillation (ENSO) and how much its three phases namely El Niño, La Niña and the neuter phase and how these have influenced the climate of peninsular India. In this study the interactions between the ocean and atmosphere leading to the alterations in the weather around the world, via Atmospheric Teleconnections will be the prime focus and thereby would help us in understanding the effects of ENSO on the climate conditions of India especially focusing on the Southern States and the Union Territory of Peninsular India, namely, Tamil Nadu (TN),

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Kerala, Karnataka, Andhra Pradesh, Telangana, Goa, Puducherry and its reception of Rainfall and its variability due to the influence of ENSO.

Materials and Methods

The gridded daily precipitation data available at 0.25° x 0.25 ° spatial resolution from the India Meteorology Department (IMD) was used to develop the gridded precipitation for the period of 1891-2020. Whereas, to assess the influence of SSTs on the drought and rainfall variability in Tamil Nadu and Kerala [8], we used monthly data from the Had SST dataset (Hadley Centre) for the period 1870–2018 at 2.0 ° spatial resolution. The Collected Precipitation Data as well as SST Data was then Pre-processed for the 4 predominant Seasons of India. These Seasons are namely, winter, summer, Monsoon and Post-Monsoon. The Pre-Processed Data also includes the Seasonal Average for the 30-year period for both the SST as well as PPT Data. In terms of SST, the Minimum, Maximum temperature recorded along with Niño 3.4 (5°N-5°S, 170°W-120°W)'s data were considered for the Pre-processing followed by the Time Series Analysis for the 4 Seasons namely Winter, Summer, Monsoon and Post-Monsoon, for the 30-year Period from 1991-2020, for the Southern States and the Union Territory of Peninsular India, namely, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Telangana, Goa, Puducherry were carried out for the Precipitation Data. As for the Sea Surface Temperature, the Time Series Analysis were carried out for the Minimum, Maximum temperature recorded along with temperature at Niño 3.4 region.

Results and Discussion

Through the Time Series Analysis, the Precipitation occurrence in the Southern States and Union Territory of India through the 4 seasons with relevance to the changes in the Sea Surface Temperature at Equatorial Pacific (Niño 3.4 Region) was studied. The following are the various results obtained through the analysis. The (Figures 1-4) depict the same [9].

Interpreting the Time Series analysis, from Figure 1. Winter, the results show Winter season Sea Surface Temperature at Equatorial Pacific in terms of the Minimum and Maximum temperature recorded at Niño 3.4 region during the 30-year period. It is inferred that the SST during the Winter season has seen peaks during the years 1992, 1998 and 2016 with 28.52°C, 28.98°C followed by 29.15°C. The rise in SST directly corresponds to the Rainfall data where less-than-Normal rainfall years were observed for the Winter Season during the 30-year period (1991-2020). Whereas, the dip in the year 2000, 2008 and 2011 owing to the lowest SST during the Winter season for the 30-year period with a recorded temperature of 24.92°C, 24.77°C, and 25.19°C respectively shows a rise-in-rainfall pattern for the States and Union Territory studied. However, there are exceptions for the said years for the States of Telangana as well as Goa. The rains in the state of Telangana did not have any influence of the dip in SST for the year 2011. Likewise, the state of Goa received a very little deviation of +0.1mm above Normal (1mm) during the year 2000.

Interpreting the Time Series analysis, from Figure 2. Summer, the Summer season Sea Surface Temperature at Equatorial Pacific in terms of the Minimum and Maximum temperature recorded at Niño 3.4 region during the 30-year period. It is inferred that the SST during the Summer season has seen peaks during the years 1992, 1998 and 2016 with 28.98°C, 28.56°C and 28.64°C. It is observed that Kerala received the maximum rainfall (year 2006-212.96mm) during the study period of 30-years for the area of interest. The rise in SST directly corresponds to the Rainfall data where less-than-Normal rainfall years were observed for the Summer Season during the 30-year period (1991-2020). Whereas, the dip in the year 1999 & 2008 of 26.69°C, 2000 with 26.73°C followed by 2011 with a dip of 26.89°C owing to the lowest SST during the Summer season for the 30-year period, shows a rise-in-rainfall in the terms of more-than-normal pattern for the most of the States and Union Territory studied during the years 1999 and 2008. However, 2011's precipitation record has no effect in regards to the SST. Especially the rains in the state of Telangana did not have any influence of the dip in SST for the year 2011. Only the State of Tamil Nadu 79.89 (Normal-43mm) had comparatively a higher reception of

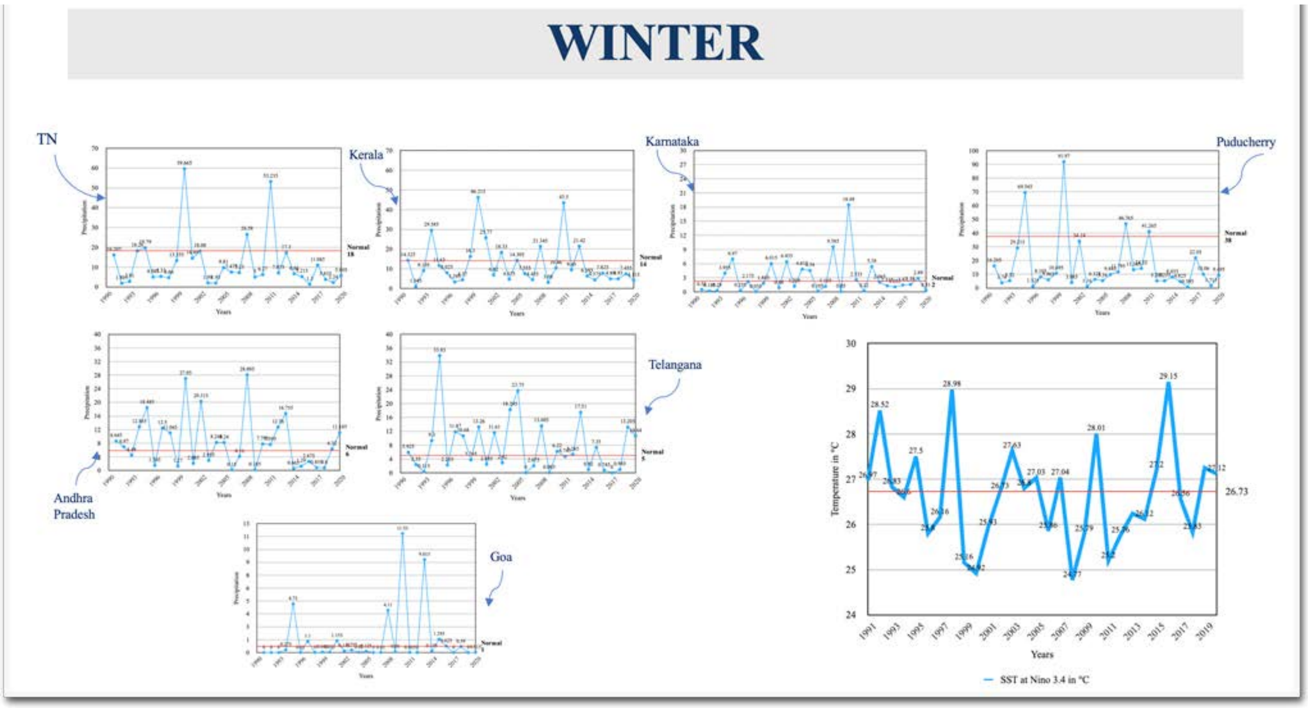

Figure 1: Winter.

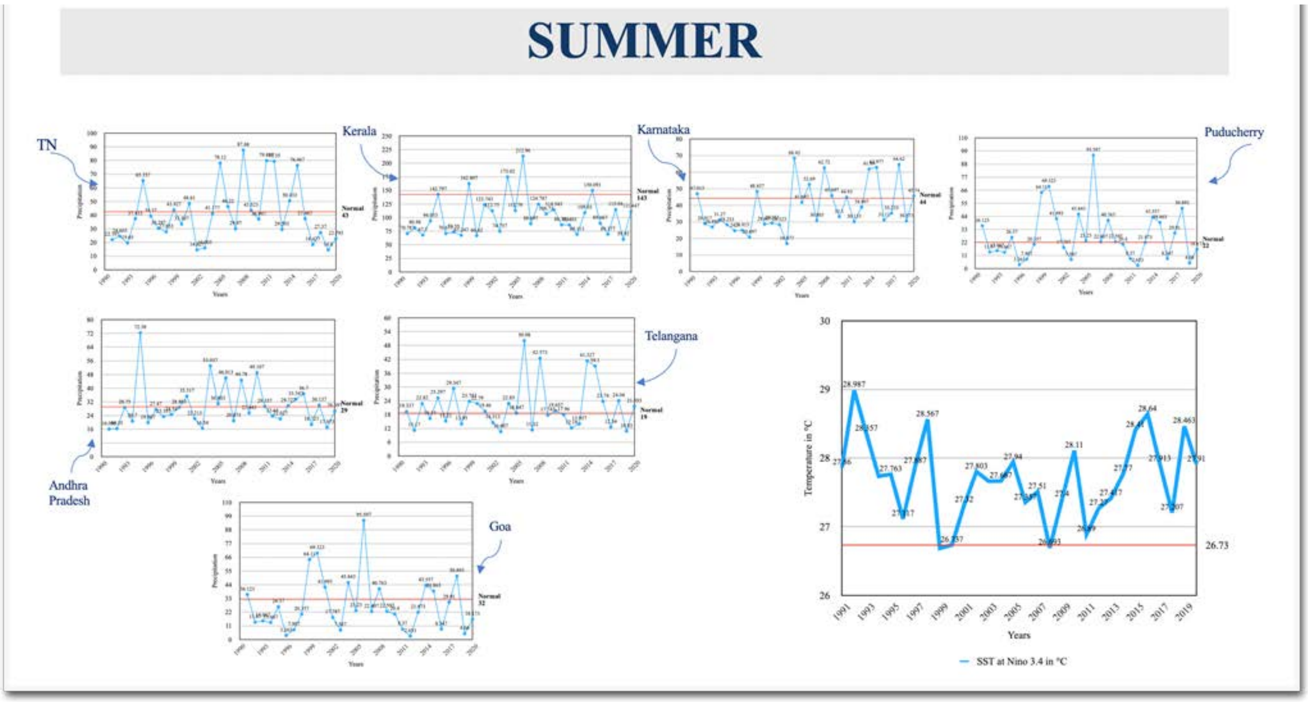

Figure 2: Summer.

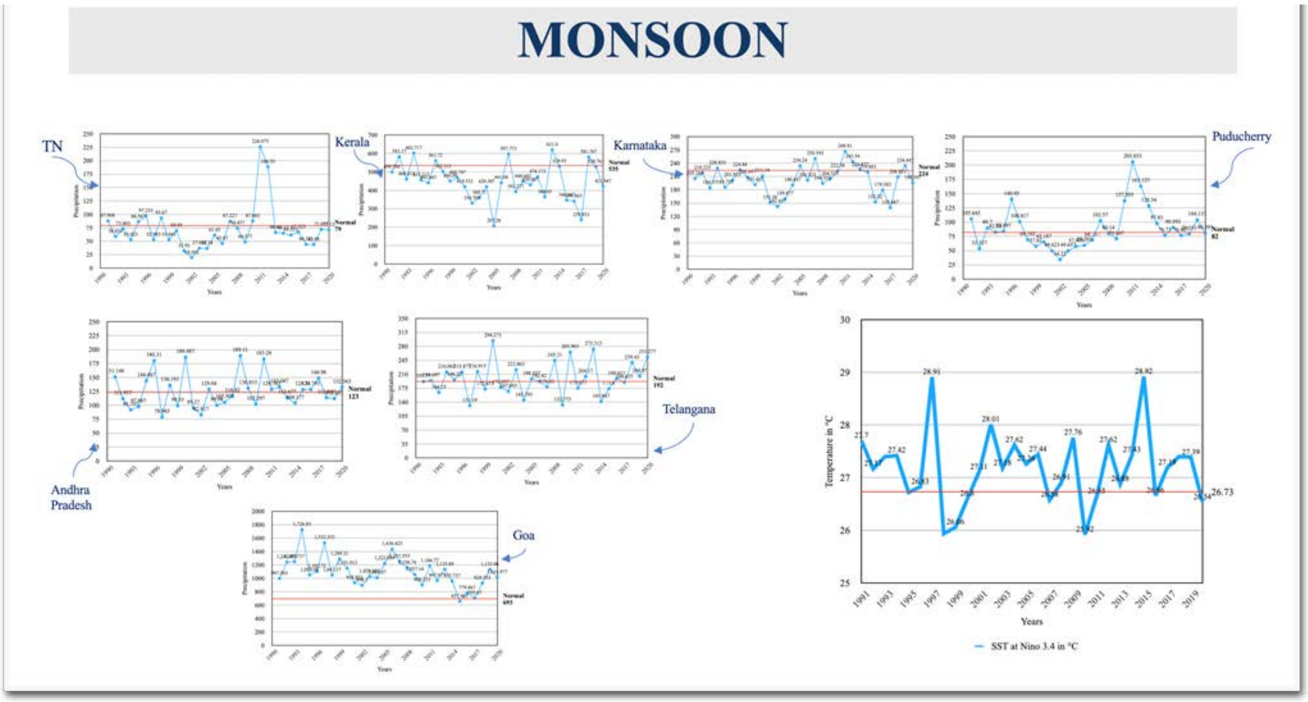

Figure 3: Monsoon.

downpour for the year 2011. Likewise, the state of Andhra Pradesh has seen a less-than-Normal rains for the year 1999.

Interpreting the Time Series analysis, from Figure 3. Monsoon, the results show the Monsoon season Sea Surface Temperature at Equatorial Pacific in terms of the Minimum and Maximum temperature recorded at Niño 3.4 region during the study period. It is inferred that the SST during the Summer season has seen peaks during the years 1997, 2002 and 2015 with 28.92°C, 28.01°C and 28.64°C. The rise in SST directly corresponds to the Rainfall data where less-than-Normal rainfall years were observed for the Winter Season during the 30-year period (1991-2020). Whereas, the dip in the year 1998, 1999, and 2010 of 25.94°C, 26.06°C and 25.92°C, owing to the lowest SST during the Monsoon season for the 30-year period, shows a rise-in-rainfall in the terms of more-than-normal pattern for the most of the States and Union Territory studied only for the year 2010. However, this remains contrary for the years 1998 & 1999. Only the States of Tamil Nadu-93.67mm (Normal-79mm), Andhra Pradesh-136.19mm (123mm), Telangana-216.91mm (192mm), and Goa-1047.17mm

(693mm) had comparatively a higher reception (more-than-Normal) of downpour for the year 1998. It is observed that Tamil Nadu received the least amount of rainfall (min PPT 19.50mm-year 2002) while Goa consistently received the maximum rainfall (max PPT 1726.83mm-year 1994) during the study period of 30-years for the area of interest. Comparing this reception of precipitation with the SST rise of 27.42°C, it shows that the influence of SST in the rainfall of Goa was merely effective.

Interpreting the time series analysis, from Figure 4. Post Monsoon, the results show the Post-Monsoon season Sea Surface Temperature at Equatorial Pacific in terms of the Minimum and Maximum temperature recorded at Niño 3.4 region during the 30-year period. It is inferred that the SST during the Summer season has seen peaks during the years 2015 with 29.38°C and 1997 with 29.27°C followed by 2002 with 28.14°C. The rise in SST directly corresponds to the Rainfall data where less-than-Normal rainfall years were observed for the Winter Season during the 30-year period (1991-2020). Whereas, the dip in the year 1998, 2007 & 2010 of 26.1°C, 25.08°C & 25.01°C owing to the lowest SST recorded during the Post-Monsoon season for the study period (Niño 3.4) [10], shows a rise-in-rainfall in the terms of more-than-normal pattern for the most of the States and Union Territory studied during the years 1998, 2007 & 2010, but is contrary for the states of Telangana and Andhra Pradesh for the years 1998 & 2007. The State of Kerala only saw a peak in the year 2007 among the 3 dips observed in the SST of Post-Monsoon. It is observed that Telangana received the least amount of rainfall (min PPT 9.44mm-year 2011) while Puducherry received the maximum rainfall (max PPT 454.66mm-year 2015) during the study period of 30-years for the area of interest. Comparing this reception of precipitation with the SST rise of 29.27°C and 29.38°C respectively, in the year 1997 as well as 2015, it shows that the influence of SST in the rainfall of Tamil Nadu was merely effective, for these were years the state had an enormous amount of high reception of Post-Monsoon precipitation recorded, of 181.20mm and 240.51mm respectively.

Identification of atmospheric teleconnection and anomalies

The region of Niño 3.4 and its anomalies are represented in terms of the average equatorial SSTs across the equatorial Pacific Ocean. For the study, the SST anomalies for the ENSO with respect to Niño 3.4 is visualized for the said 30-year period (1991-2020) with the base line of 26.73°C and the deviation recorded above/below the threshold of (+0.5°C)/(-0.5°C) has been analyzed and the output has been illustrated via SST Anomaly - ENSO - (1991-2020). With the help of it has been observed that El Niño as well as La Nina years for the study period (1991-2020). The years 1991, 1992, 1994, 1997, 2002, 2004, 2006, 2009, 2014-2016, 2018-2019 have been identified as Global El Niño years while, 1995, 1996, 1998-2001, 2005, 2006, 2008, 2009, 2010-2012, 2017, 2018, 2020 have been identified as Global La Nina years.

Summary and Conclusion

Summary

From Figure 5, the Global El Niño years are identified along with the Indian Drought years with Precipitation and SST data. The years 1991, 1992, 1994, 1997 (anomaly 2.4°C), 2002, 2004, 2006, 2009, 2014-2016 (anomaly 2.6°C), 2018-2019 Global El Niño years. It is observed that out of the 9 Indian Drought years (namely, 1991, 2002, 2004, 2006, 2012, 2013, 2014, 2016, 2017), 6 years (1991, 2002, 2004, 2006, 2014, 2016) fall under the Global El Niño years while out of the remaining 3 years, 2 years (2012 and 2017) persisted during Global La Nina years. Also, notably 7 years of Global El Niño years (1992, 1994, 1997, 2009, 2015, 2018, and 2019) had no effect in the Rainfall condition in India translating these years into Non-drought years [11-15].

The Global La Nina years are identified along with the Indian Rainfall years with the Precipitation and SST data. The years 1995, 1996, 1998-2001 (anomaly dip of -1.7°C), 2005, 2006, 2008 (anomaly dip of -1.5°C), 2009, 2010-2012 (anomaly dip of -1.5°C), 2017, 2018, 2020 have been identified as Global La Nina years [15-19]. It is observed

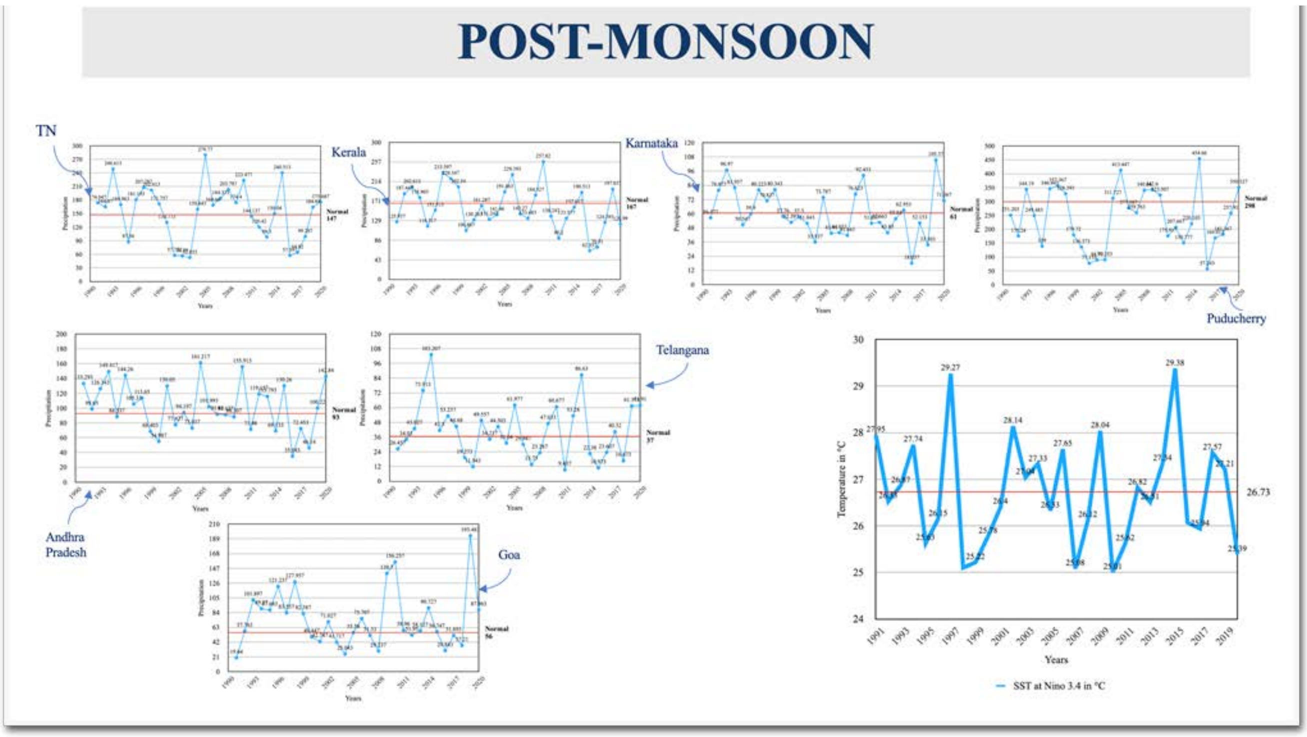

Figure 4: Post-Monsoon.

Anamoly in SST Data of Central & Equatorial Pacific for the Period 1991-2020 (in °C)

SOURCE : MetOffice UK 26.73

	Winter		Summer			Monsoon				Post Monsoon		
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	0.28	0.20	0.52	1.25	1.62	1.63	1.19	0.71	0.34	0.90	1.13	1.64
1992	1.68	1.90	2.10	2.41	2.26	1.29	0.80	-0.09	-0.25	-0.39	-0.22	0.00
1993	-0.04	0.24	0.93	1.86	2.09	1.55	0.82	0.11	0.19	0.20	0.18	0.03
1994	-0.13	-0.14	0.54	1.17	1.31	1.26	0.62	0.62	0.27	0.76	1.14	1.14
1995	0.82	0.72	0.90	1.20	1.00	0.86	0.28	-0.40	-0.77	-1.06	-1.07	-1.16
1996	-0.99	-0.88	-0.11	0.63	0.64	0.59	0.36	-0.17	-0.38	-0.49	-0.54	-0.71
1997	-0.77	-0.37	0.30	1.30	1.87	2.21	2.19	2.11	2.20	2.50	2.59	2.53
1998	2.37	2.13	1.94	1.83	1.74	-0.01	-0.79	-1.24	-1.12	-1.39	-1.55	-1.94
1999	-1.83	-1.32	-0.48	0.11	0.24	-0.13	-0.38	-1.14	-1.02	-1.09	-1.61	-1.83
2000	-2.08	-1.54	-0.65	0.28	0.39	0.30	-0.01	-0.28	-0.52	-0.77	-0.95	-1.14
2001	-0.99	-0.62	0.11	0.79	0.87	0.95	0.59	0.14	-0.18	-0.14	-0.28	-0.56
2002	-0.23	0.22	0.59	1.21	1.42	1.70	1.25	1.06	1.10	1.32	1.54	1.36
2003	1.03	0.76	1.08	1.08	0.64	0.75	0.70	0.12	0.23	0.46	0.32	0.16
2004	0.01	0.13	0.37	1.11	1.33	1.03	0.96	0.81	0.74	0.65	0.58	0.58
2005	0.37	0.23	0.82	1.34	1.47	1.32	0.74	0.15	-0.10	0.02	-0.39	-0.84
2006	-1.09	-0.65	-0.16	0.86	1.18	1.12	0.62	0.49	0.61	0.74	1.00	1.03
2007	0.53	0.08	0.45	1.05	0.84	0.82	0.06	-0.53	-0.96	-1.51	-1.67	-1.76
2008	-2.02	-1.90	-0.66	0.10	0.45	0.44	0.46	0.12	-0.29	-0.40	-0.43	-0.99
2009	-1.19	-0.69	-0.06	0.77	1.30	1.38	1.21	0.80	0.74	0.90	1.46	1.57
2010	1.34	1.21	1.56	1.63	0.95	0.27	-0.64	-1.23	-1.66	-1.72	-1.66	-1.78
2011	-1.80	-1.27	-0.50	0.29	0.69	0.73	0.23	-0.54	-0.75	-1.01	-1.13	-1.20
2012	-1.24	-0.70	-0.10	0.65	1.07	1.22	1.02	0.82	0.51	0.25	0.28	-0.27
2013	-0.57	-0.41	0.27	0.95	0.84	0.70	0.18	-0.19	-0.08	-0.37	-0.08	-0.20
2014	-0.67	-0.55	0.26	1.28	1.58	1.38	0.67	0.29	0.44	0.44	0.77	0.62
2015	0.37	0.56	1.06	1.83	2.15	2.23	2.09	2.16	2.27	2.42	2.87	2.66
2016	2.44	2.39	2.17	2.14	1.42	0.80	0.00	-0.45	-0.62	-0.77	-0.63	-0.57
2017	-0.48	0.14	0.61	1.37	1.57	1.46	0.88	-0.06	-0.44	-0.50	-0.94	-0.93
2018	-0.91	-0.90	-0.25	0.69	0.99	1.12	0.79	0.38	0.37	0.82	0.91	0.80
2019	0.35	0.68	1.49	1.87	1.84	1.51	0.90	0.24	-0.03	0.58	0.53	0.34
2020	0.36	0.41	1.09	1.59	0.86	0.57	0.16	-0.55	-0.96	-1.43	-1.39	-1.20

Figure 5: SST Anomaly - ENSO - (1991-2020).

that out of the 12 Indian Rainfall years (namely, 1995, 1996, 1998-2001, 2005, 2006, 2008, 2009, 2010-2012, 2017, 2018, 2020), 9 years (1997, 1999, 2000, 2005, 2007, 2008, 2010, 2011, 2015, 2018, 2019, 2020) fall under the Global La Nina years while out of the remaining 4 years, 3 years (1997, 2015 and 2019) persisted during Global La Nina years. Also, notably 5 years of Global La Nina years (1995, 1996, 2006, 2009, and 2017) had no effect in the Rainfall condition in India translating these years into not heavy rainfall years.

Conclusion

- Spatially coherent increasing and decreasing trends in seasonal and annual rainfall are found for the 30-year Period from 1991-2020, for the Southern States and Union Territory of Peninsular India namely, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Telangana, Goa and Puducherry.

- There were 5 years since 1990 in which India faced a severe drought and the rainfall was 15 per cent less than Long Period Average. Those aforementioned years were 2002, 2009 and 2014-2016 in which all were El Niño years and the average temperature increase was between 1°C - 2.6°C.

- Despite the 2014-2016 period being the worst El Niño drought in the eyes of World as well as India, the year 2015, TN in particular received a maximum Rainfall of 695.8 mm and the major contributor being the North Eastern Monsoons. Thereby breaking the El Niño = Drought Scenario, with a clear-cut Annual Deviation Record of 17.2%

- Coming to the famous El Niño period of 1997 requires a separate reference. The year declared as the worst El Niño year until the 2014-2016. The ONI anomaly during this period went up to a peak of 2.6°C and was the largest recorded during the entire study period. Yet, contrary to expectations of a severe drought, the Indian monsoon Rainfall that year was 2.2% above its LPA rainfall.

- While, the Drought of 2004 were also associated with greater than 0.5°C average temperature anomaly.

- Notably, out of the 9 Drought years in the Country, 3 were in non-El Niño years, among which 2 years (2012 and 2017) were in-turn Global La Nina years.

- Like-wise, of the 12 Rainfall years in India, 4 were in non-La Nina years, among which 3 years (1997, 2015 and 2019) were in-turn Global El Niño years.

- El Niño years seem to be converted into droughts for the country. However, all La Niña years does not guarantee greater-than-Normal rains and similarly an El Niño year does not always translate into less-than-normal rains.

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