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The Indian summer monsoon rainfall and ENSO

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सार – एल नीनो-दक्षिणी दोलन (ENSO) को भारतीय ग्रीष्मकालीन मॉनसून परिवर्तनशीलता का सबसे महत्वपूर्ण चालक माना जाता है। इस पत्र में हमने भारतीय ग्रीष्मकालीन मानसून पर ENSO के प्रभावों पर अब तक के शोध और विभिन्न तंत्र जो उष्णकटिबंधीय प्रशांत से मॉनसून क्षेत्र में टेली-कनेक्शन को समझाने के लिए प्रस्तावित किए गए हैं, उनका दस्तावेजीकरण करने का प्रयास किया गया है। यहाँ हमने मोडोकी और कैनोनिकल एल नीनो के प्रभावों के बारे में भी संक्षेप में चर्चा की हैं। हमारा मानना है कि मॉनसून पर हाल में एन्सो (ENSO) के आंशिक रूप से कमजोर पड़ने से जो प्रभाव पड़ा वह कई अंतर-वार्षिक से दशकों की प्रक्रियाओं के कारण हो सकता है, जैसा 2015 के दौरान कमजोर मॉनसून की स्थिति और चरम एल-नीनो के एक साथ होने के परिणामस्वरूप हुआ।

ABSTRACT. The El Niño-Southern Oscillation (ENSO) is deemed as the most important driver of the Indian summer monsoon variability. In this paper we make an effort to document the research so far on the impacts of ENSO on the Indian summer monsoon and the various mechanisms that have been proposed to explain the tele-connection from the tropical Pacific to the monsoon region. We also briefly discuss about the distinctions between impacts of canonical El Niño and El Niño Modoki. We believe that the recent apparent weakening of the ENSO impact on the monsoon may simply be due to a combination of several inter-annual to decadal processes, as evidence by the deficit monsoon conditions during 2015 which co-occurred with an extreme El Niño.

Key words – Indian Summer Monsoon, El Niño, ENSO, El Nino Modoki.

1. Introduction

The Indian Summer Monsoon (ISM) has been the focus of considerable fascination for a long time. Agriculturists have revered and seafaring traders and sailors have depended on the ISM since centuries. The scientific allure of ISM probably might have started with Henry Blandford and Sir Gilbert Walker with their early attempts at ISM observations and prediction (Blandford, 1884, 1886; Walker, 1923, 1924, 1928). The Indian Meteorological Department (IMD) has been studying and predicting ISM for over 100 years now. Importantly, Walker's attempts to find lead predictions skills for the Indian summer monsoon rainfall have resulted in the discovery of what has been later known as the Southern Oscillation, the atmospheric component of the El Niño-Southern Oscillation (ENSO). Incidentally, ENSO is known as the strongest driver of the Indian summer monsoon rainfall variability.

The present manuscript is divided into five sections. Sections 2 and 3 provide brief introductions to ISM and ENSO. Section 4 describes the relationship between ISM-ENSO, followed by a discussion is in Section 5.

For the few figures presented in this general review note, IMD gridded rainfall data for Indian regional/sub-divisional Monthly Rainfall are used (Rajeevan *et al*., 2006). We also use the Met Office Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST; Rayner *et al*., 2003).

2. Indian summer monsoon

Monsoon is an Arabic term, which, it is believed, to have been derived from the Arabic/Persian word 'Mausam', alluding to a seasonal reversal of winds. Therefore, it is not surprising that Ramage, in the year 1971, defined a few characteristics of monsoonal regions, mainly based on the kinematic consideration of the winds (Ramage, 1971). Summed up, the four criteria talk about seasonal reversal, persistence, sufficient strength. Having said this, a critical component that is missing from the definition is the rainfall, which is not only important for societal purposes, but plays a major role in monsoonal dynamics and variability (Rao, 1976). The onset of ISM is in the first week of June over Kerala coast associated with northward shift of the Sub Tropical Jet (Yin, 1949). The onset is also dependent on other factors, like warming of Eurasian region by diabatic

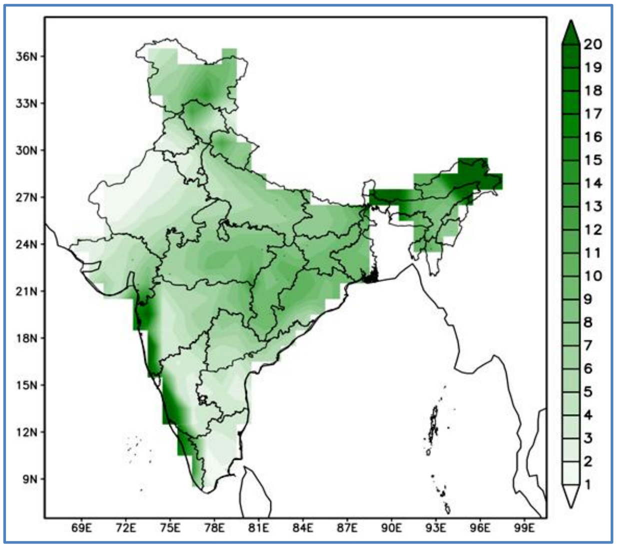


Fig. 1. Climatological distribution of the Mean summer monsoon (JJAS) rainfall (mm/day) during the 1901-2009 period

heating (Murakami and Ding, 1982) or the dynamical influences of Tibetan Plateau (Yanai *et al*., 1992; Yanai *et al*., 2006). From June to September, ISM remains over India as a stationary wave (Goswami and Shukla, 1984). ISM rainfall shows great spatial variability (Fig. 1) with highest rainfall along the western coast of India, due to the orographic effects and over the head of Bay of Bengal with a northwest-ward stretch along the monsoon trough. This northwestward stretching region is called the Monsoon Zone (Sikka and Gadgil, 1980). There are several publications and reports that have characterized the mean monsoonal features and variability. Rao (1976), Pant and Kumar (1997) and the Monsoon Monograph series (Tyagi *et al*., 2012) provide excellent summaries of all these aspects.

The interannual variability of an area-averaged ISM rainfall index is shown in Fig. 2. It has a 10% standard deviation (Gadgil, 2003). Contributions from various Sea Surface Temperature (SST) anomalies, particularly the tropical pacific, affect the ISM resulting in a prominent interannual variability (Fig. 3). The interannual variability of ISM shows about 10% standard deviation from the mean (Gadgil, 2003). ENSO is one of the primary drivers of ISM, accounting for about 40% of its interannual variability (Sikka, 1980; Keshavamurty, 1982; Shukla and Paolina, 1983; Rasmussen and Carpenter, 1983). Along with ENSO, drivers from other tropical oceans, such as strong Indian Ocean Dipole (IOD; Webster *et al*., 1999; Saji *et al*., 1999; Murtugudde *et al*., 2000) events also affect ISM interannual variability. Strong IOD events modulate the effects of any co-occurring ENSO on ISM (Ashok *et al*., 2001; Ashok and Saji, 2007). Furthermore, Atlantic is also receiving attention as a driver of the Indian summer monsoon rainfall Kucharski *et al*., 2008; Pottapinjara *et al*., 2015; Yadav, 2017). Of all these, ISM-ENSO relationship naturally demands a weighty attention.

3. The El Nino - Southern Oscillation

Due to various reasons beyond the scope of the current manuscript, in some years, we find a large-scale anomalous warming in the tropical eastern Pacific Ocean, associated with anomalous cooling in the tropical western pacific, causing widespread ramifications globally. This anomalous condition, normally seasonally phase locked from boreal spring through ensuing boreal winter when it peaks, is referred to as an El Niño. As mentioned earlier, this oceanic signature of the ENSO is strongly coupled to the anomalous changes in the associated see-saw of sea level pressure between the equatorial eastern and western Pacific Ocean, referred to as the Southern Oscillation (Bjerkenes, 1969). A positive SST anomaly in the equatorial eastern Pacific reduces the east-west thermal gradient, weakening the trade winds and thereby the Walker circulation (Gill, 1980; Lindzen and Nigam, 1987). The weaker trades further enhance the warming and this form a positive ocean-atmosphere feedback causing a very warm state - The El Niño. Conversely, a cold phase, with cooler than normal SST anomalies in the equatorial eastern pacific strengthens the trade winds and the Walker circulation - The La Niña (Philander, 1985, 1990).

ENSO, to a significant extent, can be deemed as a self-sustaining positive ocean-atmosphere feedback. The delayed oscillator theory explains that the Rossby waves generated in the eastern Pacific propagate west and reflect from the western boundary returning as Kelvin waves and reverse ENSO effect (Zebiak and Cane, 1987; Suarez and Schopf, 1988; Battisti and Hirst, 1989). From another perspective, the divergence by Sverdrup transport discharges the equatorial heat content which gets recharged by climatological upwelling. This is known as the recharge-discharge oscillator theory (Jin, 1997a). Another hypothesis is that off-equatorial SST anomalies induce equatorial easterly wind anomalies (off-equatorial anomalous anticyclones), causing upwelling and subsequent cooling. This mechanism is called the western Pacific oscillator mechanism (Weisberg and Wang, 1997; Wang *et al*., 1999). In addition, external land heating and interaction with the previous coupled anomalies play a role (Masumoto and Yamagata, 1991).

In addition to the well-known canonical El Niño, a new type of El Niño with anomalous warming in the central tropical pacific straddled by cooling of SST anomalies on its both flanks, have been occurring with increased frequency since mid-1970s (Ashok *et al*., 2007;

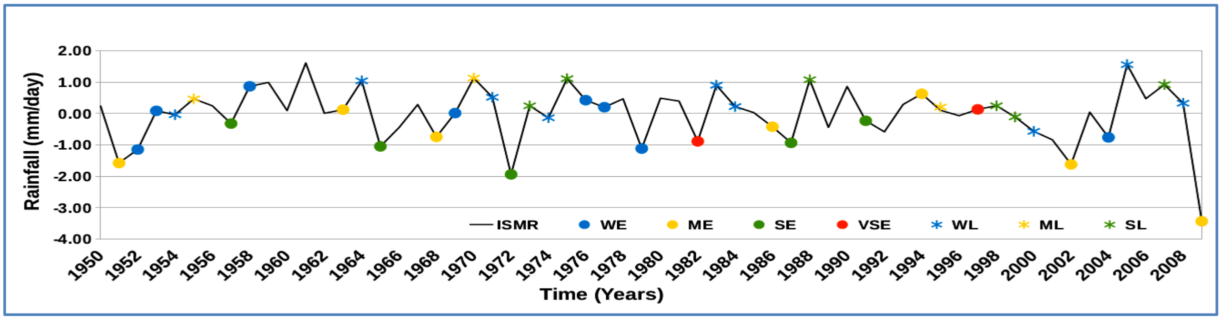


Fig. 2. The interannual variability of the Indian summer rainfall area-averaged over the Indian land region (66.5° E-101.5° E; 6.5° N-39.5° N) during the 1951-2009 period. Here WE, ME, SE and VSE stand for weak, moderate, strong and very strong El Niños, respectively; WL, ML and SL stand for Weak, Moderate and Strong La Ninas, respectively, as per <https://ggweather.com/enso/oni.htm>

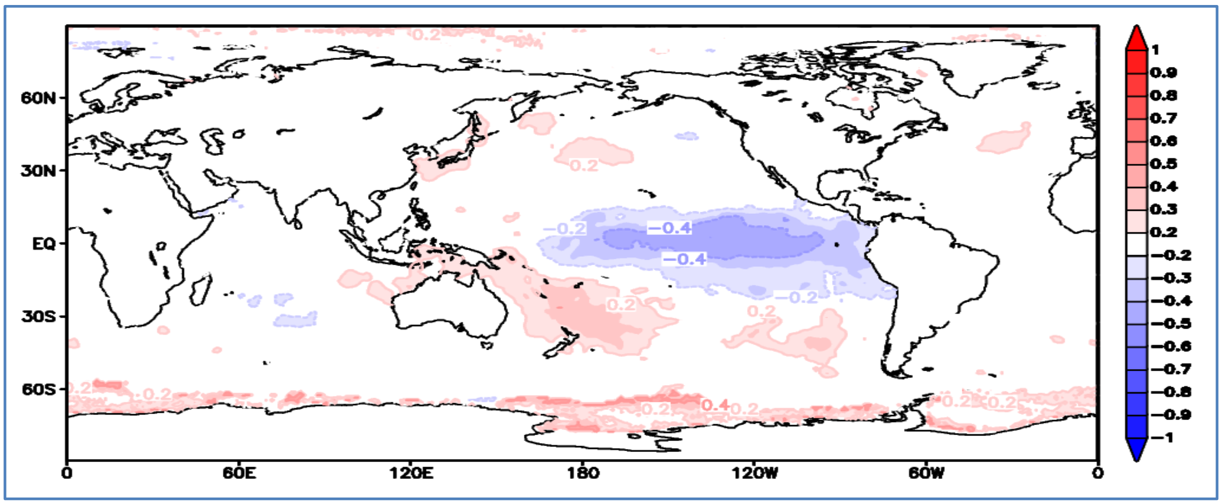


Fig. 3. Simultaneous linear correlation between the Indian summer monsoon rainfall index with the JJAS SST for the 1901-2009 period. Only significant correlation values have been plotted (±0.20 is the 0.05 significance level from a 2-tailed Student's *t*-test)

Kao and Yu, 2009; Kug *et al*., 2009; Marathe *et al*., 2015). These events, which occurred recently are seasonally phase-locked from boreal summer through ensuing winter and are named as the El Niño Modoki. Furthermore, the location of the heat source has relevance on the domain of its impacts (Matsuno, 1966; Gill, 1980; Keshavamurty, 1982; Soman and Slingo, 1987; Larkin and Harrison, 2005; Annamalai and Liu, 2005). This is particularly applicable to the ISM as well, as would be discussed later. Therefore, a study of ISM-ENSO dynamics and its variability is incomplete without considering El Niño Modoki.

3.1. *ENSO impacts on the Indian summer monsoon and mechanisms*

Most of severe summer monsoon droughts over India are associated with the El Niño events. However, as Rajeevan (Monsoon Monographs, Ed. Tyagi *et al*., 2012) mentions, there is no one-to-one relationship between them. On the simplest terms, El Niño events show a propensity to be associated with a weaker than normal summer monsoon rainfall over India, while the La Niña events with a greater than normal rainfall, as indicated by several studies. The relationship between ISM and ENSO, has been studied extensively for the past few decades (Sikka, 1980; Keshavamurty, 1982; Shukla and Paolina, 1983; Rasmussen and Carpenter, 1983; Ropelewski and Halpert, 1987; Webster and Yang, 1992; Nigam, 1994; Ju and Slingo, 1995; Yang, 1996; Zhang *et al*., 1996; Kawamura, 1998; Navarra *et al*., 1999; Slingo and Annamalai, 2000; Lau and Nath, 2000; Wang, 2000; Ashok *et al*., 2004; Ashok and Saji, 2007). Fig. 4 shows the simultaneous linear correlations between the NINO3.4 index[1] and local rainfall anomalies over India during June-September (JJAS), the summer monsoon season. It is seen that most of the correlations are negative, implying that the anomalously warm conditions during boreal summer

[1] NINO3.4 Index: defined as the area-averaged SST anomaly over the region bounded by 170° W-120° W; 5° S-5° N, which is used to represent the ENSO variability.

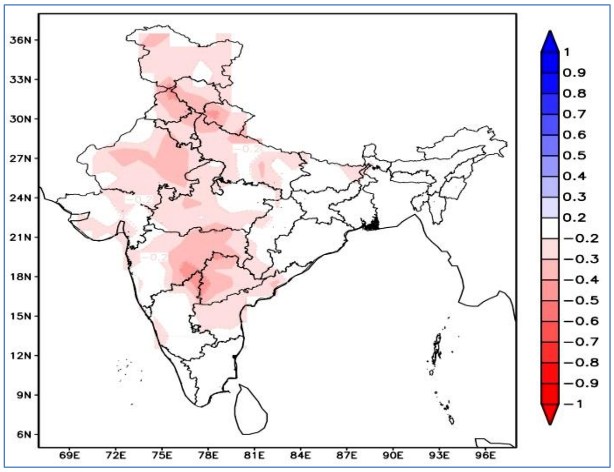


Fig. 4. Simultaneous linear correlations between Niño3.4 index with the JJAS rainfall for the period of CE1901-2009. Only significant correlation values have been plotted (±0.20 is value for 0.05 significance level from a 2-tailed Student's *t*-test)

over the eastern tropical pacific can result in anomalously deficit rainfall over India during summer monsoon season. However, Kumar *et al*. (2006) suggest that the El Niño Modoki events reduce the ISM rainfall more effectively than the conventional El Niño. From linear considerations, there is an apparent propensity for the canonical El Niños to be associated with negative rainfall anomalies along the monsoon trough, while the Modoki El Niños cause anomalously deficit rainfall more in the peninsular India (Figs. 5 & 6 from Ashok *et al*., 2007; Amat and Ashok, 2018). The composite rainfall anomalies shown in Fig. 5 indeed give a qualitative indication that Modoki El Ninos are not associated with negative rainfall anomalies along the monsoon trough. This conforms to results from various AGCM experiments (Ashok *et al*., 2009; Chen and Tam, 2010) etc.

Further, for the first time, a hitherto unnoticed anomalous basin wide warming across the tropical pacific has occurred in the tropical pacific during JJAS season of 2009, which collapsed the Walker circulation across the basin (Ashok *et al*., 2012). AGCM experiments suggest that the severe drought observed over India that season was associated with this warming (Ratnam *et al*., 2010; Ashok *et al*., 2012). The year 2014 also experienced similar conditions in the tropical pacific and at least partially responsible for the anomalous dry conditions during summer monsoon season (Jadhav *et al*., 2015).

Several mechanisms have been proposed to explain the ENSO impact on the ISM. This section revisits some of the mechanisms and attempts to introduce some outstanding issues. The suggested mechanisms to explain the ENSO teleconnections could be broadly classified into two groups.

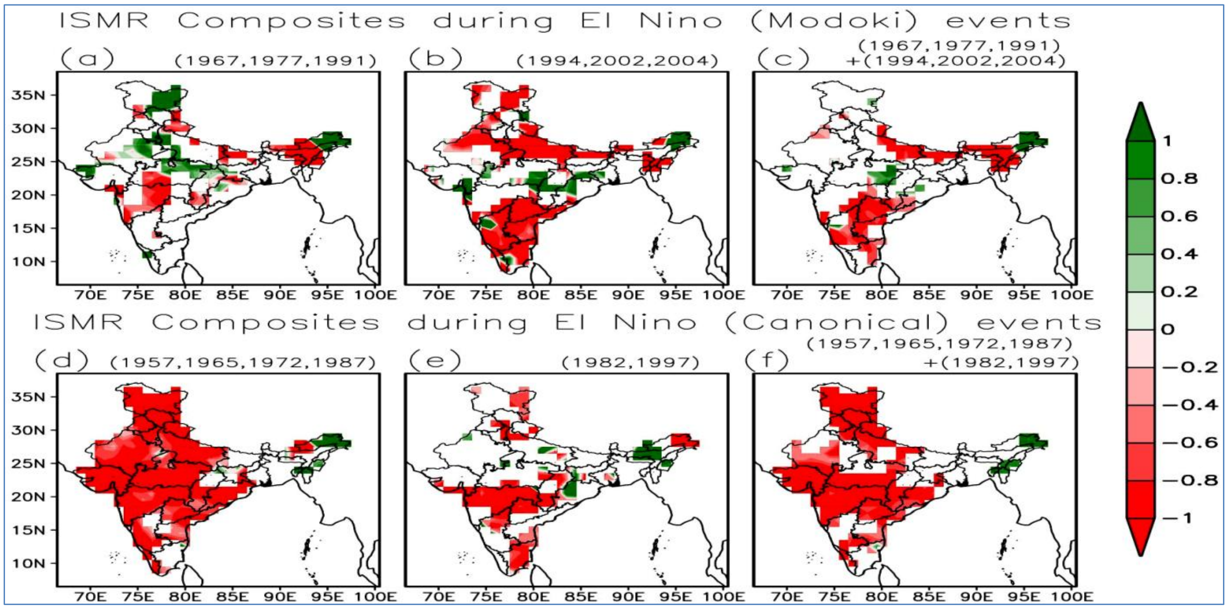
3.1.1. *The Walker and Hadley cell connections*

Given the intimate connection between the tropical pacific SST with the Walker circulation/southern oscillation, it is reasonable to consider that a mechanism of how the SST changes in the eastern tropical pacific transmit into the Indian summer monsoon region involves through a Walker circulation changes. Bhalme and Jadhav (1984), analyzing Indian rainfall datasets for the 1875-1980 period, reported a drier Indian Ocean and large monsoon rainfall deficiency occurring concurrently with weak Walker circulations. Shukla and Paolino (1983), through an analysis of Indian summer monsoon rainfall of and the Darwin pressure associated intimately with ENSO datasets for the 1901-1950, suggested that an anomalously high (low) Darwin pressure coincides with anomalously low (high) monsoon rainfall. Pant and Parthasarathy (1981 also have documented the relevance of the southern oscillation changes for the Indian summer monsoon.

Webster *et al*. (1998) indicated that boundary anomalies, such produced by ENSO, produce a temporally persistence and spatially large-scale descent over the Indian monsoon region, reducing rainfall either by producing a displacement of the seasonal mean rainfall patterns. All these studies imply that changes in the Walker Circulation with ENSO are considered to affect the ISM.

Atmospheric GCM experiments by Keshavamurty (1982); Palmer *et al*. (1992); Shukla and Wallace (1983); Navarra *et al*. (1999); Ju and Slingo (1995); Soman and Slingo (1997); Dai and Wigley, 2000; Ashok *et al*. (2004), etc. demonstrate that the tropical pacific SST anomalies associated with ENSO indeed influence the Indian summer monsoon through modulation of zonal circulation cells. Broadly, these studies suggest that large scale circulation changes due to eastward (westward) shift of Walker Circulation and decreased (increased) equatorial divergence over the tropical Indian Ocean during El Niño (La Niña) years. The anomalous convergence in the tropical Indian Ocean results in the modulation of the cross-equatorial meridional circulation, which causes an anomalous divergence over the Indian region and thereby a drier (wetter) than normal ISM. Indeed, this type of signals can be seen in the Indian region and the Indian Ocean to its south, in years such as 1987 (Ashok *et al*., 2001) when the El Niño event does not co-occur with any other tropical oceanic climate driver such as the strong IOD - which can interfere with the anomalous signal of ENSO.

Among these studies, Keshavamurty (1982) and several others explore the relative importance of anomalous signals in the western, central and eastern



Figs. 5(a-f). Composited anomaly correlations of the rainfall during (a) Moderate El Niño Modokis (b) strong El Niño Modokis (c) all El Niño Modokis. Figs. (d-f) are similar to Figs. (a-c) respectively, except that these are all for canonical El Niño events. The events have been selected based on the classification of the El Niño types by Marathe *et al*. (2015). Only statistically significant values have been plotted. For panels (a), (b), (d), (e) significance level is fixed at 0.2 and for (c), (f) significance level is fixed at 0.1 from a one-tailed Student's *t*-test

tropical pacific for the Indian summer monsoon variability. Further, local coupled air-sea feedback in the Indian Ocean is suggested to condition the ENSO impacts on the ISM (Wu and Kirtman, 2004).

3.1.2. *ISM-ENSO: Impacts through extratropics and upper atmosphere*

Suggesting a different mechanism, Ju and Slingo (1995) noted that weak ISM years are associated with an increased upper-level westerlies. This is associated with the latitudinal shift in the position of the subtropical westerly jet over northern India influenced by Pacific SST anomalies. AGCM studies by Krishnan *et al*. (1998) indicate that, in addition to the Walker circulation changes introduced by ENSO and ensuing and Hadley cell modulations, the anomalous ENSO divergent forcing over the tropical Pacific Ocean can act as a potential source for Rossby wave dispersion. Furthermore, Krishnan *et al*. (2009) suggest that meridionally propagating Rossby waves, which emanate from the El Niño forcing region, interact with the subtropical westerlies and generate quasi-stationary anomalous highs and lows in the subtropics and extratropics over west Asia, Pakistan and northwest India during drought years co-occurring with El Niños.

According to Wang *et al*. (2000), during El Niño years, as a Rossby response to the SST anomalies in the western tropical pacific, an anomalous anti-cyclonic pattern appears from the Philippine Sea through the core Indian summer monsoon region, teleconnections.

As far as the El Niño Modoki is concerned, AGCM experiments (Ashok *et al*., 2009) suggest that during the, an anomalous convergence zone is seen in the Philippines Sea region associated with these events as a Rossby response to the anomalous warming in the neighboring central tropical pacific (Chen and Tam, 2010); this not only exacerbates the local typhoon frequency (Chen and Tam, 2010; Pradhan *et al*., 2011), but also facilitates an east-west out-of-phase precipitation variability over the NW Pacific and the Indian summer monsoon region (Mujumdar *et al*., 2007) and thereby a drought-like condition in El Niño Modoki years such as 2002 and 2004 in the peninsular India.

Goswami and Xavier (2005) argue that ENSO affects the meridional tropospheric temperature gradient over the Indian region thereby effectively modulating the strength and duration of the monsoon. Shaman and Tziperman (2007) claim that ENSOs affect the upper tropospheric meridional temperature gradient during ISM through the subtropical jet.

Interestingly, (Rajeevan and McPhaden, 2004) suggest that warm water volume over the entire tropical pacific 3-4 months earlier to the monsoon has the highest lead predictive skill for the Indian summer monsoon rainfall. The decaying ENSO may also be relevant to the following ISM (Choudary *et al.*, 2015; Chakraborty *et al.*, 2018)

3.2. *ISM & ENSO - Weakening links or a slow variability?*

Kripalani and Kulkarni (1997) suggest a natural decadal variability of the Monsoon and therefore, that the ENSO impacts may not be as strongly perceived in the strong monsoonal epochs as could be in the weaker monsoonal epochs. The ISM-canonical ENSO links have shown a weakening in the recent decades (Kumar *et al*., 1999; Kawamura *et al*., 2005) argue that the recent weakening of the ISM-ENSO is in fact, a change in dominance of the spatial correlation pattern, from northwest to northeast after the late 1970s. Background and circulation changes associated with global warming have been proposed as a potential reason for the weakening by Kumar *et al*. (1999) and Ashrit *et al*. (2001). Kumar *et al*. (1999) attribute, through a running correlation analysis, that the weakening observed in late 1990s due to a shift in background circulation associated with global warming. On the other hand, Gershunov *et al*. (2001) suggest that the monsoon-ENSO relationship is less variable on decadal scales. In other words, even though many physical processes may be partially responsible for the modulation of the interannual correlation, it is not possible to distinguish their effects from stochastic noise in running correlation analyses and therefore, it could just be an issue of sampling (Cash *et al*., 2017). Having said this, from a predictability point of view, it will indeed be useful to understand if a random interaction with impacts on the monsoon from any other events could be playing a role in such weakening of an interannual variability beyond a few years. Chang *et al*. (2001) attribute this weakening to the strengthening and simultaneous poleward shift of the jet stream over the North Atlantic region. Ashok *et al*. (2001, 2004, 2007) indicate that that the apparent ENSO-Monsoon weakening during the late 20th century is due to increased frequency of positive IOD events of 1994 and 1997. This is attributed to the anomalous convergence in the Head Bay of Bengal and neighboring monsoonal trough (Behera *et al*., 1999; Guan *et al*., 2003; Rao *et al.*, 2004) induced by the subsidence from the eastern colder-than-normal pole of the positive IOD and that in the northwest portion of the monsoonal trough (Ashok *et al*., 2004) associated with the modulated meridional circulation owing to the anomalous warm conditions in the western box of the IOD region, this zone of anomalous convergence associated with strong positive IOD events in years such as 1997 results in anomalous surplus rainfall along the monsoon trough and reduces the ENSO influence. On a related note, EQUINOO (Equatorial Indian Ocean Oscillation), an atmospheric index associated with the IOD, along with an ENSO index, seems to account for most of the interannual variability of the ISM rainfall (Francis and Gadgil, 2013). In addition, as mentioned earlier, the El Niño Modoki events, which have occurred in years such as 1986, 1990, 1991, 1994, 2002 and 2004 summers are also associated anomalously dry conditions over India.

Some studies have also observed the impact of Pacific Decadal Oscillation (PDO) on ISM-ENSO relations (Krishnamurthy and Goswami, 2000; Krishnan and Sugi, 2003; Krishnamurthy and Krishnamurthy, 2014). Krishnamurthy and Goswami (2000) show that during the eastern Pacific warm (cold) phase of the interdecadal SST variation, the regional Hadley circulation associated with El Niño (La Niña) strengthens the prevailing anomalous interdecadal Hadley circulation while that associated with La Niña (El Niño) opposes the prevailing interdecadal Hadley circulation. Therefore, during the warm (cold) phase of the interdecadal oscillation, El Niño (La Niña) events are expected to be strongly related to monsoon droughts while La Niña (El Niño) events may not have a significant relation. Krishnamurthy and Krishnamurthy (2014) propose that the PDO modulates ISM-ENSO relationship by enhancing (counteracting) ENSO effects when in (out of) phase. Sreejith *et al*. (2015) claim that the reason for the recent monsoon-ENSO weakening is the change in air-sea coupled interactions over the tropical Indian Ocean. A shift in the mean ISM winds, with a cyclone-like intensification over northwestern Pacific is seen in the recent decades (Mujumdar *et al*., 2012; Feba *et al*., 2017). Feba *et al*. (2018) suggest that this decadal cyclonic intensification opposes the anomalous anticyclonic signature associated with the canonical El Niños (Lau and Nath, 2000) and therefore 'disconnects' the impact of the El Niño through this pathway. Interestingly, Feba *et al*. (2018) also find a simultaneous strengthening of cross equatorial winds over the equatorial Indian Ocean in recent decades in association with the weakening of ISM-ENSO links.

The last millennium climate is supposed to be the nearest to the current day climate, at least prior to 1970s when the anthropogenic warming is dominant. Climate simulations of the PMIP3 vintage are a valuable source to understand the long term variations of the ISM-ENSO links. Tejavath *et al*. (2019), through an analysis of model outputs from nine models, find a multi-decadal through centennial fluctuations in the correlation between an ENSO index with the area-averaged Indian summer monsoon rainfall. Their results show that the simulated interannual ISM-ENSO negative correlations are statistically significant in the two dominant epochs of the last millennium, known as the 'Medieval Warm Period' (CE 950-1350), roughly followed by a relatively cooler period, the Little Ice Age (CE 1500-1850). Importantly, these correlations are significantly modulated by slow background changes (a multi-centennial modulation), which modulate the anomalous east-west zonal circulation and the meridional circulation in the Indian Ocean-Indian region. Such changes are associated with slow changes in summer monsoon rainfall in various sub-regions of the subcontinent and not necessarily the whole India. This indicates a strong influence in the interplay of various temporal scales, which have implications for impacts at regional level.

4. Discussions

As a community, we can now ascertain that Indian summer monsoon is indeed significantly influenced by the ENSO types on interannual timescales. This relationship is of course subject to impacts from other interannual climate drivers as well as decadal processes and phenomena, which can result in an apparent weakening of the ISM-ENSO links. The important outcome of the studies such as Tejavath (2019) and Kawamura *et al*. (2005) is that any change in the association may be owing to interannual through centennial processes external to the ENSO-monsoon system. It may be that the apparent weakening is due to a shift in the impacted region, which may not be clear when a rainfall index area-averaged over the whole region is considered. The inherent decadal variability either in the monsoons and/or ENSO can also result in a stochastic weakening of the monsoon-ENSO relationship. This conclusion of course points out to a need to explore if there are mechanisms other than those proposed so far to explain the ENSO impact on monsoons. Importantly, the severe weak monsoon condition in India during 2015 was associated with one of the most extreme El Niño events. This suggests that strong El Niños indeed affect the ISM rainfall. Further, it is not just the occurrence of the ENSO that needs to be predicted with a lead time, but its intensity and, to some extent, its type.

There are studies indicating that the ENSO events can influence the intraseasonal processes of the ISM. For example, as per Joseph (2014), during a co-occurring El Niño year, the low level Jet stream can be modulated to extend eastwards up to the date line creating an area of shallow ocean mixed layer there, which in turn is proposed to lengthen the active-break cycle to two months in an El Niño year. Webster *et al*. (1998) summed up that seasonally persistent ENSO-induced boundary anomalies and spatially large-scale descent over the Indian monsoon region, reduce rainfall either by reducing the intensity and life cycle of the monsoon disturbances or by producing a displacement of the seasonal mean rainfall patterns. Discussing these scale interactions and time scales higher than interannual teleconnections is beyond the scope of the current note.

There are several other topics relevant to the association of the ENSO with the Indian monsoons, such as the impact of the Indian summer monsoon on the ENSO (Krishnamurthy and Goswami, 2000; Kirtman and Shukla, 2006), which have not been discussed in this note. For example, the tropical pacific SST indices exhibit a positive correlation with the northeastern monsoon rainfall over the southeastern peninsular India (Raj *et al*., 2004 and Boyaj *et al*., 2017 for more details, including the references on earlier works). This is owing to the fact that, unlike the summer monsoon period, the seasonal climatological winds are northeasterlies, which are enhanced by the ENSO-induced anomalous easterlies. This is a situation analogous to that in Australia where the ENSO impact is stronger during austral spring rather than austral summer (Hendon *et al*., 2007).

Recent studies even suggest that aerosol loadings can influence the Indian summer monsoon (Ramanathan *et al*., 2005; Lau *et al*., 2006; Krishnamurti *et al*., 2013; Sarangi *et al*., 2018) and these can have implications for the ENSO impacts on monsoon (Fadnavis *et al*., 2017). Needless to say, we need more observations and better models to understand the monsoon-ENSO relationship and extraneous factors that influence the relationship.

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