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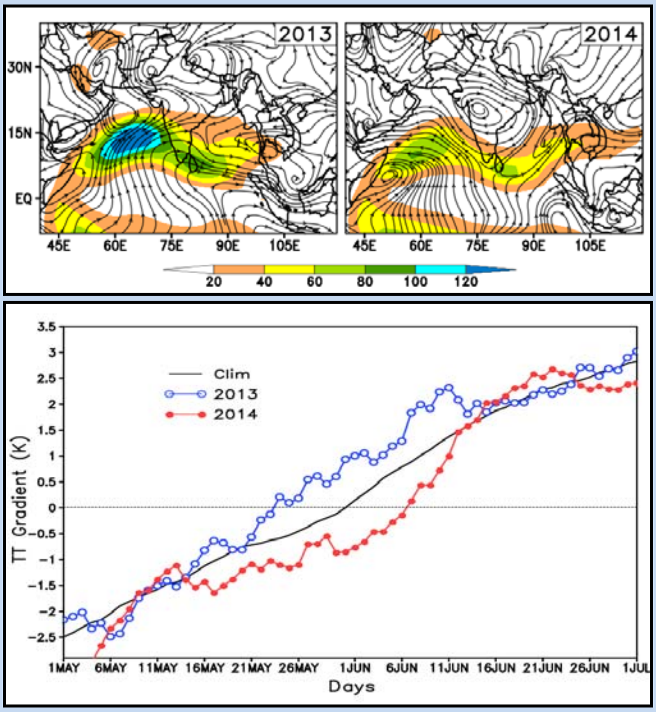

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Abstract

The Indian summer monsoons of 2013 and 2014 had contrasting onset and progression phases. The onset was timely and the progression of 2013 monsoon was the fastest in the last 70 years, whereas 2014 had a delayed onset and a very lethargic progression phase compared to 2013. The initial monsoon month of June exhibited distinct features during 2013 and 2014. This study investigates the scientific rationale behind the observed discrepancy in these years. It is found that large scale conditions played a seminal role in generating and modulating the observed disparity.

CONTENTS

Summary

The 2013 and 2014 Indian summer monsoons (ISMs) exhibited quite distinct progression phase. While 2013 had one of the fastest advancement in the last 70 years, 2014 witnessed comparatively lethargic progression phase. The major difference was felt in the early monsoon month of June, with 2013 (2014) monthly rainfall being +34% (-43%) of its long period average. This study attempts to unravel the factors that generated this observed discrepancy. During June 2013, the monsoon trough was very active in its normal position favoring low level positive vorticity generation and moisture convergence, whereas a strong anticyclonic circulation prevailed over central India during June 2014 hampering the northward progression of ISM. It has been found that June 2013 (2014) was associated with (a) stronger (weaker) north-south tropospheric temperature (TT) gradient with positive (negative) TT anomalies over Eurasia and north of 60°N, (b) colder (warmer) SST anomalies over equatorial Indian Ocean, northwestern Arabian Sea and equatorial eastern Pacific, (c) stronger (weaker) monsoonal Hadley circulation, and (d) stronger (weaker) walker circulation in response to the colder (warmer) SST anomalies over equatorial Pacific. The study undoubtedly brings out the influential role of these large scale meteorological conditions in generating and sustaining the enhanced (suppressed) convection over Indian subcontinent during June 2013 (2014). It is also found that large-scale conditions during June 2013 (2014) share some commonality with those during June 2001 (2009), when the rainfall departure for the month was +35% (-47%).

1. Introduction

The Indian summer monsoon (ISM) that commences in the month of June over the country and continues till September end accounts to about 80% of the annual rainfall in India. It significantly impacts the environment (and associated flora, fauna and ecosystems), agriculture, society, hydro-power production and geography of the subcontinent (like availability of fresh water in water bodies, underground water table) with all these factors cumulatively contributing towards the vigor of the economy of affected countries. The start of agricultural activities over various parts of the country coincides with the advance of monsoon over the region. As most of the farmlands are rain-fed, monsoon is critical to the food sufficiency and quality of life for the country. Therefore, any fluctuations in the spatio-temporal distribution or quantity of the monsoon rains may lead to conditions of floods or droughts causing the agricultural sector to adversely suffer. This has a cascading effect on the secondary economic sectors, the overall economy, food inflation and therefore the overall quality and cost of living for the general population in India.

Monsoon generally makes its onset over Kerala coast around 01 June, and progresses northward to cover the entire country by 15 July (Pai and Rajeevan 2009). The onset and progression of monsoon exhibit large amount of interannual variability. In some years they are timely, whereas during some years they are faster or slower. After its onset over Kerala, the monsoon advance is not a smooth process but is punctuated by one to three stagnations at different latitudes or longitudes (Sikka 2011). The stagnations could be caused by the influence of eastward moving westerly troughs in the subtropical latitudes (Biswas et al. 1998) or cessation in the formation of low pressure systems (LPS) in the surrounding seas or within the monsoon trough (Sikka 2011). During some years, the advancement occurs rapidly and the monsoon covers from Kerala to northwest India in just 15-20 days or so. Similarly, there are years when after a prolonged stagnation in monsoon advance, the next progression of monsoon is quite rapid due to the overlapping formation of LPSs (Sikka 2011).

The ISMs of 2013 and 2014 were quite distinct, especially in their progression phase. 2013 witnessed the fastest pace of advance of ISM in the last 70 years (IMD 2013; Joseph et al., 2013, 2014). Monsoon covered the entire country in just 16 days after its onset over Kerala on 01 June, i.e., by 16 June which is one month ahead of its climatological date. On the other hand, after a delayed onset over Kerala on 06 June, the 2014 monsoon exhibited a sluggish northward progression owing to a prolonged hiatus which occurred after a few days of its onset. Monsoon covered the whole country by 17 July in 2014. The major difference in the progression phase during these two years was felt in the early monsoon month of June, in which the monthly rainfall is 163.5 mm (source: http://www.imdpune.gov.in/mons_monitor/mm_index.html) all over India. The rainfall over the country during the month of June in 2013 was 134% of its long term mean (LTM) (IMD 2013), while that of June 2014 was only 56.5% of its climatology (source: http://www.imdpune.gov.in/mons_monitor/mm_index.html). Although there are other years when the June rainfall was >30% of its LTM (for e.g., 2001 in the last 14-year period: 2001-2014; **Table 1**), June 2013 was exceptional due to its rapid progression phase. The duration of 42 days (as in the case of 2014) is not unusual for monsoon to cover the entire country (please see **Table 1**), however a deficiency of ~43% in June rainfall is rather infrequent. Such a dearth was observed recently during 2009, when the June deficit was ~47%. During most of June 2014, the rainfall was almost absent over central India (CI). Hence, it is worthwhile to examine the underlying mechanisms that shaped the observed discrepancy in the two consecutive years.

Joseph et al. (2013, 2014) has shown that large scale conditions were very active during June 2013. They argued that the interaction between a monsoonal low pressure system which provided increased low level convergence and abundant moisture, and a midlatitude westerly trough which generated strong upper level divergence has provided conditions conducive for large scale convection and widespread monsoon rains over northwest India. They hypothesized that these large scale conditions helped monsoon to cover the entire country and facilitated the occurrence of the heavy rainfall event in the orographic region of Uttarakhand. However, their study focused mainly on the heavy rainfall event and hence did not provide a detailed study on the background monsoon conditions prevailed during June 2013. During June 2014, the daily weather bulletins issued by India Meteorological Department (IMD) indicated that an anticyclonic circulation was prevalent over CI, hampering the northward progression of monsoon. This anticyclonic circulation was persistent throughout the month of June. Therefore, the main objective of this study is to unravel the role of local as well as large scale meteorological conditions that were responsible for the observed fast (slow) progression of monsoon in the month of June 2013 (2014). It is also examined whether similar meteorological conditions as that of June 2013 (2014) were existent during June 2001 (2009) when the June rainfall departure was +35% (-47%).

2. Data and Methodology

For the present observational study, the daily NOAA high resolution Sea Surface Temperature (SST) dataset (Reynolds et al. 2007) provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, (available at http://www.esrl.noaa.gov/psd/), the daily rainfall dataset from TRMM (Huffman et al., 2007), IMD-TRMM merged rainfall dataset (Mitra et al., 2009) and atmospheric fields from National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis datasets (Kalnay et al., 1996) have been used. The meteorological parameters utilized from NCEP/NCAR reanalysis for the study are: zonal, meridional and vertical components of wind, specific humidity, air temperature and geopotential height at pressure levels and also mean sea level pressure (mslp). Additionally, the Moist Static Energy (MSE), Tropospheric Temperature (TT), Kinetic Energy (KE) of total wind as well as rotational wind, velocity potential and divergent wind have been computed.

The anomalies of various parameters, except rainfall are calculated based on the daily mean climatology of 30 years (1981-2010). Since the daily rainfall data is available from 1998 onwards, the rainfall anomalies are calculated based on the daily climatology of 14 years (1998-2011).

3. Results and Discussion

As mentioned earlier, the rainfall over the Indian subcontinent was surplus during June 2013, while it was scarce during June 2014. It is clear from **Figure 1** (which depicts the rainfall anomaly during June 2013 and 2014) that the rainfall during June 2013 was largely positive over most parts of the country making it +34% of LTM, while the rainfall was deficient (evident from negative rainfall anomalies) all over the country (-43% of its LTM) in June 2014. Here, we analyze various meteorological parameters which might provide an insight into the local as well as large scale conditions prevalent during June 2013/2014.

3.1. Observed features during onset phase

The onset of ISM is associated with substantial and sustained increase in rainfall over south peninsula after the cross-equatorial low-level jet (LLJ) is established across the Somali coast into the near-equatorial Arabian Sea (Pai and Rajeevan, 2009). Strengthening of the LLJ is associated with increased monsoon activity along the west coast of India. The strength of the LLJ during the onset phase of 2013 and 2014 can be assessed from **Figure 2a** that depicts the evolution of Somali Jet speed index (defined as the square root of twice the spatial mean kinetic energy of 850 hPa horizontal wind over the Arabian Sea, in the same spatial domain 5°S –20°N; 50°E –70°E, by Boos and Emanuel, 2009). It is noted from the figure that the cross equatorial flow was very strong compared to climatology during 2013 from May onwards. Contrarily, the LLJ strength was near normal during May-June 2014, becoming even below normal at times in June, except the onset phase.

IMD declares the monsoon onset over Kerala (MOK) based on rainfall over various stations over the state, depth of westerlies up to 600 hPa and value of outgoing longwave radiation north of equator (Pai and Rajeevan, 2009). It is to be noticed from **Figure 2a** that the LLJ was stronger than climatology one week before the month of June in 2013; however IMD declared MOK on 01 June only. The reason for the same can be understood when the time-height evolution of zonal wind is plotted for 2013 and 2014 (**Figure 2b**). Interestingly in 2013, the depth of westerlies up to 600 hPa was maintained and sustained only after 01 June. Similarly, MOK was declared in 2014 on 06 June, when both the LLJ became stronger and westerly depth was maintained. However, the magnitude of westerlies was weaker in 2014, compared to 2013.

3.2. Observed features during June

It has been mentioned earlier that low level cyclonic (anticyclonic) circulation was prevalent over the Indian subcontinent during June 2013 (2014). To elucidate this, the KE of rotational component of 850 hPa wind is plotted and shown in **Figure 3** along with the streamlines of total wind anomalies. The figure reveals that during June 2013, the cross equatorial flow was very strong and the monsoon trough was active over CI, favoring low level moisture convergence. During June 2014, the cross equatorial flow was very weak and an intense anomalous anticyclonic circulation was ubiquitous over CI region. It could be contemplated that it was the prevalence of this anomalous anticyclonic circulation that hindered the northward progression of monsoon in June 2014. The presence of anticyclonic circulation over CI can lead to the suppression of convection over the region, as illustrated in **Figure 4** that delineates the time-height evolution of anomalous omega (pressure vertical velocity in hPa s^{-1} multiplied by -1.0) over the region 70°-85°E; 10°-25°N. It is appealing that entirely contrasting omega anomalies are noticed over the region during June 2013 and 2014. The descending motion owing to the anticyclonic circulation anomalies at the lower levels (**Figure 3**) and the convergence at the upper levels (please refer **Figure 11**) has been very strong over the region till first week of July 2014.

During active monsoon periods, the monsoonal reverse Hadley circulation is characterized with ascending motion over Indian subcontinent and descending motion over the south equatorial Indian Ocean. It is noticed that during June 2013, the monsoonal Hadley circulation was very strong (**Figure 5**). In the case of June 2014, strong anomalous subsidence (which is associated with the anticyclone over the region) prevailed over the Indian region while anomalous upward motion was noticed south of the equator. Thus the atmosphere was very unstable (stable) over the Indian region during June 2013 (2014).

Large-scale organized convection, such as the ISM rainfall, is associated with reduced vertical static stability. The MSE of the surface layer is a useful measure of vertical instability and is defined as:

$$MSE = C_p T + gz + L_c q \qquad \text{--- (1)}$$

where, the first two terms on the RHS represents the dry static energy and the third term represents the moisture term. Chakraborty et al. (2006) showed that the convective available potential energy (CAPE) becomes positive and increases rapidly only after the surface MSE reaches a threshold value of 346 kJ/kg. It is found that during June 2013, the MSE values over CI region (70°-85°E; 10°-25°N) are always above the threshold value, whereas they are mostly below the threshold value during June 2014 (Figure not shown). The spatial patterns of MSE anomalies during June 2013 and 2014 are shown in **Figure 6**. The figure clearly brings out the asymmetry in these two years. During June 2013, the anomalies are largely positive over most parts of the country, whereas the anomalies are negative over CI during June 2014. The difference between the actual MSE values during June 2013 and 2014 is also given in the figure. It is evident from the figure that enormous amount of instability was existent during June 2013, compared to 2014, which might have helped monsoon to cover the entire country in a faster pace during 2013. The vertically integrated (from surface to 500 hPa level) moisture anomalies during June 2013 and 2014 are shown plotted in **Figure 7**. The positive (negative) precipitable water anomalies are noticed during June 2013 (2014), which could be attributed to the fact that the moisture term is the major contributor in the MSE equation (Chakraborty et al., 2006). Both the negative MSE and moisture anomalies are indicative of the presence of a stable atmosphere over CI during June 2014 that might have contributed to the hiatus in the northward progression of monsoon observed during the period.

From the above discussion, it could be concluded that the preponderance of the anomalous anticyclonic circulation has inhibited the northward progression of monsoon in June 2014. Presence of such anticyclonic circulation over CI is a distinguishing feature of typical break monsoon periods (Krishnan et al. 2000; Joseph et al. 2009 among others). The northward advancement of monsoon was favored only after the dissipation of the anticyclonic circulation. Thus, the analyses raise an interesting question - what caused the anticyclonic circulation to prevail over the region for such a long time? This will be addressed in the forthcoming sections of the paper.

3.3. Role of global SST

3.3.1. Pacific Ocean

Suppressed (enhanced) convection over Indian region is known to be related to the warmer (colder) SST anomalies over equatorial Indo-Pacific oceanic regions (Ashok et al., 2012; Meehl 1987; Rao and Goswami, 1998; Rajeevan and McPhaden, 2004 among others). Hence SST anomalies over the Indo-Pacific region during June 2013 and 2014 have been plotted and shown in **Figure 8**. It is remarkable to note that cold (warm) anomalies indicative of La-Niña (El-Niño) conditions are noticed over the equatorial eastern Pacific during June 2013 (2014). In conjunction with the cold (warm) SST anomalies over the equatorial Pacific, negative (positive) rainfall anomalies are observed over the region during June 2013 (2014) (**Figure 9**). Rainfall anomalies of opposite polarity to that of equatorial Pacific Ocean are seen over Indian subcontinent, indicating their out-of-phase relationship. In the case of June 2013, the La-Niña like conditions and associated upper level convergence (**Figure 11**) in the eastern Pacific could have intensified the Walker circulation (**Figure 10**) that is favorable for monsoon rains over India through modulation of monsoonal Hadley circulation. Interestingly, the warm anomalies extend across the equatorial Pacific during June 2014 exhibiting a basin wide warming signature. It is noted that the warming was ubiquitous over the region in the pre-monsoon months also (Figure not shown). Such basin wide warming can lead to suppressed convection over Indian region as in the case of June 2009 (Ratnam et al. 2010; Ashok et al., 2012) when the June rainfall departure over the country was -47%. In conjunction with this basin wide warming, anomalous upward motion is observed almost everywhere in the tropical Pacific (**Figure 10**). This is indicative of the anomalously weak Walker circulation over the region. It is found that the anomalous outflow of divergent wind over the central and eastern equatorial Pacific region, which is associated with the convection due to warm SST anomalies over the region, has an anomalous subsiding branch over the

Indian subcontinent (**Figure 11**). This is a typical El-Niño effect and similar conditions were prevalent over the Indo-Pacific region during 2009 (Ratnam et al., 2010). Ju and Slingo (1995) suggested that years with warm SST anomalies in the equatorial central and east Pacific Ocean have a weaker monsoon circulation and a delayed onset. Thus it can be envisaged that although some studies claim that the ENSO-monsoon relationship has weakened (for e.g., Kumar et al. 1999), the influence of equatorial Pacific Ocean on the ISM remains relevant even in the recent times, as evident in June 2014.

3.3.2. Indian Ocean

Another important disparity noticed during June 2013 (2014) is the presence of cold (warm) SST anomalies over northwestern Arabian Sea (AS) (please refer **Figure 8**). Such anomalous warming (cooling)in the northwestern AS is unfavorable (favorable) for monsoon activity over Indian subcontinent (Ramesh and Krishnan, 2005; Li and Yanai, 1996). The warm SSTs over the region during June 2014 seems to be generated by the weak monsoonal westerly winds (see **Figure 3**) which in turn contributed to the reduced upwelling and hence inhibited the cooling in the northwestern AS. On the contrary, the strong monsoonal currents during June 2013 might have led to strong upwelling and thereby contributed to cooling in the northern AS. The warming (cooling) over northwestern AS during June 2014 (2013) is noticed during June 2009 (2001) also (**Figure 16**).

It is to be noted that the warm anomalies during June 2014 preponderated all-across the Indian Ocean (**Figure 8**), suggesting a basin wide warming. The warming was evident even in the pre-monsoon months (Figure not shown). Joseph et al. (1994) suggested that the existence of such warm SST anomalies over the equatorial Indian Ocean can adversely affect the ISM strength by delaying its onset and advancement. They also hypothesized that such delay in the onset and advancement of ISM associated with the Indian Ocean warm SSTs is more pronounced during the onset phase of El-Niño, as experienced in June 2014.

3.4. Role of Tropospheric Temperature

It is well-known that the seasonal heating of the elevated surface of the Tibetan Plateau, and the consequent reversal of tropospheric temperature (TT; defined as air temperature averaged between 600 and 200 hPa; Xavier et al., 2007) along with the pressure gradients south of 35°N, trigger the large-scale change in the general circulation over Asia and the abrupt burst of the monsoon over the Indian subcontinent (Flohn, 1960; Xavier et al., 2007). The strength of the ISM is closely related to the sign of the meridional gradient of TT (defined by Xavier et al., 2007 as the difference of TT values between the northern box 40°–100°E; 5°–35°N and the southern box 40°–100°E; 15°S–5°N). Therefore, the TT gradient during 2013 and 2014 is plotted in Figure **12a**. It is worthwhile to note that the TT gradient during 2013 is well above climatology from second half of May onwards. Conversely during 2014, the gradient is well below the climatology till second half of June, and it became positive from negative by 06 June (the date on which MOK occurred). The large values of TT gradient during 2013 could be attributed to the warm TT anomalies present in the northern hemisphere, compared to the south of equator (**Figure 12b** that depicts the meridional profile of TT values averaged over Indian longitudes 70°-90°E). It is important to note that the TT anomalies are warmer in the equatorial region compared to 2013, although both 2013 and 2014 exhibited higher TT values w.r.t climatology. This becomes more discernable in **Figure 13** that portrays the spatial distribution of TT anomalies during June 2013 and 2014. Hence it could be concluded that it is the north-south gradient of TT, rather than the actual TT values, that are critical in modulating the strength of ISM.

Xavier et al. (2007) indicated that the warmer SSTs over equatorial Pacific Ocean during El-Niño years can regulate the ISM strength through the atmospheric response to the diabatic heating associated with the SST, leading to a substantial reduction of the meridional gradient of TT over the Indian monsoon region. The converse is true for La-Niña years. They also advocated that the negative TT anomaly over Eurasia during pre-monsoon months forced by El-Niño heating delays the onset of ISM. The January-May averaged TT anomalies during 2013 and 2014 have been plotted in **Figure 14**. Interestingly, negative TT anomalies are seen over Eurasian region during 2014. This cooling signature is evident in the monthly averaged TT anomalies plotted for individual months from January-May (Figure not shown). The negative TT anomalies preponderate over the midlatitudes even during June 2014 (**Figure 13**). This proved to be detrimental for the monsoon activity over Indian subcontinent. As suggested by Xavier et al. (2007), these negative TT anomalies over Eurasia in the pre-monsoon months as well as in June might have weakened the north-south TT gradient, thereby delaying the onset of 2014 monsoon and weakening the monsoon activity during June. In contrast, the anomalously warmer TT anomalies over Eurasian region supported the enhancement of monsoon activity over Indian region during June 2013.

3.5. Midlatitude Influence

During summer monsoon season, the subtropical westerlies move northward away from the Indian region and the tropical easterlies dominate in the upper troposphere. The southward incursion of these upper tropospheric westerlies associated with the midlatitude troughs can adversely affect the ISM and can cause break-like conditions over Indian region (Ramaswamy, 1962; Krishnan et al. 2009). Krishnamurti et al., (2010) showed that the intrusion of westerlies associated with the midlatitude troughs and the associated cold air advection was instrumental in generating the subdued convective activity over Indian region during June 2009. It has been noted from the previous sections that June 2014 share some commonality with June 2009. Hence, we have plotted the zonal component of 200 hPa wind along with its magnitude in **Figure 15**. The prevalence of midlatitude westerlies over Indian region is evident during almost whole of June 2014. Interestingly, the intrusion is noticed during 2013 from 11-20 June. The heavy rainfall event over Uttarakhand occurred in concurrence with this intrusion. Joseph et al. (2013, 2014) indicated that the interaction between the midlatitude westerly trough and a monsoonal low pressure system played seminal role in generating this extreme event over the orographic region. They hypothesized that the low pressure system provided huge amount of moisture to the region and the westerly trough intrusion has instigated the heavy rainfall event in the moist environment, as suggested by Li and Fu (2006). Thus it is found that the same meteorological condition, i.e., the midlatitude westerly intrusion, has forced the generation of contrasting phenomena over Indian region during June 2013 and 2014. This finding supports the theory proposed by Sikka (2011). According to his study, the interaction between ISM and the upper tropospheric westerlies associated with the midlatitude troughs and its influence on the ISM depends upon the status of the monsoon activity at the time of beginning of interaction period and also the phase of the Rossby wave. The study proposed that if the monsoon is in its weakening phase, the approach of a westerly trough would alleviate ‘break conditions’ in the monsoon, while if the monsoon is in intensifying stage, such interaction would result in enhancement of rainfall over Indian subcontinent.

4. Conclusions

The present study investigates the scientific rationale behind the observed contrasting progression phase of ISM during 2013 and 2014, with special emphasis on the disparity noticed in the early monsoon month of June. It is identified that during June 2013, the cross equatorial flow was very strong and brought ample amount of moisture to the Indian region, favoring low level moisture convergence and prevalence of positive MSE anomalies (which is indicative of large scale instability) over the region. The La-Niña conditions over eastern equatorial Pacific, warmer SSTs over western AS and warmer TT anomalies over the Eurasian region also provided an environment that is conducive for large scale convection over the Indian region. Additionally, a midlatitude westerly trough interacted with a monsoonal low pressure system in this highly unstable environment around 16 June (Joseph et al., 2013, 2014). These large scale conditions helped monsoon to cover the entire country by 16 June. In contrast, during June 2014, the cross-equatorial flow was weak owing to weak north-south gradient of TT. The weak TT gradients could be ascribed to the colder TT anomalies over Eurasia and warmer troposphere over equatorial regions. The reduction of the meridional gradient of TT over the Indian monsoon region might also be related to the atmospheric response associated with the basin wide warming noticed in the equatorial Pacific in the pre-monsoon months and June. The warmer SSTs over the equatorial Indian Ocean and western AS also proved to be fatal for the ISM activity in June. Moreover, the pervasiveness of midlatitude westerlies over the Indian region (which is unfavorable for ISM activity) was noticed during June 2014. All these factors contributed to the existence of negative MSE anomalies over the Indian region, which subsequently favored the formation and sustenance of anticyclonic circulation over CI region.

Now there remains an interesting question - what caused the increased wave activity in the midlatitudes during 2014, which in turn made the midlatitudes colder and contributed to the weakening of meridional TT gradient? A recent study by Coumou et al. (2014) provided evidences for the weakening of the zonal mean midlatitude westerly jets and an amplification of quasi-stationary waves by resonance between free and forced waves in the midlatitude waveguides, in the recent decade. They argued that the rapid warming in the Arctic during the past few decades (termed as Arctic Amplification; Screen and Simmonds, 2010; Pithan and Mauritsen, 2014, among others) and associated changes in the zonal mean zonal wind have created favorable conditions for double jet formation in the extratropics, which promotes the development of resonant flow regimes (i.e., larger north-south meanders in the flow) over the region. As this meandering develops, troughs may be expected to extend further southwards bringing in cold polar air to the tropics and ridges push the warm tropical air further northwards. The southward penetration of these troughs to the tropical regions can cause the mid-latitude weather systems to be more persistent (Francis and Vavrus 2012; Coumou et al., 2014) and can modulate the ISM activity significantly. However, the manner in which this interaction modulates the ISM activity depends upon the background conditions prevailing over the Indian region at the time of interaction (Sikka, 2011), as noticed during June 2013 and 2014. Hoskins and Wang (2005) indicated that large-scale tropical heating such as El-Niño can support the generation of stationary Rossby waves in the midlatitudes through Rossby wave dispersion from tropics to midlatitudes. The southward penetration of these midlatitude Rossby waves may lead to cold air incursion into the tropical domain. It was noted from **Figure 8** that El-Niño conditions were prevalent in the equatorial tropical Pacific during June 2014. Hence it could be envisaged that the SST anomalies also might have contributed to the increased wave activity in the midlatitudes.

It is to be noted that the large scale conditions observed during June 2013 (2014) share some commonality with those during June 2001 (2009), when the rainfall departure for the month was +35% (-47%). During both June 2001 and 2013, the La-Niña like conditions were prevailing over eastern equatorial Pacific (**Figure 16;** also refer **Figure 8**). Moreover, the TT gradients were very strong (well above climatology) from second half of May onwards during both these years (**Figure 17**). Regarding June 2009 and 2014, both the years witnessed a basin wide warming over the equatorial Indo-Pacific Oceans (refer **Figure 8** and **Figure 16**), which in turn weakened the ISM activity over Indian region through slackening of the equatorial Walker circulation and subsequent modulation of the monsoon Hadley circulation. The warmer SSTs also contributed to the weakening of meridional TT gradient in these two years (see **Figure 17**). During both June 2009 and 2014, the southward incursion of troughs embedded in the midlatitude westerlies was identified (please refer Krishnamurti et al. 2010 and **Figure 15**). Such westerly incursion favored the decreased monsoon activity during June 2009 and 2014.

Having noticed the increased wave activity in the midlatitudes and their frequent intrusion into the Indian region, together with warmer SSTs over the equatorial Pacific even in August 2014 (the present situation when this article is being written; source: http://www.cpc.noaa.gov/products/Global_Monsoons/Global-Monsoon.shtml), it is to be feared that 2014 monsoon may end in a deficient note.

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Table 1: Observed June rainfall in mm and its % departure from long term mean. Years with excess (deficit) June rainfall are marked in blue (red) color. The onset date, the date on which the ISM covered the whole country and the total number of days taken for the same are also given in the table

Year	June Rainfall (mm)	Departure from Mean in %	MOK Date	Date of covering the entire country	Total Days taken to cover the country
2001	**219.0**	**35.6**	**23 May**	**24 June**	**32**
2002	180.1	9.4	29 May	15 August	66
2003	179.9	9.8	08 June	05 July	28
2004	158.7	-0.8	18 May	18 July	62
2005	143.2	-9.5	05 June	30 June	26
2006	141.8	-12.7	26 May	24 July	60
2007	192.5	18.5	28 May	04 July	38
2008	202.0	24.3	31 May	10 July	41
2009	**85.7**	**-47.2**	**23 May**	**03 July**	**42**
2010	138.1	-15.6	31 May	06 July	37
2011	183.5	12.2	29 May	09 July	42
2012	117.8	-28.0	05 June	11 July	37
2013	**219.8**	**34.4**	**01 June**	**16 June**	**16**
2014	**92.4**	**-43.5**	**06 June**	**17 July**	**42**

Figure Captions

Figure 1: Rainfall anomaly (mm day^{-1}) during June 2013 and 2014

Figure 2: (a) Time evolution of Somali Jet Speed Index (m s^{-1}) at 850 hPa and (b) time-height evolution of zonal wind (m s^{-1}) area-averaged over the region 55°-80°E; Eq-10°N, during 2013 and 2014. Positive (negative) values in Figure 2b denote westerlies (easterlies).

Figure 3: 850hPa anomalous wind (m s^{-1}; *streamlines*) and the KE (m^2 s^{-2}; *shaded*) of its rotational component during June 2013 and 2014.

Figure 4: Time - height evolution of anomalous omega (pressure vertical velocity in hPa s^{-1} multiplied by -1.0; *shaded*) over Central India (70°-85°E; 10°-25°N) during 2013 and 2014. Positive (negative) values represent ascending (descending) motion.

Figure 5: Latitude-height sections showing monsoon Hadley circulation anomalies during June 2013 and 2014. To construct the meridional circulation anomalies, the meridional and vertical velocities are averaged over the longitudes 70°-90°E. The shading represents omega (hPa s^{-1}) anomalies taken with a negative sign.

Figure 6: Moist Static Energy (MSE; kJ kg^{-1}) anomalies during (a) June 2013 and (b) June 2014. The difference between actual MSE values during June 2013 and 2014 is plotted in (c).

Figure 7: Vertically integrated (surface to 500hPa) moisture (mm day^{-1}) anomalies during June 2013 and 2014

Figure 8: Sea surface temperature (unit: °C) anomalies during June 2013 and 2014

Figure 9: Rainfall anomalies (mm day^{-1}) over the Indo-Pacific region during June 2013 and 2014

Figure 10: Longitude-height cross-sections depicting the east–west (Walker) circulation anomalies over Indo-Pacific region during June 2013 and 2014. In constructing the east–west circulation anomalies, the zonal and vertical velocities are averaged over the latitudes (5°S -5°N). The shading represents omega (hPa s^{-1}) anomalies taken with a negative sign

Figure 11: Velocity potential (x 10^{-5} m^2 s^{-1}; *shaded*) and divergent wind anomalies (ms^{-1}; *vector*) at 200 hPa during June 2013 and 2014

Figure 12: (a) Time evolution of north-south TT gradient (K) during 2013 and 2014 (b) Meridional profile of TT (K) averaged over 65°-95°E during June 2013 and 2014

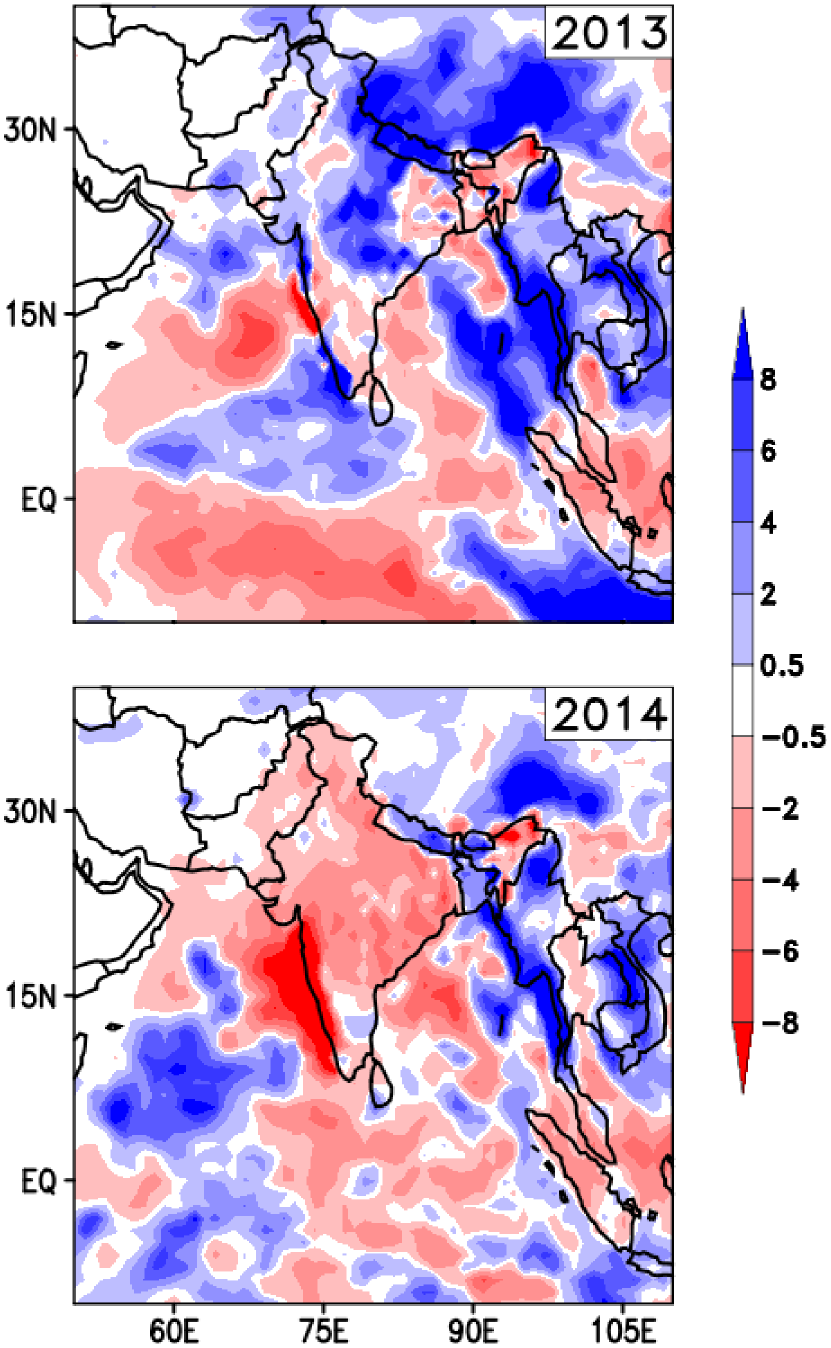
Figure 13: TT anomaly (K) during June 2013 and 2014

Figure 14: January-May averaged TT anomaly (K) during 2013 and 2014

Figure 15: 200 hPa zonal wind (m s^{-1}; *vector*) during June 2013 and 2014. Magnitude of wind is *shaded* in the figure.

Figure 16: Same as Figure 8, but for 2001 and 2009

Figure 17: Same as Figure 12a, but for 2001 and 2009



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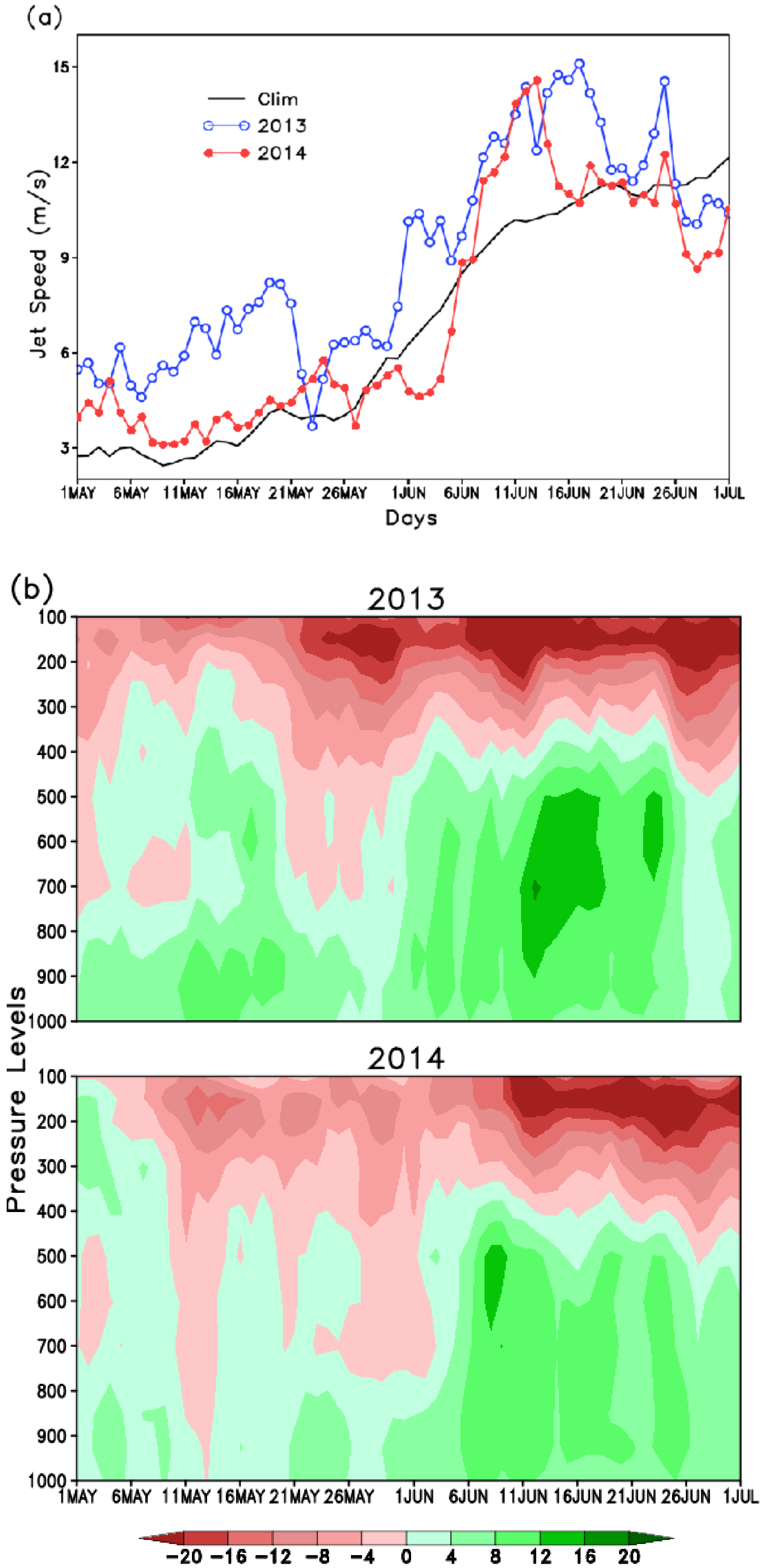

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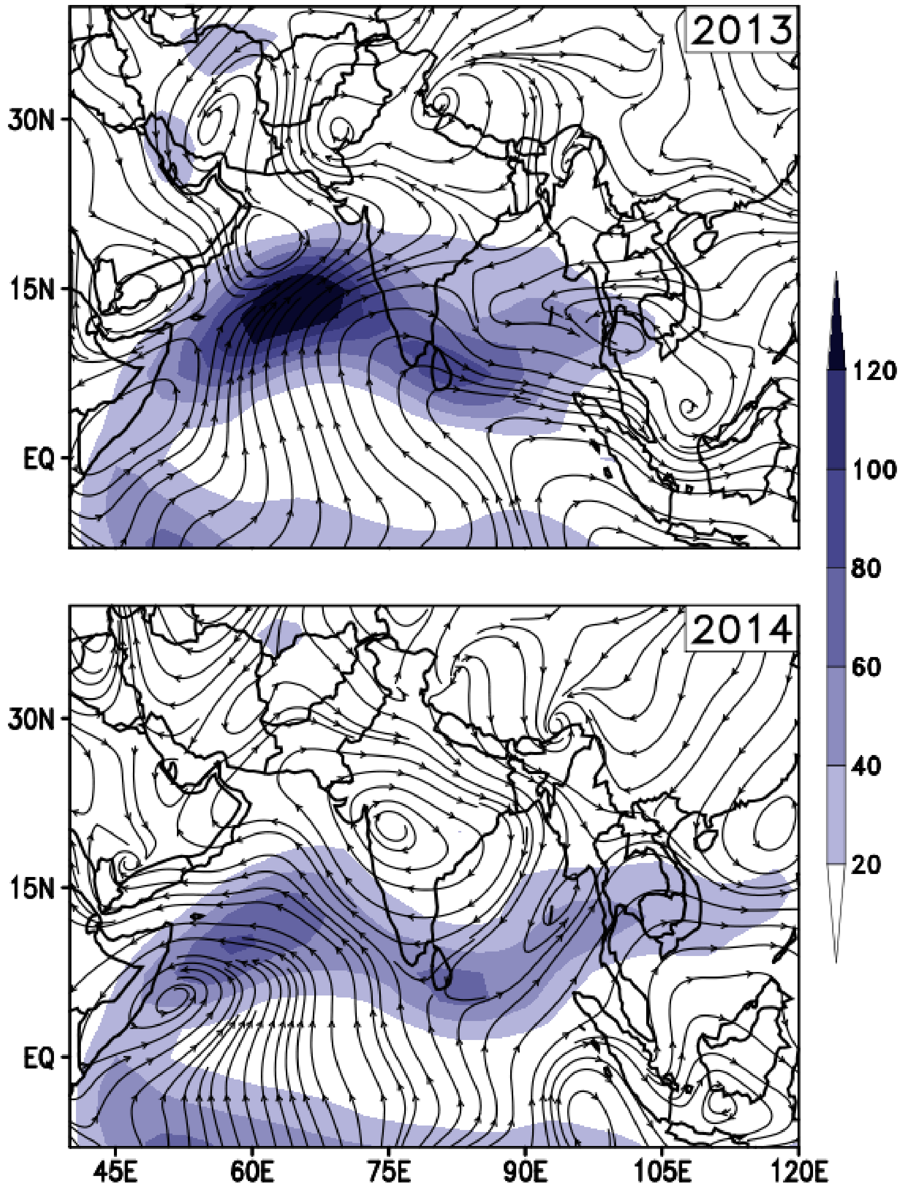

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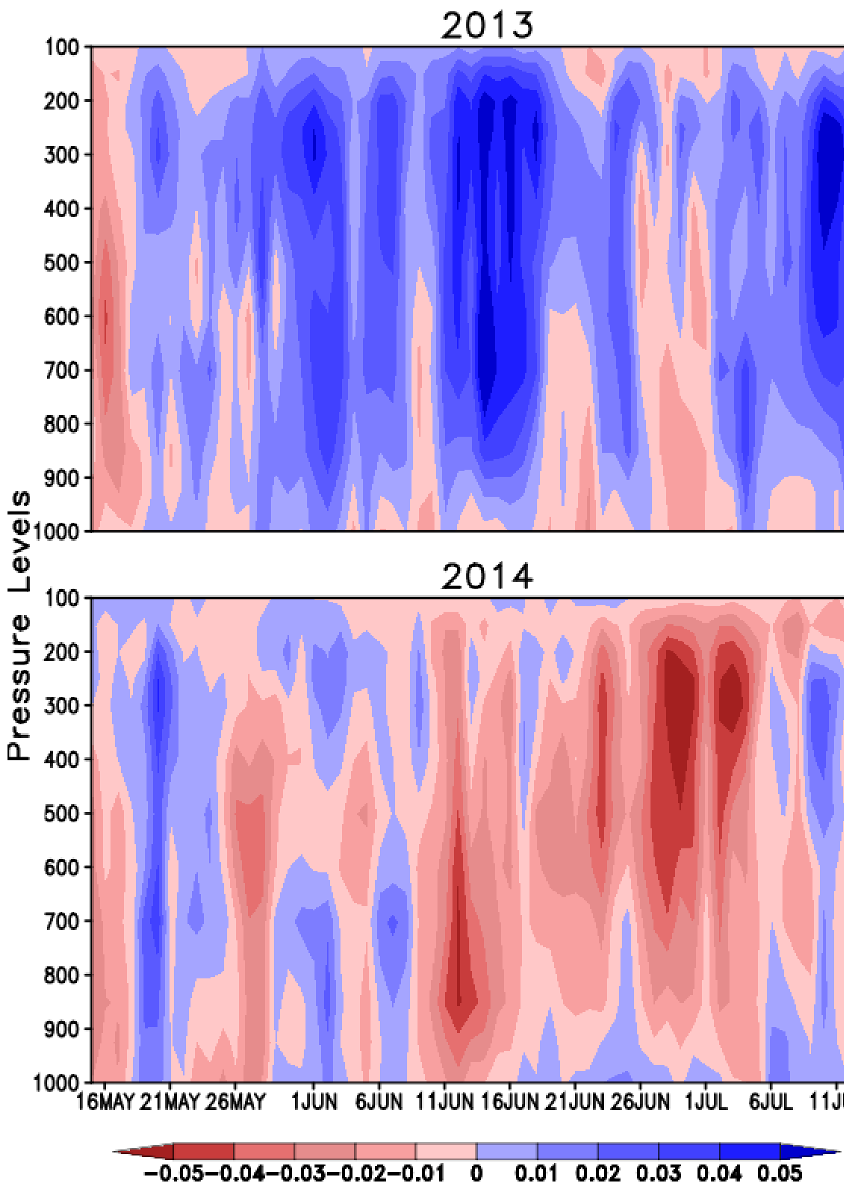

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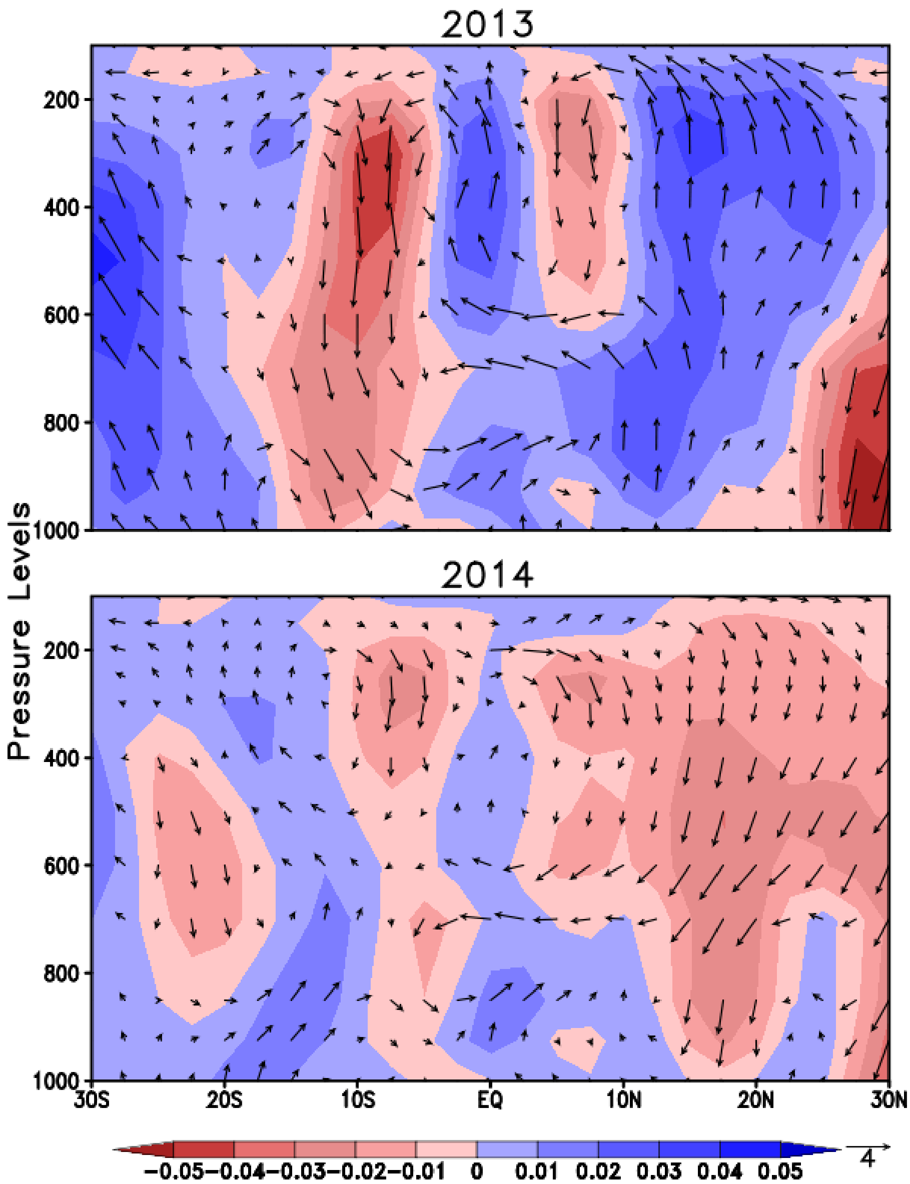

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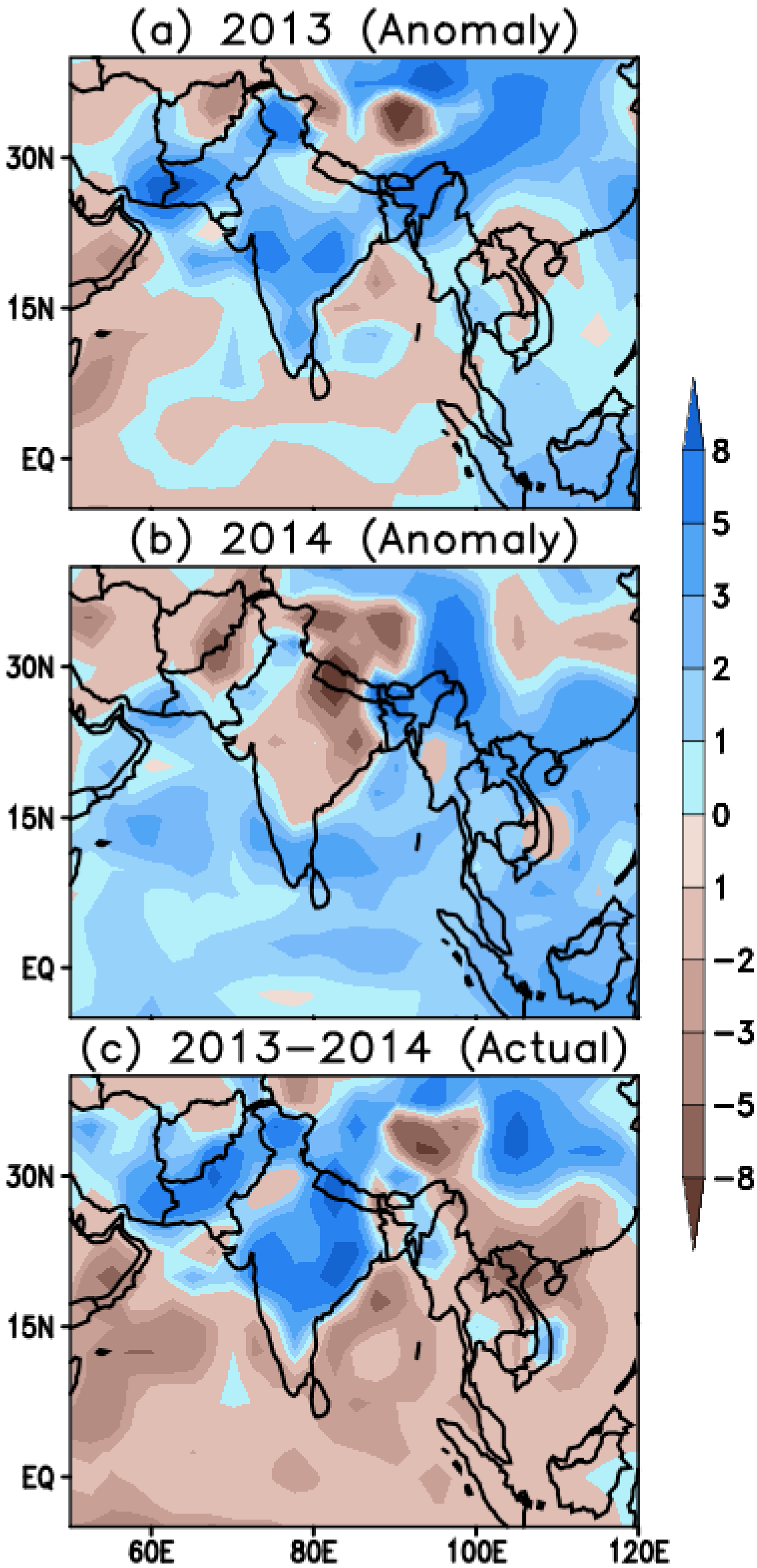

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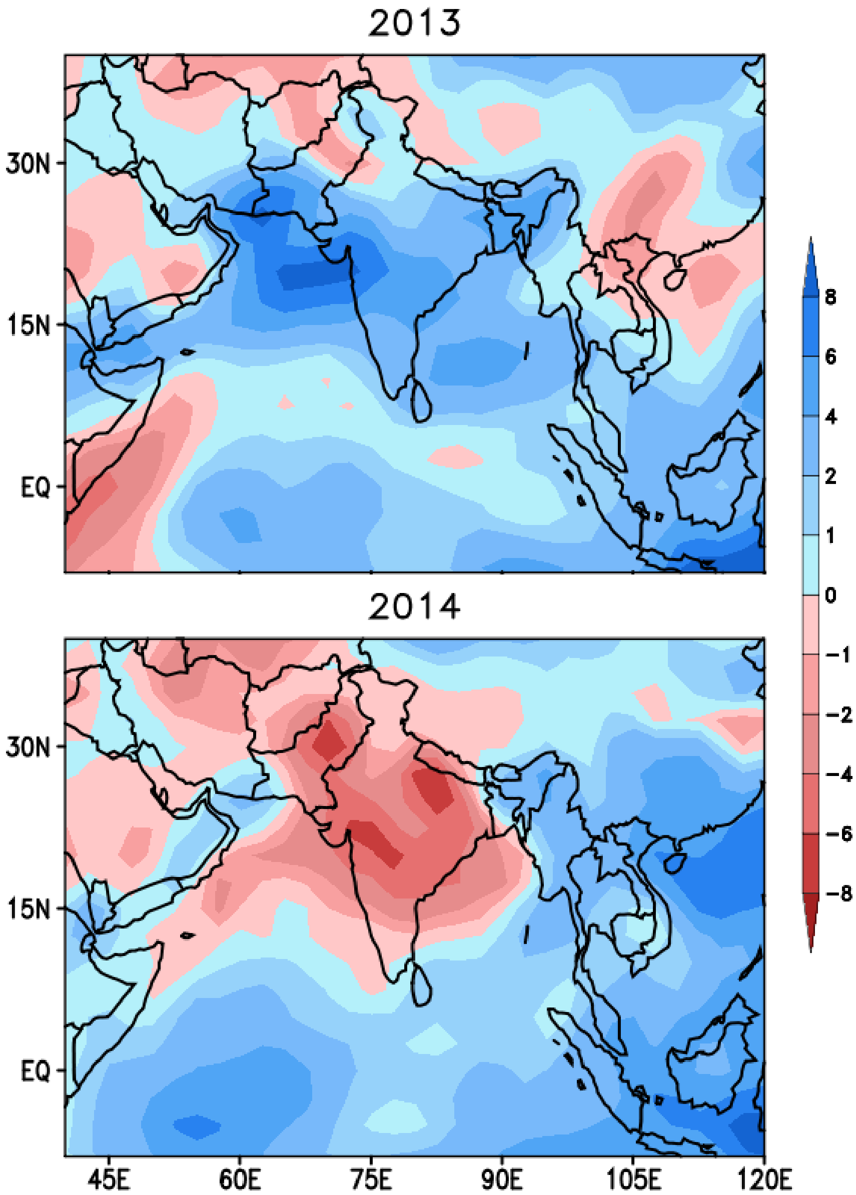

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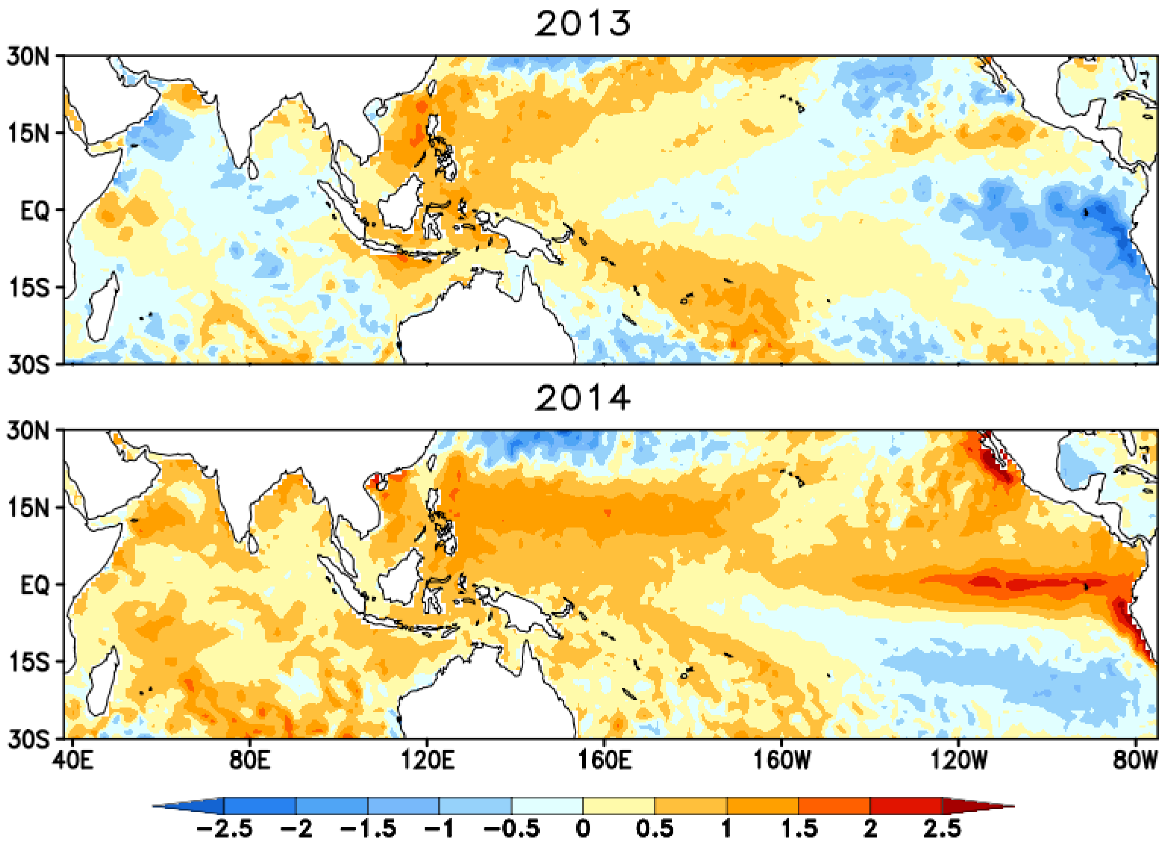

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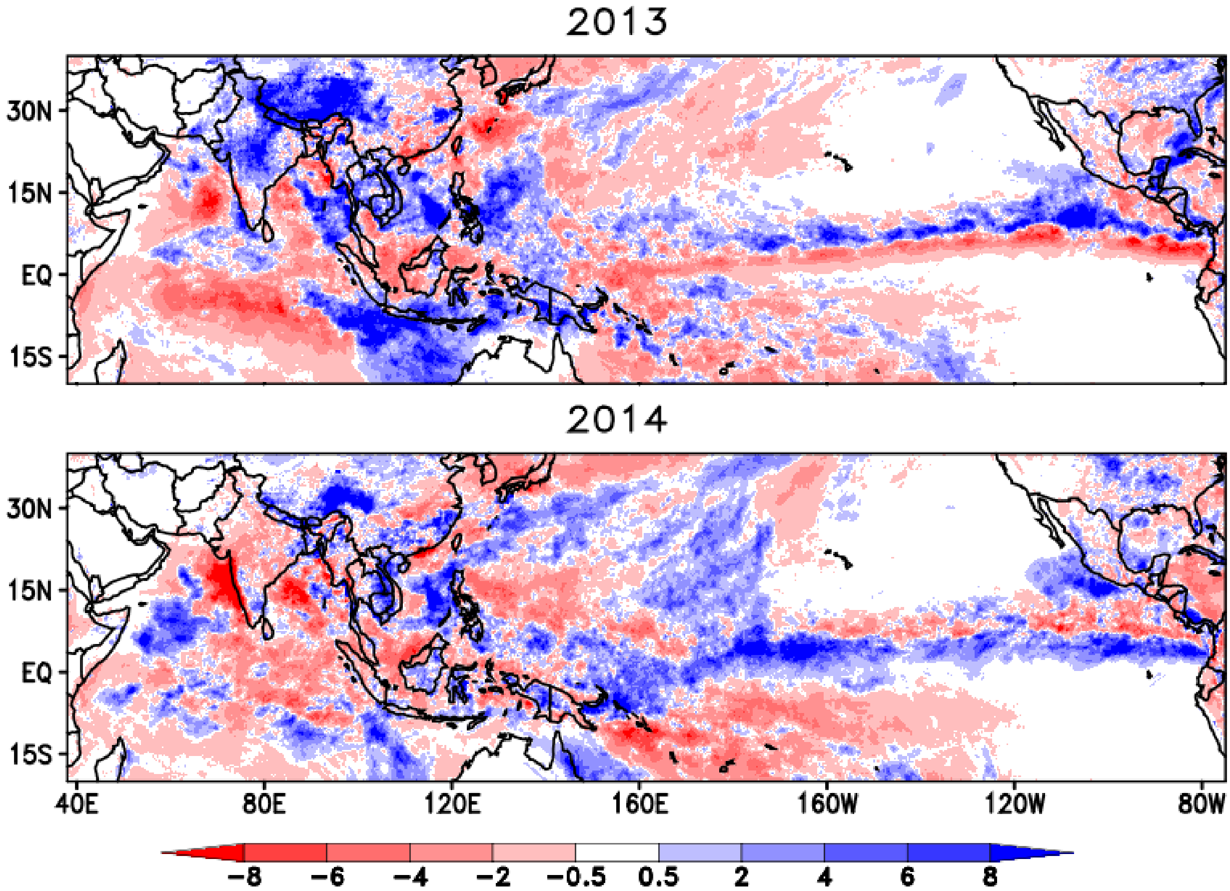

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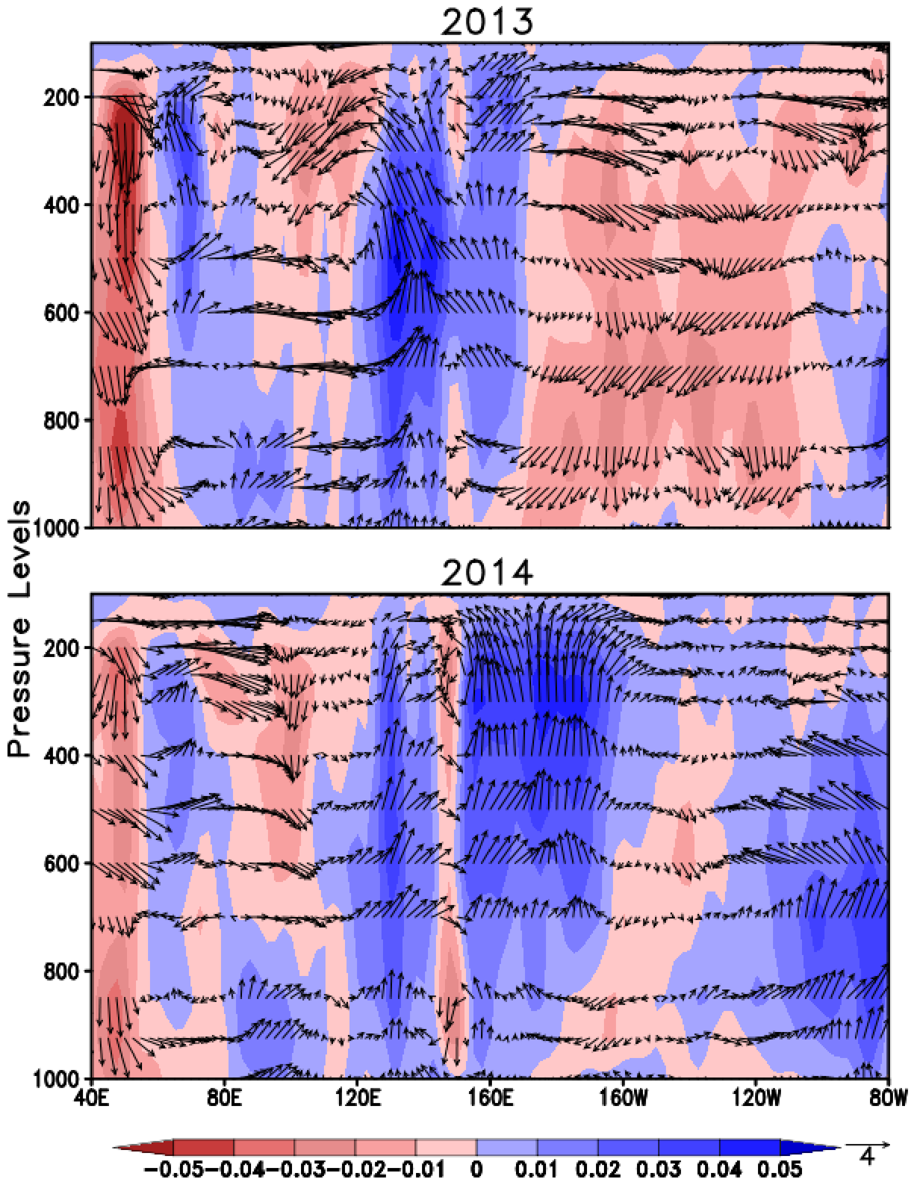

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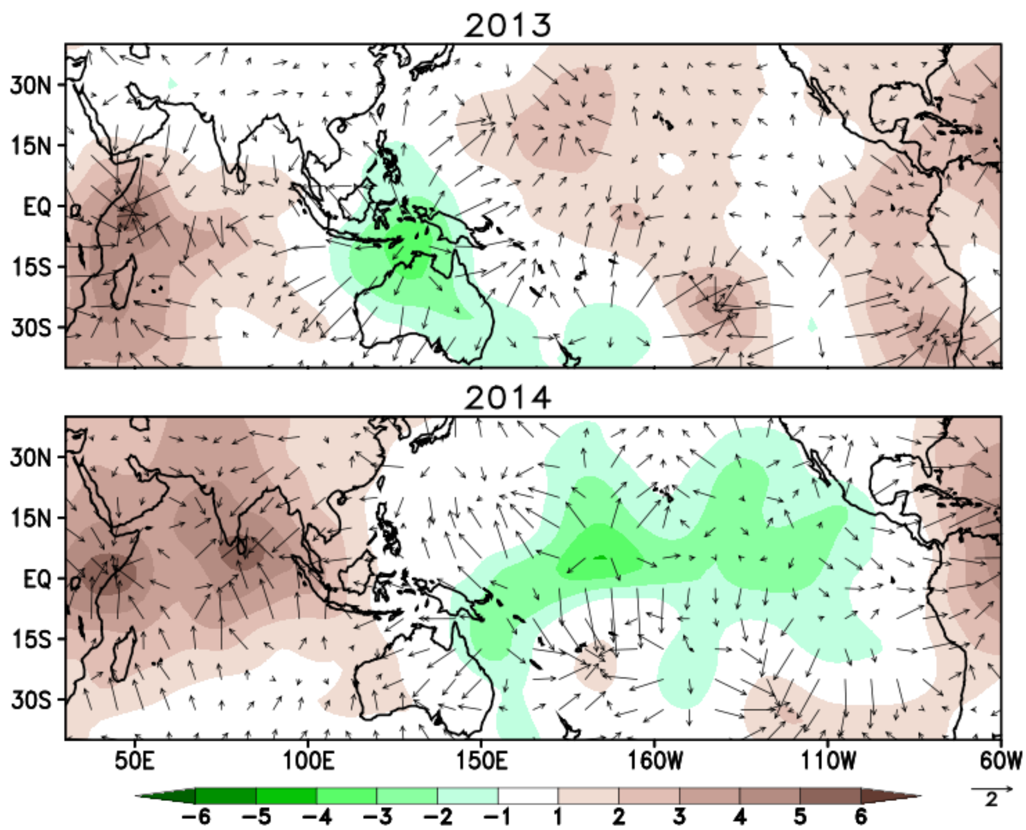

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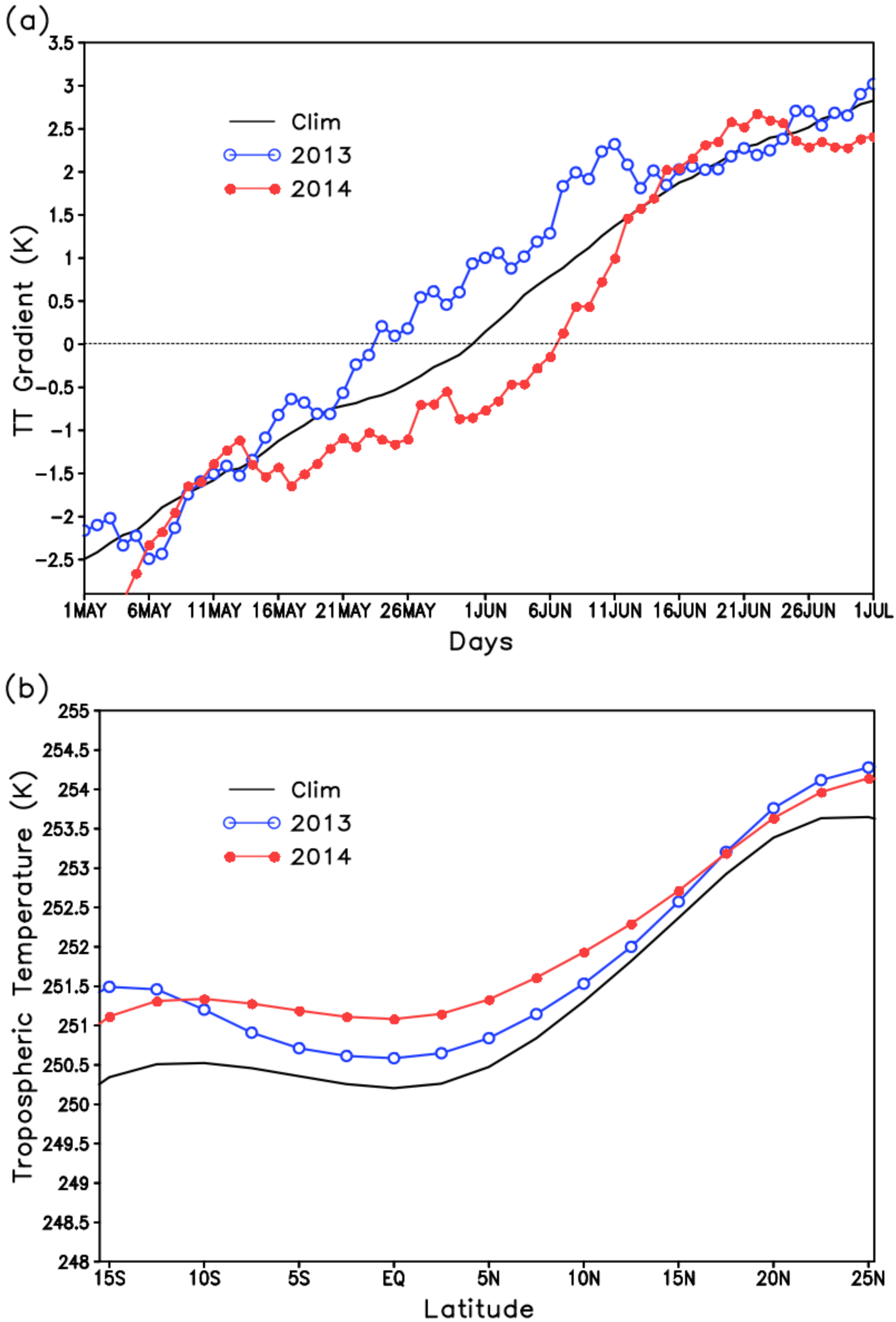

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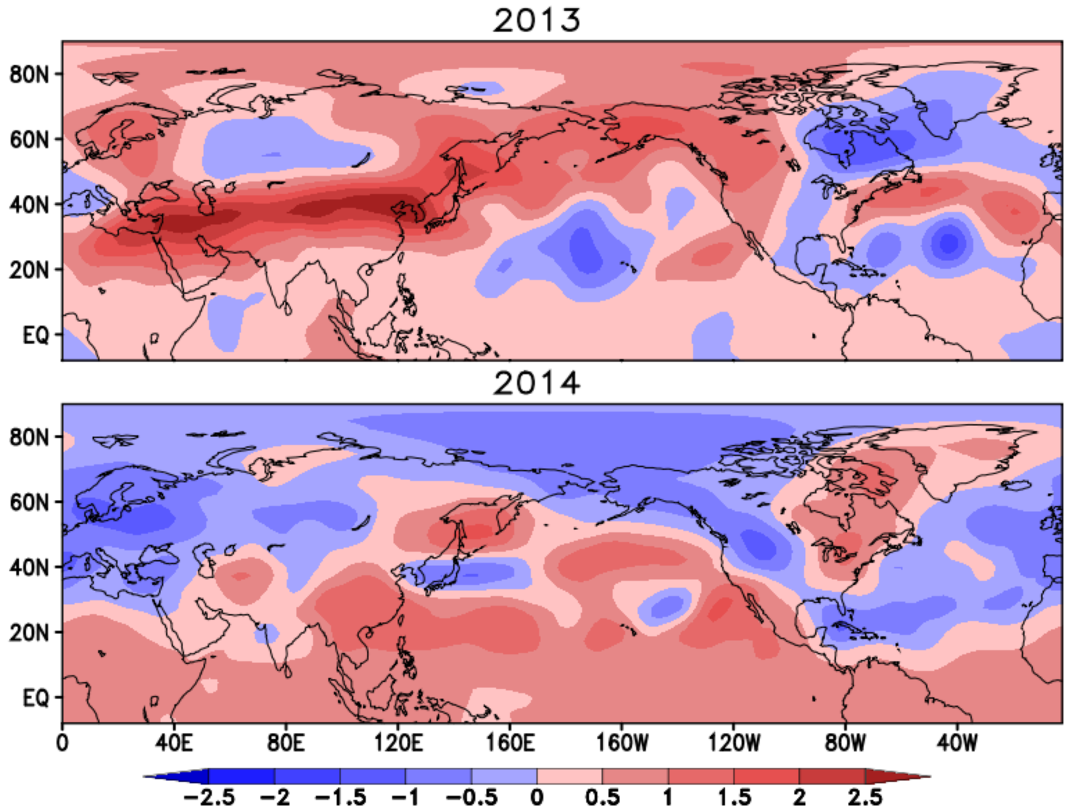

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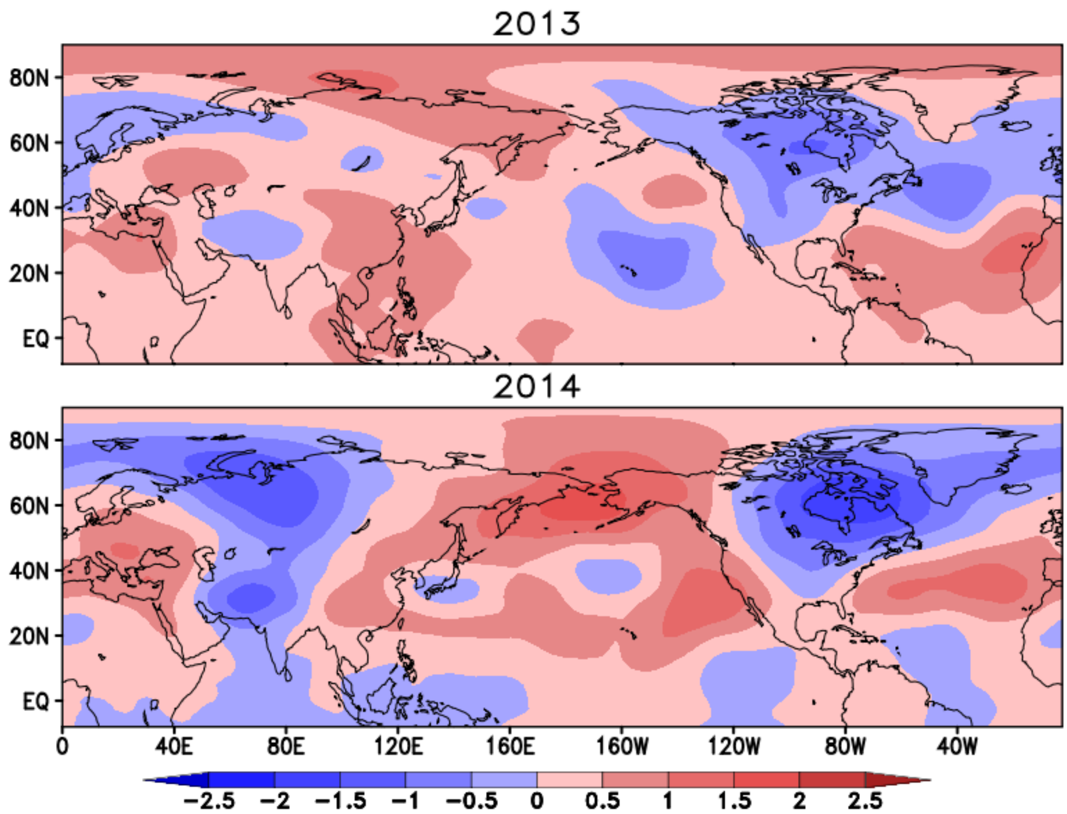

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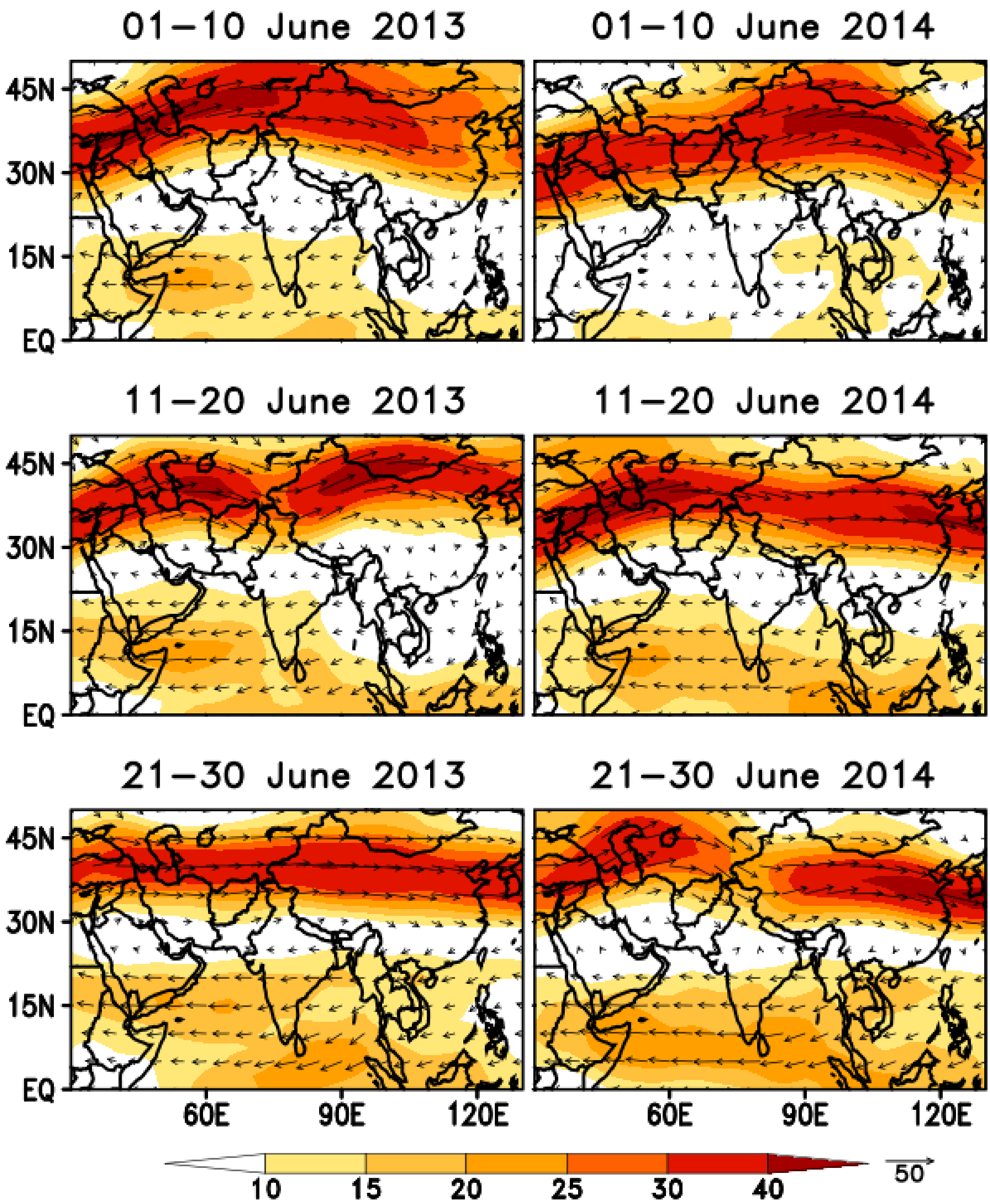

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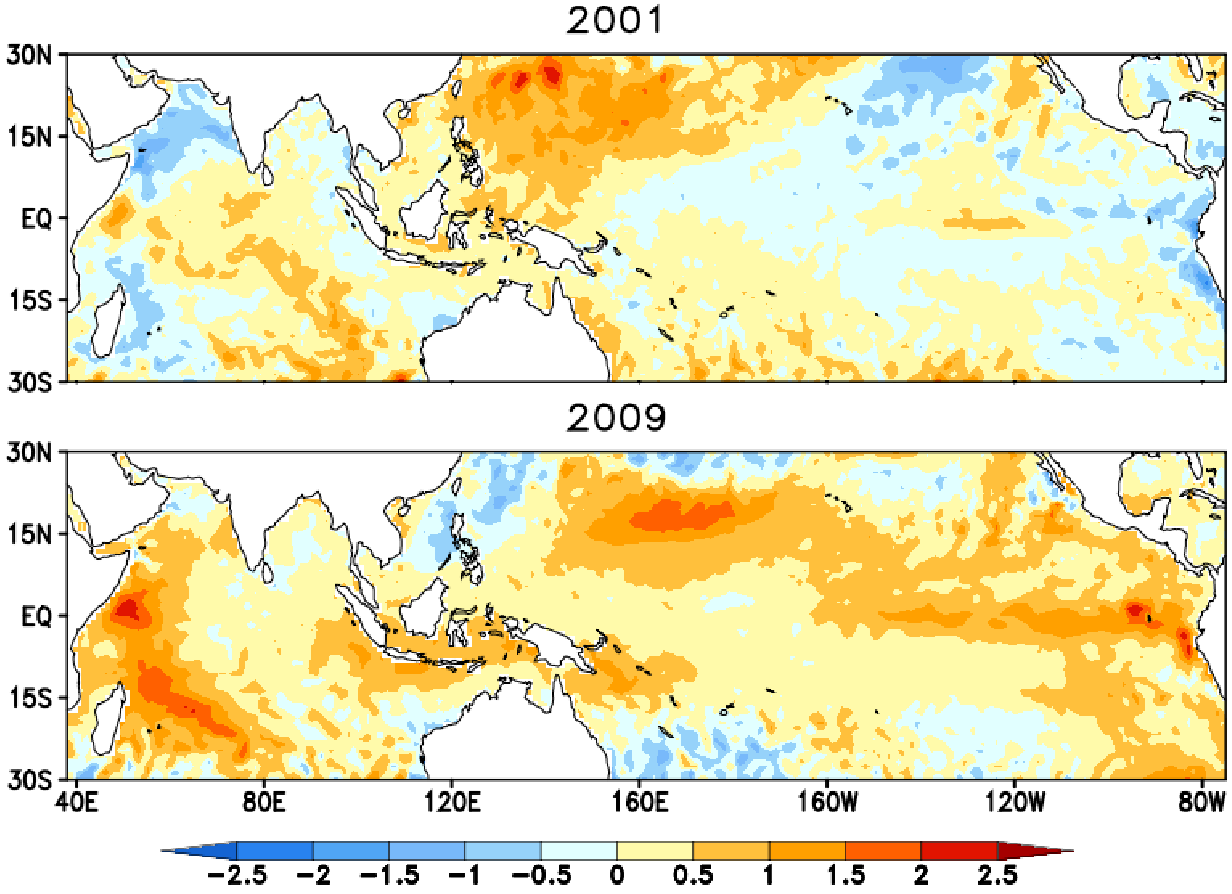

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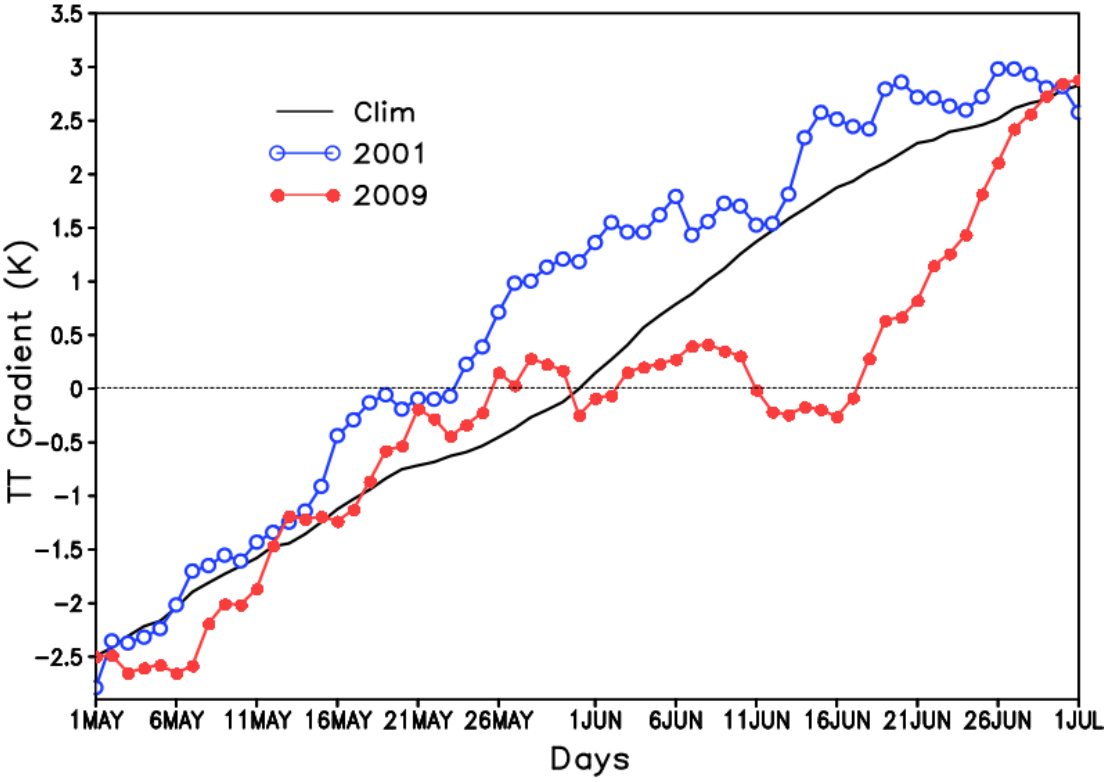

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