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Review of Droughts over Indian Region

Review Article

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Abstract

None of the two Indian monsoons are similar in nature, special coverage, intensity, affecting the people, and withering the crops. ENSO is one of the major role player in influencing rainfall worldwide and thus over Indian region as well. In the literature of Indian monsoon, ENSO is widely studied in association with droughts. Apart than ENSO there are IOD, influence of mid-latitude cold-dry air intrusion, low count of monsoon depressions, west Pacific Ocean convection, east equatorial Indian Ocean convection and few more, those induces the droughts over Indian subcontinent. A compact view of their impact and relationship with ISMR is been described in this review paper.

Introduction

The monsoon is known for its distinct seasonal reversal of wind between winter and summer season from northeasterly to southwesterly [3, 37, 44]. Among the various summer monsoons, which are well known around the globe (e.g. south Asian monsoon, east Asian monsoon, African monsoon, north American monsoon), Indian monsoon is one of the most studied and fascinating ones. Monsoon, an atmospheric-oceannic coupled system is one of the most popular and studied research topic other than hurricanes, typhoons, ENSO (El-Nino Southern Oscillation), droughts, and floods. To understand the monsoon dynamics throughly, some of the well known experiments were performed over and around the Indian region. A number of monsoon projects and field experiments were done to realize the dynamics of monsoon e.g. International Indian Ocean Expedition (IIOE around 1960), the Monsoon Experiments (MONEX in 1978-1979, [11]), the Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE in 1992, [43]), the GEWEX Asian Monsoon Experiment (GAME in 1996-2000), the Bay of Bengal Monsoon Experiment (BOMEX in 1999, [2]) and the Joint Air-Sea Monsoon Interactive Experiment (JASMINE in 1999), the Arabian Sea Monsoon Experiment (ARMEX in 2002, [42]) and the Cloud Aerosol Interactions and Precipitation Enhancement Experiment (CAIPEEX in 2013, [20]). As a complete system, Indian summer monsoon rainfall (ISMR) has a comprehensive cycle of onset, northward progress of monsoon, active-break spells and withdrawal of monsoon.

Subsidence is one of the known reasons of aridity occurrence over land which extends over a significant portion of ocean as well [41]. These are the well-known desert regions over mid-latitudes in both the hemispheres. Present review talks about the drought like situations arising in a rainy season, which brings the hardship to a common man by affecting the agriculture growth, water shortage, heat waves and dust devils. In the literature of monsoonal droughts, a local, regional and remote influences from sea surface temperatures, snow cover, high pressure tendencies, subsidence, dry air intrusion, internal dynamics, western Pacific typhoon activities, monsoon-mid-latitude interaction, decreasing of monsoon depressions, disruption of the organization of convection, and aerosol concentration have been studied in depth. In spite of all, monsoon has its own memory to repeat its annual cycle of summer monsoon activity over Indian region.

Anatomy of the monsoonal cycle

For the operational purposes, the type of droughts are categorised as meteorological, agricultural, hydrological and socio-economic droughts [5]. An "Indian monsoon drought" is defined when the seasonal rainfall is below 1-standard deviation (1σ or 10% below the climatological normals, see [36]). The meteorological drought are categorised into 5-categories based on the their intensity and widespredness viz. mild drought (1σ-1.24σ), moderate drought

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(1.25σ-1.49σ), severe drought (1.5σ-2σ), phenomenal drought (more than 2σ), and calamitous drought (if the rainfal is more than 50% of the climatological normal).

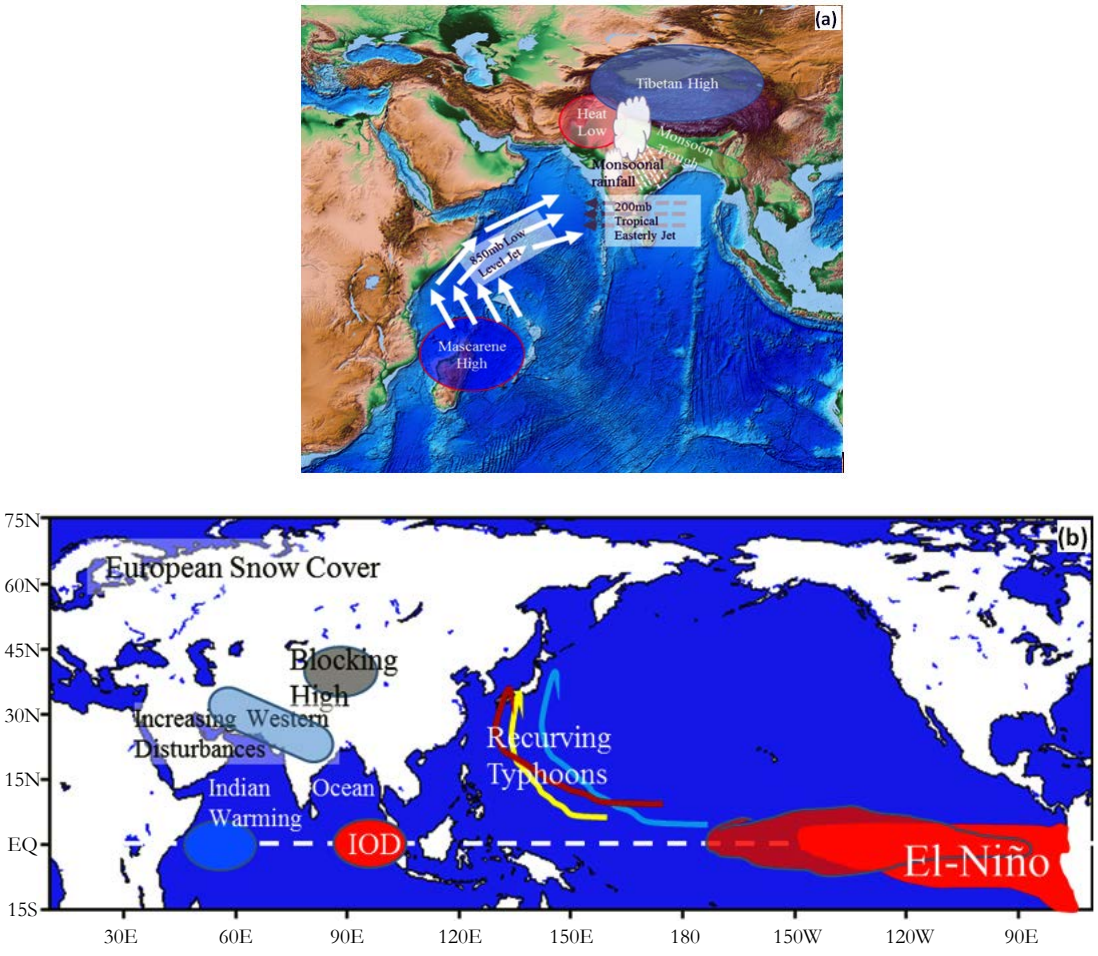
In the literature of ISMR the semi-permanent elements were defined by Krishnamurti and Bhalme (1976) [14]. They are known as semi-permanent features because of their variable nature with location and intensity during summer monsoon. Table 1 also lists the semi-permanent features of Indian monsoon and their instantaneous locations. Spatial locations and of the semi-permanent element and the global locations of teleconnections are shown in the schematic of Figure 1a and 1b. The variability of the ISMR depends on the location and intensity of these elements and teleconnections. Various phases of each one or more affect the Indian summer monsoon [30].

Sensible heat from Tibetan plateau and surface warming over northwestern Indian region creates a "heat low". The heating over northwestern Indian region and Tibetan Plateau are important for the onset of the ISMR by establishing meridional gradient of heating across the land and ocean [28]. Southern flank of Tibetan high provides Tropical Easterly Jet (TEJ) over southern part of the Indian region [10]. Somewhere in the end of May and early of June a cross equatorial flow (or low level jet, LLJ) is estabilised neat the Somali coast [4] and a cyclonic/onset vortex is formed [13]. June 1 is marked as the normal onset date of Indian summer monsoon over the southern most state of India [1]. According to the definition of monsoon onset, rainfall should be widespread (14 rainfall stations), persistent for two consicutive days (2.5 mm or more), westerlies of 15-20 knots and outgoing longwave radiation of 200 wm^{-2} or less, over this region to declare onset of monsoon. Onset date of monsoon has a quite varaibility of

Table 1. Listing of the Semi-Permanent Features of Indian Summer Monsoon.

1	Heat low over northwestern Indian region	~(75°E, 25°N)	994mb, a low pressure at surface
2	Tibetan High (Large anticyclone)	~(90°E, 35°N)	Between 200mb-150mb
3	Monsoon Trough	~25°N	Low pressure at surface
4	Tropical Easterly Jet	~20°N	Between 200mb-100mb; 15km above the surface; around 40m/sec
5	Low-Level Cross-equatorial Jet	~(50°E, 1°N)	
6	Mascarene High	~(60°E, 30°S)	1023mb on surface

Figure 1. (a) The semi-permanent features of the ISMR, (b) Location of the teleconnections and regional processes, those influences ISMR.



around ± 10-15 days [9]. Once the monsoon is set as ON in a year around in the month of June, its progress over Indian landmass becomes ineresting and important one for many purposes. In south Asian countries rain varaibility is very much tied with the agricultural growth.

Onset of monsoon brings a lot of changes in wind circulation, rainfall and weather conditions over the region. There are various intriguing and strange facts about the propagation of monsoon in the direction of north and northwest ward over Indian landmass [6]. The stagnation and propagation of rainfall is influenced by synoptic-scale disturbance, boundary layer processes, regional processes, depressions and sometime large scale processes.

The interaction among monsoonal rain bearing systems, moisture suply, formation of depressions, land surface processes lead to the internal dynamics of the monsoon. Such complex interaction makes difficult to predict the progress of the monsoon. Sometime, monsoon does not progress northward, and reason becomes smiple the lack of cloud cover and rain bearing systems. July 15 is the normal date when monsoon reached to the northwestern most region of India. Once the Indian summer monsoon is reached to the northern limit of monsoon over Indian region, the variations in the monsoon rainfall are termed as active and break. Sometimes and many, It is raining here but not there, is a kind of truth, but a persistance and intense rain over a region can lead to flood while a "no rain" over a region can lead to a droughts. Continuous rainfall for 3-4 days termed as active while no rain continuous for 3-4 days is termed as break [27].

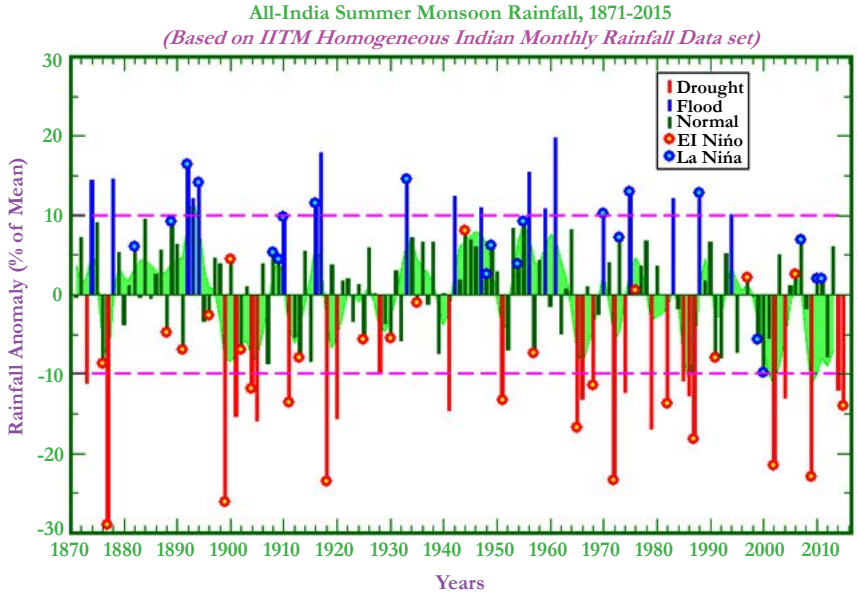
The breaks in the ISMR can also occur due to monsoon-midlatitude interaction [17], subsidence from Northwest Pacific cyclonic activity region [22, 26], and dry air intrusion from south Asian middle-east desert regions [12]. The intera-seasonal variability of the ISMR is the manifestation of meridional sway of the ITCZ (or monsoon trough) over the Indian landmass. This meridional sway of the monsoon trough may be due the result from superposition of various oscillations e.g. 2-7 days synoptic, 10-20-day quasi-bi-weekly and 30-60-day MJO oscillations.

Interestingly, most of the severe monsoonal droughts are associated with the ENSO event of the eastern Pacific region [23, 29, 38]. Walker (1924) [39] was the first who linked ISMR to ENSO, which has been faded with the time [19]. These all studies show the subsidence from and importnace of the eastern and central Pacific region of warm sea surface temperatures (SSTs) on the ISMR region via. east-west Walker circulation. No doubt, one can not ignore the importance and influences from regional ocean varaibility on ISMR e.g. Arabian sea, Bay of Bengal and Indian Ocean and also kown as IOD (Indian Ocean Dipole, [33, 34, 40]). Thus monsoon emerged as one of the couped ocean atmosphere system, infuenced by both land and ocean varaiability. During breaks and droughts, the enhancement of rainfall is seen over eastern equatorial convection region at around 5°S. These periods of active and breaks are thought to be associated with shift in the location of the monsoon trough over India [15]. During the break spells the monsoon trough remains along the foothills of Himalaya, while rest of the India suffers from the lack of rainfall. A break lasts from 3 to 7 days, while prolonged breaks can lead to droughts [8, 17, 32].

Another important phenomenon known as the "Blocking high over central Asia around 115°E-90°E", in the upper troposphere is linked with the weak monsoon [31]. The meridional shear of the low-level zonal wind and cyclonic vorticity at 850hPa are significantly weakened during breaks. Furthermore, during the breaks the condition of the cyclogenesis is decreased by around one fourth [7].

Various atmospheric phenomenon and constituents are discussed for drought and dry spells of Indian viz. 30-60 days oscillation [46], 10-20 day oscillation [36, 45], aerosol concentration [25] can influence it. ISMR has a varaibility of interannual intera-seasonal, inter-annual, inter-decadal and epochal. These breaks are part of intera-seasonal oscillation (variability) of the Indian summer monsoon. Last in this cycle is "withdrawal" which has a start date

Figure 2. Annual varaiation of the all-India summer monsoon (June-September) rainfall (AISMR) anomalies during from 1871 to 2015 (courtesy: http://www.tropmet.res.in/~kolli/mol/Monsoon/frameindex.html)



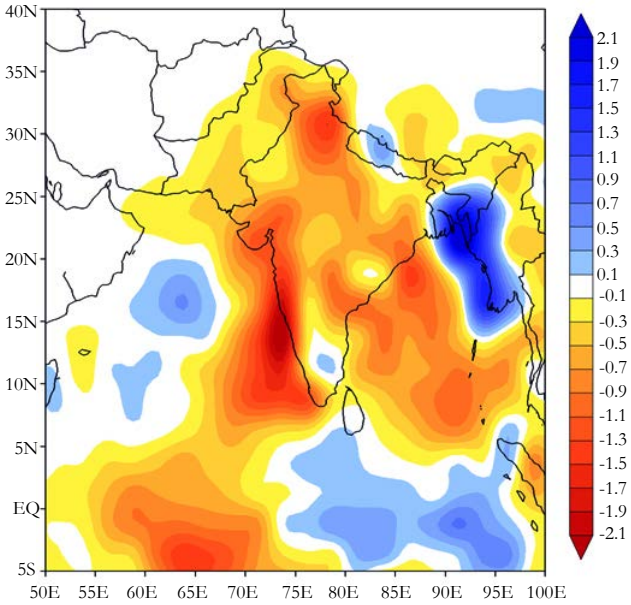
September 1 from northwestern part of India. ISM withdrawal starts from the northwestern parts of the India, Rajasthan in 1st week of September [6].

Annual cycle and seasonal march of the Asian monsoon

Presence of Himalayan orography makes Indian monsoon unique with a strong annual cycle as compared to other monsoons. Figure 2 shows inter annual variability of ISMR since 1871. Long term mean of the Indian summer monsoon rainfall is 874mm. ISMR does not show any kind of decreasing or increasing trend. Out of 125 years 22 were the drought years, among those 12 were influenced by ENSO. Figure 1 is based on the 306 Indian meteorological raingauge station's datasdets for rainfall. This series shows the long term annual rainfall variability for summer season. The red/blue stars and collors are corresponding to El-Nino/La-Nina years show the global teleconnection of ISMR. Further more Figure. 2 shows the ISMR anomalies, expressed in percentage departure from long term climatological normal of rainfall. On counting from 1871 to 2015, India witnessed 19 major drought years (1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009, 2014, 2015).

Figure 3 shows the spatial pattern of rainfall for the composite of monsoonal drought years (from 1979 to 2015). Most of the parts of India is been deprived from rainfall except eastern part of India. Due to global warming, Indian Ocean is also showing a warming trend, thus the meridional temperature gradient is decreasing across land and sea [33]. As an another fact, pre-monsoon western disturbances are increasing over northwestern part of Indian and producing increasing western disturbances in pre-monsoon season producing lot more rainfall [24], adding land sea contrast favoring for a weak monsoon start. It has been advocated that the central pacific warming is more vulnerable to produce more drought conditions over India [17]. Some of the recent researches: the call for the influence on the droughts are disruption of the organization of convection [16], soil moisture sensitivity [21], regional ocean impact [18] are suggesting various

Figure 3. Rainfall composite anomalies of Indian summer monsoonal droughts.



theories of monsoonal advancement and weak monsoon.

Conclusion

Drought is one of the outcomes of the ISMR. ENSO is the main factor in producing drought over Indian region, while next ones are dry air intrusion, recurving of typhoons, and Indian Ocean warming. ISMR is influenced by local, regional and remote factors of atmospheric phenomenon. The association between the ISMR and the various teleconnection patterns are being altered by global warming. This is one of the reasons, why every year the prediction of ISMR and drought becoming a complex task for meteorologists.

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