To Study the Various Factors Affecting the Summer Monsoon Rainfall in Nepal

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ABSTRACT:

Various factors affecting the monsoon rainfall in Nepal have been studied. The impacts of the factors have been correlated with the rainfall pattern observed in a small sub catchment – marshyangdi of west Nepal. The monsoon rainfall in Nepal is significantly affected by the three major factors: (a) Sea Surface Temperature Anomalies (b) Aerosol Accumulation in the Tibetan Highlands and (c) El Nino /La Nina. The rainfall pattern observed in Nepal/Marshyangdi sub catchment has been correlated with these global phenomenon.The trends of rainfall recorded in the Marshyangdi catchment is in excellent agreement with the El Nino and La Nina events. On the whole the rainfall pattern in this catchment shows no long-term trend.

Key words: Monsoon, El Nino, La Nina, Aerosol, Sea surface Temperature

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1. Introduction:

Situated between the Indian plain and the high majestic Himalayan ranges, Nepal observes excess of rainfall in some months of a year while deficit in some other months. Almost more than 80% of the annual rainfall occurs within the monsoon months of June to September. Roughly speaking, Nepal is flooded with rain in these monsoon months and faces the scarcity or drought in the rest 8 months of a year (Ichiyanagi et.al.2007). Indian summer monsoon is the result of differential heating between Tibetan highland plateau and the downwind Indian ocean (Lecture: Prof. Rong Fu, UT Austin 15/10/2008).Asian monsoon is one of the most energetic monsoon systems in the world (Zhang and Li 2007).Monsoon is the major rainfall event upon which most of the agriculture and agro-industries are based in Nepal. Recent studies indicate the variation in the monsoon rainfall event in Nepal. This could consequently have immense impact upon the country whose more than 65% citizens depend upon the subsistence farming for their livelihoo (MOPE, 2005). Due to heavy rainfall in monsoon period, Nepal faces serious problems of flooding and events associated with flood. For example; the flood of 1993 caused landslides, flooding 5584 ha of land area. A total of 540mm and 482mm of rainfall was recorded in 24hrs in Makwanpur district on 20 July, 1993. It claimed 1336 human lives and 85,451 families were affected (MOPE, 2004). Total estimated loss of all properties due to flood in 1996 was USD 182 million and in 2000 it was USD 1.7 million. In 1994 the impact of flood was observed directly in 37 districts out of 75 districts of Nepal. Interestingly in the same year 35 districts were affected by drought (MOPE, 2004). Hence there is problem of extreme natural events and variation in Nepal. Some parts of a year observe extreme drought while some other parts observe extreme flood events.

2. Monsoon Variability:

The major schools of thoughts regarding the monsoon variability in Indian subcontinent could be summarized into two headings:

2.1. SST anomalies

Equatorial Indian Ocean has experienced recent warming in the past few decades that is linked closely with the rainfall variabilities especially monsoon in these areas. Rainfall events of more than 100 mm/day classified as the extremes are found to be positively related with the cool sea surface temperature anomalies in the south eastern equatorial Indian Ocean (Ajayamohan et.al.2007). The study shows that the recent trend of warming of the ocean could further escalate the scenarios in future potential extreme rainfall episodes. However, a decreasing trend of light to moderate rainfall events in the central India in monsoon seasons (June to September) have been shown by an analysis of rainfall events between 1950 and 2000 (Goswami et.al. 2006). A number of studies carried out on the variability of Indian summer monsoon also show the similar results of positive correlation with the cool sea surface temperature anomalies (Guan et .al. 2003; Ashok et. al. 2004; Vecchi and Harrison, 2004).

2.1.1 Formation of Indian Ocean dipole (IOD):

Ocean- atmospheric condition in the Indian Ocean determines the availability of moisture in the atmosphere above. Indian Ocean dipole (IOD) is one of the major coupled ocean atmosphere phenomenon in the Indian ocean that modulates the rainfall extremities in the rainfall over Indian subcontinent (Saji et.al. 1999).The cool SST anomalies appear first in the Lombok strait coasts of Indonesia in May – June that will be accompanied by south easterly wind anomalies of the tropical Indian ocean. In the subsequent months, the intensified cool SST begins to migrate towards the tropical Indian ocean and the warm SST just begins to form towards the west of the

Indian ocean. When SST is cool in the east and warm in the west, the equatorial winds change direction from westerlies to the easterlies that is during the positive IOD episodes. Because of the change in the direction of the winds, the thermocline level rises in the east and subsides in the west. South eastern Indian Ocean starts cooling in May/June along the coasts of Java/Sumatra and there by spreads equator ward and in July/August it starts spreading towards westward. Eventually the IOD strength peaks in September/October. The monsoon season's mean (June-September) SST anomalies show remarkable cooling in the south east Indian Ocean in many IOD years. The IOD hence has potential to influence the monsoon.

2.1.2 Modeling Outputs:

The IOD does not coincide with the El Nino and La Nina events especially for the year 1961, 1967 and 1994. However the IOD coincides with the El Nino and La Nina events for the year 1992 and 1997. The overall correlation coefficient between the two is just 0.35 which is a weak correlation in itself (Saji et. al. 1999). The maximum change in the zonal winds occurs towards the central equatorial regions where a correlation of more than 0.60 has been reported between the SST dipole mode and zonal wind anomalies (Saji et.al.1999).

2.2 Aerosol accumulation:

Aerosol has significant impact upon the distribution and the amount of rainfall modulating the entire hydrological cycle and this has major impact upon the monsoon water cycle that supports over 60% of the world's population. The Asian monsoon is especially very sensitive to the dust aerosol that is accumulated over the Tibetan highlands (Hansen et.al.2000, Jacobson, 2001; Ramanathan et.al.2001). Various researches have shown that the black carbon from the coal burning is the major cause of atmospheric circulation anomalies that finally resulted in long term drought over northern China and excessive rainfall over the southern China and India (Menon et.al.2002).

Nepal is a landlocked country situated between India and China. The Himalayan range extends from east to west in Nepal at the northern China border of the country. A study shows the heavy accumulation of Indian origin sulphate aerosol over the sky of Nepal. The study further indicates that this will affect the monsoon by offsetting the increasing trend in the rainfall that would otherwise have been caused by the increment of GHG only (Arndt et.al 1998). The Himalayan range serve as a good barrier against the free flow of pollutant across the border of China. The figure.1 below shows the accumulation of aerosols over Nepal and focusing especially the valley of Kathmandu.

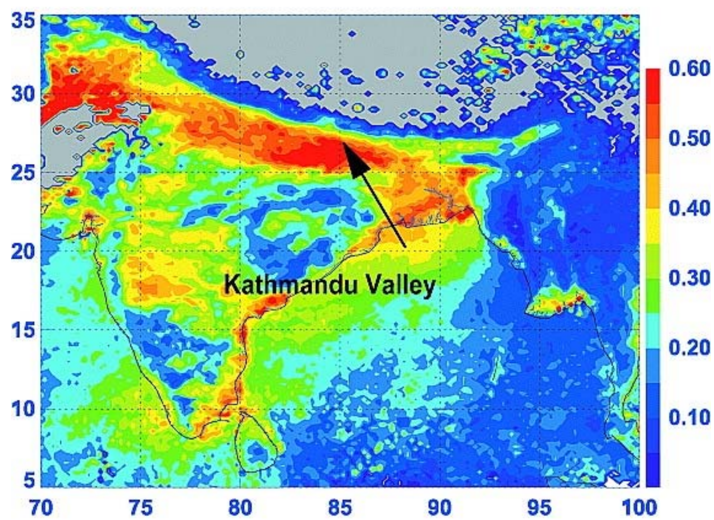


Fig.1 Regional distribution of natural and anthropogenic aerosol optical depth at 0.55 μm derived from Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Terra satellite (December 2002) (Source: Ramana et.al.2004).

The Table 1 below basically summarizes the status of land surfaces in this region before the onset of Indian summer monsoon. The differential heating over the region of Tibetan Plateau (TP) and the Region South (RS) during the months of April-May has been summarized in the Table 1. The figure also shows that the TP area mostly consists of high albedo land surface and the RS consists of darker surfaces, ocean and vegetated surfaces with low albedos. Because of the compensation between LW and SW at the TOA, the anomalous fluxes are much larger at the surface and in the interior of the atmosphere than at the TOA. Also noticeable is the difference in SW heating at TP (16.8 Wm^{-2}) and RS (14.3 Wm^{-2}); It may be because of the multiple reflection of the aerosol layers coupled with high albedo land surface. The remarkable difference between the two is sensible heating (SH) of the surfaces; TP (12.4 Wm^{-2}) and for RS (6.7 Wm^{-2}).On the whole, there is small heating over the surface at TP (0.2 Wm^{-2}) while there is net cooling of the surface by -3.7 Wm^{-2}.Hence this differential heating between the two surfaces creates a large scale differential heating anomalies in the south Asian region.

Table 1 Aerosol induced change in April–May mean heat budget of shortwave (SW), long wave (LW), sensible heat (SH) and latent heat (LH) of the atmosphere–land region over the TP(60–120 ^{o}ne, 25–40 ^{o}n) and the RS (60–120 ^{o}ne, 10–25 ^{o}n), at the top of the atmosphere (TOA), the atmospheric column (ATM), and at the surface (SFC).

	TP					RS				
	SW	LW	SH	LH	NET	SW	LW	SH	LH	NET
TOA	-4.5	2.9			-1.6	-5.5	4.5			-1.0
ATM	16.8	-5.8	-12.4	-0.4	-1.8	14.3	-1.6	-6.7	-3.3	2.7
SFC	-21.3	8.7	12.4	0.4	0.2	-19.8	6.1	6.7	3.3	-3.7

(Source:Lau et.al. 2006)

2.2.1 Atmospheric Brown Clouds (ABC):

Atmospheric brown clouds are the strata of air pollutant that is comprised of organic carbon, dust particles that absorb the solar radiation, many other anthropogenic aerosols as nitrates, sulfates that basically play major role in scattering solar radiation than absorbing.

These aerosols eventually heat up the atmosphere and finally reduce the solar radiation reaching the surface of the earth and this process of reducing the solar radiation reaching the surface of the earth is called Solar Dimming. These aerosol particles also act as nuclei that coagulate more cloud drops and hence reduce the solar radiation reaching the surface of the earth further by positive feedback mechanism.

2.2.2 Impact Mechanism:

The aerosol getting accumulated in the atmosphere block the solar radiation reaching the surface of the earth and hence causes solar dimming, because of this, the earth cools that finally leads to gradual spin-down of the tropical hydrologic cycle which in turn weakens the Asian monsoon (Ramnathan et.al.2005).The black carbon i.e., heat absorbing aerosols suspended in the atmosphere absorbs the shortwave radiation of the sun and heat up the atmosphere. The other non absorbing aerosols scatter the solar radiation though has little effect upon the heating up of the atmosphere. Hence aerosols on the whole have dimming effect. Many past studies conclude that the fluctuation of Asian summer monsoon is basically due to the reversal or meridional temperature gradient in the upper troposphere over the Tibetan Plateau during the months of May and early June (Yanai et.al.1992; Meehl 1994; Li and Yanai 1996; Wu and Zhang 1998).

The effect is more prominent in the northern hemisphere. The dimming effect reduces evaporation hence the rainfall and stabilizes the atmosphere. This stability of the atmosphere could be further linked with the impact upon the health and well living of the living things upon the earth. The aerosol though have short lifetime in the atmosphere, get accumulated in the northern hemisphere thus cooling the northern hemisphere more than the southern hemisphere. This differential temperature between the two hemispheres weakens the Hadley cell or ITCZ and hence reduces the rainfall over the northern Africa (Ramanathan et.al.2005). Figure 2 below shows the shrinking of the Hadley cell.

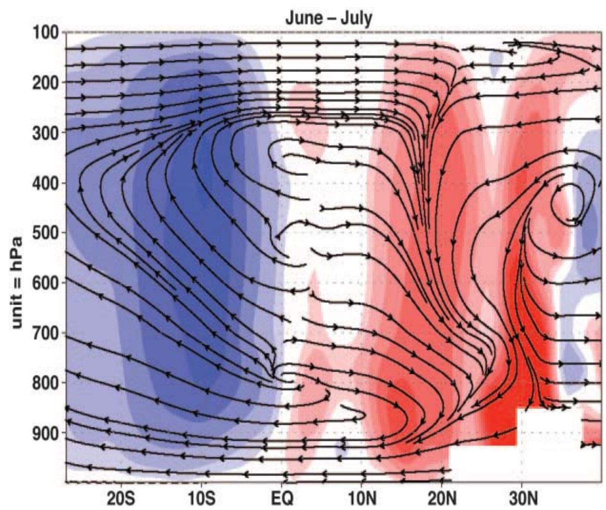


Fig. 2. Change in the meridional circulation due to the ABC from 1985 to 2000 for June and July. The fields have been averaged from 60°E to 100°E, essentially covering the entire Indian Ocean and the South Asian region. The changes were obtained by differencing the 1985–2000 averaged streamlines: ABC-1998-GHGs-SO4-1998. The red shade indicates a region with increased sinking motions, and the blue shade indicates regions with increased rising motions(Ramanathan et.al.2005).

2.2.3 Recent Modeling Outputs:

The comparative studies between the solar dimming effect in the South Asian regions is less understood because of the unavailability of adequate past data. Ten weather stations data taken from the various parts of India between 1960 and 2000 were studied. The observed and the simulated trends have been found to be in excellent agreement. The observed rate of dimming for the period was - 0.42 Wm^{-2} while the simulated rate of dimming was found to be - 0.37 Wm^{-2} (Ramanathan et.al. 2005).The Figure 3A and 3B shows the contribution of various factors in the surface heat balance over India. The figures show an excellent degree of match between the simulated and the observed data.

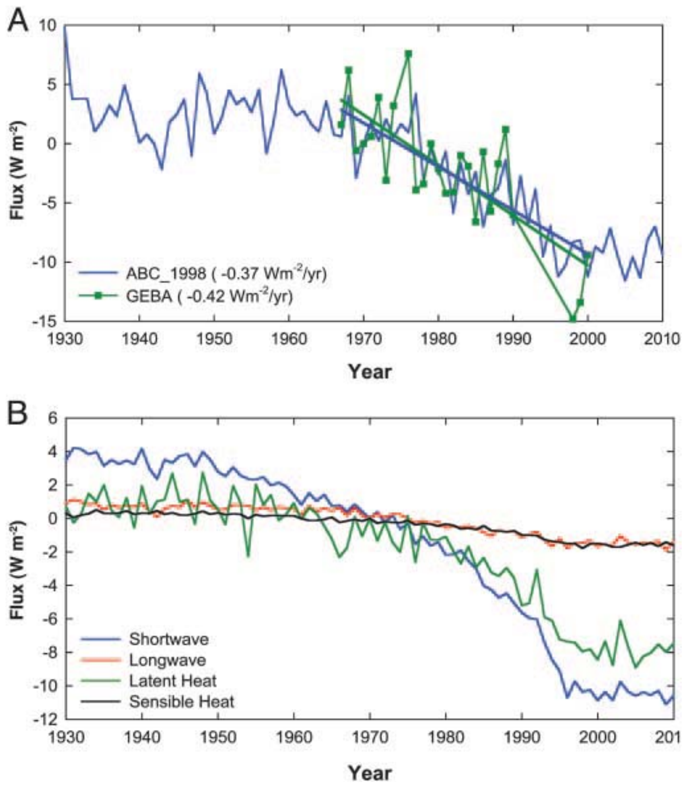


Fig. 3. Time series of surface heat budget terms. (*A*) Simulated (blue) and observed (green) annual mean solar fluxes for India at the surface. The fluxes are for average cloud conditions. The simulations are averaged over 5°N to 25°N and from 70°E to 90°E. The observed values are from 10 surface stations distributed between eastern, western, northern, and southern India. The trend in Global Energy Budget Archive is -0.42 Wm^{-2} per year (± 0.15; 95% confidence level), and the trend in the ABC-1998 run is -0.37 Wm^{-2}per year (± 0.12) (2SD of the trends from the five runs of the ensemble). (*B*) The simulated annual mean surface heat budget for the Indian Ocean from 10°S to 30°N and from 60°E to 100°E (Source: Ramanathan et.al.2005).

Ramanathan and his co-workers also found that there has been decrease in evaporation of the Indian Ocean especially in the Northern parts due to the decrease in incoming solar radiation over the northern Indian Ocean surface. In Fig 3B above, the decrease in SW (Short Wave) is accompanied by the decrease in LH(Latent Heat); almost about 70% reduction in

Incoming solar radiation has been balanced by the reduction in evaporation. The reduction in surface incoming solar radiation was maximum during the months of January to April and the reduction in evaporation peaked to -10% for the same period. During the months of June to July, there was continuous moderate decrease (-5%).

The maximum surface cooling was observed during the dry months of October to May. They have observed an excellent agreement between the simulated temperature trends and the observed temperature trends for the dry season. For the period of 70 years (1930-2000) ,the temperature warming trend for GHG-SO_4-1998 has been found to be 0.76 ^oK and for ABC-1998 it was found to be 0.37 ^oK. For the same duration of 70 years, the annual mean surface temperature warming trends for GHGs-1998, GHG-SO_4-1998 and ABC-1998 are respectively 0.8 ^oK, 0.67 ^oK and 0.45 ^oK respectively. The observed trend i.e., 0.44 ^oK is in excellent agreement with the ABC-1998 simulations. On the grounds of these evidences, they have concluded that ABC has strong cooling effect.

The recent variability in the observed and simulated rainfall in the Indian subcontinent has been presented below by Ramanathan et.al 2005. The figure clearly shows that the Observed rainfall trend agrees better with the ABC-1998 than with the GHG+SO_4-2050.

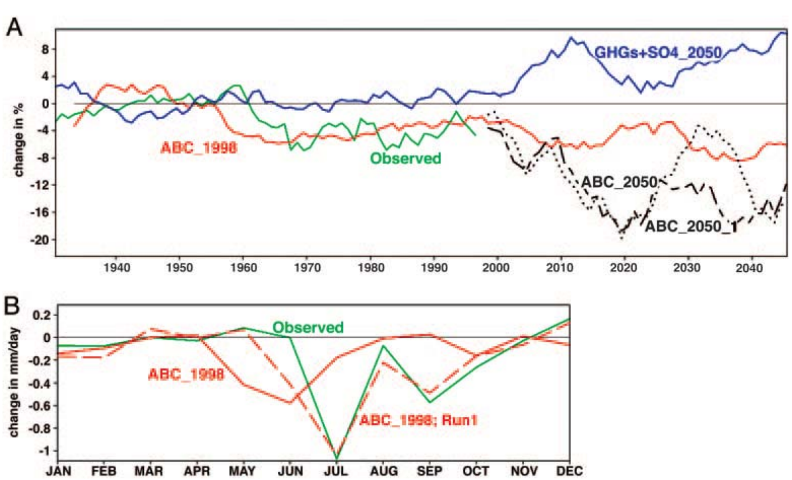


Fig. 4. Rainfall trends. (*A*) Time series of observed and simulated summer (June to September) rainfall for India from observations and PCM simulations. The results are the percent deviation of the rainfall from the 1930–1960 average. Observed rainfall data were obtained from ref. 28. The data are smoothed by an 11-year running mean averaging procedure. (*B*) Trend for 1930–2000 in monthly mean rainfall for India. The uncertainty of the model trend, as estimated from Five realizations, is ~0.4 mm/day from May to July and <0.2 mm/day in the other months. For the observed trend, the 95% confidence level is ± 0.9 mm/day (wet season) down to ± 0.2 mm/day (January–March) (Source:Ramanathan et.al.2005).

2.3 El Nino/ La Nina :

Many research studies in the past have tried to focus upon the impact of pacific SST anomalies with the rainfall variability in the Indian monsoon. However, the subject still remains a poorly understood phenomenon of the atmosphere.This section tries to discuss the monsoon variability in connection with the ENSO. El Nino associated with the continuous spring to summer heating anomalies over the Pacific and Indian ocean that regulate the low level westerlies monsoon flow intensity over the equatorial Africa and the northern Indian ocean which in turn brings moisture flux into Sahel in Africa and Indo-China(Nigam,1994). El Nino as been shown to be associated with the deficit summer monsoon rainfall over India and also with the interannual rainfall variability in the tropics and extratropics(Weare 1979;Rasmusson and Carpenter 1983; Ropelewski and Halpert 1987).

ENSO is most basically an oscillation between El Nino and La Nina in the eastern and central Pacific Ocean water mass.Warm phase - El Nino involves the abnormal warming of the ocean water mass and hence there is more convection of water vapor to the atomsphere above while the cold phase-La Nina involves the abnormal cooling of the ocean water that suppresses the convection above to the atmosphere.Droughts are more pronounced during the El Nino(ENSO index lesser than -1.0) and excess rainfall events are more pronounced during the

La Nina(ENSO index greater than 1.0).In conection with the monsoon in Indian subcontinient, positive ENSO indices are more favorable to the monsoon (Gadgil et.al.2007).

Figure 6 below shows the ENSO indices against the Indian Summer Monsoon Rainfall which depicts the fact that the subcontinient observes no drought when the ENSO index is greater than 0.6 and the subcontinient observes no excess monsoon rainfall when the index is less than -0.8.

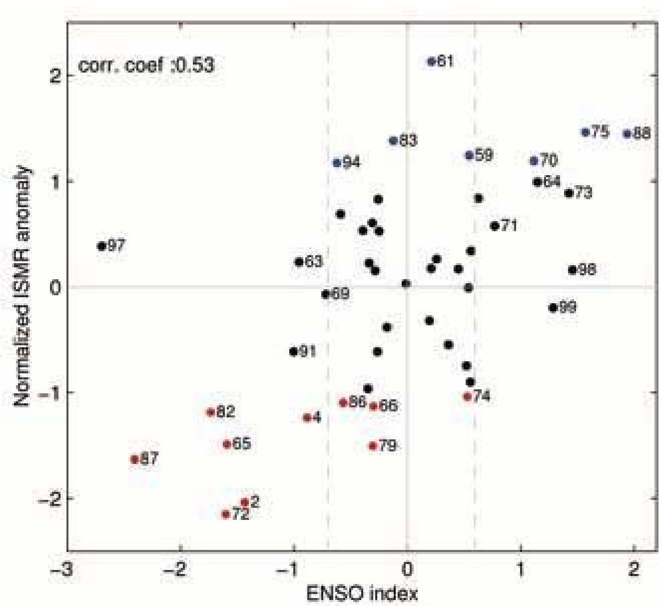


Figure 5. Normalized ISMR anomaly versus ENSO index for all the June–September seasons between 1958 and 2004. Red represents droughts, i.e. seasons with ISMR deficit greater than 1 standard deviation in magnitude; whereas blue represents excess monsoon seasons, i.e. with ISMR anomaly greater than 1 standard deviation.(Source: Gadgil et.al.2007)

How important is it to consider the phenomenon going on in the Pacific to predict and study the variability trend in Indian Summer Monsoon ? A study carried out by Ihara et.al 2007 describes the mechanism why there occurs no deficit ISMR despite the occurrence of EL Nino event. ISMR observes no deficit also even when the El Nino occurs, when the eastern Pacific starts warming from northern hemisphere winter and remains as that is throughout the reference summer.The El Nino induced deficit of ISMR occurs only when the eastern equatorial Pacific starts warming rapidly only about a season before the reference summer maintaining cool temperatures over the western central Pacific during the summer monsoon season.

On the contrary, Terray (1995) opines that ENSO phenomenon could not be accounted for most variability of the Indian summer monsoon. With a few more researches carried out by Shukla and Misra (1977), Weare (1979),Shukla (1987); he concludes that the correlation between monthly SST over Arabian sea and rainfall over India to be weak positive or in other words, heavy (deficient) rainfall to match with the negative(positive) SST; which in its own contradict with the research findings of Weare (1979) who concludes warmer Arabian sea temperature to be associated with the decreased Indian Summer Monsoon.

3. Monsoon in Nepal :

Rainfall variability in Nepal still remains a subject of unexplored mystery to a huge extent. A few studies have been carried out so far in case of the Monsoon rainfall in this Himalayan belt though a considerable studies have been done in Indian Summer monsoon. The rainfall analysis of the Indian Summer Monsoon fails to address some of the variability of monsoon especially, the spatial among the different landscapes. Ichiyanagi (2007) and his co-workers have carried out the analysis of the rainfall data from 1987 to 1996 collected from various rain gauge stations. The maximum yearly precipitation was found to increase with the altitude below 2000m but decreased for elevations of 2000-3500m. In case of the western belt of Nepal, there was negative correlation between elevation and precipitation.

Ichiyanagi(2007) analyzed the annual precipitation on a grid size 0.25^{o} and showed that the precipitation in Central Nepal was more than 3000mm/year and less than 1000mm/year in the northwestern mountains. On the whole as the monsoon starts from the eastern side, and hence the eastern sides receives the maximum amount of precipitation and the western sides receive the least. However , the long term analysis of the data shows no trend of precipitation in Nepal.

Their modeling results shows that the moist air from Arabian Sea causes more precipitation over western Nepal where as the cold dry air blowing from the Tibetan highlands decreases the precipitation over eastern Nepal.

The onset of monsoon in Nepal has been linked with the depression of monsoon in the Bay of Bengal (Barros,2000). Efforts have been made to correlate the pattern of rainfall in Nepal with the landscape type. Nepal , with the steeply varying topographic barriers, observes varying amount of rainfall even within a short distance. Hence the sampling of the rainfall data should take into account the position and the minimum number of stations required for the place. There is only one station above 4000m and 10 stations between 2500 and 4000 m altitudes (Kansakar et.al.2004). Kansakar(2004) divides rainfall into two basic zones as: maximum annual precipitation linearly depending with the altitude for altitudes less than 2000m(average annual rainfall varying between 3000mm and 5000mm) and for altitudes above 2000m (average annual rainfall varying in less than 1000mm/year). On the whole, the average annual rainfall in Nepal is between 1000 and 2000 mm/year. The annual rainfall amount exceeded 2000mm/year towards the eastern Nepal. Further, Pokhara is the place that receives the highest amount of rainfall in the country.

Shrestha et.al. 2000 studied the relationship between Nepalese Monsoon and ENSO. He claims an excellent agreement between the two phenomena. The drought of 1992 in Nepal has been correlated with the ElNino of 1992-1993 and the eruption of mount Pinatubo in 1992 which cooled the Tibetan plateau significantly decreasing the monsoon rainfall in Nepal. The ISMR has been shown to be decreasing after 1960 by Kothyari and Singh(1996) as said earlier and the rainfall lacks any trend when analyzed for quite a long duration in ISMR. The year 1992 is the driest period of Nepal and has the decreasing trend since 1990.Roughly 2-5 year oscillatory characteristics have been observed in many of the regions of Nepal (Shrestha 2000).

Case Study:

Three closest representative weather station's data of rainfall were collected from Marshyangdi Catchment of west Nepal. The rainfall data were averaged to represent the average rainfall in the area. The data available in most cases since 1970 were used for the analysis. The upperparts of the Marsyangdi catchments lie in the Mahabharata Range (1500-2700m) and the lower part of the catchments lies in Churia range (700-1500m). The total area of Marsyangdi catchment is 4600 km^2 extending to a length of 153km with the average gradient of 0.039 (Shrestha , 1999).In Nepal, 70-90% of the total annual rainfall occurs in summer monsoon period (Nayava, 1980).The average monthly rainfall and annual rainfall of the sub catchment are173.6mm and 2083.8mm respectively; for comparison, the national annual average rainfall is 1550mm. The maximum i.e. more than 80% rainfall occurs during four months- June, July, August, and September i.e., Monsoon period of Nepal in the Marsyangdi catchment.

The Table 2. below shows the amount of rainfall in the respective years for the Marshyangdi subcatchment.

Table 2. Annual rainfall in the Marshyangdi subcatchment.

Year	Total	3yr Mm	11yr Mm
1970 yr	2489.1		
1971 yr	2705.4	2576.356	
1972 yr	2534.567	2361.356	
1973 yr	1844.1	2070.644	
1974 yr	1833.267	2076.689	
1975 yr	2552.7	2122.722	2136.073
1976 yr	1982.2	2085.089	2103.152
1977 yr	1720.367	2095.6	1998.17
1978 yr	2584.233	2009.322	1965.918
1979 yr	1723.367	1945.033	2033.245
1980 yr	1527.5	1792.611	2052.712
1981 yr	2126.967	1735.022	1986.191
1982 yr	1550.6	1952.456	2037.864
1983 yr	2179.8	2105.033	2022.758
1984 yr	2584.7	2270.633	1949.109
1985 yr	2047.4	2151.022	2026.424

1986 yr	1820.967	2139.656	2027.697
1987 yr	2550.6	1975.256	1945.791
1988 yr	1554.2	1959.633	2029.486
1989 yr	1774.1	1967.378	1994.465
1990 yr	2573.833	1963.144	1937.274
1991 yr	1541.5	1780.444	2007.195
1992 yr	1226	1746.25	1984.039
1993 yr	2471.25	1830.606	1881.788
1994 yr	1794.567	2073.806	1983.606
1995 yr	1955.6	2188.9	1981.112
1996 yr	2816.533	2112.794	1898.997
1997 yr	1566.25	1936.206	2004.473
1998 yr	1425.833	1888.761	2062.052
1999 yr	2674.2	1948.9	2011.765
2000 yr	1746.667	2030.478	2036.614
2001 yr	1670.567	2039.656	1979.005
2002 yr	2701.733	2077.222	
2003 yr	1859.367	2159.733	
2004 yr	1918.1	1948.456	
2005 yr	2067.9	1769.3	
2006 yr	1321.9		

The figures below show the rainfall distribution in various monsoon months and the trend of rainfall variability in the Marshyangdi subcatchment.

Fig. 6. Monthly Rainfall for June between 1970 and 2006 in the Marshyangdi subcatchment.

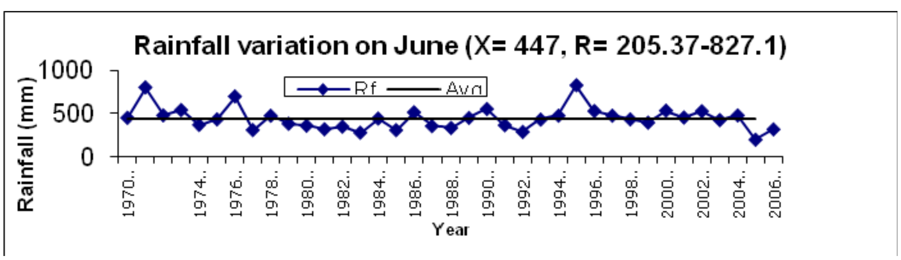


Fig. 7. Monthly Rainfall for July between 1970 and 2006 in the Marshyangdi subcatchment.

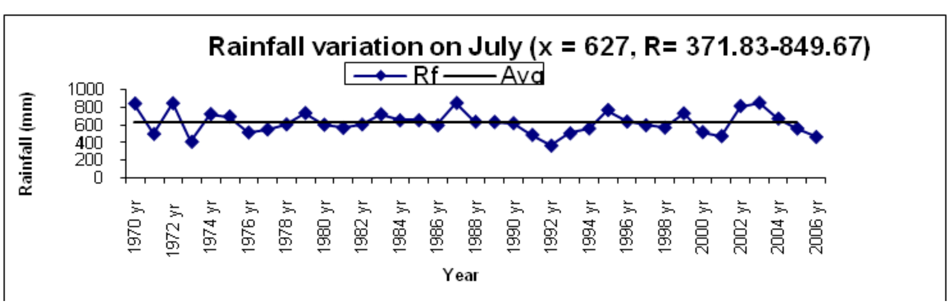


Fig. 8. Monthly Rainfall for August between 1970 and 2006 in the Marshyangdi subcatchment.

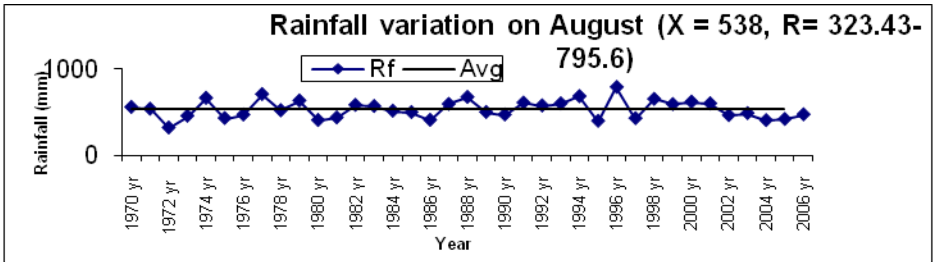


Fig.9 Monthly Rainfall for Sept. between 1970 and 2006 in the Marshyangdi subcatchment.

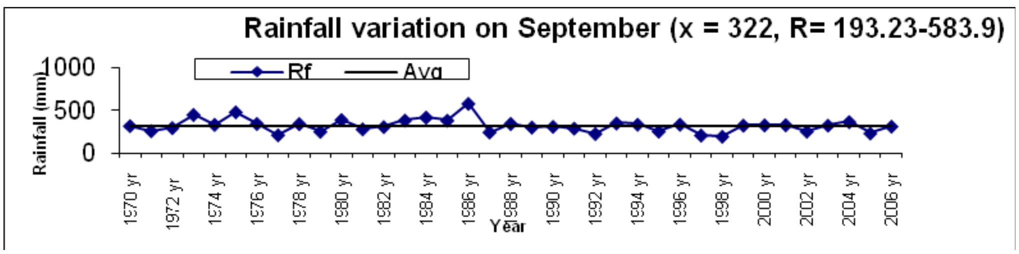


Fig.10 Moving average Rainfall for the Marsyangdi catchment for July between 1970 and 2006

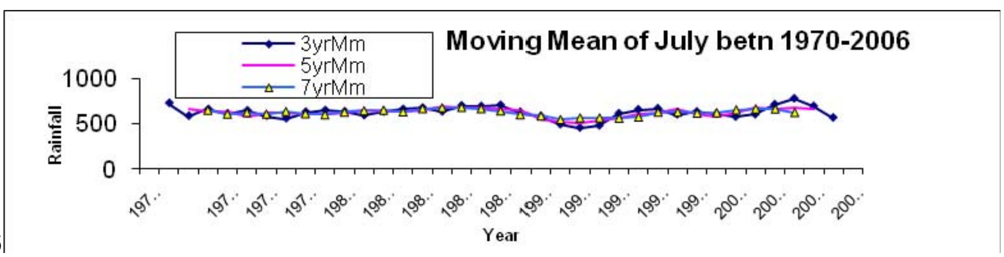


Fig.11 Annual Rainfall in the Marshyangdi sub catchment between 1970 and 2006

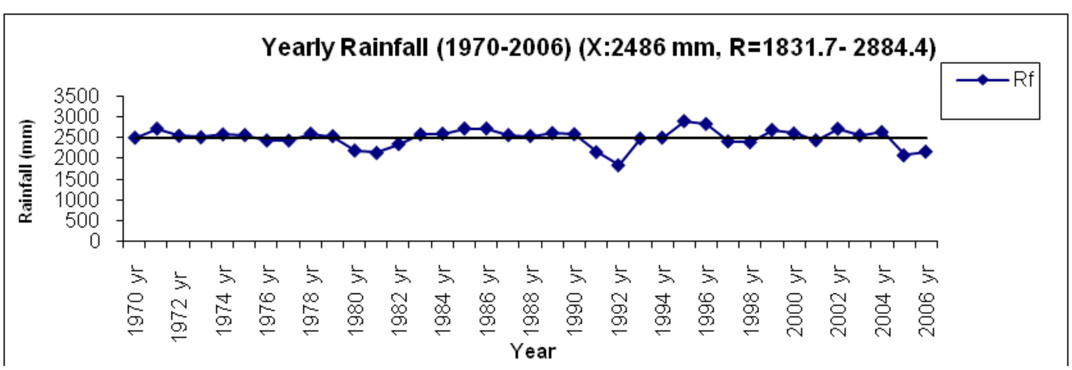


Fig. 12. Annual moving Mean for the Marsyangdi subcatchment between 1970 and 2006

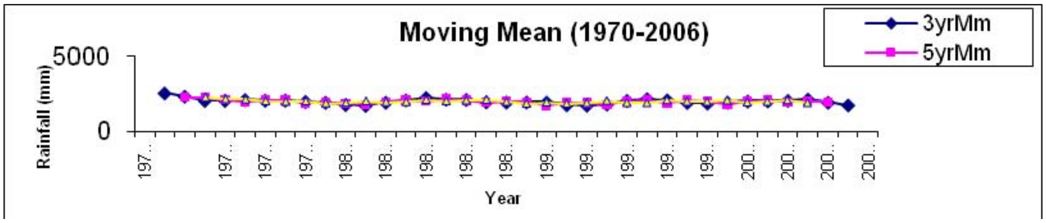


Fig. 13. Monthly Distribution of Rainfall in the year 1992

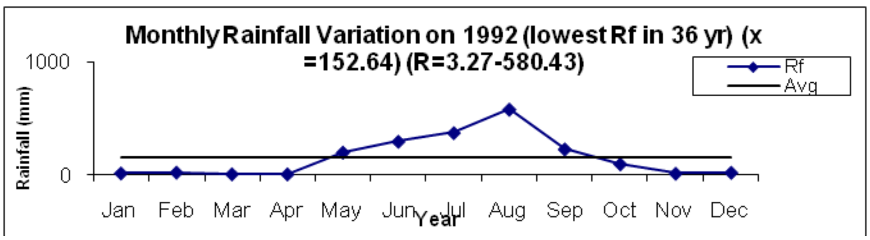


Fig.14 Monthly distribution of rainfall in the year 1995

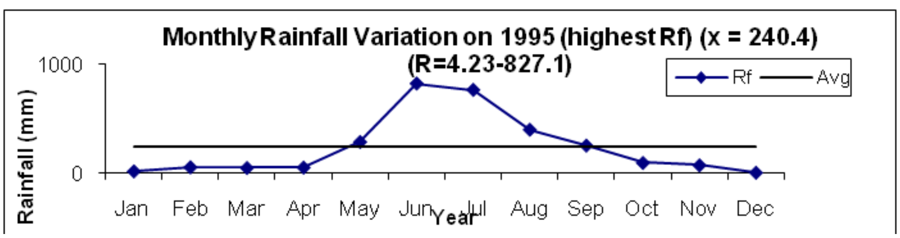
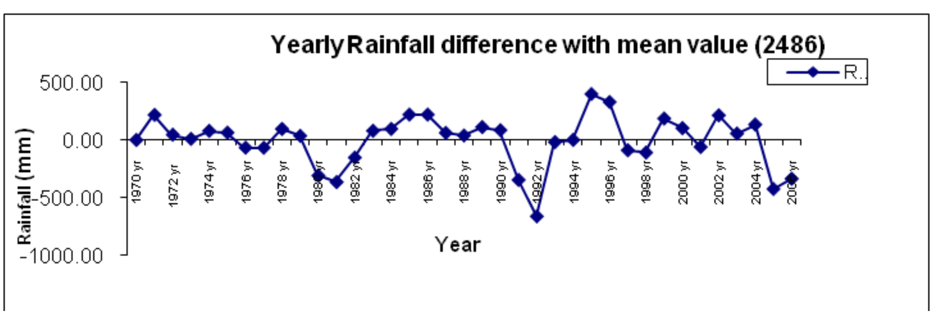


Fig. 15 Rainfall anomalies between 1970 and 2006 for the Marshyangdi subcatchment



4. Discussion:

The correlation coefficient between the eastern pole of IOD and the number of extreme events is -0.69 and more extreme rainfall events (more than 150mm/day within a grid box of $3^{o}X3^{0}$) is -0.61. The year 1994 was the strongest IOD years in summer in the past two decades. For the recent IOD year 2006 had quite a high number of extreme events and for this the correlation coefficient is -0.74 (Ajaymohan et.al.2007). Hence the extreme rainfall events over the central India were modulated by the cool SST anomalies in the south equatorial Indian Ocean during 1982-2003.There are evidences of occurrences of such cool SST anomalies more frequently over the south equatorial Indian Ocean with the warming of the Indian Ocean.

The IOD in the region is claimed to be independent of the ENSO and accounts for 12% of the SST variability in the Indian Ocean and has been found to be responsible to cause severe rainfall in eastern Africa and droughts in Indonesia(Saji et.al.1999).Hence IOD and SST anomalies have considerable impact upon the monsoon rainfall. However the heating anomalies over the Tropical Indian Ocean during El Nino year and its impact over the Asian circulation is still not understood fully.

As the atmosphere stabilizes at the low level two connected things happen- increase in boundary layer humidity and decrease in the upward transport of the moisture. Hence the evaporation decreases and the decrease in latent heat flux from the surface balances the dimming of the surface. Hence, the dimming coupled with the corresponding increase in atmospheric solar heating eventually decreases the evaporation. Fig 2.a (Ramanathan et.al 1999) shows that the ABC has strong cooling effect on the surface i.e., negative surface forcing.

Ramanathan and his coworkers observed that the average monsoon rainfall decreased after 1950 in both observation and the ABC-1998 simulations. They also observed for GHG-

SO_4-1998 but that showed no trend and just a slight positive trend after 2000.They conclude that there is decrement in monsoon rainfall recently and that is due to ABC. Figure 3 A (Ramanathan et.al.2005) shows that the Observed trend of rainfall variability matches to a good extent with the trend of ABC-1998 than with the GHG+SO_4. Hence does it seem that we are neglecting the importance of ABC in future rainfall and temperature prediction.

The simulation record shows that there is reduction of -5%(-3%) between 1930 and 2000 (ABC-1998) in the Indian rainfall amount. Interdecadal variability of - 2-3 % has been recorded by both observation and model simulations analysis.Their simulation study further concludes that ; remaining the GHG-SO_4-1998 value constant, there will be 15-20% decrease in the average precipitation if ABC continues to increase at the present rate in 2050. The observed dimming trend for the period between 1960 and 2000 is -0.42 Wm^{-2} and the simulated trend is 0.37 Wm^{-2} and the total dimming caused by ABC from 1930 to 2000 is 8%. The impact of this cooling by ABC will have global impact as well. The ABC contributed cooling of about ±0.04^{o}K (±0.02) and the global average rainfall decrease of ±1%(±0.5%) during the period between 1950 and 2000. If we count upon what Ramanathan et.al.2005 have found, are we unnecessarily overemphasizing the importance of GHG and GHG+SO_4 in estimating the trend of temperature rise ! All these factors acting on together, the summer monsoon rainfall has been shown to decrease by - 5% in the end in 2000.

Figure 1 also shows reverse circulation with the rising branch at 15^{o}S and sinking branch at 5^{o}N. Nepal lies between 27^{o}N and 31.5 ^{o}N latitide. It seems that the sinking branch of the cell will have significant impact upon the general circulation pattern. What would be the effect of this in Nepal ! Ramanathan et.al.1999 discusses that this increment in the rising motions south of equator and the subsidence in the Northern parts may eventually shift the monsoon circulation towards the south. Consequently, Nepal would observe decrement in the amount of monsoon rainfall than the usual. The detail mechanism is yet to be understood !

Gadgil et. al. 2007 shows a linkage of 1982, 1987 droughts with the El Ninos and 1988 excess rainfall with the La Nina. However, in case of ISMR, the subcontinient has observed no droughts between 1988 and 2002 and also the subcontinient observed above long term average raifall during the occurrence of the strongest El Nino event in the year 1997.Several other studies carried out in the past have discovered linkage between ISMR and ENSO(Mooley and Parthasarthy,1983, Barnett et.al.1991).However, the Indian subcontinent observed deficit rainfall or drought in the year 2002 and the El Nino was much weaker than in the year 1997. Hence the relationship between ENSO and the monsoon remains a subject of poorly understood in case of ISMR.

Kansakar (2004) observed sudden decrease in the rainfall amount during several years as: 1990 -1991 ; 1993-1994 and a sudden increase in rainfall in the year 1992 and 1995. There was high intraseasonal variation during 1987-1990 and 1995-1996 and it was low during 1991-1994. However he found no any long term trend in the rainfall variability. In general he observed 100mm decrement in precipitation for every 500 m elevation.

The annual mean reduction of solar flux in the Kathmandu valley is 25 Wm^{-2} and the aerosol heating has been found to be $1^{o}K$ per day within the first few kilometers (Ramana et.al. 2004). Hence there is considerable reduction in solar radiation reaching the surface in Kathmandu/Nepal. Fig 4 shows the accumulation of aerosols over the December sky of Nepal. The thick accumulation of aerosols over the sky could be potentially harmful in modifying the circulation pattern over the south Asian region.

While considering the Marshyangdi subcatchment of west Nepal, we could derive to the following findings:

1. Years of deficit rainfall: In 37 years of observation, 13 years have received less than annual

average rainfall in the Marsyangdi sub catchment. The year and the amount of deficit rainfall as percentage of the average annual rainfall have been indicated in the brackets respectively, 1991 (14%) 1992 (26%), 2005 (17%) and 2006 (13%). As per the ONI value of NOAA, El Nino indices for the years are as indicated within the brackets respectively, 1991 & 1992 (2.8), 2005 (0.9) and 2006 (1.2).The guideline claims that the index values more than 0.5 are significant , then is it affecting the Indian Summer Monsoon distribution in Nepal ?

2. Years of Excess rainfall: The years of more than 10% rainfall over as compared to the annual average rainfall , percentage and the corresponding ONI values for La Nina have been indicted in the brackets respectively, 1995 (16%,La Nina: - 0.8), 1996 (13%, La Nina: -0.8). From 1983 to 1990 there is above average rainfall and for the year 1984-85 the ONI value if - 1.1 and between 1988-89 the ONI value is - 2.0. The guidelines claim that the La Nina values more than -0.5 is significant, then is this also affecting the excess rainfall in Nepal ?

As shown in Table 2, the year 1992 was the rainfall deficit year and the year 1996 was the year with excess amount of rainfall in Nepal. Hence a huge loss of property occurred in Nepal in the year. Marshyangdi subcatchment also observed the least amount of rainfall in the year 1992 and the highest amount in the year 1996 as per the national average (MOPE,2004).

Figure 6, 7, 8 and 9 corresponding to June, July, August and September respectively show the trend of rainfall in the monsoon months in Nepal. The maximum monthly rainfall in 37 years of average is for the month of July i.e. 627 mm. The fluctuation in rainfall amount is maximum for June , i.e., between 205 and 827 mm.

Figure 10 shows the moving average plot for the monsoon month of July between 1970 and 2006. The graph shows no clear trend and same was the case with the other months of the monsoon. Hence there lacks a clear trend of monsoon variability in Marshyangdi subcatchment.

Figure 11 shows the annual rainfall in the Marshyangdi subcatchment. The average annual rainfall for the catchment is 2486 mm and the range of fluctuation is between 1831 and 2884 mm. The years of deficit rainfall are shown by the troughs projecting below the average line.The year 1992,1981 and 2005 clearly show the years of deficit rainfall .

Figure 12 shows the annual moving mean plot. This figure also does not show any trend in the fluctuation of monsoon in the subcatchment.Hence ther lacks clear annual trend.

Figure 13 shows the distribution of rainfall for the driest year n 37 year's of observation i.e., for the year 1992. The average monthly rainfall for the year is 152mm. January, March, April, November almost received no rainfall. Hence here is almost significant contribution from all the months of the year 1992 to make it the driest year.

Figure 14 shows the rainfall distribution throughout a year in 1995 that received the highest amount of rainfall in 37 year's of observation. The contribution from all the months' excepting January and December is higher than the usual average precipitation in the area.

Figure 15 shows the rainfall anomalies between the period 1970 and 2006 in the Marshyangdi catchment. The crests for the year 1992, 2005 and 1981 are more pronounced. However in many of the years, the rainfall is above the average rainfall for the observation period.

The different simulations and different research designs have given us with some of questions in the research activities carried out so far. To summarize we could conclude the following points as the major drawbacks of the researches :

- The conclusion derived by Ramanathan et.al.2005 would have been more convincing if adequate temperature data over the surface of Indian Ocean were available and taken into consideration.

- Impact of increase of temperature over the land surface to the evaporation of oceanic water over the surface of the Indian ocean has not been considered by Ramanathan et.al. 2005.
- Lack of adequate use of data over the oceanic surface to study the oscillation.
- Overlooking the importance of the number of weather stations and their positions with respect to the landscape while collecting data.
- As said by Barros et. al. 2000, our understanding of the monoon in this region could be related to the inavailability of operational weather radars or radiosonde networks.

5. Conclusion

The aerosols modify the heating of the atmosphere and create a gradient that may eventually alter the monsoon distribution in the south Asian regions. The importance of IOD, and Aerosol distribution is more significant with respect to the monsoon rainfall in Nepal.recent computer simulations show upto -3-5% decrement in the monsoon rainfall amount in the Indian and the rainfall variability trend fits to a good extent with the impact of ABC upon the atmosphere over the Indian subcontiient. However no long term trend in the rainfall variability in Indian subcontinent and hence in Nepal could be found .The El Nino and the La Nina years match with the deficit and excess rainfall years in the Marsyangdi Subcatchment. IOD coincides with the El Nino and La Nina years of 1992 and 1997.Hence there is cumulative effect of various fcators upn the rainfall distribution in Nepal.

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