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EQUINOO: The entity and validity of this oscillation to Indian monsoon

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Abstract: *The recently noticed dipolar nature of convection on either side of Indian Ocean called EQUINOO is subjected to more observations and analysis to understand its effect on ISMR between the period from 1950-2005. The positive phase of EQUINOO with increased cloud on the western side of Indian Ocean accompanied with dominating easterly wind anomaly found to affect ISMR strength positively and the reverse conditions leads to negative results. The floods and droughts go well with EQUINOO incidents but normal monsoon do not display equal uniformity with EQUINOO affect. It is not binding that the positive neither negative phase of this phenomena should show expected results when it co-occur with similar big oceanic or atmospheric oscillations. The ambiguity about the origin of EQUINOO if removed throwing more light into IOD EQUINOO connection and proper parameterization of the issue may perhaps wide open the arena for inclusion of EQUINOO for predictive purposes, model studies and disaster management etc. The work analyze the scenario of ISMR, EQUINOO and ENSO from 1950-2005 and try to understand how it complement and contradict each other and the conditions leading to it. After 1995 the El Nino effect on ISMR has gradually decreased and the paper studies in detail the effect of ENSO on ISMR for long 55 years. The SST, zonal wind and OLR anomalies of individual EQUINOO years are cross checked and their composites are also drawn. The paper also checks the validity of the index used for measuring EQUINOO strength. It emphasizes the necessity of developing an OLR index for better assessment of this oscillation. Zonal wind observation on EQUINOO region during the pre-monsoon month can leave good clue about the performance of forthcoming monsoon season claims the work.*

Key words: *monsoon, ENSO, index, SST, Equatorial Indian Ocean Oscillation.*

I. Introduction

Precipitation is a complicated issue involving boundary layer processes, planetary scale circulations, microphysics of cloud structure and complex convective process of Cumulus cloud. The rain in any tropical country is mainly associated with the movement of inter tropical convergence zone, a region in the boundary layer where intense convergence occur due to increased cyclonic rotational tendency. A portion of tropical convergence zone extending from India to tropical Pacific well known as continental tropical convergence zone (TCZ) and its oscillation above India is mainly answerable for the onset and strength of summer monsoon rainfall of India (Yukari N. et al 2011)

Similarly Tropical Biennial Oscillation can bring forth a situation in which rainfall swings in between the widest extremes on every couple of years among Indo-Pacific region largely due to land ocean atmospheric interaction. The effect of TBO on Indian rainfall is found to be increasing in the recent years of increased global warming may be as a resultant of ever increasing ENSO-Walker circulation dependency (…who.) The Madden Julian oscillation (MJO) is another eastward moving convective pattern at an interval of 30-60 days from the Indian Ocean to Pacific give convection, precipitation and thunderstorm activity respectively as the troughs and ridges of the wave pass by (Collin Jones 2008). Five to ten days prior to the strengthening of MJO precipitation in South Asia Indian Ocean display a noticeable hike in temperature and the domination of westerly wind component aloft. The outbreak of monsoon in July is often related to the passage of MJO. Madden Julian Oscillation index (Hendon 2004) is demarked with increased convection in Indian Ocean and a corresponding decrease in Western Pacific and is connected with the positive polarity of Arctic Oscillation (Lin et al 2009,2011).

Similarly Equatorial Indian Ocean Oscillation can be defined as a phenomenon that display a dipole formation in terms of cumulus convection accompanied with zonal wind and rainfall anomaly in equatorial Indian Ocean mainly confined to Arabian Sea and Bay of Bengal. The ability of this oscillation to explain extreme events of Indian monsoons are widely approved, but when we think in terms of normal years it doesn't correlate according to the expectation. EQUINOO is found to be independent of ENSO influence but can be treated as an atmospheric outcome of Indian Ocean Dipole (Webster 1999). Gadgil who first noticed the event donated an index for measuring its intensity based on surface zonal wind component prevailing in the equatorial Indian Ocean (60◦–90◦E, 2.5◦S–2.5◦N) at 925 H pa Even today when the relationship between IOD and ISMR remains debatable its atmospheric component going well with Indian monsoon is really a paradox. The opulence of cloud formation over Arabian Sea with a linear decrease in the right hand side of equatorial Indian Ocean with sustain easterly component of surface wind is the most striking characteristic of the positive phase of EQUINOO. In this condition the clouds get naturally shifted towards the west. During summer monsoon the cross equatorial flow of SW trade wind as well as low level jet streams carries of this excess cloud over southern as well as central India complementing Indian summer monsoon. Suppose the excess cloud formation was on the eastern side of equatorial Indian Ocean westerly would have dominate carrying off the excess cloud further to east. When the SW wind co occur the cloud get drifted off to Pacific region pushing India to drought condition during summer monsoon season Even though many of the models failed to simulate EQUINOO effect, in reality swinging of this convective belt in either sides of Peninsular India in Arabian Sea and Bay of Bengal can most effectively influence and predict the course of monsoon of the country as evident from 100 years of analysis. Things are more skeptical when we understand that the correlation of IOD with Indian summer rainfall is far inferior to that of EQUINOO correlation.

EQUINOO being considered as an atmospheric component of IOD (Gadgil 2003, 2004) has to be validated checking with the time of occurrence of the event. Moreover the ability of IOD to focus active convection confined to a particular EQUINOO region has to be cross checked because normal case IOD can give intense rain in Indonesia and some parts of Africa than in India. An absolute one to one relation between ISMR and different phases of Indian Ocean Dipole cannot be derived from the observation of last fifty five years rainfall data, where as ENSO and EQUINOO individually or together never fail to explain an extreme ISMR event of these years. This also keeps the role of IOD in the generation of EQUINOO under suspicion. The lagged dipolar nature of SST and convection makes the scene analogous but ambiguity sustains when checked with the polarity of indices. The proximity of EQUINOO with India and its capacity to influence the strength of our monsoon emphasize the urgency to enquire the real origin of this entity. If the origin of EQUINOO is only related to IOD the next task is to know how the flux during IOD is getting diverged beneficial to different places at different occasions. Since ENSO is also a major oscillation that has less amplitude with Indian Ocean its effect on ISMR (has to be elucidated while studying EQUINOO.

It is generally believed that the grant total of the precipitation over the earth is not varying very much, only what matters is the spatial distribution of precipitation. Over the Indo Pacific tropical belt it is often found difficult to assume the region of convergence and convective zone throughout the year. The flow charts of 850 and 200 H pa prepared during TOGA experiment revealed that ENSO affected monsoon regions of South East Asia and Northern Australia are exposed to dry conditions and wet monsoon when low level anti cyclonic as well as cyclonic anomalies coincide. The paper also points out that such prominent precipitation anomaly leads to the western half of dipolar heating and east west shifting mainly around the ascending branch of Walker circulation. Associated cloud condensation leaves out additional latent heat flux improving the absorption of short wave radiations helping to heat up Indian Ocean more than normal giving a remote suppressive effect to South Asian monsoon in turn. The SST anomalies observed in Indian Ocean respond well with observational result (**Lau and Nath 2000**). In many years when the prevailing conditions over India favors drought in the beginning of the monsoon season the migration of cloud from Bay of Bengal westwards replenish the season with adequate or above normal monsoon. This shifting in the convective belt associated with pressure change has to be investigated to get more insight towards process like EQUINOO. Such observation can be more prospective as the predictive aspect of it remains large because it can be noticed weeks ahead, and in this respect EQUINOO can be used as a precursor to the intensity of rain much ahead of its occurrence (Gadgil et al 2003).

II. Result and Discussion

Out of 55 years data a hand full of years agree to the concept that EQUINOO can be considered as the atmospheric component of IOD, but another large set of years do not agree with this generalization. Moreover the correlation of EQUINOO with ISMR is far ahead of IOD. While coming to ENSO, the ENSO index shows even more positive correlation with ISMR than EQUINOO. So no doubt if both the events are on the same phase it will result in abundant ISMR and if they are together in the opposite phase it will end up in a drought in ISMR. In other words it is more viable to explain the floods and droughts of India based on their combined index (Gadgil et al 2004). IOD doesn’t come to this picture very much as regards India as it cannot pull the rain to either side effectively. Another noticeable problem regarding various oscillation index are based on different variables even though all are set to reach at one and the same ambition of predicting the precipitation more effectively. The possibility of developing a unique index for all type oscillation based on OLR measurement from satellite pictures pertaining to respective local region can be an effective technique to obtain precision in precipitation measurement. As long as convection and the pressure difference are the two main criteria on which precipitation directly depends on deriving a common index based on OLR for all major oscillation can relocate the problem to a great extent. Especially ENSO effect has to be studied in terms of OLR distribution as it can influence summer monsoon extensively. Not only that the index for ENSO, EQUINOO, IOD all based on OLR can be developed giving regional wise importance, what I mean the index is not just common for all places as the amplitude of effectiveness is varying randomly with seasons and proximity for each country.

Tropics are always exposed to maximum variability in cloud coverage and OLR value is inversely correlated to precipitation around the globe (Xie and Philip 1996). Using the regression coefficient of precipitation anomaly related to OLR a more acceptable linear function for local precipitation and OLR of that particular region can be obtained. Based on this technique monthly precipitation over the globe can be estimated. Calculating mean annual cycle of precipitation from OLR anomaly field using coefficient value appropriate for mean annual cycle of precipitation for a local region is calculated. Summing up all such local regional calculation country wise precipitation can be successfully derived from OLR anomaly values. This is called OLR based precipitation index (OPI) By the help of OPI index it is possible to make stable high quality assessment of annual variability of precipitation and ENSO effect on precipitation particular location especially that over ocean (Xie and Phillip 1996). This can be exploited as an efficient method for studying EQUINOO based on OLR measurements of Indian Ocean. The impact of El Nino on ISMR is also correlated to the equatorial Pacific Ocean OLR/cloud anomalies.

Table (1) agrees to the common concept that El Nino leads to droughts and La Nina contributes excess rain to India. But 1969, 1976, 1991, 1992 and 1997 were exceptions especially during 1997 the biggest El Nino of the century failed to give any impact on Indian monsoon. But obviously none of the El Nino conditions led to flood in India. Some of the Indian droughts were not associated with El Nino too. Similarly La Nina situations led to floods in general but all Indian floods were not the outcome of La Nina.

When the convection, SST and wind pattern of 1950-2005 is analyzed EQWIN values above +1 STD is taken as positive EQUINOO and that below -1 as negative EQUINOO. By the above criteria the strong EQUINOO years are 1952, 1953, 1956, 1961, 1962, 1963, 1994, 1997, 1999 and 2007and weak years are 1957, 1969, 1971, 1979, 1981, 1984, 1985, 1986, 1992, 1996, 2002 and 2005. Positive EQUINOO composite picture (Fig: 4) obviously show additional clouding in the west side with suppression in the east, low level jet stream and SW trade wind dominating in the Indian Ocean. SST over the west is slightly higher than the east. Negative EQUINOO composite reflects (Fig: 5) the opposite scene with extra clouding in the east at expense of the westerly wind. India experiencing substantially less rain, strong easterly jet stream along the equator and dipole pattern of SST is the noticeable features.

The fig: 1 agrees to the general principle that ISMR is extreme if EQUINOO and ENSO are acting together in the same phase; there exist few exceptions too. But when they are not in phase it is difficult to say the rain is controlled by their net effect. After 1999 the graph can contribute only very vague ideas about EUINOO. Since there are observational techniques to recognize the right phase of ENSO well in advance of summer monsoon, similarly if we develop methods to locate the correct phase of EQUINOO by March or April, the theory can be worth utilized for the prediction of subsequent drought or flood of our country. The presence of westerly zonal wind can be seen in March itself in 1965, by April in 1967, during May both in 1966 and 1968 all were drought years for India (Fig: 2). Similarly 1973, 1974 and 1975 display the persistence of easterly in March, April and May whereas 1976 show only westerly wind during the same period over the same longitudes of Indian Ocean resulted flooding in 73,74 & 75, but drought conditions during 76 (Fig: 3). Studying the zonal wind between 60E and 90E during the pre monsoon period can give an indication about the phase of EQUINOO.

In order to assess the modifications happening to EQUINOO conditions wet, dry and normal phase of Indian summer monsoons are analyzed with respect to EQUINOO region. 1953, 1956, 1961and 1994 are the wet monsoon years in which 1956 was a La Nina year and the rest were positive EQUINOO come IOD years. The negative phase of the EQUINOO associated with dry monsoon years are 1979, 1986 and 2002 out of it 1986 and 2002 were El Nino years too. Ironically both negative and positive phases of EQUINOO have witnessed normal rainfall in plenty of years like 1952, 1957, 1962, 1963, 1969, 1971, 1981, 1984, 1985, 1992, 1996, 1997, 1999, 2005 and 2007. In general the SST during positive EQUINOO phase was somewhat cooler than negative EQUINOO phase. The OLR pattern is quite different for the strong and weak EQUINOO composites (Fig: 6 & 7). During weak EQUINOO throughout the Northern part of Indian Ocean and Northeastern peninsular India witnessed suppression of convection and a corresponding increase in OLR anomaly. Only in the southeastern part showed deep convection. The strengthening of low-level westerly at the equator and variable winds on the northwestern Indian Ocean were noticeable. The deep convection was not confined to a particular region. This may be due to strong variable wind. Because of low convection in the western part of India the rainfall is deficit throughout the monsoon season. So the correlation analysis between normal ISMR of June to September and EQUINOO index for the period 1950-2005 to assess the overall relationship of EQUINOO and monsoon is carried out. Both the parameters have correlation coefficient of 0.43, which is highly significant. Thus we can say throughout the study period (1950-2005), EQUINOO is positively related to Indian summer monsoon rainfall. EQUINOO and IOD are concerned; both are physical processes in the Indian Ocean affecting the inter-annual variability of summer monsoon. Some of the strong EQUINOO years (1953, 1961, 1994 and 1997) are associated with positive phase of IOD. In these years 1961 and 1994 are wet monsoon years and 1953 and 1997 have normal monsoon rainfall (slightly positive). Similarly negative EQUINOO years like 1984, 1992 and 1996 are associated with negative phase of IOD. All these years have normal (slightly negative) rainfall over India. Thus even if the IOD and Indian monsoon are assumed to be negatively correlated, in the presence of EQUINOO, the IOD phase is made favourable for monsoon.

When the relationship of anomalies of ISMR from June to September with averages of EQUINOO index (EQWIN) and the ENSO index are studied, ISMR is found to be significantly correlated to ENSO index (correlation coefficient 0.52) whereas EQWIN is related by correlation coefficient of 0.43). ENSO index is poorly correlated with EQWIN (coefficient -0.09) (Gadgil et al, 2004).The partial correlation of ISMR with EQWIN (after removing ENSO effect) is 0.56, whereas that with the ENSO index (after removing EQUINOO effect) is 0.63 The zonal wind index (EQWIN) is taken as the negative of OLR anomaly hence the positive values of EQWIN are favorable for the monsoon. EQWIN values fluctuate between +3 and -3. When EQUINOO is favorable (EQWIN >0.2), there are no droughts and when it is unfavorable (EQWIN<-0.8) there are no excess monsoon seasons (Gadgil et al 2007). There appears to be no relation between ISMR anomalies and either the ENSO index or EQWIN or the composite index when the variation of summer monsoon rainfall amount is within one standard deviation.

III. Conclusion

EQUINOO is a phenomena happening in Indian Ocean with dipole characteristics in convective activity which can modify the strength of ISMR more directly than any other similar Indian Ocean oscillations as it is closer to our boundary. Still the origins of this issue remain skeptic though it is accepted as the atmospheric component of IOD. As long as the positive phase of IOD cannot contribute largely to ISMR, EQUINOO origin attributing to IOD is not fully justifiable. All IOD is not followed by an EQUINOO and no trend in EQUINOO occurrence is observed so far. In order to understand EQUINOO in detail the real reason of its origin has to be experimented. A realistic approximation for the entrainment in the EQUINOO region giving importance to synoptic and intra-seasonal scale, giving relevant partitioning between mid level and deep convection which is really responsible for rainfall in Indian monsoon has to be calculated. The second problem lies in the formulation of the index. Presently EQUINOO index is based on the zonal wind which is assumed to be related to cloud anomaly over central Pacific. These ambiguities in formulating the index decrease the credibility of its measurements. OLR index based on Indian Ocean and Pacific basin can be far more transparent and perfect though it is more complicated, expensive; requiring more effort and expertise.

Another striking achievement that can be derived from locating EQUINOO is that it can be used as a pre cursor for the performance of summer monsoon of India. Because from zonal wind observation the reversal of wind is observable in favor of or opposite to clouding by the end of March or at least by the beginning of April or lately by May. It gives good indication to the position of accumulation of increased convection and hence the following performance of monsoon. This property can be exploited towards prediction about the strength of the summer rain. The significance of EQUINOO study is well agreed among scientists but the non uniformity of its occurrence leads to the difficulty to tackle it.

The present study analyzes the atmospheric and ocean patterns associated with both positive and negative phases of EQUINOO using SST, lower level wind and OLR data sets. The Sea Surface temperature, lower level wind and convection have opposite patterns in both positive and negative phases of EQUINOO. Composite analysis of strong EQUINOO years shows enhanced convection over the western equatorial Indian Ocean and reduced one in the eastern side. Thus a dipole like structure is created in the equatorial convection. Easterlies are strengthened along the equator and positive dipole SST structure is seen over the Indian Ocean. Reverse patterns are seen for negative phase of EQUINOO composites. Strong EQUINOO years are always associated with positive phase of monsoon and vice-versa. Monsoon rainfall and EQUINOO are significantly positively correlated during the study period.

Analysis of individual years shows that in the absence of ENSO the wind and convection pattern are similar to positive or negative EQUINOO composites in years of good and bad monsoon which make one assume that the strength of Indian monsoon is largely controlled by EQUINOO. In years like 1953, 1961, 1962, 1979, 1984, 1985, 1994, 2005 EQUINOO only decided the fate of monsoon, while in 1951, 1956, 1957, 1969, 1986, 1992, 1999, 2002 both ENSO and EQUINOO co-occurred and the effect of both was evident on amount of rainfall. But in the years like 1963 and 1997 the ENSO and EQUINOO was opposite (both these years El Nino in the Pacific co occurred with strong EQUINOO in the Indian Ocean) the convection and wind patterns looks like that of strong EQUINOO composites and monsoon was wet. In the years in which IOD and EQUINOO co occurs both are on same phase and monsoon was also in excess. Since IOD has weak correlation with monsoon rainfall, years with presence of EQUINOO the effect of any phase of Indian Ocean Dipole on Indian Summer Monsoon Rainfall is really over shadowed. More vivid picture of EQUINOO effect can be obtained only if we can delineate similar small oscillations which can coincide and modify the course of ISMR like TCZ its intra-seasonal variability and the capability to drive the clouds from the Pacific to the west and from the equatorial Indian ocean to northwards just like the EQUINOO does, MJO another eastward propagation of convective belt found in Indian Ocean occurring almost in the same period, TBO its biennial travel from the stratosphere to the lower level and the dynamic nature to interact with ocean atmosphere coupling giving way to extreme rain events.

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Drought Years	Flood Years	El Nino Years
1951		**1951**
	1956	
		1957
	1961	
1965		**1965**
1966		
		1969
	1970	
1972		**1972**
1974		
	1975	
		1976
1979		
1982		1982
1983		
1986		1986
1987		1987
	1988	
		1991
		1992
		1997
	1998	
	1999	
2002		2002

Table: 1 Comparison of droughts and floods of Indian Summer Monsoon with El Nino years

Year	Rainfall anomaly(cm)	EQUINOO index (standardized)	DMI (June to Oct Average)	Wet/dry monsoon	EQUINOO phase
1950	3.71	0.52	…		
1951 El Nino	-10.1	0.87	…	Drought	
1952	-4.69	1.58	…		positive
1953	8.31	2.32	…		positive
1954 La Nina	4.57	-0.16	…		
1955 La Nina	9.03	0.39	…	Flood	
1956 La Nina	14.34	0.99	…	Flood	positive
1957 El Nino	-5.13	-1.00	…		negative
1958	4.96	0.12	-0.438		
1959	10.43	0.33	-0.262	Flood	
1960	0	0.06	-0.372		
1961	18.05	2.95	0.688	Flood	positive
1962	-3	1.43	-0.183		positive
1963 El Nino	1.81	1.66	0.376		positive
1964 La Nina	8.28	0.24	-0.533		
1965 El Nino	-13.04	-0.36	…	Drought	
1966	-9.99	-0.10	0.177	Drought	
1967 La Nina	**-8.52**	**0.62**	**0.425**		
1968	-8.52	0.06	1.256	Drought	
1969 El Nino	-0.88	-1.06	-0.147		negative
1970 La Nina	10	-0.82	-0.426	Flood	
1971 La Nina	4.7	-1.11	-0.398		negative
1972 El Nino	-18.69	-0.53	0.664	Drought	
1973 La Nina	7.36	-0.57	-0.220		
1974 La Nina	-9.16	-0.69	-6.443	Drought	
1975 La Nina	12.31	-0.84	-0.216	Flood	
1976 El Nino	1.7	-0.46	0.134		
1977	4.34	-0.08	0.378		
1978	6.95	0.16	...		
1979	-13.2	-1.01	…	Drought	negative
1980	4.3	-0.69	-0.163		
1981	1.24	-1.10	-0.145		negative
1982 El Nino	-10.44	-0.06	0.424	Drought	
1983	11.59	0.55	0.410	Drought	
1984	-0.31	-1.48	-0.238		negative
1985	-8	-1.26	-0.211		negative
1986 El Nino	-9.68	-1.05	…	Drought	negative
1987 El Nino	-14.25	-0.68	0.167	Drought	
1988 La Nina	12.17	0.52	-2.059	Flood	
1989	2.69	0.06	-0.240		
1990	6.89	-0.46	-0.127		
1991 El Nino	-5.45	-0.34	0.251		
1992 El Nino	-5.49	-1.16	-0.559		negative
1993	2.64	0.22	…		
1994	11.23	1.97	1.009	Flood	positive
1995	-3.96	-0.29	-0.238		
1996	1.97	-1.19	-0.678		negative
1997 El Nino	3.16	1.65	0.489		positive
1998 La Nina	1.92	-0.69	-0.273		
1999 La Nina	-1.75	1.10	0.383		positive
2000	-6.24	-0.46	…		
2001	-4.51	-0.89	…		
2002 El Nino	-17.73	-1.19	…	Drought	negative
2003	1.09	0.66	…		
2004	-9.3	-0.66	…	Drought	
2005	0.20	-0.81	…		Negative

Table 2: Comparison of wet/dry ISMR with positive/negative EQUINOO index

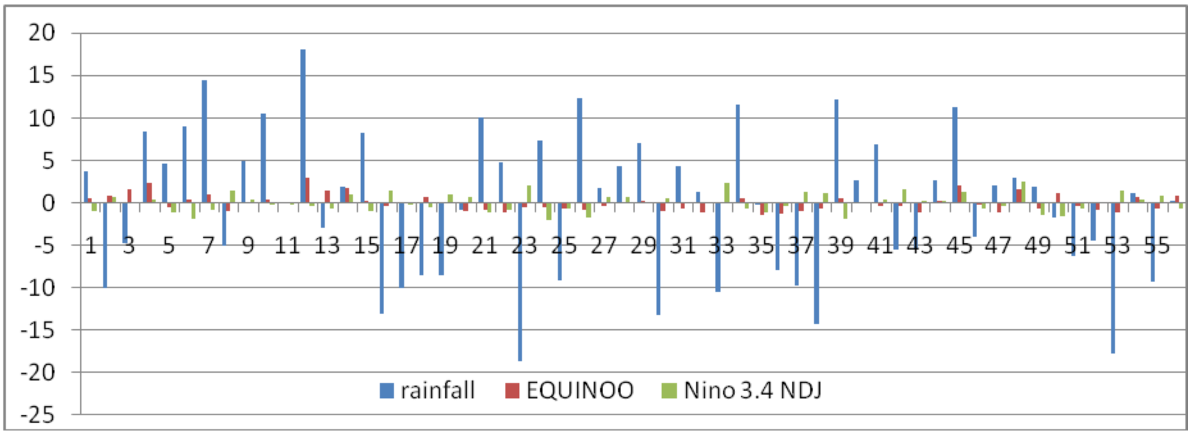


Fig: 1 Bar diagram for comparison if indices of ISMR, EQUINOO (June to September) and Nino 3.4 (N, D, J)

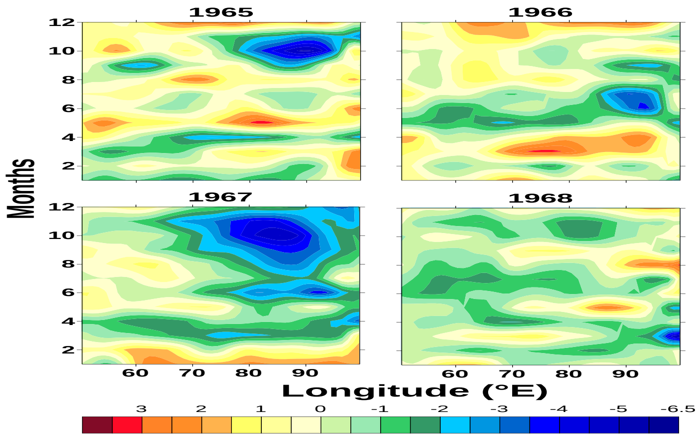


Fig: 2 Bi monthly zonal wind analyses for 1965, 66, 67 & 68 all drought years

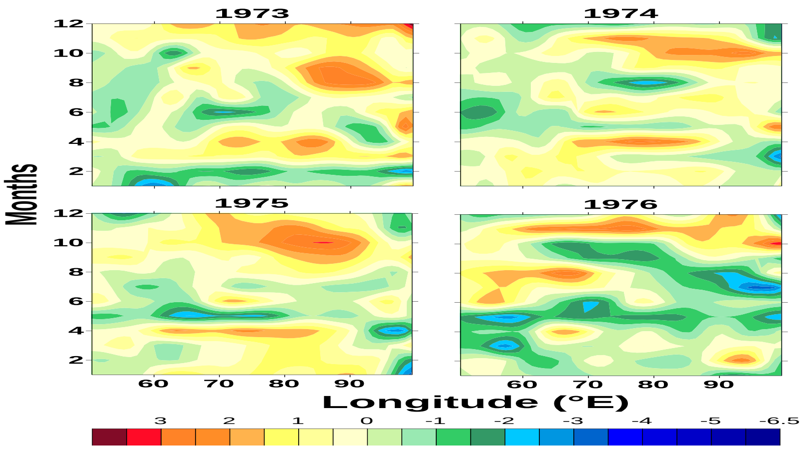


Fig: 3Bi monthly analyses of zonal wind for 1973, 74, 75 (La Nina years) & 76 El Nino year.

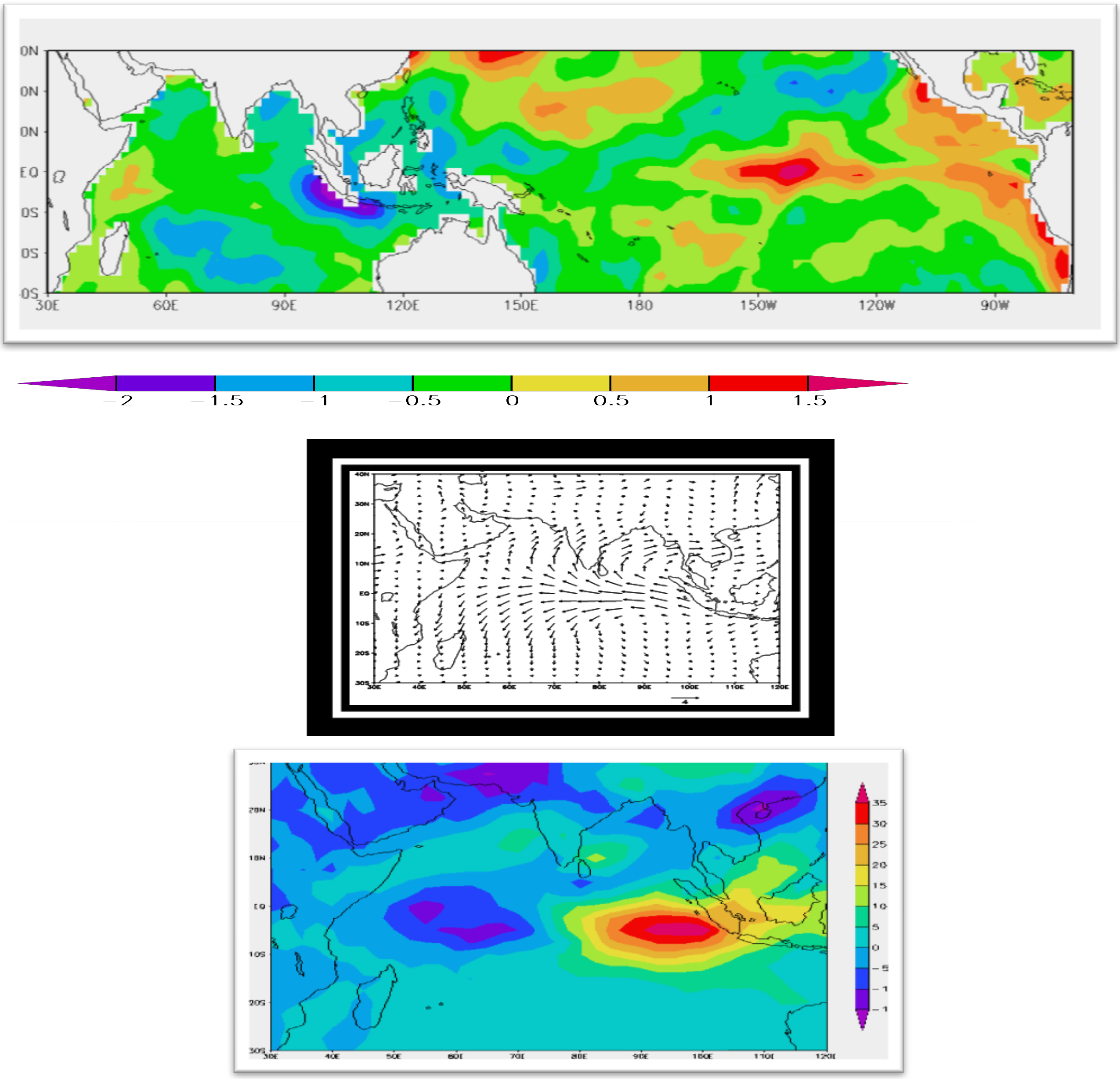
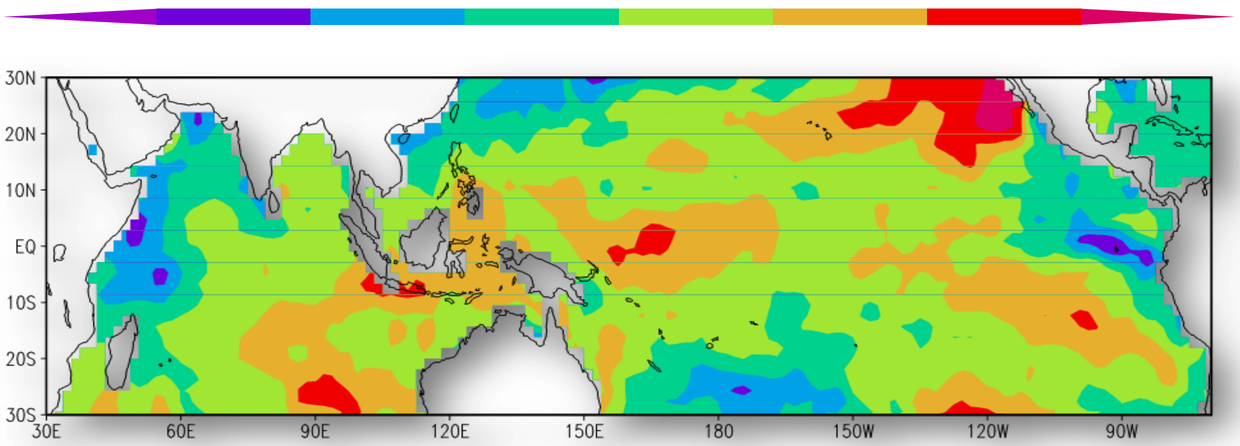


Fig: 4; Positive EQUINOO composite of June to September SST, surface wind and OLR



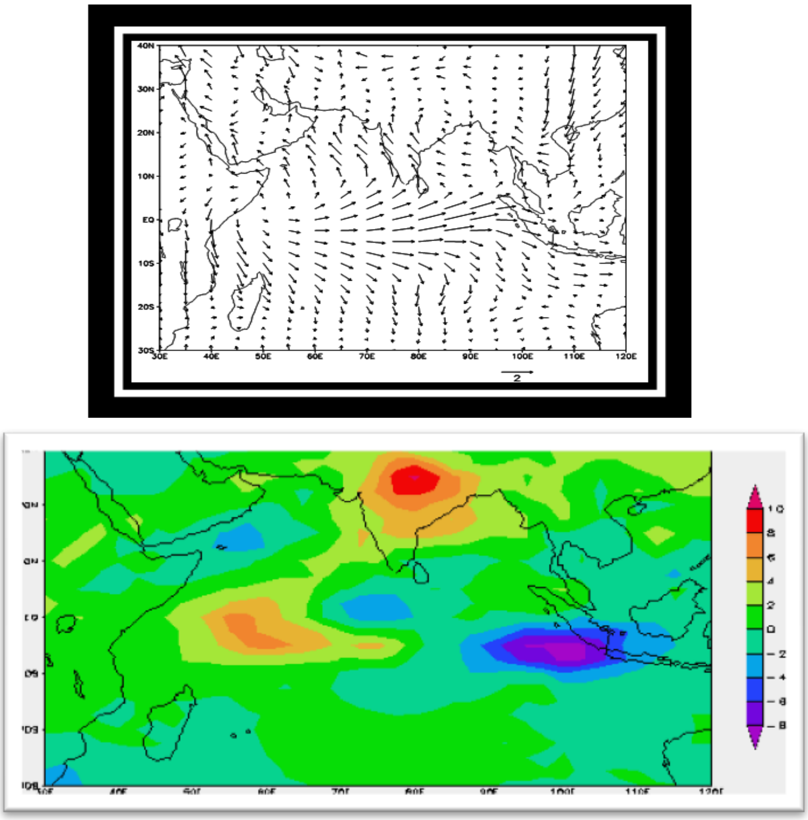


Fig: 5; Negative EQUINOO composite of June to September SST, zonal wind and OLR

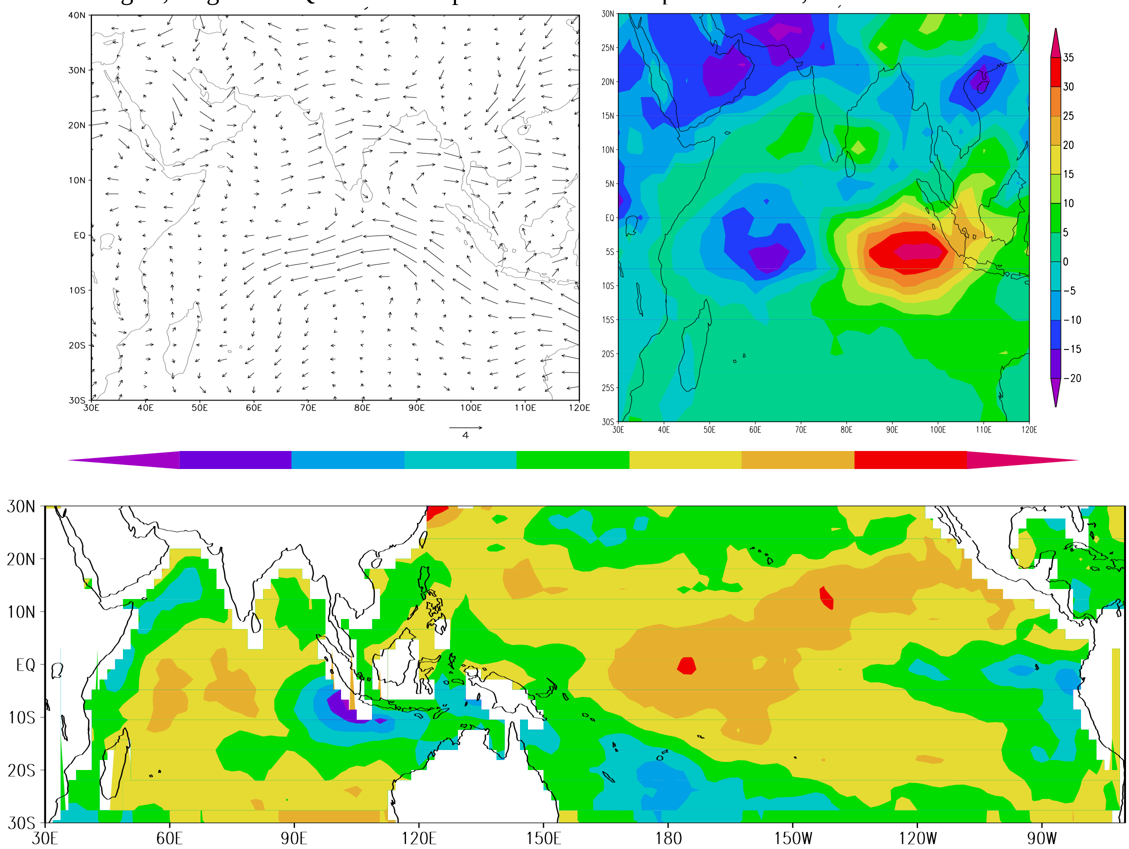


Fig: 6; 1994: A grant positive EQUINOO year with SST, OLR and wind average anomalies of June to September

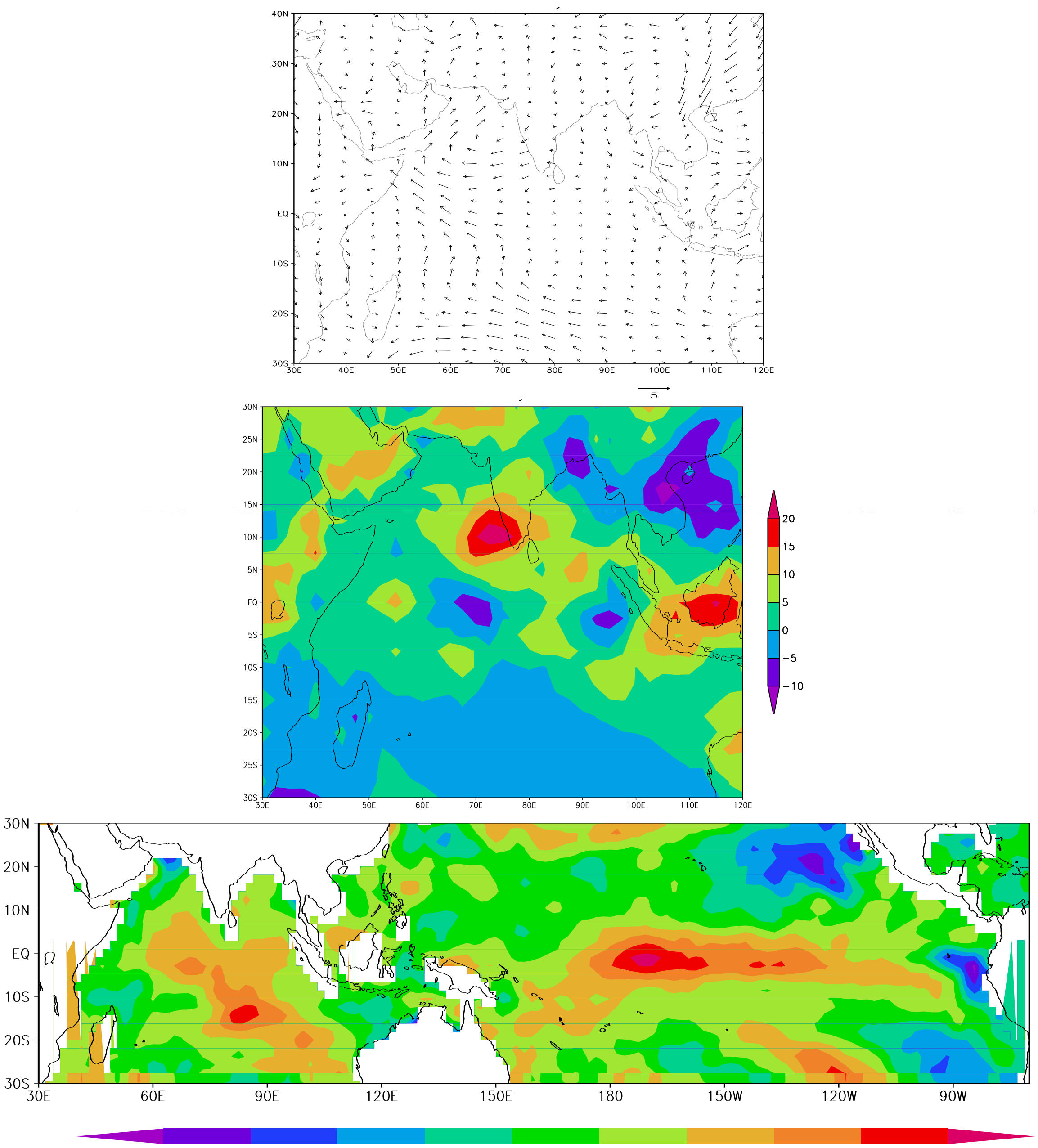


Fig: 7; 2002: An extreme negative EQUINOO year with SST, OLR and wind anomalies