

# **On Forecasting the Indian Summer Monsoon : the Intriguing Season of 2002**

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### **Abstract**

This year the rainfall over India during the first half of the summer monsoon season was 30% below normal. This has naturally led to a lot of concern and speculation about the causes. We have shown that the shortfall in rainfall is a part of the natural variability. Analysis of the past data suggests that there is a 78% chance that seasonal mean rainfall this year will be 10% or more below the long term average value. We discuss briefly how forecasts for seasonal rainfall are generated, whether this event could have been foreseen, and share our perspective on the problems and prospects of forecasting the summer monsoon rainfall over the Indian region.

## **Introduction**

The monsoon governs the very pulse of life in India. It is no wonder, therefore, that the public and particularly the media, are very much concerned when there is a large shortfall in monsoon rainfall. This year, the rainfall during the first half of the summer monsoon season (June and July) has been much less than the average (Fig. 1 from the web site of the India Meteorological Department, IMD, – <http://www.imd.ernet.in>) and fears are being expressed of a possible collapse of the monsoon.

We attempt to address these concerns in the light of the rich historical data of the Indian monsoon and the recent advances in our understanding of the system. Firstly, it is important to assess whether the deficit in rainfall is truly something abnormal, an unprecedented catastrophe, or is a part of the natural variability of the monsoon. If it is a part of the natural variability, then can we, on the basis of past observations, assess the chances that this deficit will be made up in the second half of the season (August – September). After addressing these questions we discuss briefly how forecasts for seasonal rainfall are generated, whether this event could have been foreseen, and share our perspective on the problems and prospects of forecasting the summer monsoon rainfall over the Indian region.

## **Natural variability of the Indian summer Monsoon**

Fortunately, IMD has a rich data set of meteorological observations from which the nature of variability of the summer monsoon (June–September) rainfall over about 130 years can be elucidated. Mooley and Parthasarthy<sup>1</sup> and Parthasarathy et. al.<sup>2</sup> derived the time–series of all India average rainfall on seasonal and monthly time–scales as a weighted average of the data at 306 stations obtained

from the IMD. This data set (extended up to 2000 by scientists at the Indian Institute of Tropical Meteorology, IITM – and available on-line at <http://www.tropmet.res.in>) reveals that, in 4 years out of 130 years, the rainfall during the first half of the season was less than that received this year. Clearly, what we have experienced this year is not an unprecedented catastrophe, but an event very close to the lower limit of the observed variation in June–July rainfall, i.e., a part of the natural variability of the system.

For each year during 1871–2001, the departure of the all-India summer monsoon rainfall (ISMR) from the long-term average (expressed as a percentage of the average), is shown in Fig. 2. An year with a deficit (excess) larger than the standard deviation (which is about 10% of the average) is considered to be drought (excess monsoon) year. In the other years the rainfall is said to be 'normal'. In the past 130 years, there have been 21 droughts, 92 (i.e. 70%) normal rainfall years and 18 years with excess rainfall. It can be seen that the frequency of droughts has varied on the decadal scale. For example, whereas ten droughts occurred during 1965–87, in the last 13 years the rainfall has been normal. Such extended runs of normal rainfall occurred twice in the past: during 1878–1890 and 1921–32 (Fig. 2)

What are the chances of recovery by the end of the season, from such a large deficit in the first half? It is seen from Fig. 3a that it is difficult to predict the rainfall during August–September on the basis of historical data, since its correlation with the rainfall in June–July is poor. However, it is seen that when the years in which the rainfall in the first half of the season tends to be low so is the rainfall in the second half as well. In fact, all the four years in which rainfall during June–July was lower than that received this year (1877, 1918, 72, 87) turned out to be major droughts (Fig. 3b). Analysis of the variation in the last 130 years

shows that, when the deficit of rainfall during June and July is more than one standard deviation (i.e. 11.7 %), the probability of the summer monsoon rainfall being normal is only 0.33, that of a drought 0.67, with almost zero probability of above normal rainfall. In fact, this year the deficit in June and July is about 30%, while that of July alone is at an unprecedented level of 49%. The probability of adequate rainfall in August and September so as to make the seasonal rainfall within the normal range is only about 22%.

Thus on the basis of the observed variation, it appears that this season is likely to be a drought and the IMD prediction of a normal monsoon may turn out to be inaccurate. If this happens, then it will be important to understand why the approach adopted by IMD, that yielded successful predictions for the last 13 years, has failed this year.

### **How do meteorologists generate forecasts?**

Scientists and laymen often find it difficult to understand the reasons for the painfully slow progress in forecasting of weather and climate in the modern day milieu of satellites and computers. When solar eclipses can be predicted to fractions of a second and the position of a satellite pinpointed millions of miles out in space, it is not readily understandable why reliable weather predictions cannot be made for a day, week, month, season, or years in advance. The problem of generating predictions of meteorological events (such as heavy rainfall over a region) is more complex than that of generating predictions of planetary orbits. This is because the atmosphere is unstable and the systems responsible for the events that we are trying to predict, such as clouds or a monsoon depression (in which thousands of clouds are embedded) are the culmination of the instabilities and involve nonlinear interaction between different spatial scales from kilometers (as in a single cloud) to hundreds of kilometers (as in a monsoon depression or a

hurricane). The climatic variables on the monthly or seasonal scales, such as the monsoon rainfall over the Indian region is the total effect of a series of such systems occurring during the season. The problem of generating long range predictions (such as predictions of monthly/seasonal rainfall) is according to the late Von Neumann, "the second most difficult problem in the world"; human behavior presumably being the first<sup>3</sup>

Meteorological forecasts are generated for three time-scales viz. short range (1–2 days ahead), medium range (3–10 days ahead) and long range forecasts for monthly and seasonal scales. In India, IMD generates the short and long range predictions whereas the National Centre for Medium Range Weather Forecasting (NCMRWF) is responsible for the medium range predictions. The short and medium range forecasts are for weather (i.e. temperature, rainfall) over meteorological subdivisions of India (shown in Fig. 1). Since space and time scales are inexorably linked, long range forecasts are made for larger regions such as the all-India scale or two or three subregions of the country.

The first weather forecasts were made by meteorologists with empirical knowledge of how weather maps evolved from day to day. By the 1950s, developments of physical models of the atmosphere on the one hand and detailed observations of the system on the other, led to insights into the physics of the variation on the scale of a few days. With the advent of satellites and computers, the density of observations increased enormously and complex models of the atmosphere, that could simulate the short and medium range variation realistically, were developed by the 1980s. Now, the integration of such models with initial conditions obtained from the worldwide observation network, is a major

input for weather prediction on these time scales. Atmospheric models are run regularly for this purpose at IMD and NCMRWF.

It is well known that there is a limit to predictability of weather of about 7–10 days because the system is chaotic – i.e., solutions of the governing equations corresponding to initial conditions which are arbitrarily close, diverge significantly over this time<sup>4</sup>. However, the variation of climatic elements on longer time scales e.g., the seasonal rainfall over the Indian region from year to year, responds to conditions at the lower boundary of the atmosphere such as the sea surface temperature (SST) or snow cover over Eurasia. Hence such variables can be used as predictors for this time–scale. Thus seasonal forecasting is primarily a boundary value problem while short or medium range weather forecasting is an initial value problem. Hence ensemble runs of atmospheric models with specified boundary conditions and varying initial conditions are used to generate predictions on the seasonal to interannual scale. Since oceans evolve more slowly than the atmosphere, the conditions at the surface of the ocean could be specified for these runs. The unraveling of the physics of El Nino and Southern Oscillation in the 90s<sup>5</sup> has led to a major thrust to programmes for generating long range predictions by atmospheric models with specified boundary conditions or by coupled models in which the oceans also evolve.

For long range predictions, an alternative approach is the traditional one, which involves developing empirical models for prediction on the basis of past observations of that variable (in our case rainfall) and/or other variables such as pressure, temperature of the atmosphere or ocean etc. We consider next these two approaches for prediction of the Indian summer monsoon rainfall

## **Forecasting the Indian summer monsoon rainfall**

### **Empirical Models**

A major drought and famine occurred in India in 1877 (fig 2) soon after the IMD was established. The first long –range prediction in the world was made by Blanford, who was the Chief Reporter of the IMD, at the request of the colonial government in the wake of this drought. The predictor used was the extent and depth of the Himalayan snow cover in the preceding winter<sup>6</sup>. In the early part of the last century, Walker<sup>7, 8, 9</sup> initiated extensive studies of the worldwide variation of weather elements (e.g. pressure, temperature etc.) with the aim of developing models for monsoon prediction. During this endeavour, he discovered a major feature of the tropical atmosphere over the Pacific called the Southern Oscillation (SO) which, in the 1960s was found to be linked to the El Nino. After the discovery of strong links between the El Nino and the Indian monsoon<sup>10, 11, 12</sup>, the empirical models for monsoon prediction have developed rapidly.

Since excellent reviews of the empirical models used for prediction of Indian summer monsoon rainfall are available<sup>13, 14, 15, 16</sup>, we mention only a few important facets here. In the tradition of Walker, a large number of potential predictors have been identified by analysis of the ever increasing data from conventional and satellite observations on many atmospheric and oceanic variables and their lag correlation with ISMR. Some of these parameters are related to El Nino and southern oscillation, some to snow over the Himalayas and Eurasia while some to global and regional conditions on spatial scales ranging from one station (e.g. surface temperature at De Bilt in Holland)<sup>14</sup> to hemispheric (e.g. northern hemispheric surface air temperature in January and February). However, it has been found that the relationship of several of these parameters varies with time on the decadal scale<sup>17, 18, 19</sup>. Rajeevan<sup>16</sup>

showed that the correlation of ISMR with the first principal component derived from five important parameters (representing ENSO forcing, land surface conditions over Eurasia and the heat low over northwestern parts of India) exhibited decadal variation similar to that of ISMR and that in extended periods with normal monsoon rainfall, the relationship of ISMR to the predictors tends to be weaker.

Different types of models are used for generating predictions. During 1924 to 1987 multiple regression models were used. In the last two decades new techniques based on Auto-regressive Integrated Moving Average method (ARIMA)<sup>20</sup>, power (nonlinear) regression models<sup>21, 22</sup> dynamic stochastic transfer models<sup>15</sup> as well as neural network models<sup>23, 24</sup> have been used. In addition, a model – the so called parametric model – which utilizes qualitative input (favourable/unfavourable) from 16 parameters to provide qualitative predictions (drought/normal/excess monsoon) on the basis of the fraction of favourable parameters has been developed<sup>21, 22</sup>. The power regression model for quantitative prediction of ISMR was proposed in 1989<sup>21</sup>. It is based on the same set of 16 parameters as the parametric model. Since the model uses such a large number of parameters, it is likely to have the problem pointed out by Lorenz<sup>25</sup>, that inspite of a good fit in the 31 years from which the model was developed, it is likely to give large errors other years. In 1995, Krishna Kumar et. al<sup>14</sup> proposed a linear regression model with just three parameters (which happened to be all regional circulation parameters), that performed as well as the 16 parameter non-linear regression model. In particular, these two models were able to simulate the droughts and excess monsoon years in the validation periods<sup>14, 15</sup>.

It must be noted that the autocorrelations of ISMR with lags varying from 1 to 5 years are not statistically significant<sup>26</sup>. However, a

neural network model has been developed which uses only information on past history of rainfall variation<sup>23</sup>. It has been used to generate predictions in the last five years, but it is not clear whether this model can predict droughts or excess monsoon years.

The official forecast of the IMD is based on the parametric model and the quantitative models, particularly the 16 parameter power regression models. It must be noted that the world over, long range forecasts are generally made by taking inputs from various forecasts and different models<sup>27</sup>. From 1988 to 2001 IMD generated correct qualitative forecasts (i.e. normal/excess etc) the summer monsoon rainfall. For the quantitative prediction for the total rainfall during the summer monsoon, the root mean square error was 7.6%.

#### *Physical Models*

Models based on the equations governing the dynamics and energetics of the atmosphere have been used for simulation and prediction of variation over different time-scales.

#### Simulation of variability

Since El Nino involves major changes in SST patterns and the Indian monsoon is known to be linked to the El Nino, we expect some success in prediction of the interannual variation of the monsoon with this approach. However, before an atmospheric model can be used for this purpose it is important to examine whether it is capable of simulating reasonably well, the observed response of the monsoon to changes in the SST patterns. Several atmospheric general circulation models from all the leading centres of the world were run with SST specified from observations during 1978–88 under an international programme called the Atmospheric Model Intercomparison Project (AMIP). Analysis of the AMIP simulation of thirty models by Gadgil and Sajani's<sup>28</sup> showed that a large number of models could not simulate

the rainbelt over the Indian region in the summer monsoon season. Simulation of the seasonal mean rainfall pattern over the Indian region has turned out to be a more difficult problem than that over the rest of the tropics. This is because over the Indian longitudes, there are two favourable zones for the rainbelt to occur – one over the heated subcontinent (over our monsoon zone) and another over the warm waters of the equatorial Indian ocean<sup>29</sup>. In the presence of multiple equilibria, the simulated rainbelt in models tends to get locked into one or the other location whereas in nature it fluctuates between the two. It was found that<sup>28</sup>, very few models are able to simulate the year to year variation of the monsoon.

The knowledge gained during the first phase helped the modellers to improve the models and the second phase of AMIP (AMIP-2) is presently being conducted with all the participating models simulating the period of 1979–1995. During this period (79–95) India experienced three years of drought (1979, 1982 and 1987) and two years of high rainfall (1983 and 1988). About twenty models participated in the AMIP-2. We consider here the simulations by three models viz. National Centres for Environmental Prediction (NCEP, USA), European Centre for Medium Range For Forecasts (ECMWF, the European Community) and Centre for Ocean, Land and Atmosphere studies (COLA, USA) for these extreme years. These models were chosen because they are in use for medium and long range forecasting – NCEP by USA, ECMWF by the European Community and COLA in Brazil (the only other tropical country with medium range forecast capability other than India). It should be noted that one version of the NCEP model is presently used at our National Centre for Medium Range Forecasting at New Delhi. A comparison of ISMR for the summer monsoon seasons of 1979, 82, 83, 87, 88 by these three models is shown

in Fig. 4. It can be seen that whereas NCEP got the correct sign of the departure from average (i.e. whether it is deficit or excess) in all the five years, ECMWF got it right in four out of five, whereas COLA got it right in only two out of five years. It can also be seen that the magnitude of the deficit/excess is not realistically simulated by any of the models. Of the years in which the sign of the departure was correctly simulated, the magnitude in NCEP simulation was larger than observed in three out of five years whereas the magnitude in ECMWF simulation was smaller than observed in three out of four years.

Prediction of year to year variations was generated with atmospheric models under a co-ordinated European project (PROVOST) for the period 1979–93. Here also it was found that the error was large for several years including the droughts of 1979 and 1987<sup>16</sup>. Magnitude of the systematic error in simulation of the seasonal mean monsoon was identified as a major contributing factor to poor predictability<sup>30</sup>. Although some models are not able to simulate/predict the variation of ISMR from year to year, Krishnamurthi et. al.<sup>31, 32</sup> have shown that by using a "super ensemble" the simulations improved significantly. When AMIP simulations by the different models in the superensemble were combined, the resulting values matched closely with observations not only for the control run of eight years (from which the coefficients were determined), but also for the remaining two years. Thus, as the models improve, reasonable forecasts could be generated by combination of different models.

Most forecasting centres have started issuing seasonal forecasts from 2001. The forecasts are generated with coupled atmosphere ocean models from an ensemble of runs with varying initial conditions. It has been pointed out that there could be considerable errors in the forecasts and hence they should not be used indiscriminately. With the rapid

increase in computational power and improvements in the modelling of physical processes, we can expect the forecasts from such numerical models to improve significantly over the next decade.

However, given the difficulties faced in simulating the interannual variation of the monsoon, empirical methods will continue to play an important role in generating predictions. In fact, in a recent review of long-range forecasting methods, Goddard et al<sup>33</sup> have stated that empirical methods for prediction of Indian summer monsoon rainfall continue to outperform methods based on physical models. This is because most of the atmospheric models have not been able to simulate accurately the inter-annual variability of the Indian summer monsoon rainfall.

### **The summer monsoon season of 2002**

We have shown that what we have experienced this year is a part of natural variability. We believe that considerable research is required before we can pinpoint the factors and mechanisms that led to the large deficit in rainfall in the first half of the season. However, the unprecedented deficit in July, has led to several speculations about the possible causes. For example, some have attributed the drought to global warming. It is important to note that the time scale on which global warming occurs is of the order of a century. We expect the effects of global warming to be manifested as a slow change in the mean seasonal rainfall and in frequency of droughts and /or floods. A single event such as a drought in 2002 cannot be attributed to these longer term changes. Furthermore, most of the climate models suggest that global warming will be associated with increased monsoon rainfall and an increase in the frequency of floods. This is consistent with the expectation that global warming will intensify the hydrological cycle. Clearly, there is no basis for attributing the drought of 2002 to global

warming. The other speculation is that the aerosol haze present over the Indian region in winter can cause a reduction in monsoon rainfall. There is no scientific basis for this speculation either. It is important to note that most of the aerosols present in winter over India are usually washed out by the first monsoon rains. Secondly, even if some black carbon aerosols remain during the monsoon, model simulations show that they will lead to heating of the atmosphere and hence increase in rainfall over the Indian region.

One special feature of the monsoon season of 2002 is the scarcity of cloud systems over the Arabian Sea and the large deficits of rainfall over the west coast (Figs. 1 and 5). Another is the increased clouding over a coherent belt across the tropical Pacific ocean (Fig. 5) with a very large number of typhoons over the west Pacific. It is believed that there is a competition for convergence of moist air (and hence rainfall organized over large scales) between the atmosphere over the Pacific ocean and that over the Indian region. Hence it is not surprising that increased cloudiness over the Pacific ocean is associated with deficit monsoon rainfall. However, as in many instances in meteorology, while the association between events over different regions is clear, it is difficult to discern the cause –effect relationships. It is clear that further insights into the physics of the variation of the monsoon from year to year are required before we can fully understand the evolution of the monsoon in 2002. For this, multipronged efforts with detailed analysis of data including that from satellites, buoys, model simulations and new observational experiments in critical regions (such as the Bay of Bengal Monsoon experiment BOBMEX – during the summer monsoon of 1999<sup>34</sup>) are necessary. The second observational experiment under the Indian Climate Research Programme (viz. the Arabian sea monsoon experiment) – ARMEX during which detailed observations have been

made for July – August 2002 should provide some insights into why the monsoon over the Arabian Sea failed during July 2002.

It is clear that the large deficits experienced during this monsoon season were not anticipated. By the end of May, two predictions were released to the public. The IMD predicted ISMR of 101% and CMMACS<sup>35</sup> of 99% of the long term average. Estimates from several other empirical models also suggested above average rainfall for this season since most of the parameters were favourable. For example, the three parameter model of Krishna kumar et. al.<sup>14</sup> suggested ISMR of 110%. As a matter of fact, the slew of empirical models developed over the years of at IITM indicated a consensus forecast of 105% for the season of 2002. It is important to note that extensive testing of forecasts of most of the empirical models has been done mainly in the last decade during which the variation from year to year was not large. We have seen that, based on past experience, the chance of recovery of the monsoon from the deficit of 30% in June–July to the normal range is only around 22%. In fact the ISMR will come to close to the long–term average only if the rainfall in August–September is near the maximum observed in the past 130 years. Thus it appears that the rainfall during the summer monsoon of 2002 will be well below the predictions of IMD and CMMACS.

Why did the empirical models fail to predict the large deficit in July? The empirical models are based on the premise that the evolution of the complex system from the pre monsoon season to the monsoon season is similar in the years from which it was developed and years for which predictions are made. Specifically, it is assumed that the precursors identified by analysis of the observations over the few years used for development, contain information about the forecasting monsoon season. Meteorologists are aware of the limitations of this

approach and have documented secular changes in correlation of different predictors with ISMR. So several parameters and several models are considered in the expectation that when there is convergence in the predictions, the consensus prediction may be reasonably accurate. This season has proved to be a major exception to this, for reasons we do not understand. One possibility is that it is a manifestation of the changes that are supposed to have occurred in the last decade in the teleconnections between the Indian monsoon and other phenomena in the tropics such as El Nino<sup>36</sup>.

The forecast for June, July and August by the ECMWF model with initial condition in May suggested some deficit only over the southwestern peninsula and near normal rainfall over the rest of the country (Fig. 6a). The forecast in May, from the International Research Institute for Climate Prediction (based on the forecasts of several models) also suggested normal rainfall over the entire country. However, the forecasts generated with initial conditions in June, did suggest major deficits over the northwestern parts of the country (Fig. 6b for the ECMWF forecast). Thus it appears that the large deficit in June–July, and the expected deficit for the season as a whole, could not have been foreseen in May, when the official predictions were made. This suggests that some unforeseen changes in atmospheric circulation on the planetary scale occurred in May and hence the atmospheric models with June initial condition could provide a reasonable simulation of deficit rainfall.

Srinivasan and Nanjundiah<sup>37</sup> have shown that both in 1983 and 1997, the conditions in May were similar to that of a drought year but the appearance of westward migrating cloud systems in June in the Bay of Bengal changed the course of the monsoon (which turned out to be above normal). Thus events on time–scales of weeks during the

evolution of the monsoon can have an impact on the seasonal rainfall. In fact, in the season 2002, an important parameter for atmospheric convection and rainfall viz. the total water vapour in the air column over India decreased markedly in the third week of May and remained below that in 2001 most of the time right upto the end of July (Fig. 7). Whether the large rainfall deficit in the monsoon 2002 is related to the major depletion of water vapour content in May needs to be investigated. However, it is clear that important parameters need to be monitored on time-scales of weeks rather than months, not only in the pre monsoon season but during the evolution of the monsoon in June as well.

As more and more data become available from satellites and buoys, the empirical models are expected to improve. With advances in our understanding of important facets of physics such as interaction between ocean and atmosphere and the role of clouds and surface processes, the physical models will also perform better in the future. We expect significant improvement in our understanding of the variability of the monsoon and hence forecasting in this decade. However, even with overall decrease in errors of predictions, the models, whether physical or empirical, will fail once in a while. When dealing with complex and chaotic systems one must be ready for surprises.

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## Figure Captions

Figure 1: Rainfall distribution during June and July 2002 over India. Small figures show the actual rainfall, bold figures represent normal rainfall and % departure from mean are shown in parenthesis for each meteorological sub-division.

Figure 2: Indian Summer monsoon Rainfall ISMR as percentage departure from the mean during 1871–2001. Dotted lines indicate the standard deviation of the rainfall (as %) about the mean.

Figure 3a: Scatter plot of August and September rainfall (mm) versus rainfall (mm) during June and July

Figure 3b: Scatter Plot of June–September rainfall (mm) versus June and July rainfall (mm). Arrow indicates the cumulative rainfall during June and July of 2002.

Figure 4: Comparison between the observed rainfall (ISMR) and model simulated rainfall for the five extreme years between 1979 and 1994 for three physical models (viz. COLA, ECMWF, and NCEP). Shown are the departures of the rainfall from the mean normalized by their respective averages.

Figure 5: Outgoing Longwave Radiation (OLR, a proxy for rainfall) anomaly (i.e. departure from mean) during July 2002. Higher OLR implies lower rainfall. Note the high positive OLR anomaly (implying lower rainfall, shown in red) over the Indian region and the large region

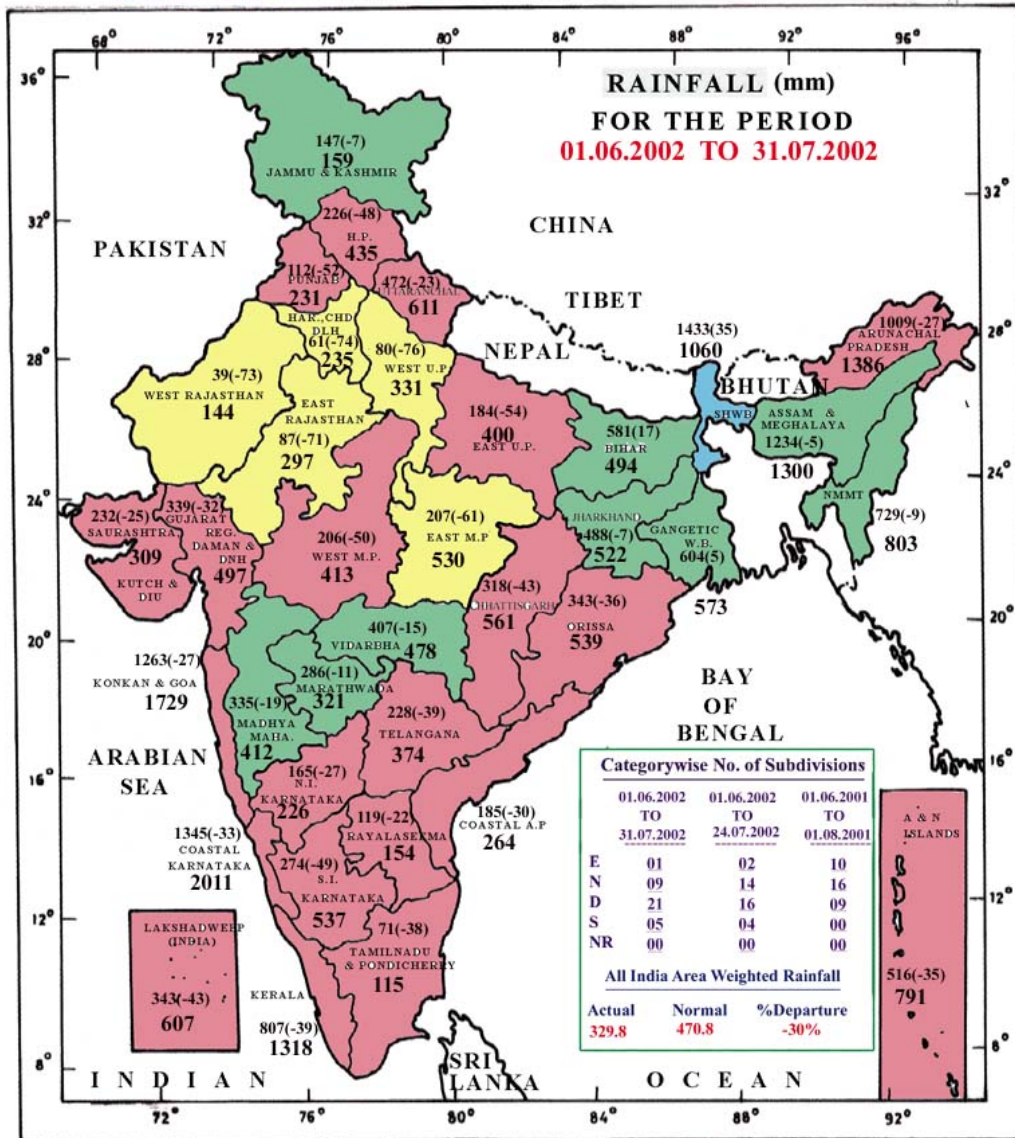
of negative OLR anomaly (shown in blue, implying high rainfall) over the Equatorial Pacific region.

Figure 6a: Forecast of Rainfall (departure from the mean, mm) by the ECMWF coupled model for June–August using initial conditions of May.

Figure 6b: Forecast of Rainfall (departure from the mean, mm) by the ECMWF coupled model for July–September using the initial conditions of June.

Figure 7: Variation of total water vapour in a vertical column of air over India during May to July in 2001 and 2002. Three point smoothing has been applied.

## भारत मौसम विज्ञान विभाग INDIA METEOROLOGICAL DEPARTMENT



	Categorywise No. of Subdivisions		
	01.06.2002 TO 31.07.2002	01.06.2002 TO 24.07.2002	01.06.2001 TO 01.08.2001
E	01	02	10
N	09	14	16
D	21	16	09
S	05	04	00
NR	00	00	00

All India Area Weighted Rainfall		
Actual	Normal	%Departure
329.8	470.8	-30%

**LEGEND :**

- EXCESS (E)  
+ 20% OR MORE
- NORMAL (N)  
+19% TO -19%
- DEFICIENT (D)  
-20% TO -59%
- SCANTY (S)  
-60% TO -99%
- NO RAIN (NR)  
-100%
- \* \* NO DATA

**NOTES:**  
 (a) Rainfall figures are based on operational data.  
 (b) Small figures indicate actual rainfall (mm), while bold figures indicate normal rainfall (mm). Percentage departures of rainfall are shown in parenthesis.

Figure 1: Rainfall distribution during June and July 2002 over India. Small figures show the actual rainfall, bold figures represent normal rainfall and % departure from mean are shown in parenthesis for each meteorological sub-division.

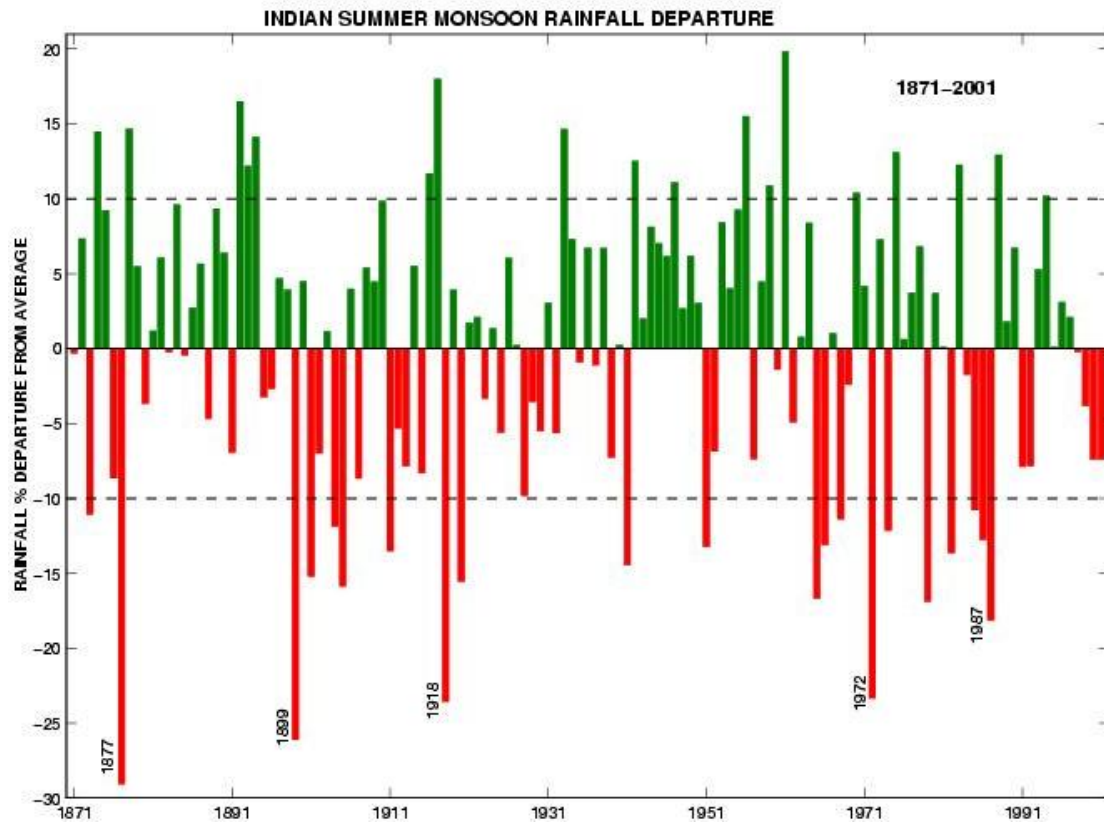


Figure 2: Indian Summer monsoon Rainfall ISMR as percentage departure from the mean during 1871–2001. Dotted lines indicate the standard deviation of the rainfall (as %) about the mean.

### INDIAN SUMMER MONSOON RAINFALL (1871–2000)

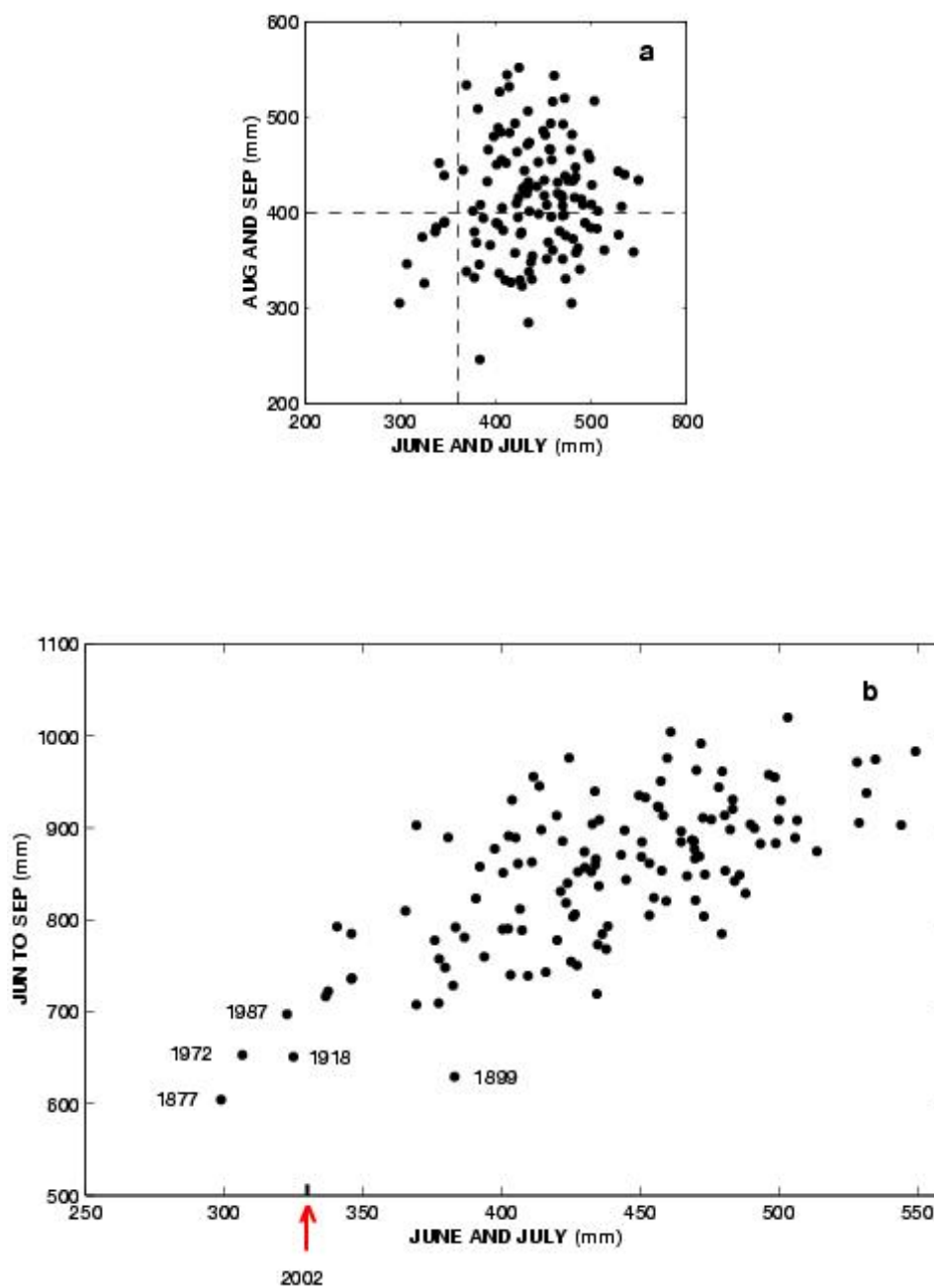


Figure 3a (upper): Scatter plot of August and September rainfall (mm) versus rainfall (mm) during June and July

Figure 3b (lower): Scatter Plot of June–September rainfall (mm) versus June and July rainfall (mm). Arrow indicates the cumulative rainfall during June and July of 2002.

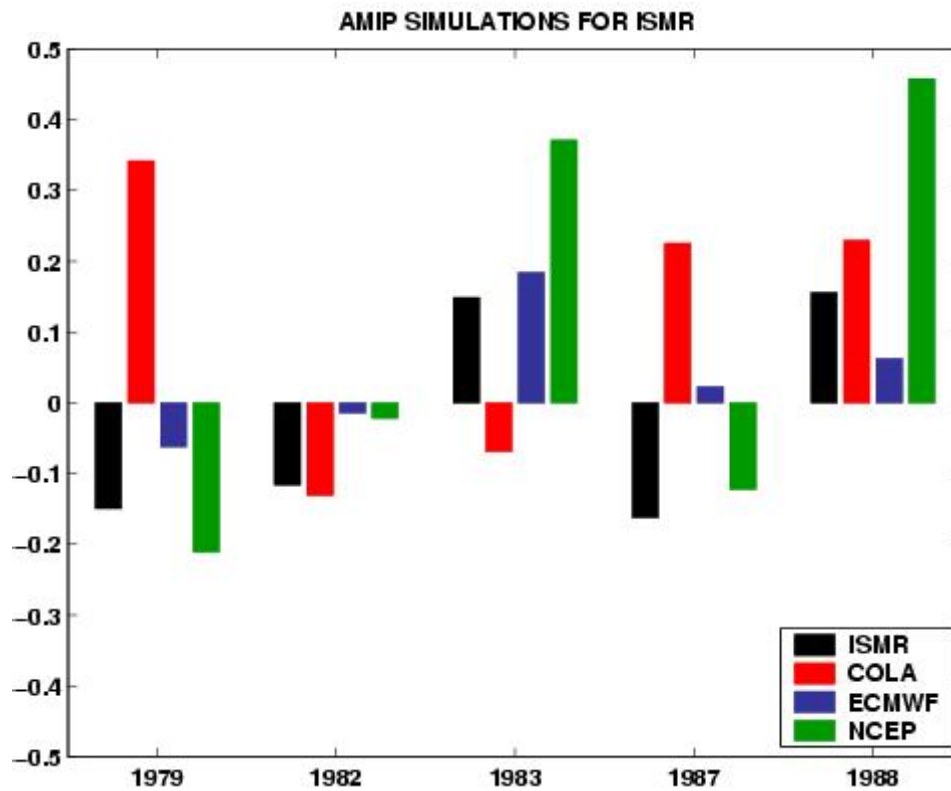


Figure 4: Comparison between the observed rainfall (ISMR) and model simulated rainfall for the extreme years between 1979 and 1994 for three physical models (viz. COLA, ECMWF, and NCEP). Shown are the departures of the rainfall from the mean normalized by their respective averages.

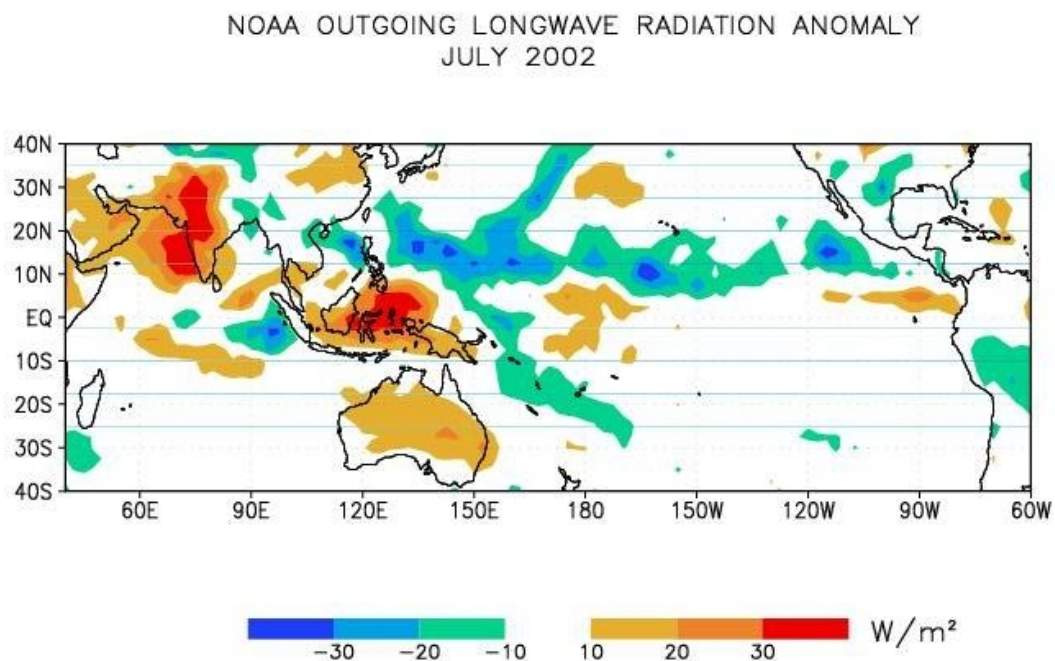


Figure 5: Outgoing Longwave Radiation (OLR, a proxy for rainfall) anomaly (i.e. departure from mean) during July 2002. Higher OLR implies lower rainfall. Note the high positive OLR anomaly (implying lower rainfall, shown in red) over the Indian region and the large region of negative OLR anomaly (shown in blue, implying high rainfall) over the Equatorial Pacific region.

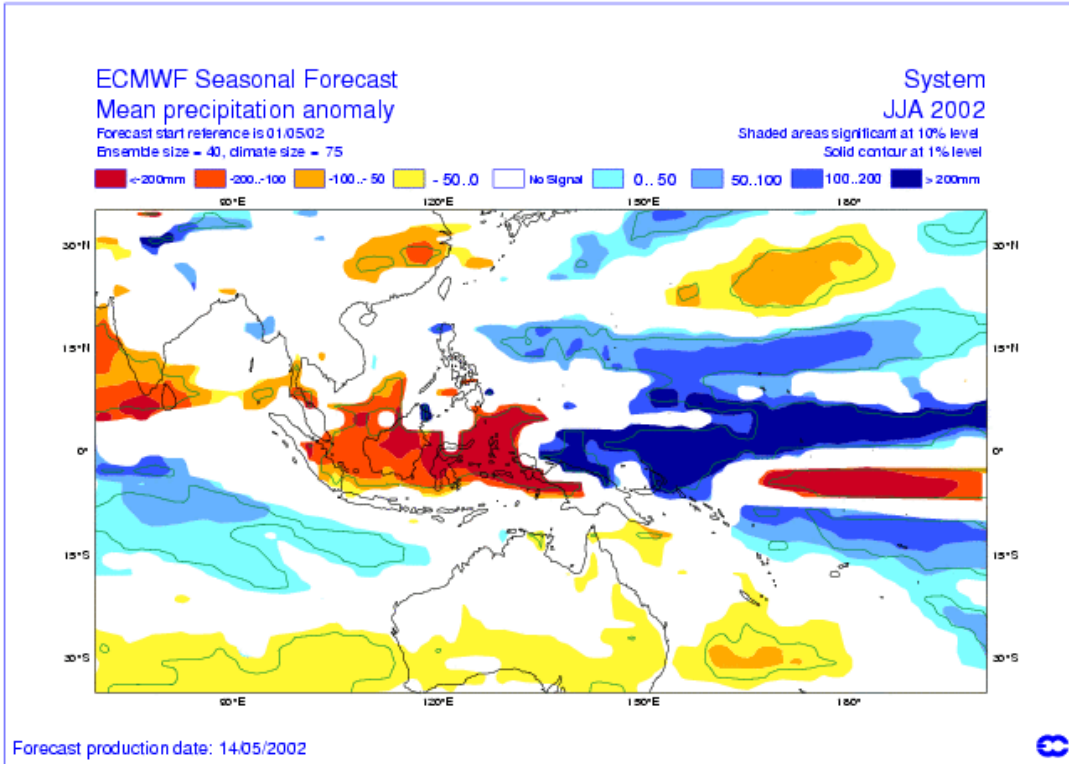


Figure 6a: Forecast of Rainfall (departure from the mean, mm) by the ECMWF coupled model for June–August using initial conditions of May.

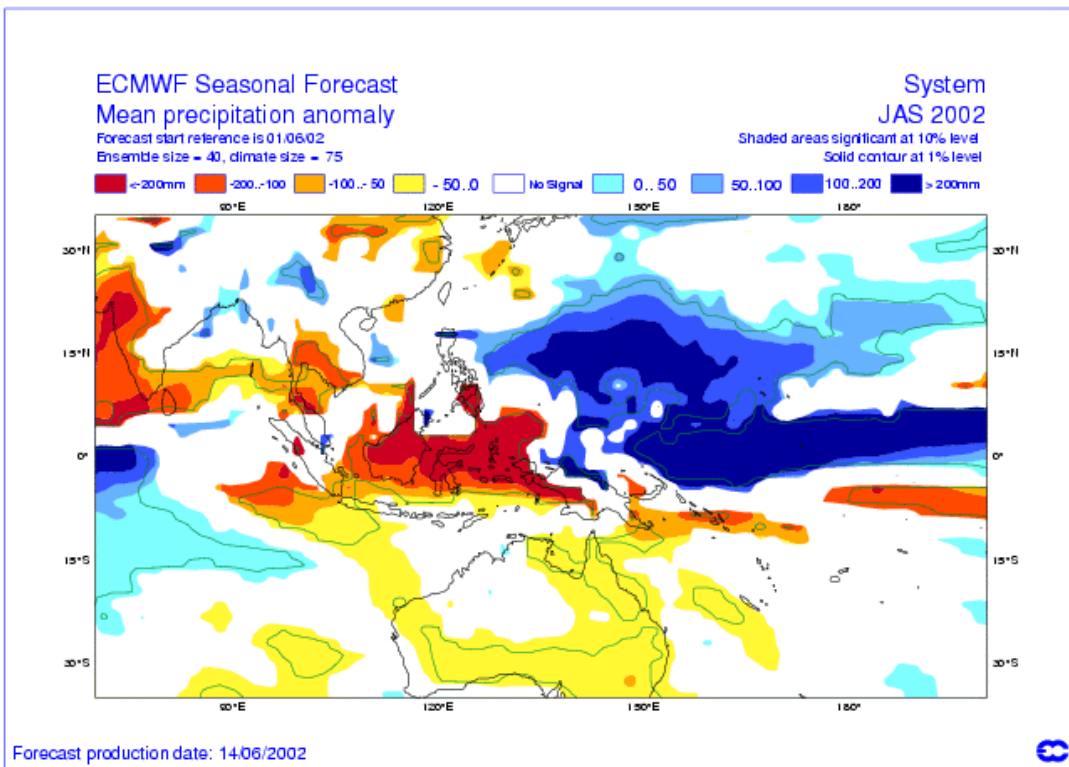


Figure 6b: Forecast of Rainfall (departure from the mean, mm) by the ECMWF coupled model for July–Sep using initial conditions of June

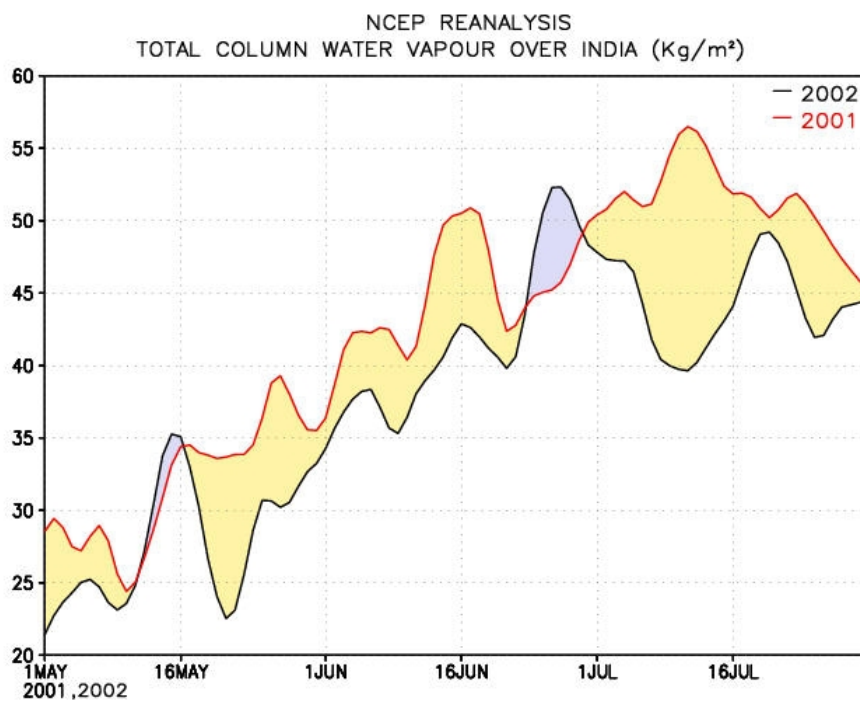


Figure 7: Variation of total water vapour in a vertical column of air over India during May to July in 2001 and 2002. Three point smoothing has been applied.