The Monsoon and Its Variability
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Lecture - 40
Monsoon Prediction - Part 1

So today I am going to talk about Prediction of the Monsoon.

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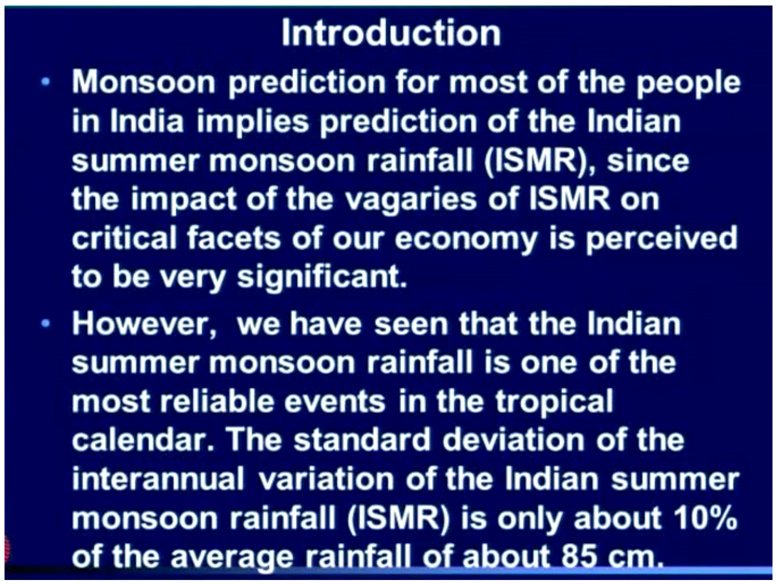

Because billions of people around the world are interested in prediction of the monsoon. Now monsoon prediction for most of the people in India implies prediction of the Indian summer monsoon rainfall ISMR. Since the impact of the vagaries of ISMR on critical facets of our economy is perceived to be very significant. However, we have seen that the Indian summer monsoon rainfall is one of the most reliable events in the tropical calendar.

The standard deviation of the interannual variation of the ISMR is only about 10% of the average rainfall of 85 centimeters.

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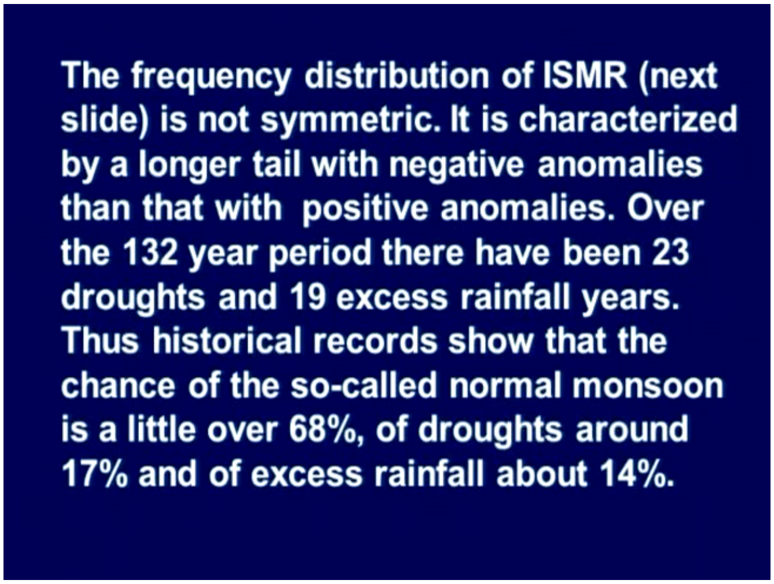

Now the frequency distribution of ISMR is not symmetric.

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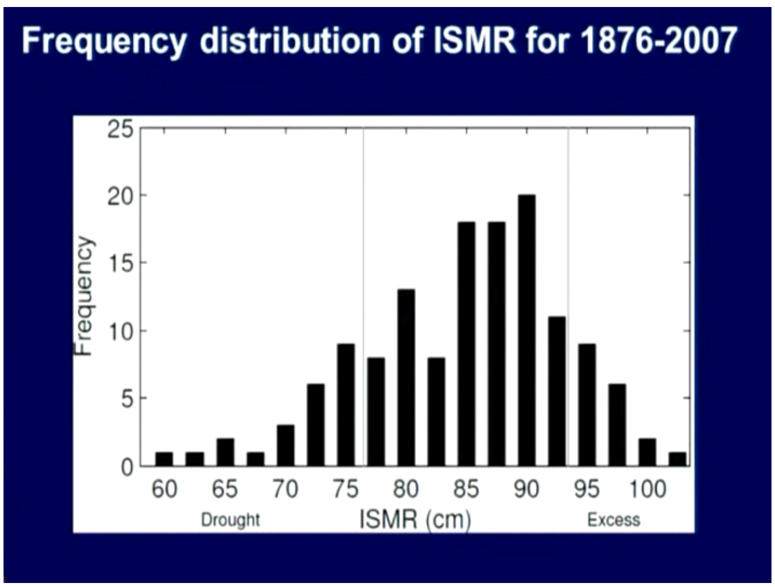

See this is the frequency distribution, so this shows what is the percentage of years in which the rainfall is around 85, around 87.5, around 90 and so on and so forth okay, and this is based on the data from 1876 to 2007, so the frequency distribution is not symmetric and you can see that you know it has a very long tail towards the low rainfall region compared to the high rainfall region. High rainfall region it is fairly sharp ending, but here there is a long tail.

So we say that it is not symmetric it is characterized by a longer tail with negative anomalies than that with positive anomalies, over the 132-year period there have been 23 droughts and 19 excess rainfall years. Thus, historical records show that the chances of the so-called normal monsoon which means neither a drought nor an excess rainfall is a little over 68%, droughts around 17% and excess rainfall around 14%. So this is just a chart based on historical data.

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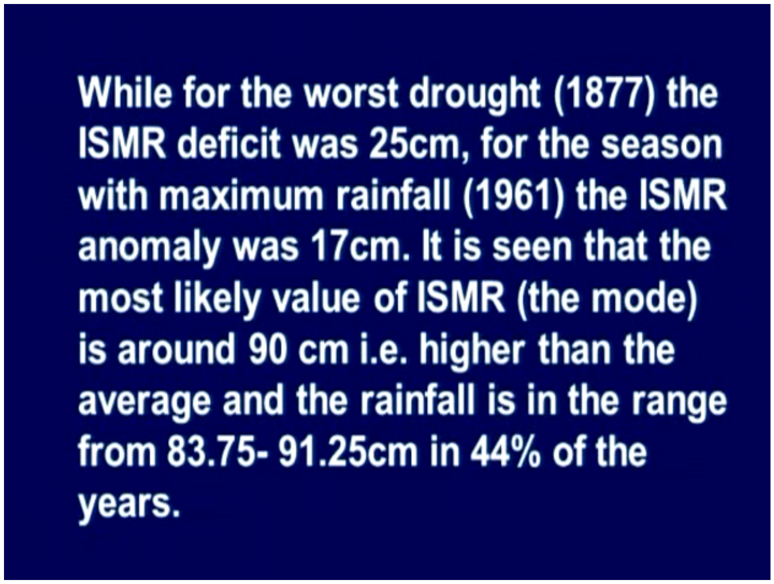

While for the worst drought 1877 the ISMR deficit was as large as 25 centimeters, for the season with maximum rainfall 1961 ISMR anomaly was 17 centimeter. It is seen that the most likely value of ISMR the mode is around 90 centimeters. You can see here maximum chances that is almost 20%, when the rain is around 90 or so. So the mode is around 90 centimeters that is higher than the average.

And that the rainfall is in the range from 83.75 to 91.25 that is to say 1.25 on either side of the 85 is 44% of years. So large number of years have rainfall rather close to the normal.

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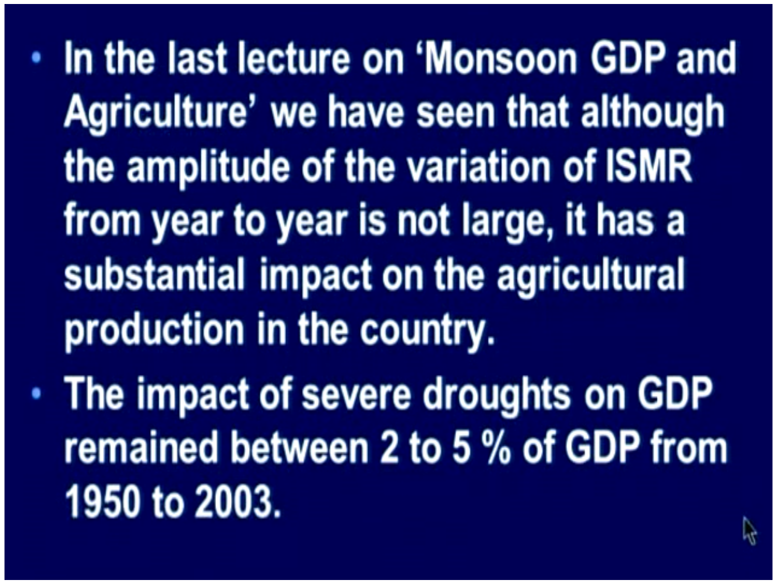

Now in the last lecture on monsoon GDP and Agriculture, we have seen that although the amplitude of the variation of ISMR from year to year is not large, it has a substantial impact on the agricultural production in the country and also the GDP. The impact of severe droughts on GDP remained between 2 to 5% of the GDP from 1950 to 2003.

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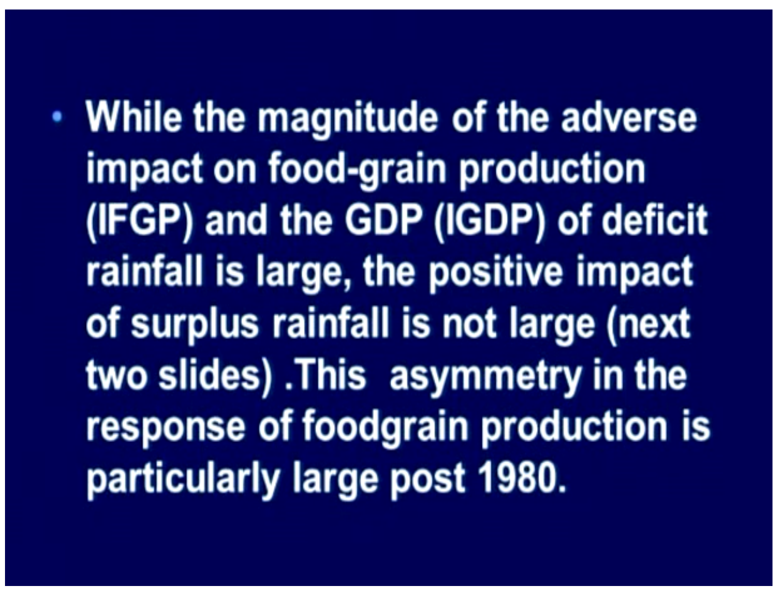

So while the magnitude of the adverse impact on food-grain production and GDP of deficit rainfall is large, the positive impact of surplus rainfall is not large, next 2 slides. So this asymmetry in the response is particularly large after 1980.

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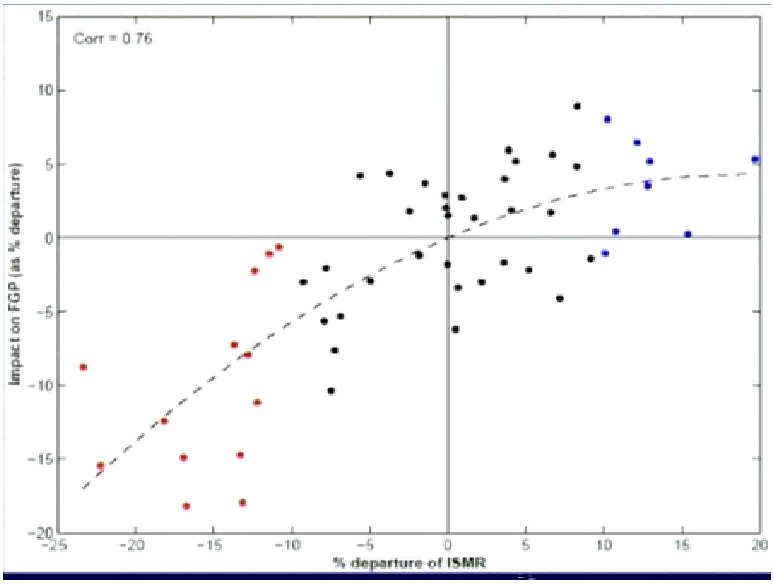

This is in fact the food-grain production impact, impact on food-grain production, and this is ISMR anomalies. And what you see here is that on the positive side the curve is rather flat, on the negative side very sharp impact as you get more and more severe deficit. And the same story is there also for GDP, this is for FGP and the last one is for GDP.

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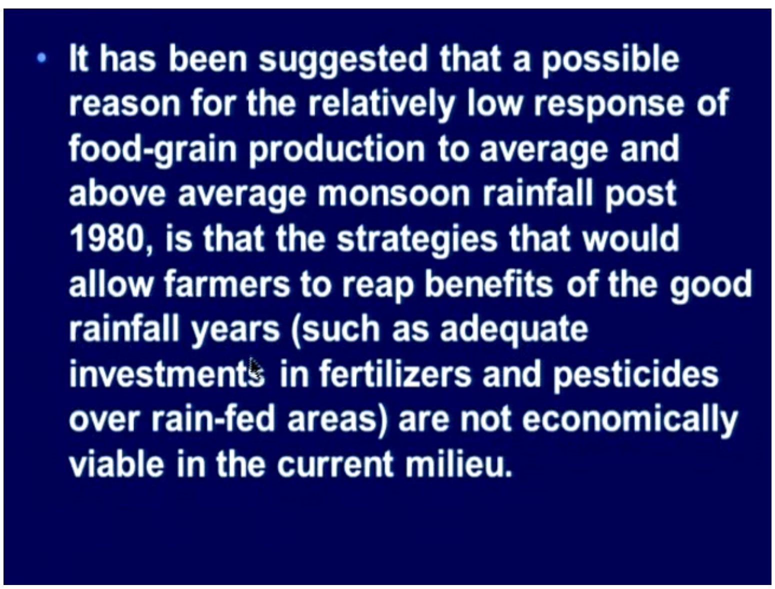

It has been suggested that a possible reason for the relatively low response of food-grain production to average and above average monsoon rainfall post 1980, is that the strategies that would allow farmers to reap benefits of the good rainfall years such as adequate investments in fertilizers and pesticides over rain-fed areas are not economically viable in the current milieu. So why is the response asymmetric?

It has been suggested that in the present current milieu the situation is such that even if the rainfall is good you cannot get good yields unless there is enough investment in fertilizers and pesticides. And farmers are reluctant to make that investment because they do not know that it is going to be a good rainfall year, basically that is the problem.

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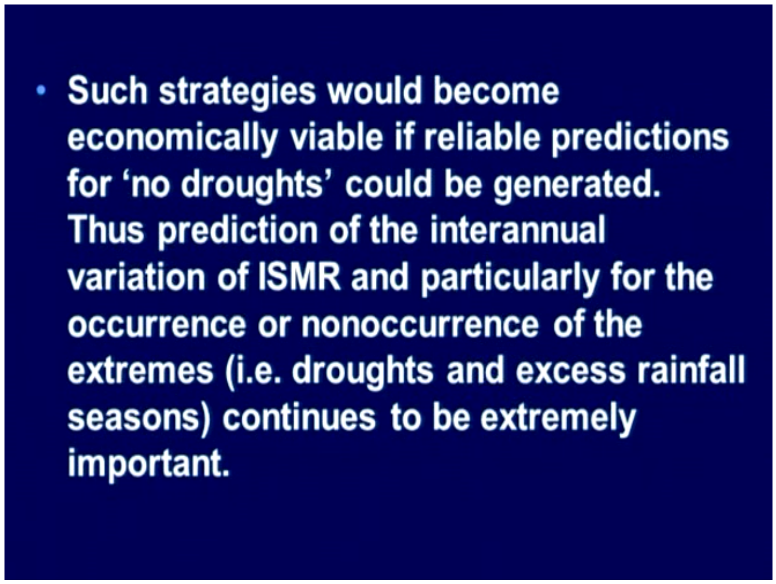

Such strategies would become economically viable if reliable predictions for no droughts could be generated, thus prediction of the interannual variation of ISMR particularly for the occurrence or non-occurrence of the extremes that is droughts and excess rainfall seasons continuous to be extremely important.

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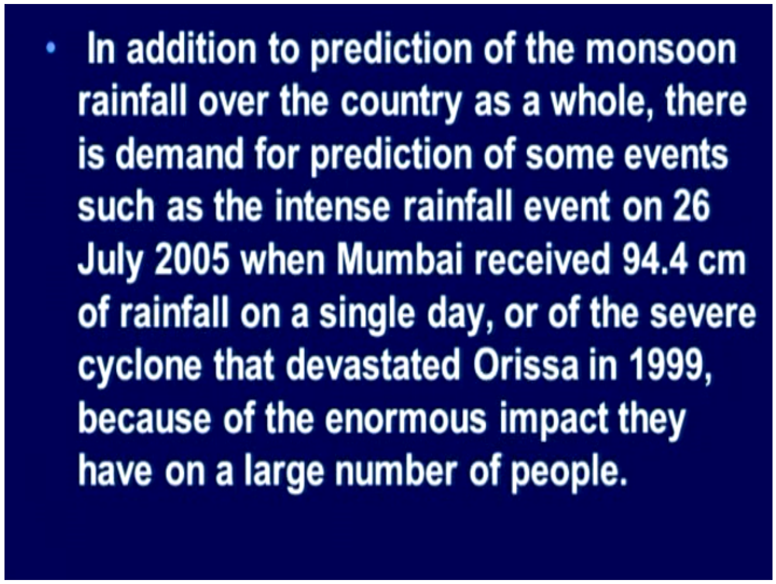

So there has been not surprisingly focus of the monsoon prediction has been on seasonal prediction, prediction of the seasonal rainfall. Now in addition to prediction of the monsoon rainfall over the country as a whole, there is a demand for prediction of some events such as the intense rainfall event on 26th July 2005, when Mumbai received 94.4 centimeters of rainfall on a single day, or of the severe cyclone that devastated Orissa in 1999.

Because of the enormous impact they have on a large number of people, so these are predictions in a much shorter time-scale, for an event which is also of much shorter time-scale, these are also in demand.

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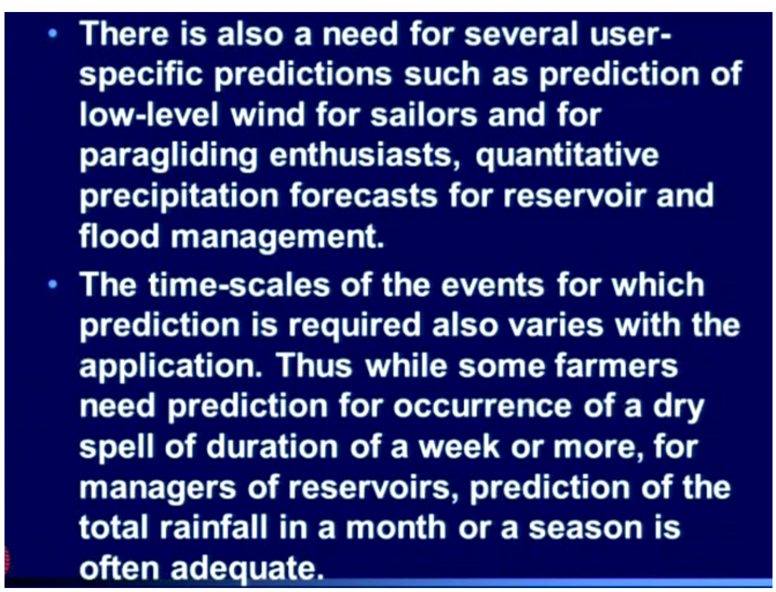

There is also need for several user-specific predictions such as prediction of low-level wind for sailors and for paragliding enthusiasts, quantitative precipitation forecasts for reservoir and flood management and so on. The time-scales of the events for which prediction is required also varies with the application. Thus, while some farmers need prediction for occurrence of a dry spell of duration of a week or more, for managers of reservoir prediction of the total rainfall in a month or a season is often adequate.

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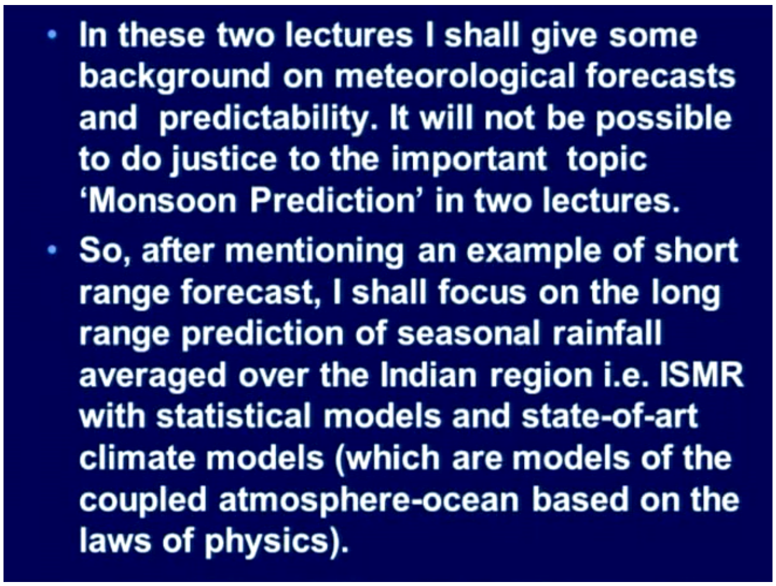

In these 2 lectures, I shall give some background on meteorological forecasts and predictability. It will not be possible to do justice to the important topic of monsoon prediction in 2 lectures, so after mentioning an example of short range forecasts, I shall focus on the long-range prediction of seasonal rainfall averaged over the Indian region that is ISMR with statistical models and state-of-the art climate models which are models of the coupled ocean atmosphere system based on the laws of physics.

So I have to in fact omit many topics which would be of interest simply because this to 2 larger topics to be covered in 2 lectures.

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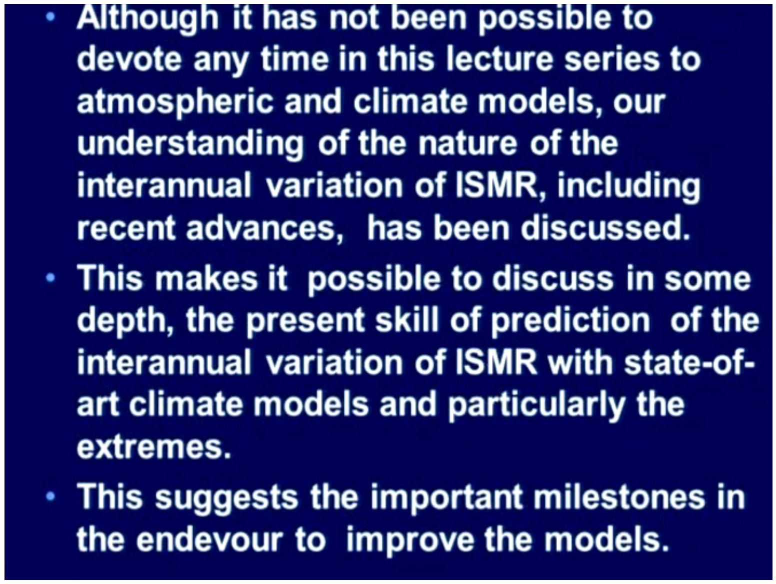

So I must mentioned that although it has not been possible to devote anytime in this lecture series to atmospheric and climate models, our understanding of the nature of the interannual variation of ISMR including recent advances has been discussed in some detail here. So it is now possible to discuss in some depth, the present skills of prediction of the interannual variation of ISMR with state of art climate models.

And particularly prediction of extremes, because you know that is more important prediction of extremes that is to say droughts and excess rainfall season. So with this then this kind of analysis of how good the climate models are in predicting interannual variation of ISMR suggests important milestones that have to be crossed in the endeavor to improve the models to give satisfactory predictions of the monsoon.

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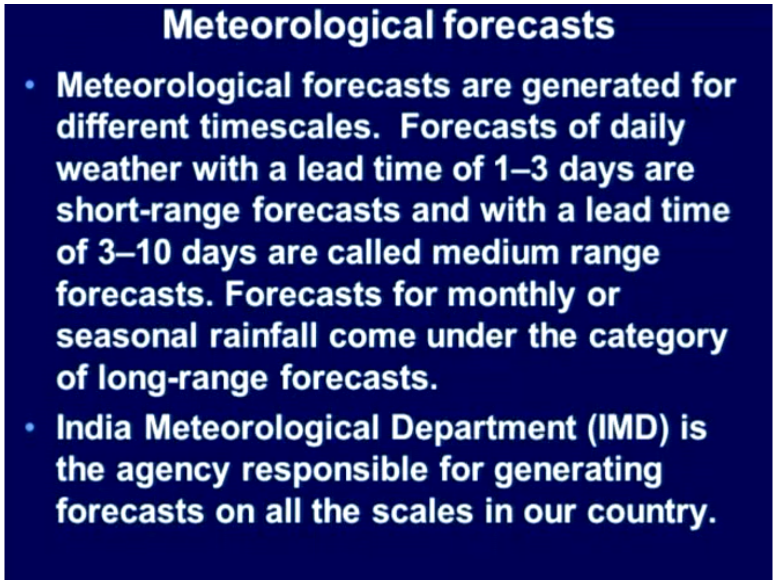

Now so let us begin at the beginning, what are meteorological forecasts? Meteorological forecasts are generated for different time-scales. So forecasts of daily weather with a lead time of 1-3 days are called short-range forecasts, and with a lead time of 3-10 days are called medium-range forecasts, forecasts for monthly or seasonal rainfall come under the category of long-range forecasts. So depending on the time-scale we have forecasts which are short-range, medium-range and long-range.

India Meteorological department IMD is the agency responsible for generating forecasts on all the time-scales in our country, but I must also mentioned that there is a Centre, National Centre for medium-range weather forecasting which does a lot of research on models which can generate forecasts on the medium-range.

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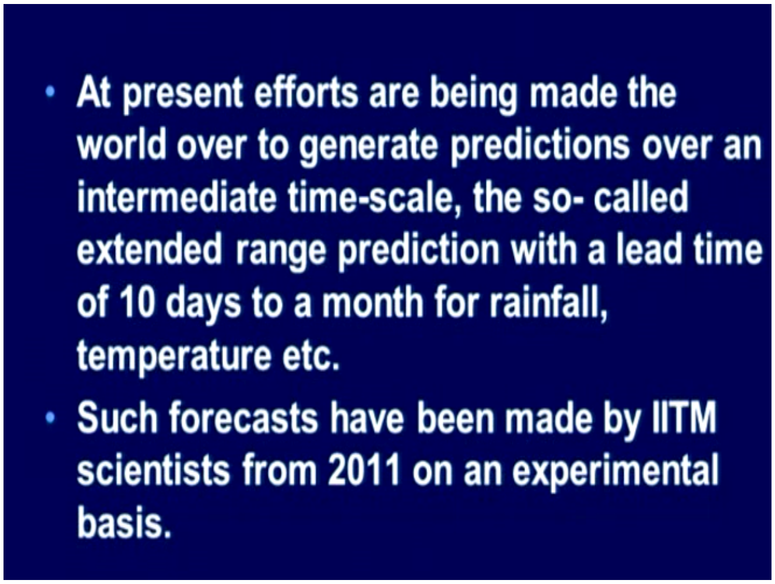

Also at present the efforts are being made the world over to generate predictions over an intermediate time-scale, the so-called extended range prediction with a lead time of 10 days to a month, so this is between medium-range and long-range for rainfall, temperature etc. in fact such extended days predictions have been made by IITM scientists from 2011 that is for the past 2 years and going on for this year as well on an experimental basis.

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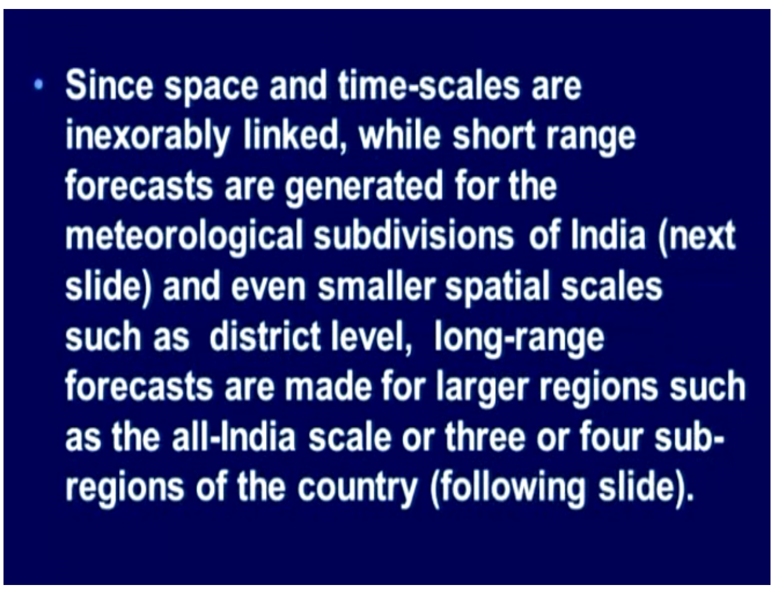

Now space and time-scales are inexorably linked, so while short range forecasts are generated for the meteorological subdivisions of India which are given here.

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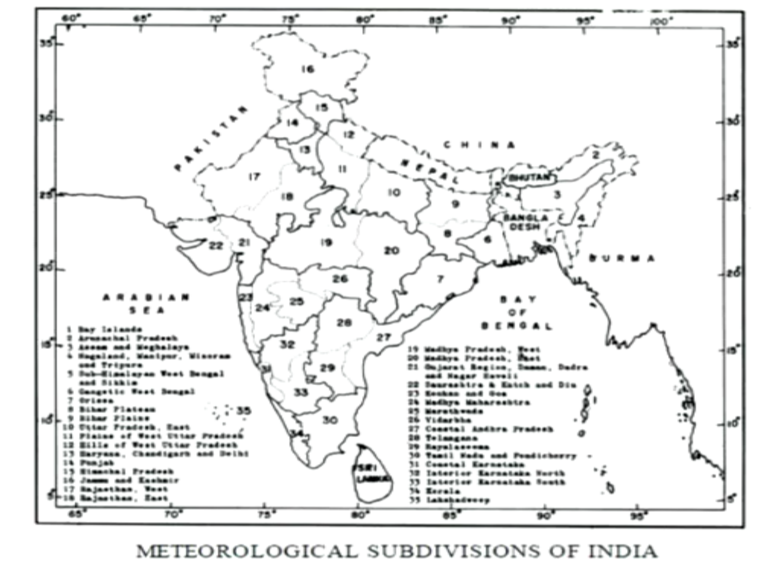

METEOROLOGICAL SUBDIVISIONS OF INDIA

These are the meteorological subdivisions of India, and even smaller spatial scales such as district level and so on, long-range forecasts are made for large regions such as the all-India scale or 3 or 4 subdivisions of the country. So this is for the short range.

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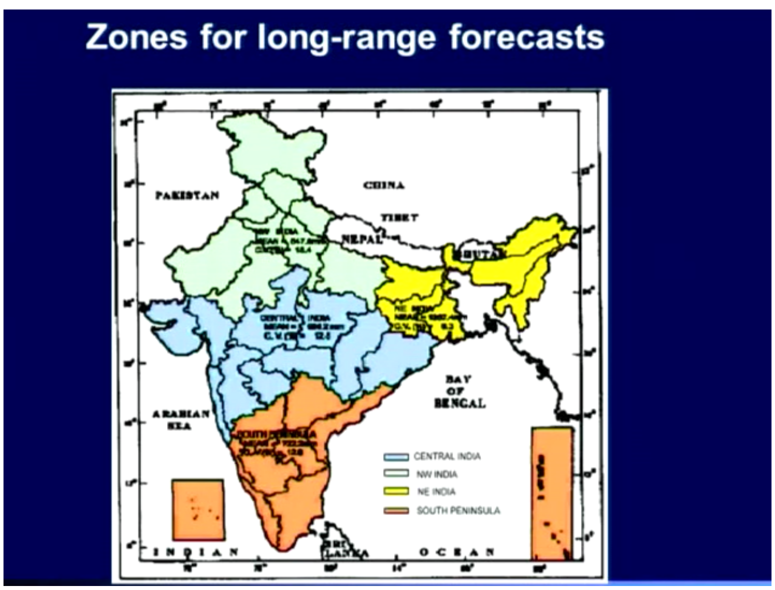

And for long-range these are zones over which India Met Department generate forecasts, in addition to the all-India scales okay.

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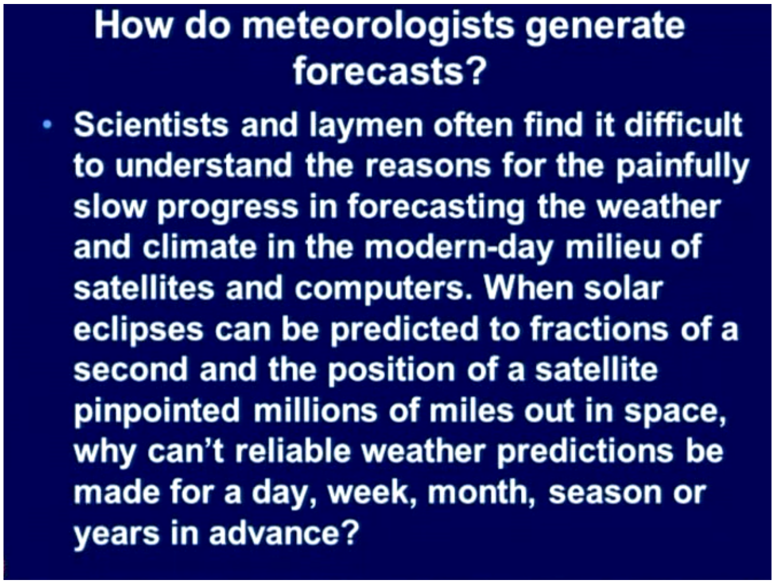

Now how do meteorologists generate forecasts? Scientist and laymen often find it difficult to understand the reasons for painfully slow progress in forecasting the weather and climate in the modern-day milieu of satellites and computers. When solar eclipses can be predicted to fractions of a second and the position of a satellite pinpointed millions of miles out in space, why cannot reliable weather predictions be made for a day, a week, a month, a season or a years in advance? See this is a question that is often posed by laymen, the meteorologist.

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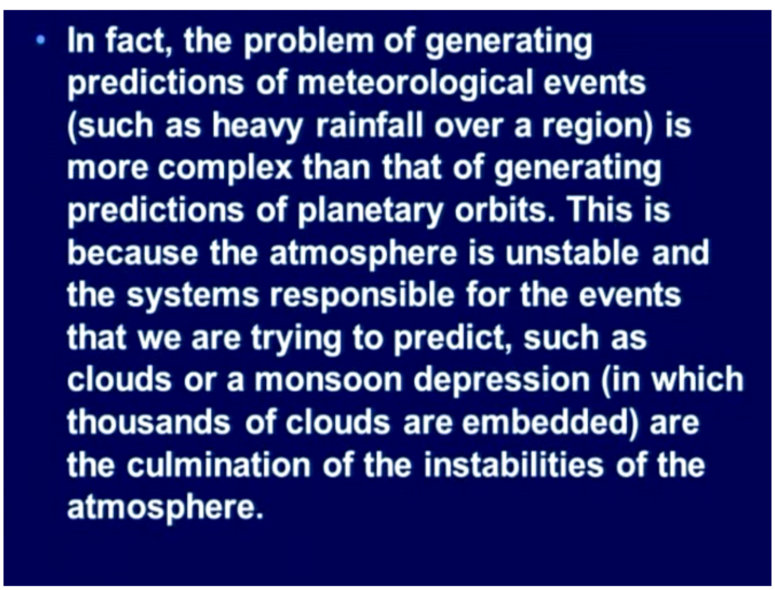

In fact, the problem of generating predictions of meteorological events such as heavy rainfall over a region is more complex than that of generating predictions of planetary orbits. This is because the atmosphere is unstable, and the system responsible for the events that we are trying to predict such as clouds or a monsoon depression in which 1000s of clouds are embedded are the culmination of the instabilities of the atmosphere.

We have actually seen this, in this course how the systems that are responsible for rainfall are actually culminations of instabilities of the atmosphere. So by its very nature, these systems are different from the stable systems which characterized planetary orbits.

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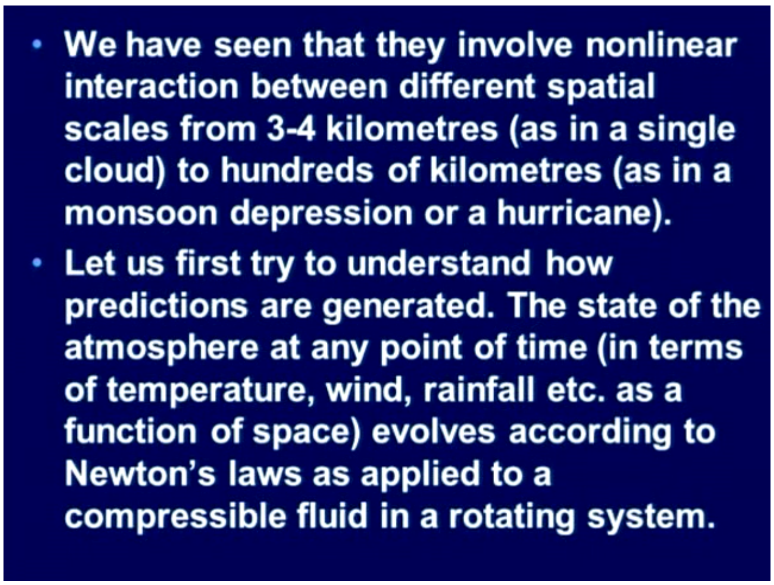

Now we have sent that they involve nonlinear interaction between different spatial scales from 3 to 4 kilometers as in a single cloud to 100 of kilometers as in a monsoon depression or hurricane, so this is what makes the problem of weather or climate prediction, inherently more complicated than that of prediction of planetary orbits. Let us first try to understand how predictions are generated.

The state of the atmosphere at any point of time in terms of temperature, wind, rainfall etc. as a function of space evolves according to Newton's Law as applied to a compressible fluid in a rotating system.

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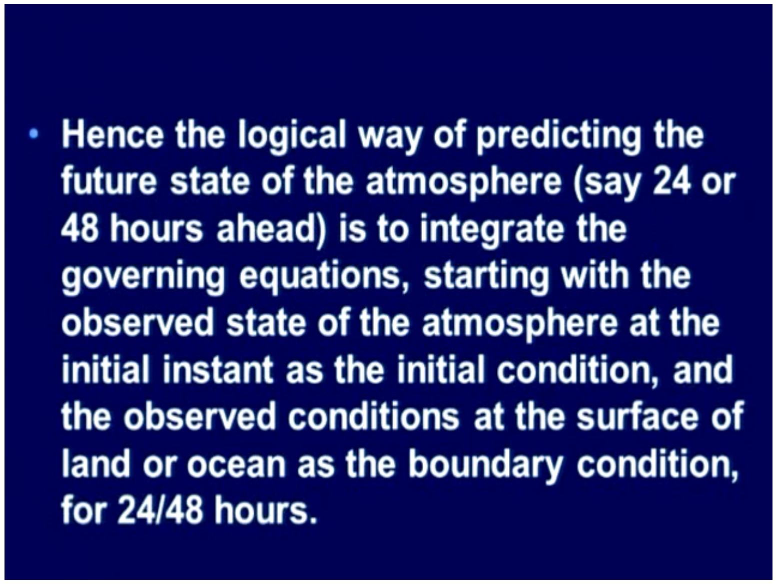

Hence the logical way of predicting the future state of atmosphere say 24 or 48 hours is to integrate the governing equations starting with the observed state of the atmosphere at the initial instant as the initial condition, and the observed conditions at the surface of land or ocean as the boundary condition for 24 or 48 hours as required. So this is the logical way we have laws, which tell you how things will change with time.

So you start with an initial condition from observations and integrate those equations governing equation derived from the laws to tell you what the next date would be say 24 hours or 48 hours ahead, which may come after several time steps in the numerical integration of course.

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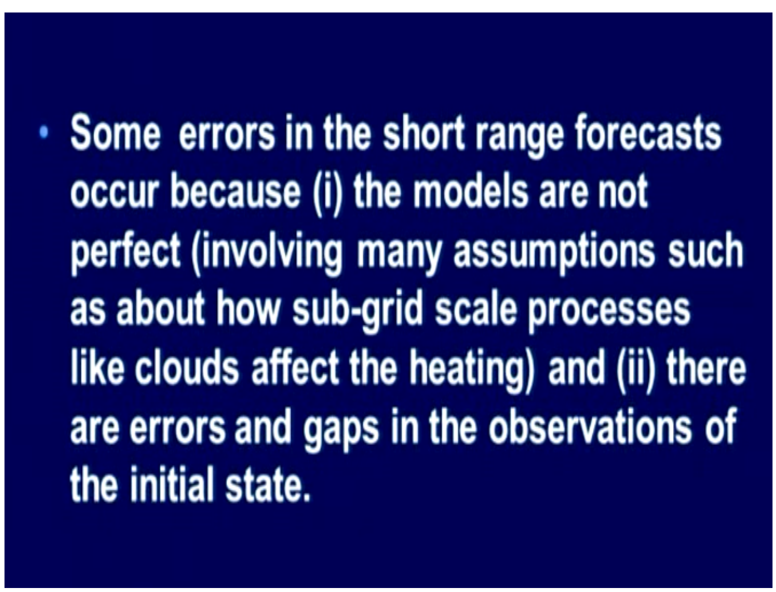

Now some errors in the short range forecasts occur, because the models are not perfect you know the models involved many assumptions such as about how the sub-grid scale processes like clouds affect the heating. See the typical grid size of a model is of the order of 100 kilometers, although now much higher resolution models are being developed. Whereas the cloud scale is a few kilometers, so cloud is necessarily sub-grid scale phenomena.

And how to incorporate the effects of the clouds in terms of special variables which vary over the grid scale is a very important problem, this is what is called parameterization, and these parameterizations involved many assumptions which means that the models are not perfect in this respect, also there are large errors and gaps in the observations of the initial state. So first of all the models are not perfect, secondly, the observations are not perfect in giving the kind of initial conditions that is demanded, so these are 2 elements that cause error.

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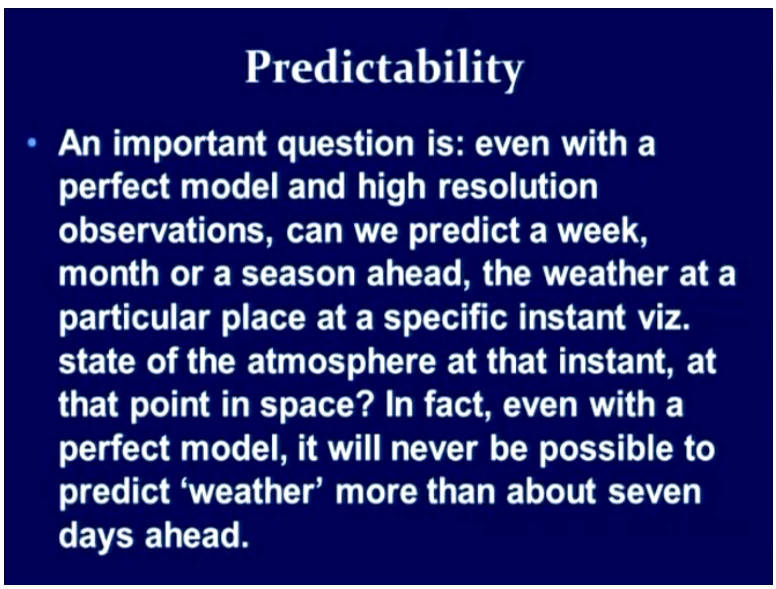

But there is even a more fundamental event that comes in, and Lorenz was the first who elucidate this, and this is the predictability of the atmosphere. See an important question is, even with a perfect model and high resolution observations, can be predict a week, month or a season ahead, the weather at a particular place at a specific instant namely the state of the atmosphere at that instant at that point in space?

So even with the perfect model can we predict say a certain time period ahead say a week, month or season. The weather at a particular place say Bangalore at the specific instant namely this implies that can we actually say what the state of the atmosphere would be at a specific instant, at a specific point in space. In fact, even with the perfect model, it will never be possible to predict weather more than about 7 days ahead. So there is an inherent limit to predictability of weather.

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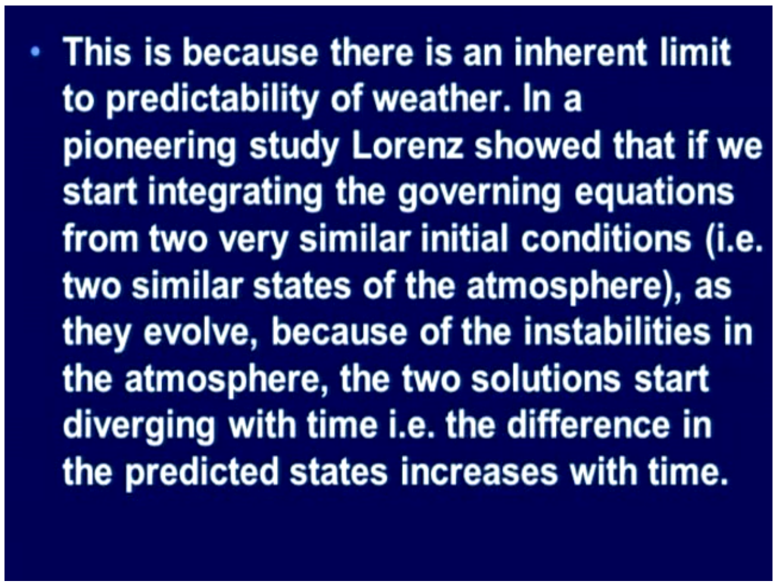

And this is because there is an inherent limit to predictability of weather, in a pioneering study Lorenz showed that if we start integrating the governing equations from 2 very similar initial conditions that is to say we take an initial condition and take a second initial condition which is only very little different from the other in the face space of meteorological variables. So if you start with very very similar states if the system was stable than the solution would stay close throughout.

However, in the atmosphere not being stable, when we start from 2 very similar initial conditions as they evolve because of the instabilities of the atmosphere, those 2 solutions start diverging with the time, so they go on going further and further apart with time and the difference in the predicted states increases with the time. So this is what is called you know sensitive dependence on initial conditions, which is a property of the atmosphere which arises due to the presence of instabilities.

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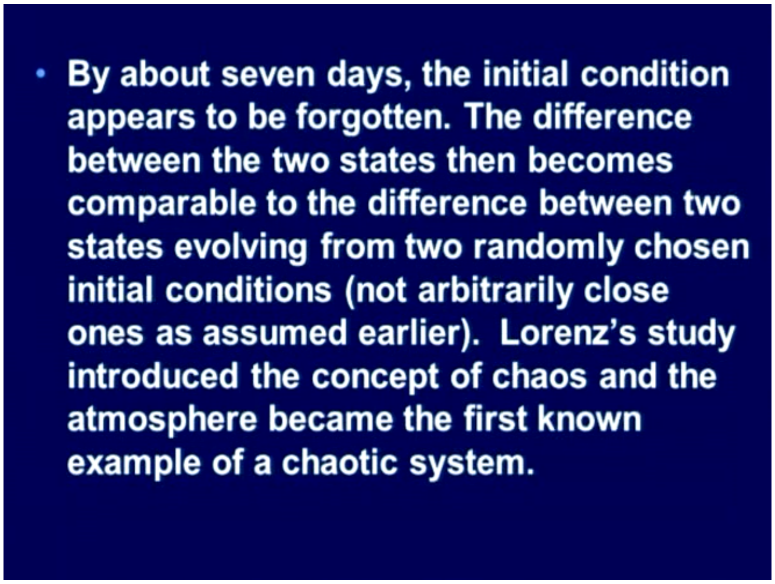

By about 7 days the initial conditions appear to be forgotten, the difference between the 2 states then become comparable to the difference between 2 states evolving from 2 randomly chosen initial conditions. So what is happening is by about 7 days, the atmosphere does not remember the initial conditions at all. And Lorenz's study introduced the concept of chaos, and the atmosphere become the first known example of a chaotic system.

So this is what happens in the chaotic system, the 2 states which are initially close become after period of time in the case of the atmosphere about 7 days as far apart as states which have evolve from 2 random initial conditions which are not at all close. So this is the chaos that you see in the atmosphere.

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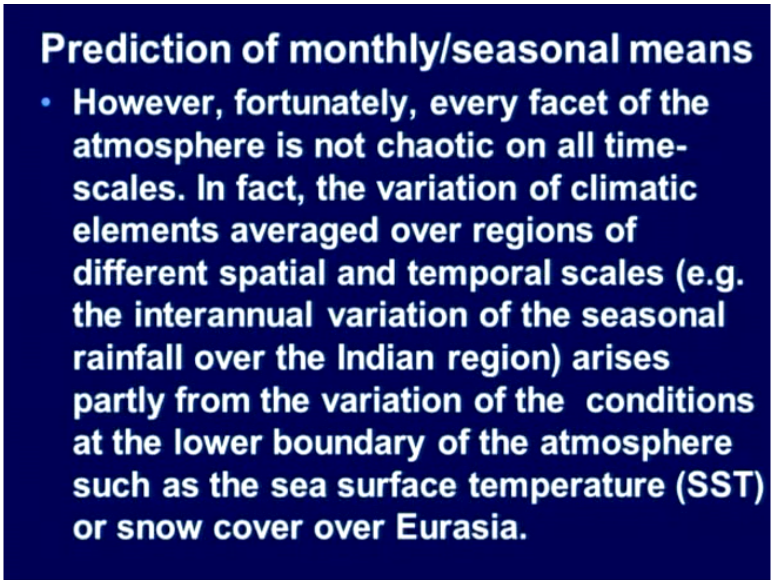

So there is an inherent limit of prediction of the atmosphere therefore, you can never ask for say rainfall at Bangalore on 16th of July 2014, it is a foolish question to ask because it is way beyond the limits of predictability. But what you can ask is something else, prediction of monthly and seasonal means. So although weather is inherently unpredictable beyond about a week fortunately every facet of the atmosphere is not chaotic on all time-scales.

In fact, the variation of climatic elements averaged over regions of different spatial and temporal scales, example the interannual variation of the seasonal rainfall over the Indian region, so here is rainfall averaged over a fairly large scale region the Indian region, and over time as well from June to September. Now the variation of this beast, which we are tested in ISMR arises partly from the variation of conditions at the lower boundary of the atmosphere such as the sea surface temperature or snow cover over Eurasia.

So part of the variation is actually driven by boundary forcing, sea surface temperature when the atmosphere is over the ocean, or conditions like snow cover over Eurasia, or land surface conditions over other parts of land.

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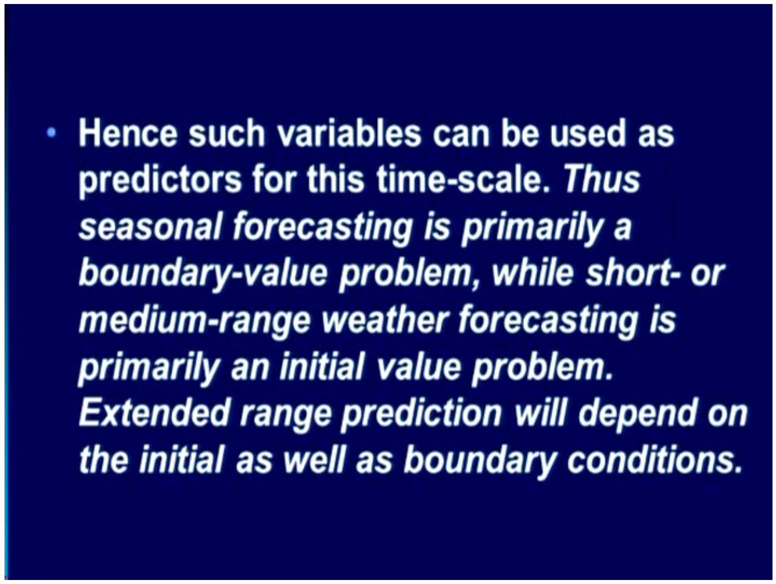

Hence such variables can be used as predictors for this time-scales. Thus, seasonal forecasting is primarily a boundary-value problem, although even when doing seasonal forecasting with model some initial conditions have to be specified, but the signal comes from the boundary forcing when it comes to seasonal scales. So seasonal scale forecasting is a boundary-value problem, while short-or medium-range weather forecasting is primarily an initial value problem.

Extended range prediction is between and it will depend on initial as well as boundary conditions.

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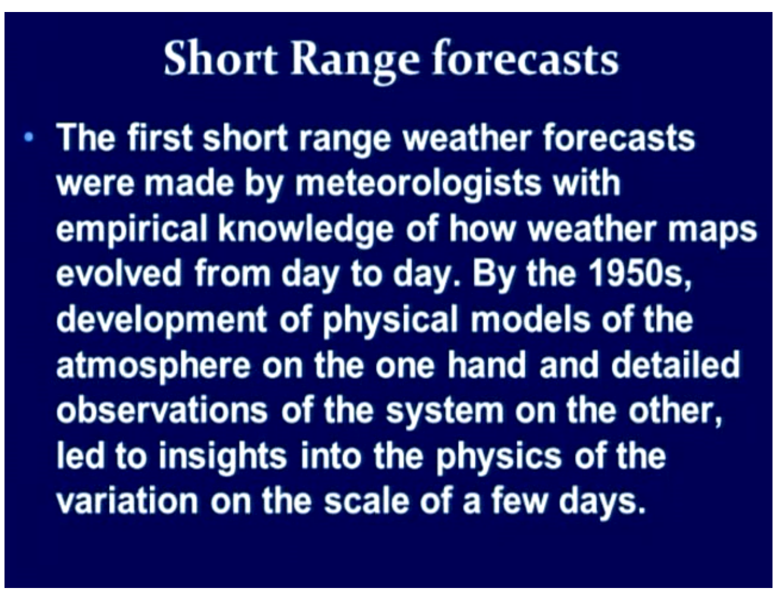

So this is the general introduction to forecasts, now let me give an example of short range forecasts. See the first short range forecasts were made by meteorologist with empirical knowledge of how weather maps evolved from day to day. So in the old days before we started having numerical models to integrate and give us the state of the atmosphere which is predicted from the initial condition, what meteorologist had were weather maps.

And they knew by looking at the whole series of weather maps, how systems and the weather maps evolved, and this empirical knowledge was translated into methods for prediction. So by 50s development 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.

So initially it was natural understanding of how weather charts evolved, and then we have development of physical models, and detailed solutions which gave insights into the critical physics of the important weather phenomena.

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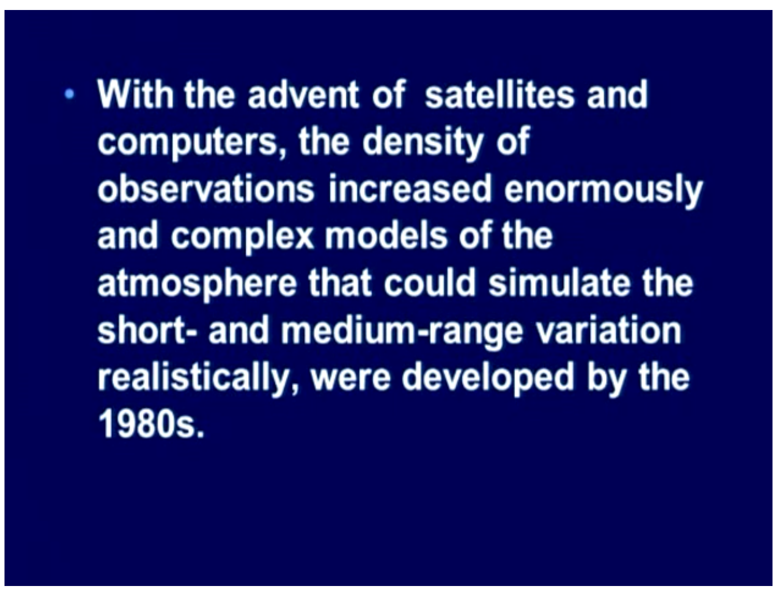

So with the advent of satellites and computers, the density of observations increased enormously and complex models of the atmosphere that could simulate the short-and medium-range variation realistically, were developed by the 1980s.

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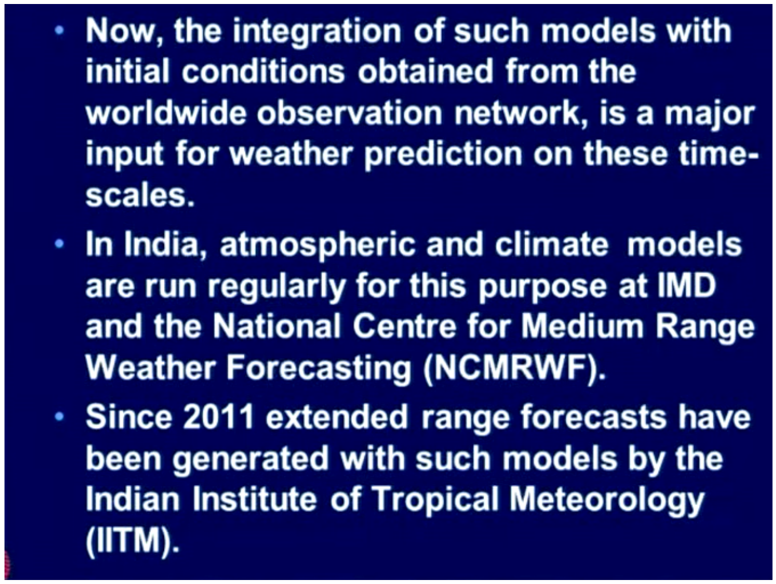

Now the integration of such models with initial conditions obtained from the worldwide observation ne2rk, is a major input for weather prediction on this time-scales. In India atmospheric and climate models are run regularly for this purpose at IMD and the National Centre for Medium-Range Weather Forecasting NCMRWF. Since 2011 as I mentioned before extended range forecasts have been generated with such models by the Indian Institute of tropical meteorology IITM.

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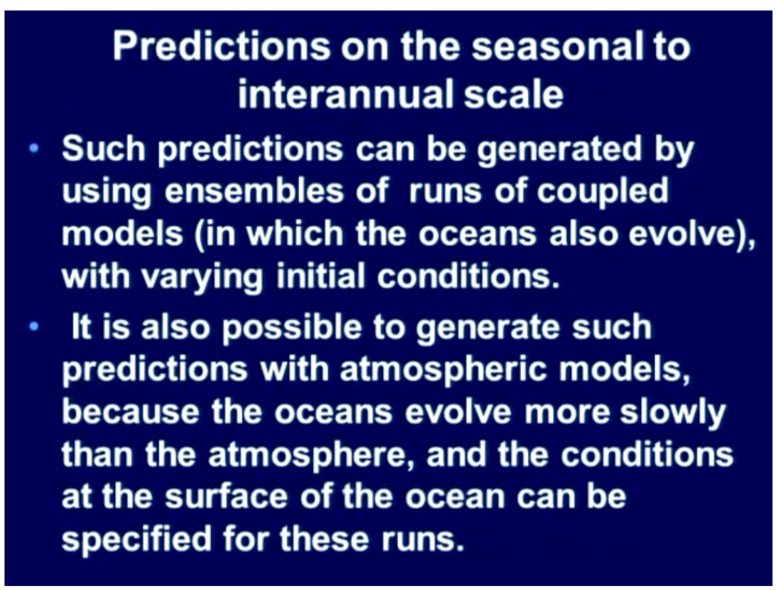

Now predictions on the seasonal to interannual scale, there are 2 ways by which these predictions can be made. Such predictions can be generated by using ensembles of runs of coupled models in which oceans also evolve with varying initial conditions. It is also possible to generate such predictions with atmospheric models, and why is that? Because the oceans evolve more slowly than the atmosphere.

So the conditions at the surface of the ocean can be specified and atmospheric models can be run to get a prediction of the atmospheric conditions on the seasonal scale.

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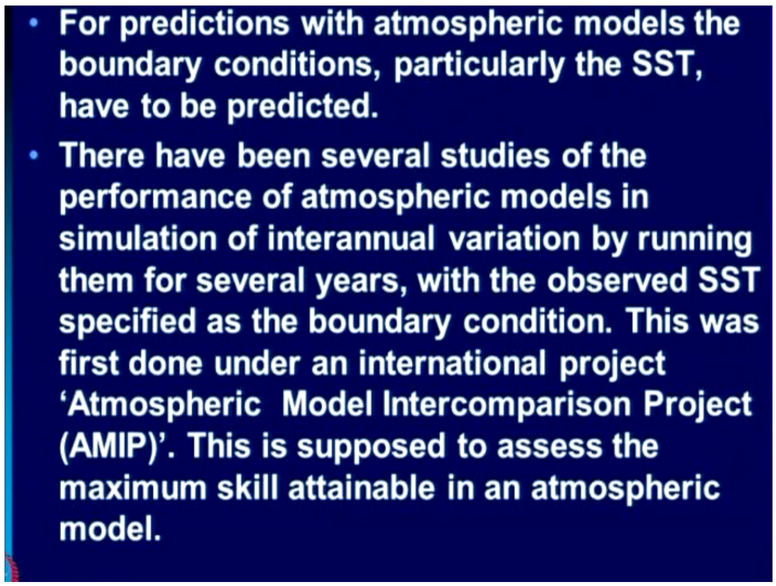

For predictions with atmospheric models the boundary conditions particularly the SST sea surface temperature have to be predicted. Now there have been several studies of the performance of atmospheric models in the simulation of a interannual variation by running them for several years with observed SST specified as the boundary condition. So what has been done is to actually specify the observed SST for a set of years which are obviously, past years several years and run the atmospheric model.

This was first done under an international project Atmospheric Model Intercomparison Project AMIP, this is supposed to assess the maximum skill attainable in an atmospheric model.

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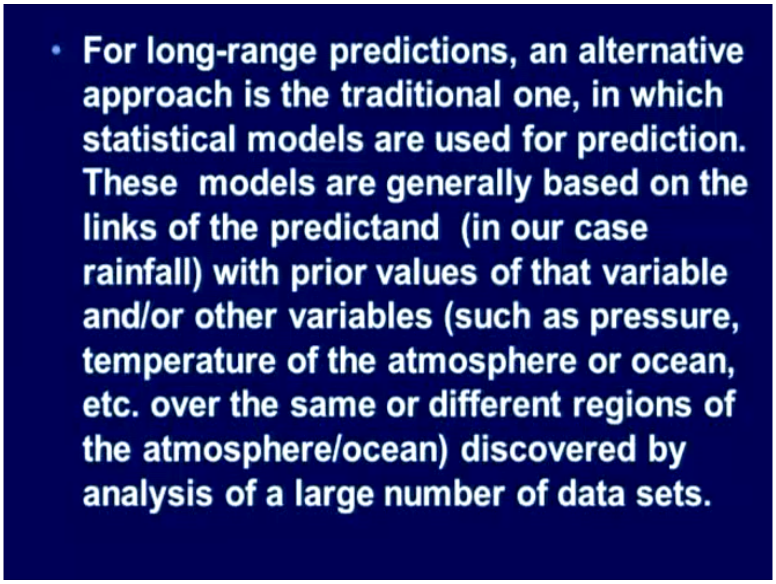

For long-range predictions, an alternative approach is the traditional one, in which statistical models are used for prediction, just like in the earlier short range predictions also, and statistical models based on empirical knowledge of how weather charts evolve were used. Now for long-range predictions an alternative approach is the one, in which statistical models are used for prediction.

So what are these models based on? These models are based on the links of the predictand what we want to predict in this case rainfall with prior values of that variable, in other words with prior values of rainfall and or other variables such as pressure, temperature of the atmosphere or ocean etc. over the same or different regions of the atmosphere-ocean discovered by analysis of a large number of datasets. So this involves looking at large number of datasets and trying to discern links with some quantities prior to what we want to predict.

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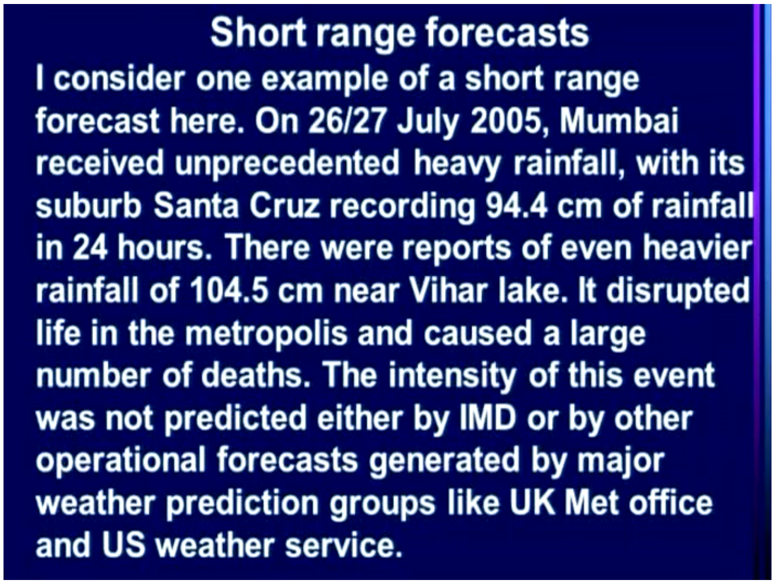

So this is the general background of short range and long-range forecasts. Now let me give an example only one example of a short range forecasts, and this is the event on 26-27 July in 2005, in Mumbai when it received unprecedented heavy rainfall, with its suburb Santa Cruz recording 94.4 centimeters of rainfall in 24 hours. And there were reports of even heavier rainfall of 104.5 centimeters near Vihar Lake.

So this was the very intense rainfall, it disrupted life in the metropolis and caused a large number of deaths. The intensity of this event was not predicted either by IMD or by other operational forecasts generated by major weather prediction groups like UK Met office, US weather service and so on, so none of them really predicted the intensity of this event.

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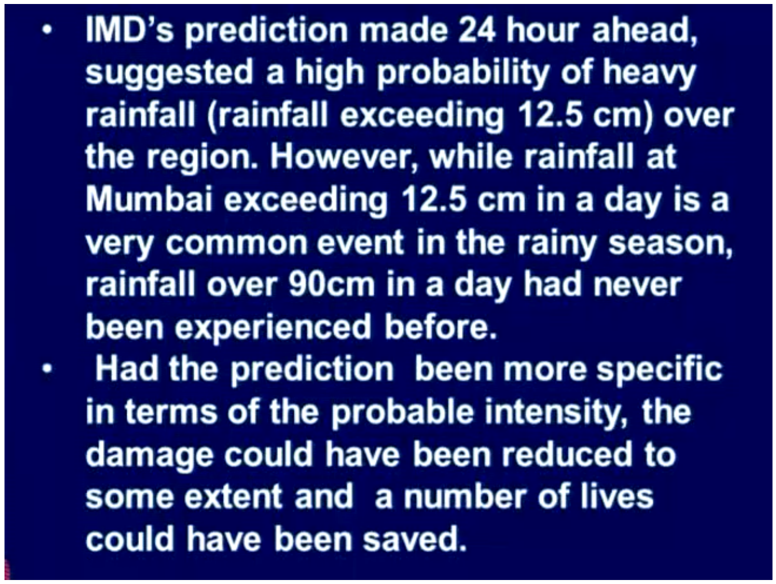

IMD's prediction mad 24 hours ahead, suggested a high probability of heavy rainfall, rainfall exceeding 12.5 centimeters over the region. However, while rainfall at Mumbai exceeding 12.5 centimeters in a day is a very common event in the rainy season, rainfall over 90 centimeters in a day had never been experienced before. So certainly they did predict that there will be heavy rain, but they could not at all assess or predict the actually intensity of the rain event that occur.

Had the prediction been more specific in terms of the probable intensity, the damage could have been reduced to some extent and a number of lives could have been saved.

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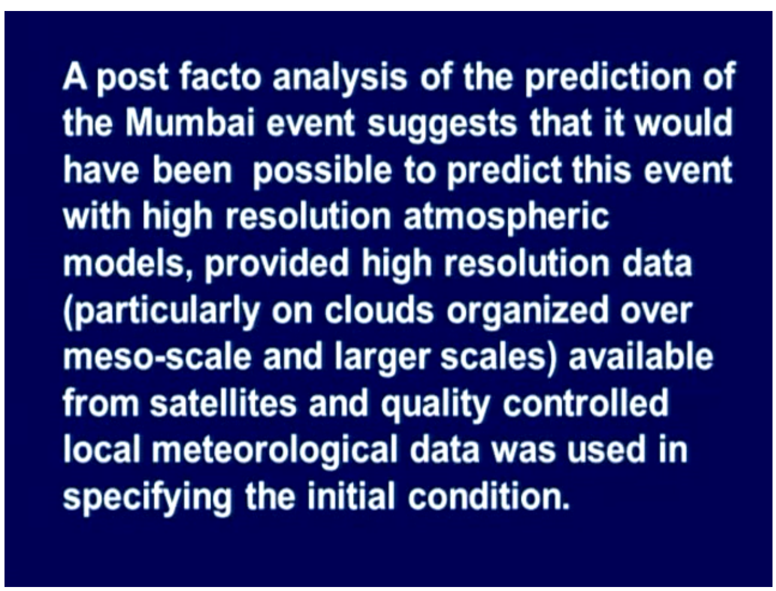

Now a post facto analysis of the prediction of the Mumbai event suggests that it would have been possible to predict this event with high resolution atmospheric models, so this means with a grid size which is smaller than the usual 2.5 degree, which is 250 kilometers or 100 kilometer much smaller grid that is high resolution atmospheric model provided high-resolution data on clouds, particularly on clouds organized over meso scale and large scales available from satellite and quality control local meteorological data was used in specifying the initial condition.

So both are important, see the initial condition has to be accurately specified, particularly in terms of the clouds and cloud systems that occur in the initial condition, and that satellite is the only way one can get high resolution input on that, and resolution as well as over a large spatial scales. And the second is to run the models also with high resolution.

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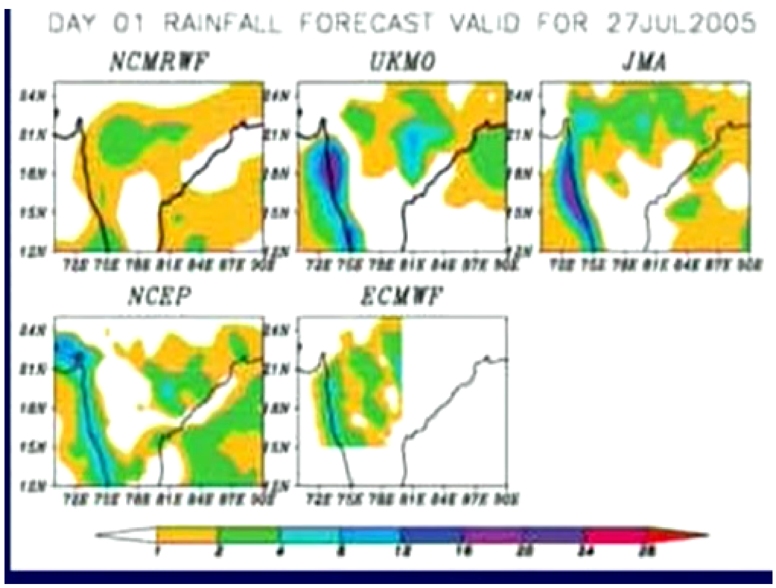

If both those were there then one would get the rain. And this is just an example you can see yellows and greens mean not very high rain 2 centimeters, and 4 centimeters and so on, and this is the NCMRWF model. This is the UK Met office model, UK Met office is at least getting good rain but it is still of the order of only 12 or 14 centimeters over Mumbai. JMA is also getting rain but more spread out. And NCEP is not getting much of rain over west coast and neither ECMWF.

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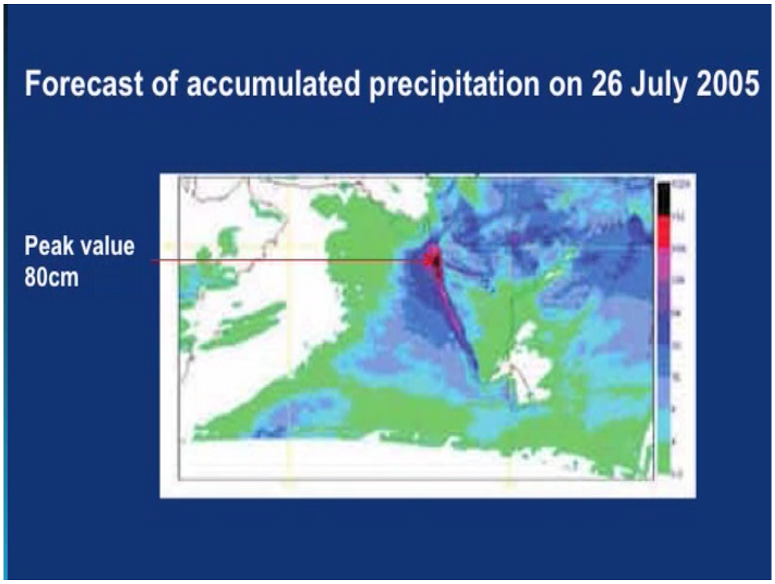

However, if we now actually specify the initial conditions properly and run a high resolution model then a peak value of about 80 centimeters can be predicted, so 80cm is pretty close to 90 centimeters, so I had the forecasts been made for this one would have been much better prepared. So what this tells us is that if we want to predict events of this kind in advance in the reliable manner, it is essential to assimilate satellite data of high resolution into the initial condition.

And also essential to run models with very high resolution, which take into account the topography also in high resolution grid, because you know the near the Western Ghats topography also plays an important role in the dynamics okay.

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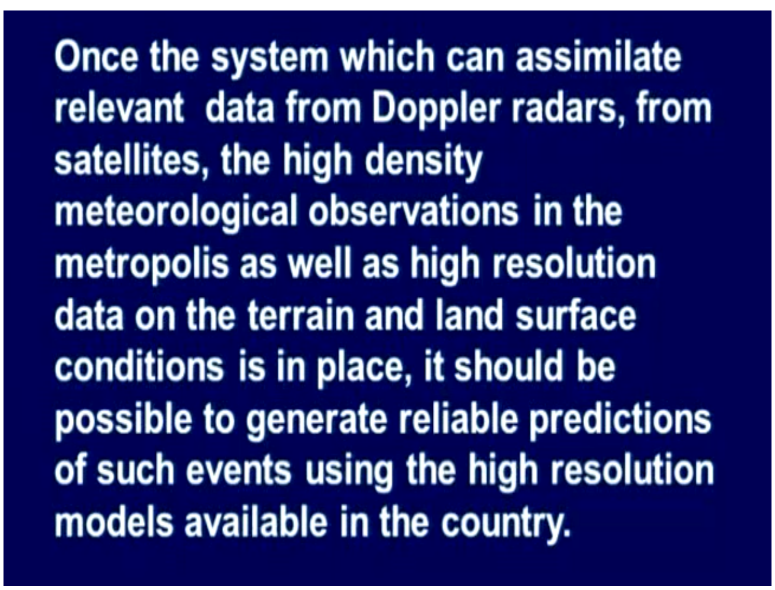

Once the system which can assimilate relevant data from Doppler radars, from satellites, high-density meteorological observations in the metropolis as well as high resolution data on the terrain and land surface conditions is in place, it should be possible to generate reliable predictions of such events using the high resolution models available in the country. So this is in way post facto analysis which leads to optimism that we should be able to harness our resources and generate reasonable prediction of intense rainfall events.

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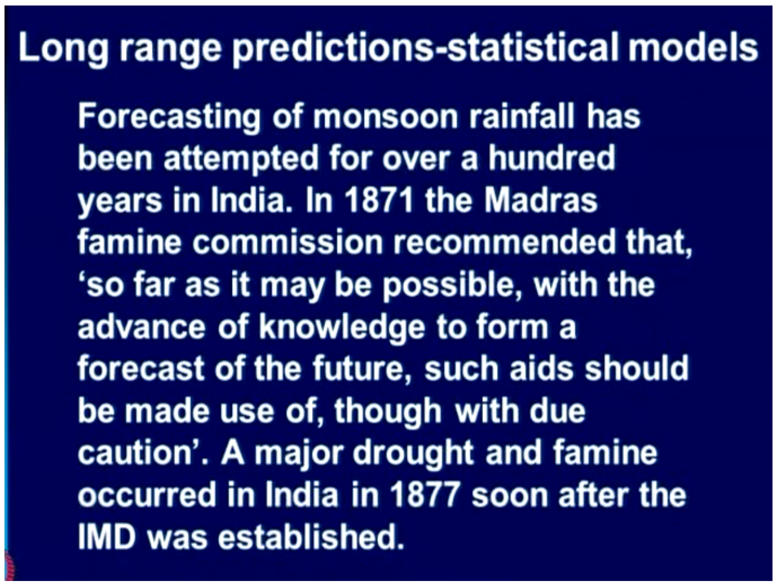

Now let us consider long-range predictions, and in this lecture I will only consider the statistical models, in the next lecture I will discuss how the climate models of the state of art coupled atmosphere-ocean models systems performed in predictions of the monsoon. So forecasting of monsoon rainfall actually has a very long history over India. It has been attempted for over 100 years, in 1871 the Madras famine commission recommended that, so far as it may be possible.

With the advance of knowledge to form a forecasts of the future, such aids should be made use of though with due caution, this is the comment from Madras famine commission. And a major drought and famine occurred in India in 1877 and soon after that the Indian Meteorological Department was established.

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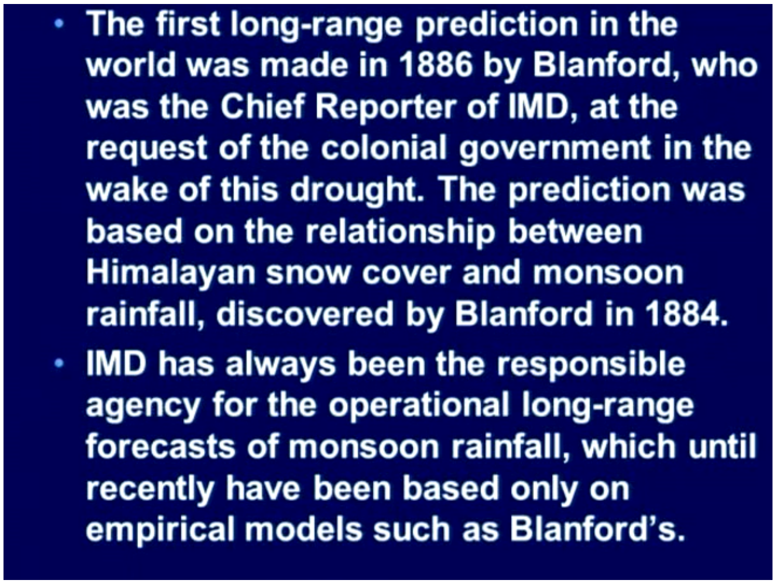

The first long-range prediction in the world was made in 1886 by Blanford, who pioneering contributions to our understanding of monsoons we have already this in the earlier lectures, but even in terms of prediction, he was the first to make prediction. Blandford, who was the chief reporter of IMD at the request of colonial government in the wake of this drought. The prediction was based on the relationship between Himalayan snow cover and monsoon rainfall discovered by Blandford in 1884.

So Blandford had found that the snow covers over Himalaya if it is in excess in winter than the monsoon will be weaker, and this relationship was used by him to predict. Now IMD has always been the responsible agency for the operational long-range forecasts of monsoon rainfall, which until recently have been based only on empirical models such as Blandford's.

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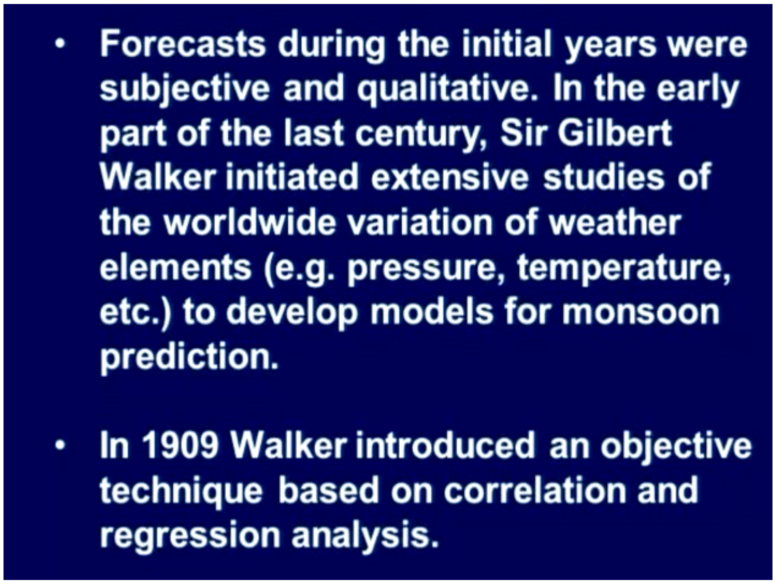

Forecasts during the initial years were subjective and qualitative. In the early part of the last century sir Gilbert Walker, whom we have met earlier when we discussed of course the El Nino and southern oscillation as well as of course Walker circulation over the Pacific, which was so named by Bjerknes. So sir Gilbert Walker, who has become more famous for the most exciting phenomena in tropics perhaps and so.

Actually initiated extensive studies of the worldwide variation of weather elements pressure, temperature etc. to develop models for monsoon prediction. In 1909 Walker introduced and objective technique based on correlation and regression analysis.

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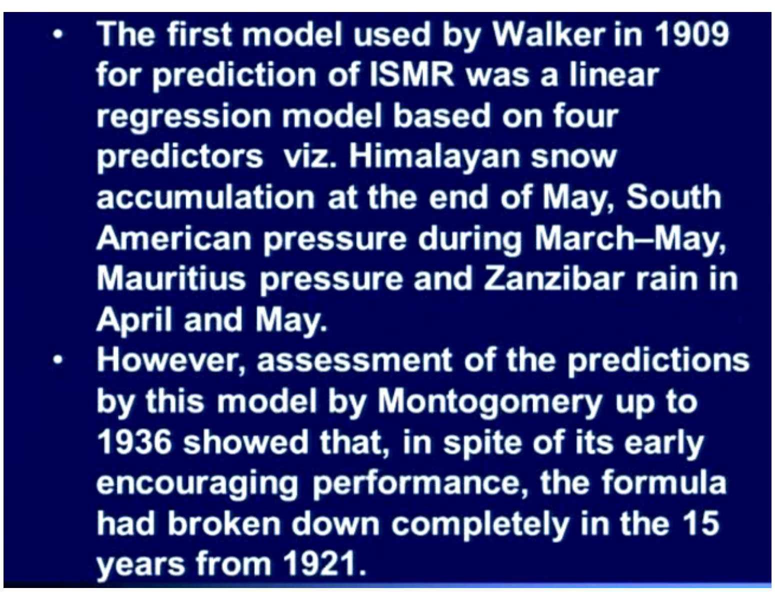

The first model used by Walker in 1909 for prediction of ISMR was a linear regression model based on 4 predictors, and you can see how much data they looked at to discover this predictors, because it was based on Himalayan snow accumulation at the end of May, and South American pressure during March to May, Mauritius pressure and Zanzibar rain in April and May.

So amongst all this rainfall and pressure variations and snow variations that he looked at he found these 4 variables are related to the subsequent monsoon, and he actually predicted using that model. However, assessment of the predictions by this model by Montogomery up to 1936 showed that, in spite of its early encouraging performance, the formula had broken down completely in the 15 years from 1921.

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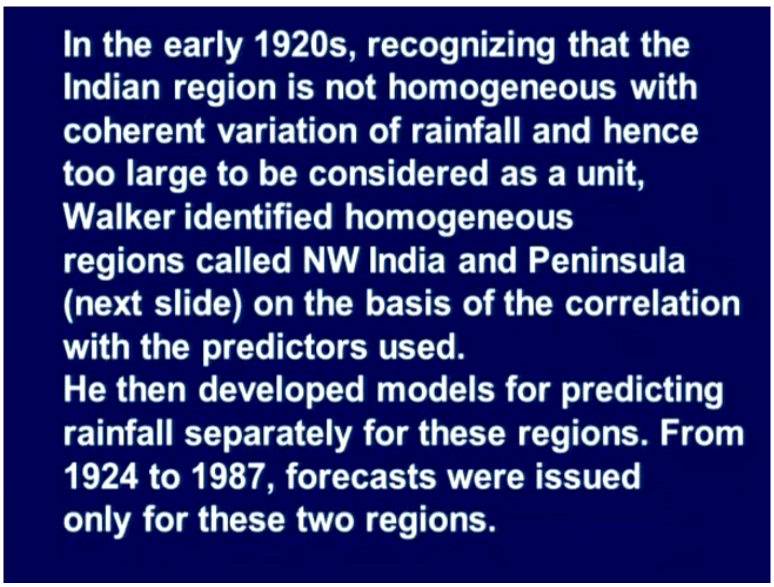

In the early 20s recognizing that the Indian region is not homogenous with coherent variation of rainfall, and hence too large to be considered as a unit, Walker identified homogeneous regions called northwest India and Peninsular on the basis of correlation between predictors used.

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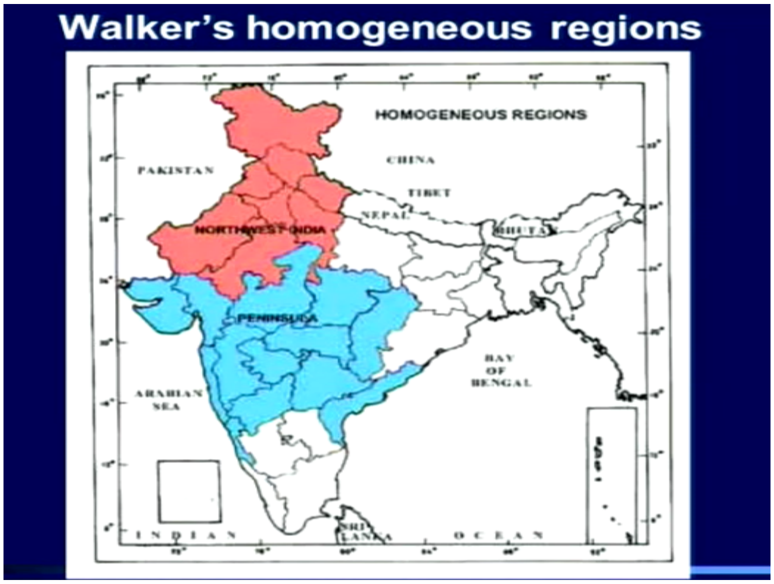

So he did it in a very logical way, suppose you are using a predictors say the southern oscillation index, then you correlate that southern oscillation index with the rainfall over the regions, and then you if you find that this region has correlation of a certain kind and these regions has a correlation of a different kind, then these regions can be considered as homogenous with respect to correlation with the predictor, so that is how he defined these homogeneous regions.

And he then developed models for predicting rainfall separately for these regions, from 1924 to 1987 forecasts were issued only for these 2 regions. So only for these 2 regions of course the name is bit peculiar because he calls this region, which is sort of northern part of Peninsula as Peninsula leaving the southern Peninsula totally out of it, and northwest India including Jammu and Kashmir is called northwest India, these were Walker regions though.

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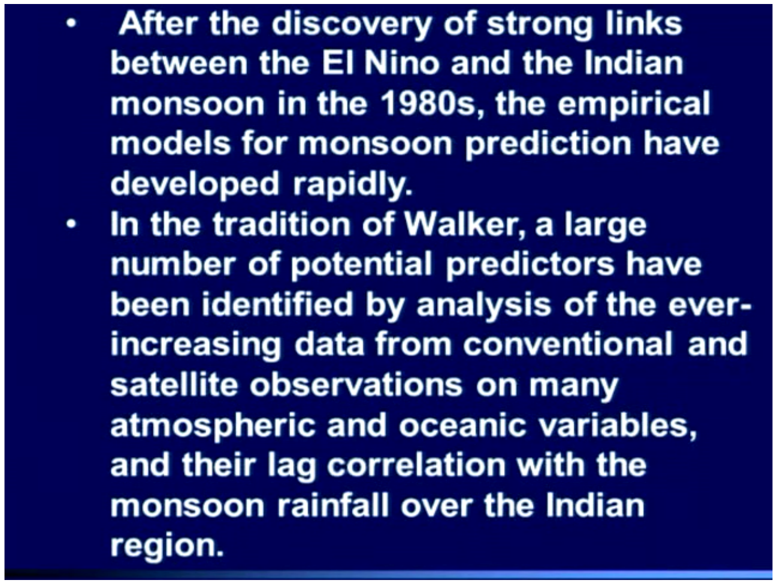

After the discovery of strong links between El Nino and Indian monsoon in the 80s with work by Shikara (()) (35:06) and so on, the empirical models for monsoon prediction have developed very rapidly which is not surprising. In the tradition of Walker, a large number of potential predictors have been identified by analysis of the ever increasing data from conventional and satellite observations on many atmospheric and oceanic variables, and they lag correlation with the monsoon rainfall over the Indian region.

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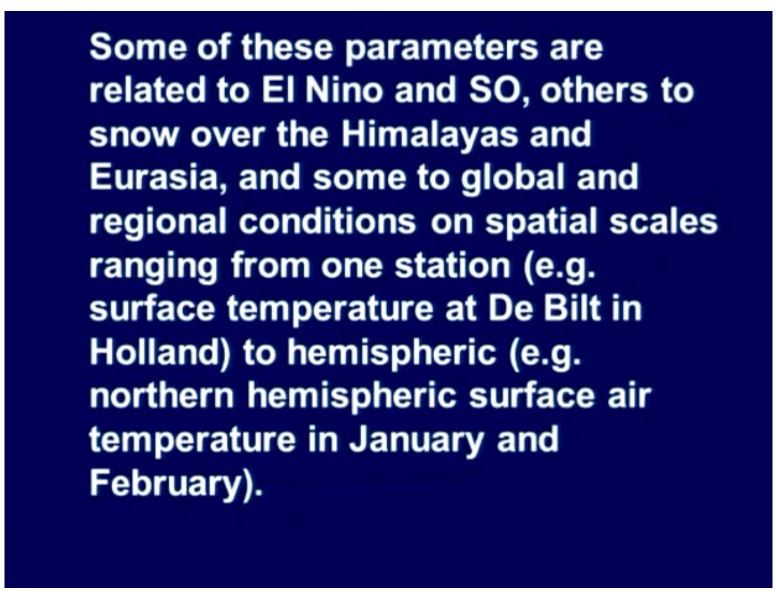

Some of these parameters are related to El Nino and southern oscillation, others to snow over Himalayas and Eurasia, and some to global and regional conditions on spatial scales ranging from one station, for example surface temperature at De Bilt in Holland to hemispheric, example northern hemispheric surface air temperature in January and February. So whole variety of parameters had been identified.

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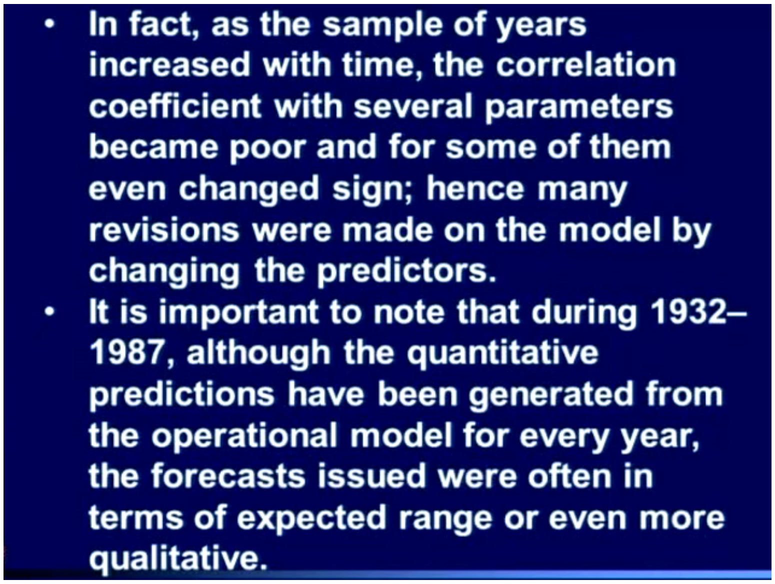

In fact as the sample of years increased with time, the correlation coefficient with several parameters became poor, and for some of them even changed sign; hence many revision are made on the model by changing the predictors. So it was an ongoing process all the time the models were being updated and as the correlation become poor the predictors were dropped, and new predictors added and so on so forth.

It is important to note that during 32 to 87, although the quantitative predictions have been generated from the operational model for every year, the forecasts issued were often in terms of expected range or even more qualitative. Now this is the matter of political decisions, and in fact nowadays what we get are quantitative forecasts are what is issued by IMD. But in the earlier era people were very careful not to give quantitative predictions.

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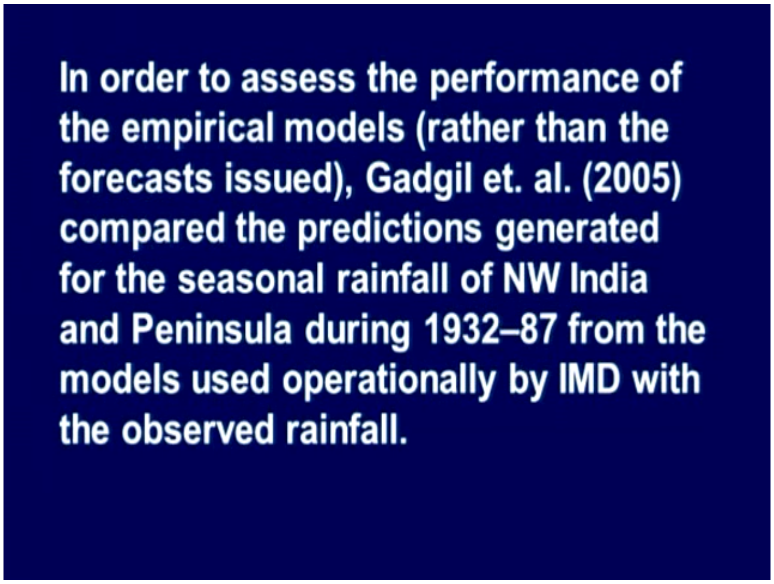

In order to assess the performance of the empirical models rather than the forecasts issued in this paper Gadgil and et. al. compared the predictions generated for the seasonal rainfall of northwest India and Peninsular during 32 to 87 from the models used operationally by IMD with the observed rainfall.

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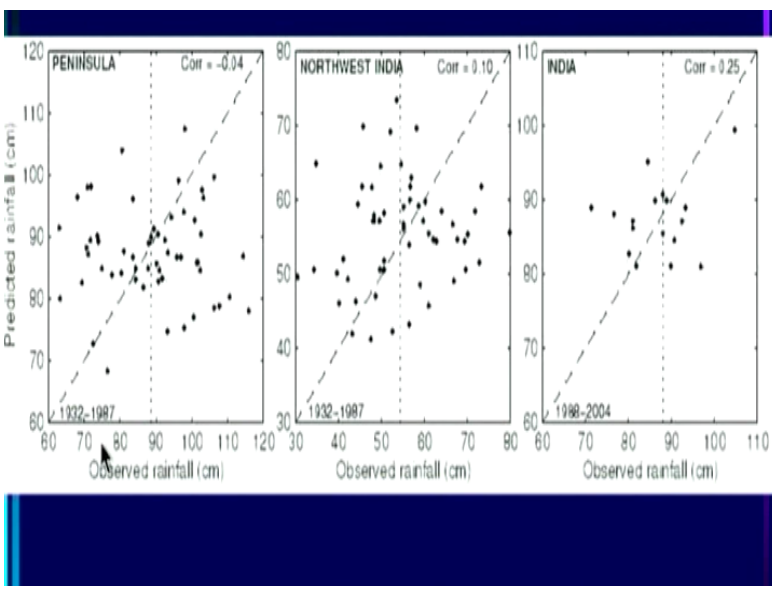

So now what you see here is for the 3 regions this is the Peninsula which you have seen, and this is predicted rainfall, and this is observed rainfall. The northwest India predicted rainfall, observed rainfall. And for all-India the predicted rainfall and observed rainfall, but this all-India is only from 88 to 2004, this is new model introduced by IMD which I will come to. But this is all the earlier models empirical models, which are basically linear regression models.

So if the predictions were perfect, there should have been along this line here, because predicted should have been equal to observed, but what you see is a cloud of points here, most of the time you can see predictions are around 85 and 95 or so. And again for northwest India also it is not at all impressive okay, there seem to be very large errors.

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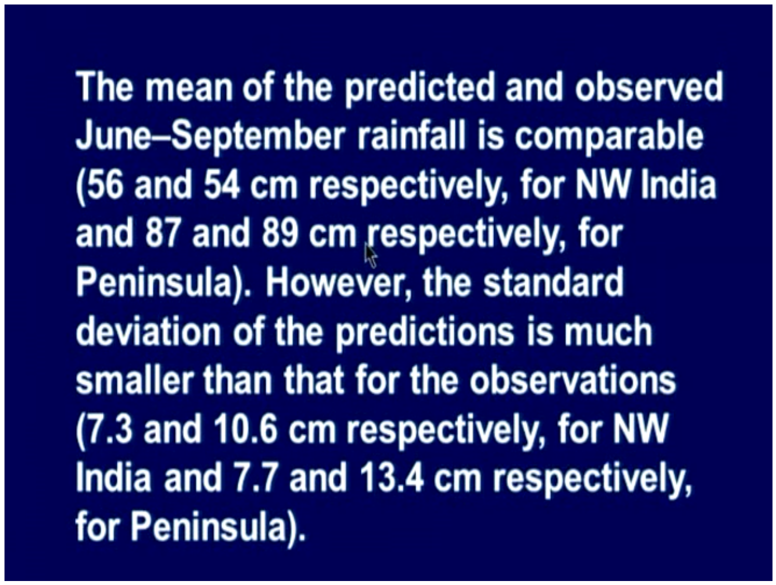

So the mean of the predicted and observed June to September rainfall is comparable 56 and 54 centimeters respectively, for northwest India, and 87 and 89 centimeters respectively for Peninsula, so the means of the predicted and observed came close to it. However, the standard deviation of the predictions is much smaller than that of the observations for northwest and Peninsula.

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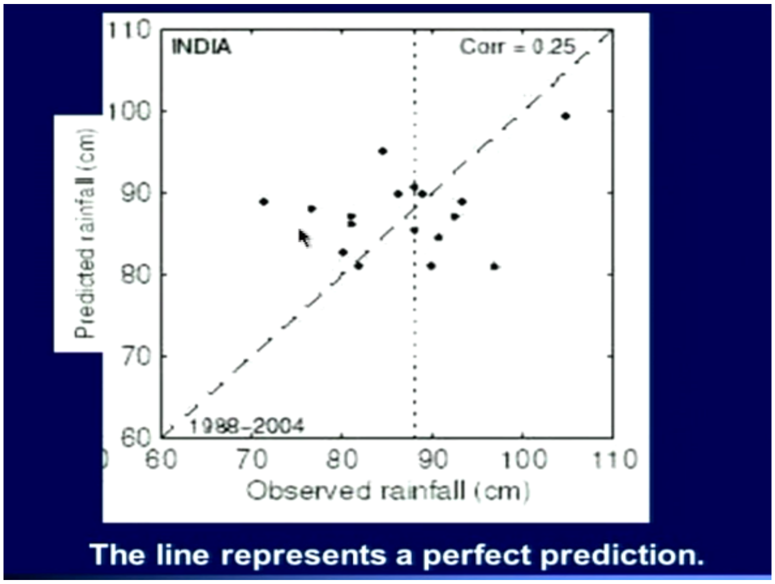

And see now this is the IMD rainfall, and you can see how bad it is the correlation is only 0.25, it is really a cloud here, and there is no way by which the low observed rainfall has never been predicted, high observed rainfall has been predicted only ones here okay.

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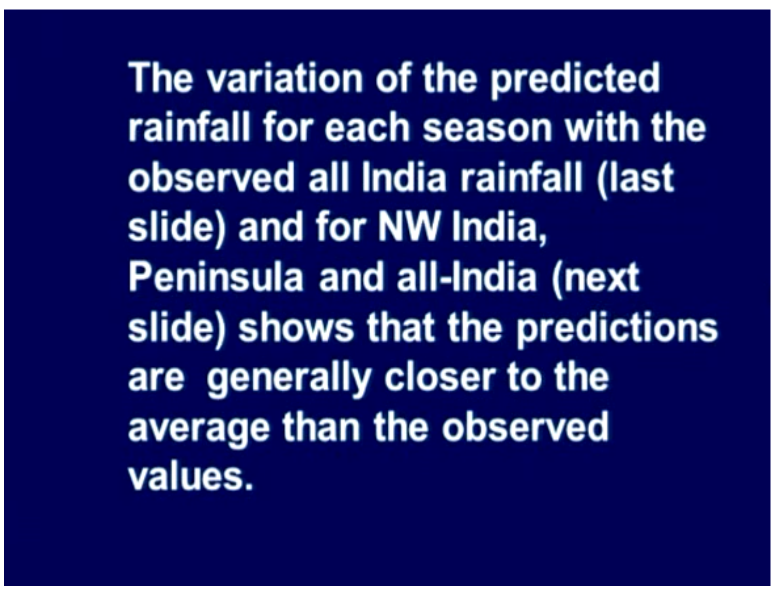

The variation of the predicted rainfall for each season with the observed all-India rainfall for this shows that the predictions are generally closer to their average than the observed values.

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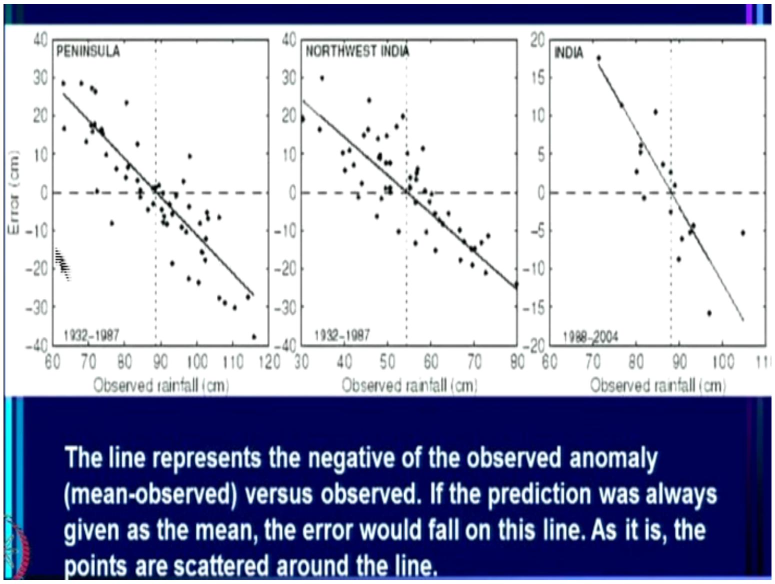

Now what you see here is the error okay, this is the error in the predictions, and this is the observed rainfall okay. So the observed anomaly will be what? The observed annually will be which is the mean-observed okay, so in any here the rainfall is given then mean-observed is the observed anomaly of that year, the negative of the observed anomaly at that here. So what you have that straight line that you see here is the mean-observed.

And the points are predicted-observed, which is the error right. And what is very interesting is that these points are falling very much around this line, see the line almost looks like good linear fit to the cloud of points, so this is very interesting the points are scattered around the line and what does the line represents?

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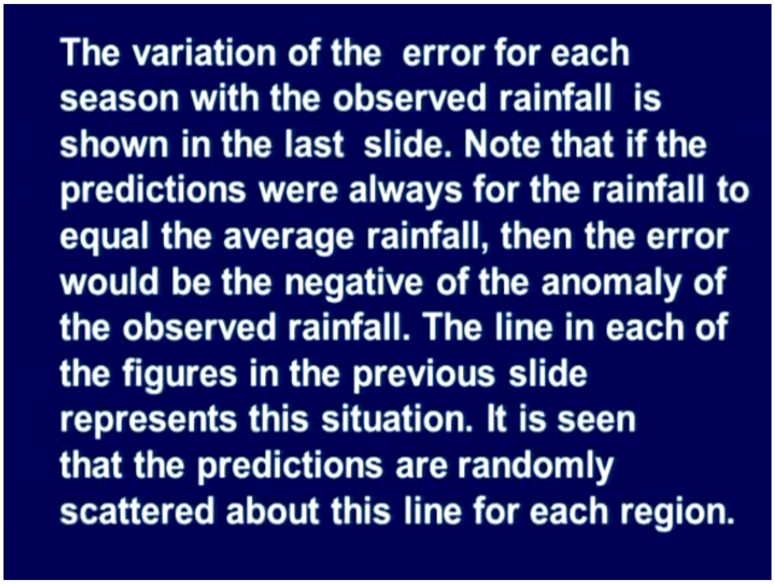

The variation of the error for each season with the observed rainfall is shown in the last slide. Note that if the predictions were always for the rainfall equal to the average rainfall, then the error would be negative of the anomaly of the observed rainfall right. Because if the predictions were always for the mean right, then the mean-observed would be the error, and mean-observed is just a negative observed anomaly right.

So if the predictions were always for the rainfall equal to the average rainfall, then the error would be negative of the anomaly of the observed, and line in each of the figures just represents this situation. So it is seemed that the predictions are randomly scattered about this line.

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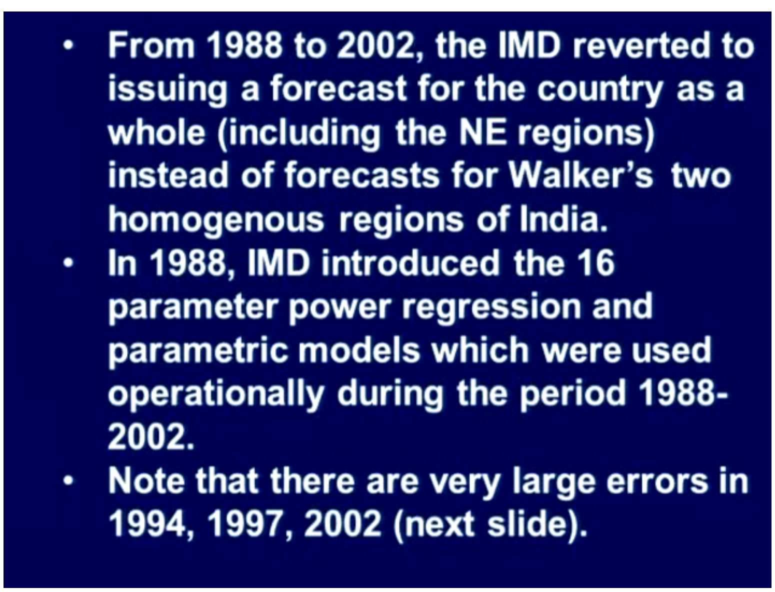

So by and large the predictions are predictions from mean rainfall, with additional stochastic components around that. From 88 to 2002 IMD reverted to issuing a forecasts for the country as a whole including north East region instead of forecasts for Walker's to homogeneous regions of India. In 88 IMD introduced the 16 parameter power regression parametric models, which were used operationally during 88 to 2002.

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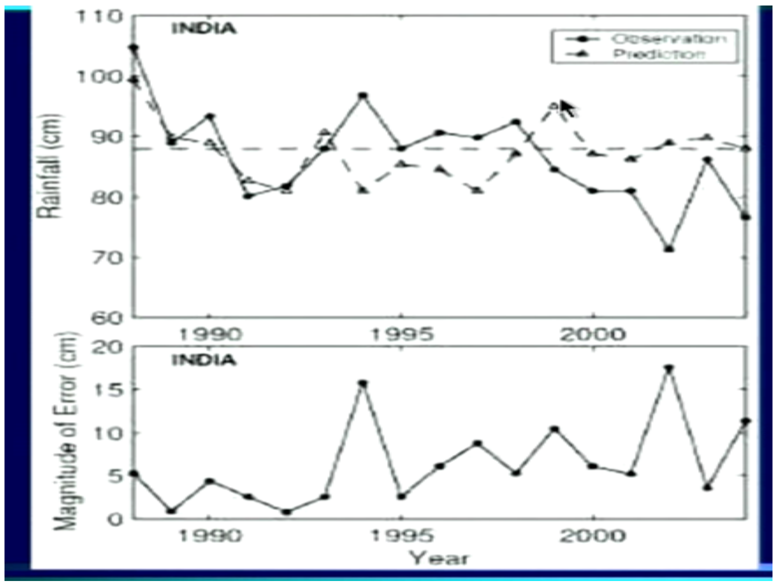

Now how did they do? So what you see here is rainfall, and this is the observation, and this is the prediction, and this is the magnitude of the error, and you can see that errors are very very large at some points, 94 the error is very large and so it is in 2002. So in fact errors are very large even though they made the model extremely complicated by going to power regression and so on and so forth.

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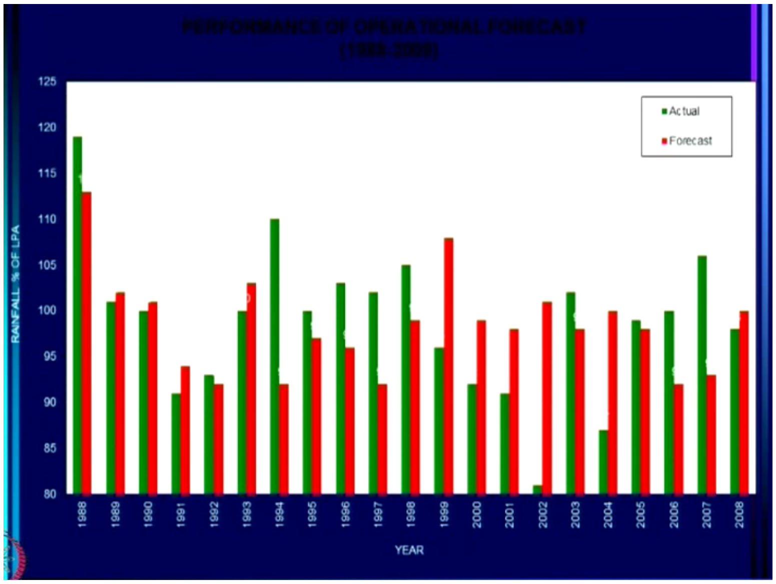

And this is the same actual and forecasts, you can see that there is a huge gap on several occasions between what is predicted and what is observed.

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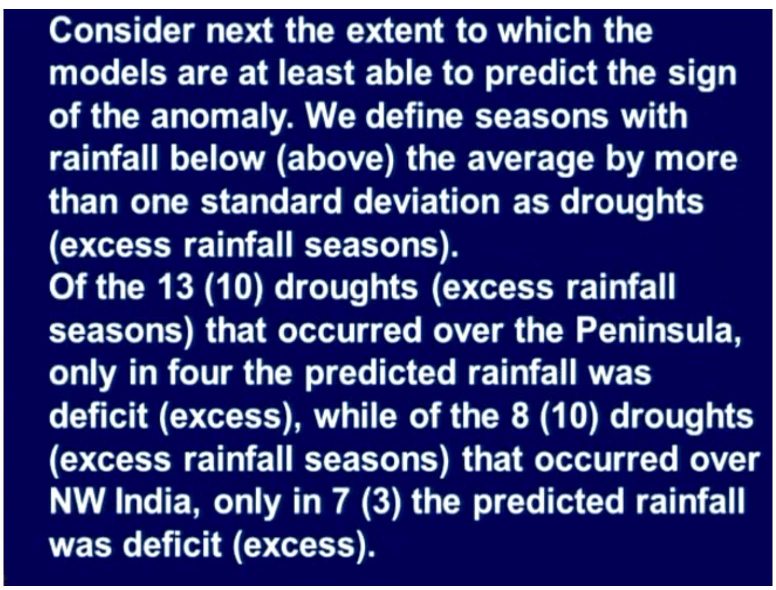

Now consider next the extent to which the models are at least able to predict the sign of anomaly, we define seasons with rainfall below or above the average by more than 1 standard deviation as droughts or excess rainfall seasons okay. So as we do for ISMR for these regions also Peninsula and northwest region of Walker, we define seasons with rainfall below the average by more than 1 standard deviation as drought, about the average by more than 1 standard deviation from the mean as excess rainfall season.

Of the 13 droughts that occurred over the Peninsula only in 4 the predicted rainfall was deficit, so even the sign was predicted correctly in the case of drought only in 4 out of 13 cases okay. And of the 10 excess rainfall years that occurred also only in 4 cases the sign was positive, anomaly predicted was positive. While of the 8 droughts that occurred over northwest India only 7 the predicted was deficit, so this is not too bad. But out of 10 excess only 3 the sign was right.

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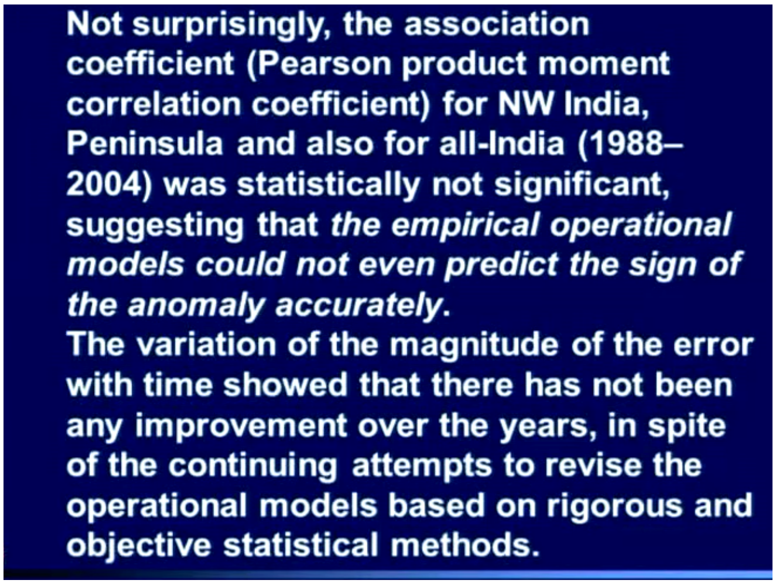

So on the whole it is not able to capture the sign even the sign of the extremes, and so the association coefficient which is the Pearson product moment correlation coefficient for northwest India and Peninsula and also for all-India were statistically not significant, suggesting that the empirical operational models could not even predict the sign of the anomaly accurately.

The variation of the magnitude of the error with time showed that there has not been any improvement over the years, in spite of the continuing attempts to revise the operational models based on rigorous and objective statistical methods.

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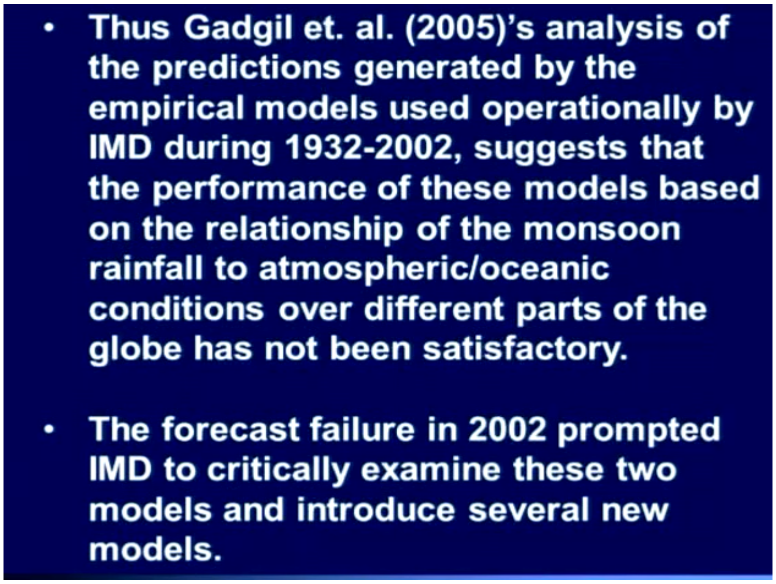

Thus, Gadgil et. al. analysis of the predictions generated by empirical models used operationally by 32 to 2002, suggest that the performance of these models based on the relationship of the monsoon rainfall to atmospheric and oceanic conditions over different parts of the globe has not been satisfactory. The forecasts failure in 2002 prompted IMD to critically examine these 2 models and introduced several new models.

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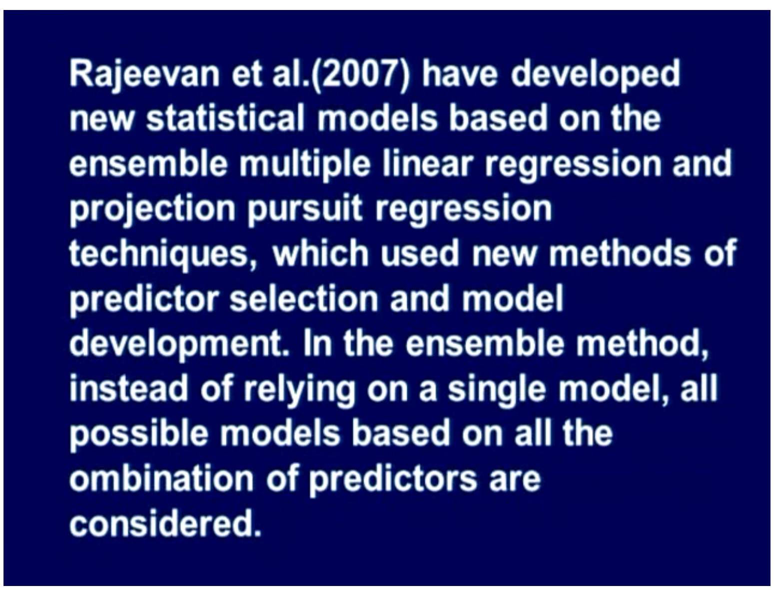

Now since then actually there has been flurry of activity led by very good meteorologist, who used to be in IMD called Rajeevan, and they have developed new statistical models based on the modern techniques called ensemble multiple linear regression and projection Pursuit regression techniques, which used new methods of predictor selection and model development. And in ensemble method instead of relying on a single model, all possible models based on all the combination of the predictors are considered.

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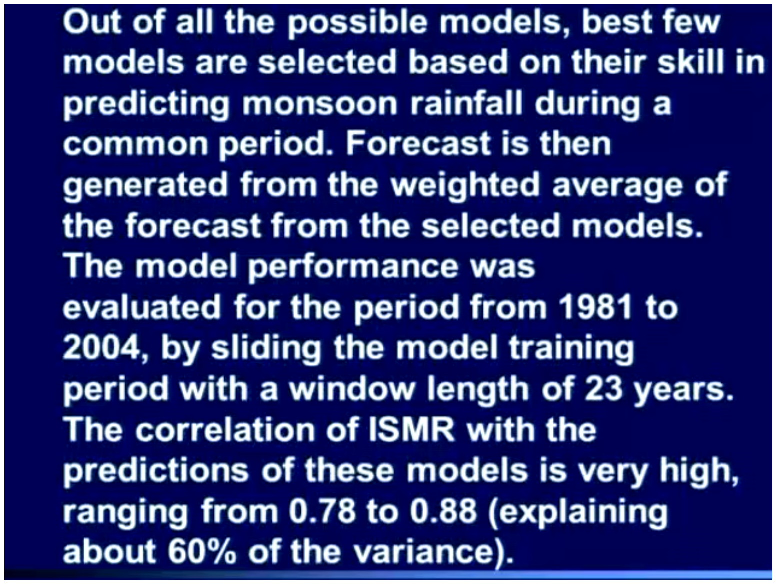

So out of all the possible models, best few models are selected based on their skill in predicting monsoon rainfall during a common period. Forecasts is then generated from weighted average of the forecasts from the selected models. So using all this modern tools has certainly seemed to have health, and the model performance was evaluated for the period from 81 to 2004 by sliding the model training period with a window length of 23 years.

And the correlation of ISMR with the predictions of these models is very high, it is of the order of 0.78 to 0.88 explaining about 60% of the variance.

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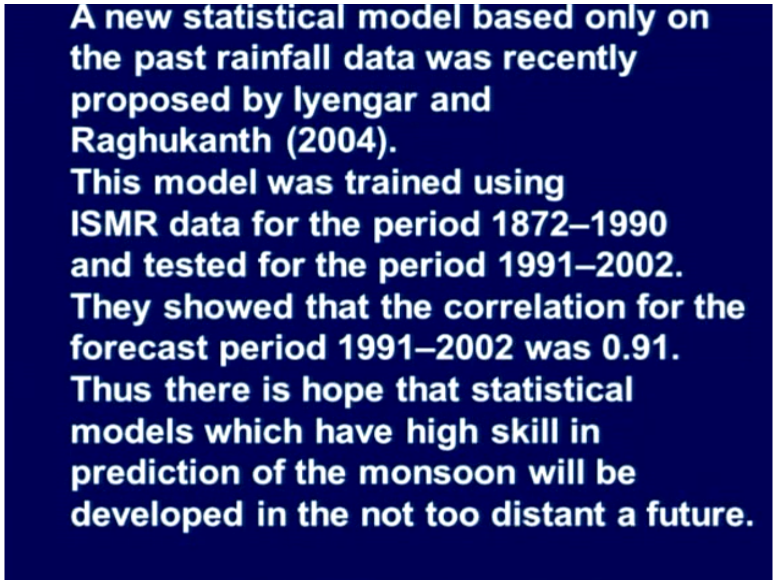

So we seem to have with all these modern techniques hit on models which are reasonable. Then there is another statistical model developed by Iyengar and Raghukanth, this model was trained by this is the statistical model which uses past rainfall data as the input, and this model was trained using ISMR data for the period 1872 to 1990 and tested for 91 to 2002, and they showed that the correlation for that forecasts period although it is not very long was 0.91.

So it seems like there is hope that statistical models which have high skill in prediction of the monsoon will be developed in the near future. Now I have not had a chance to go into great detail of the new version of the statistical models, partly because the new methods themselves would require exposition of the background, you know these are not standard linear regression kind of models and lot of work is involved.

And it is only by harnessing intelligent methods, and some of the methods such as those of Iyengar actually involved nonlinearities in the predictions schemes, so it is only because of that, that there appears to have been a success. I forgot to mention that the methods developed by Rajeevan et. al. in fact successfully predicted the drought of 2009, which none of the dynamical models that is to say coupled models of the ocean atmosphere system could predict,

So the recent large drought of 2009 could be predicted by this models which were only tested in the paper they were published after 2004, so 2002 and 4 were droughts and so was 2009. And

Rajeevan et. al. models have been able to predict the extreme which is a very good thing. Now let me just, so I will not talk very much more in details about the statistical models, but for people who are interested I have given the key references.

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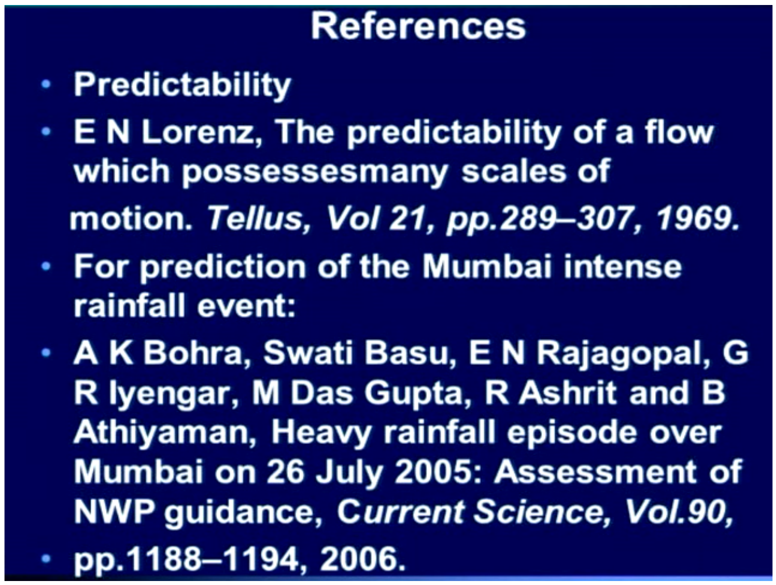

Here, first of all Lorenz one of the greatest meteorologist of the century, he is a pioneer in the study of chaos Predictability and Chaos, and the first paper on that is predictability of flow which possess many scales of motion, this is in 1969. For prediction of the Mumbai intense rainfall event, there is a paper by Bohra et. al. these are all from NCRMWF National Centre for Medium-Range Weather Forecasting. And they have actually done heavy rainfall episode over Mumbai 26th July 2005 assessment of numerical weather prediction guidance.

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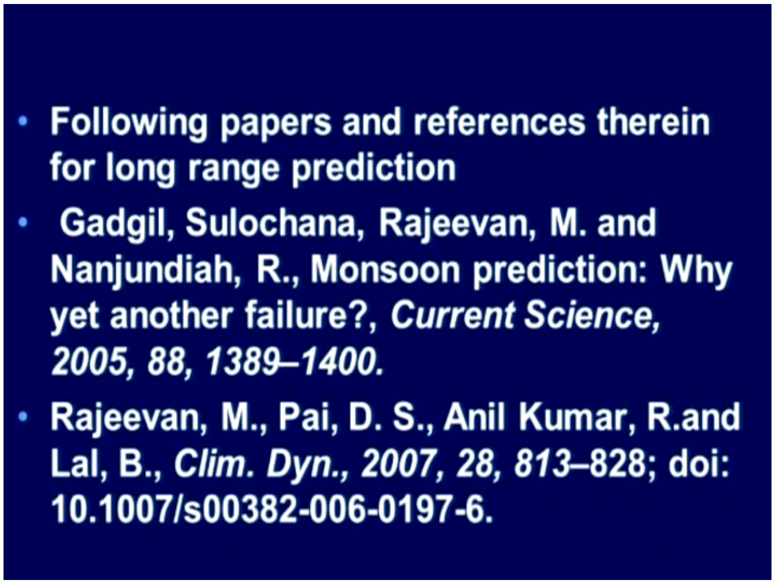

So this has the references to the modern models high resolution models which could predicted. Now there are many papers written on long-range prediction, because long-range prediction is a very long history of more than 100 years here, and what I have done here is given you some of the recent references which in turn have references to all the older papers as well. One of them I have already mentioned from which I showed you data on how the models did from 1932 onwards, what were the errors like and so on.

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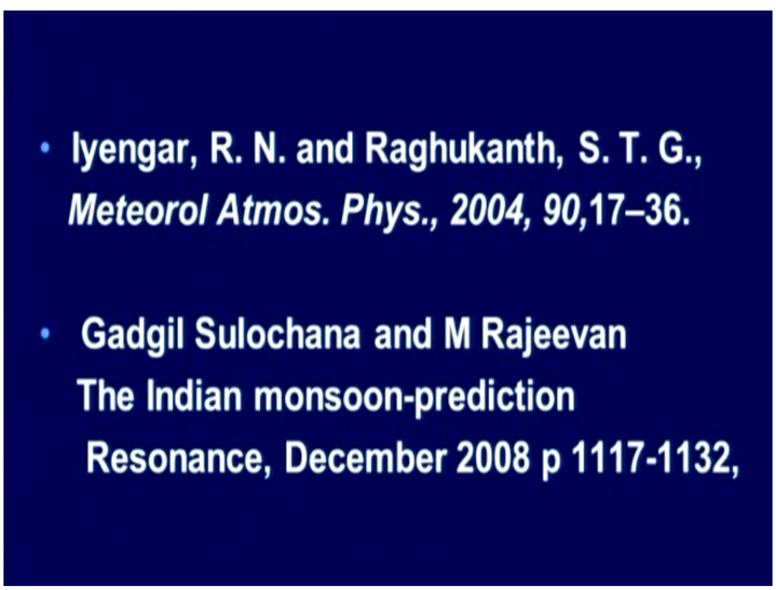

Then there is this paper by Rajeevan, which talks of the new models. Iyengar and Raghukanth again of the new models. And for the uninitiated a popular review of the Indian monsoon prediction is in a Science Journal Resonance for, 8th December 2008, thank you.