The Monsoon and Its Variability

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Lecture – 41
Monsoon Prediction – Part 2

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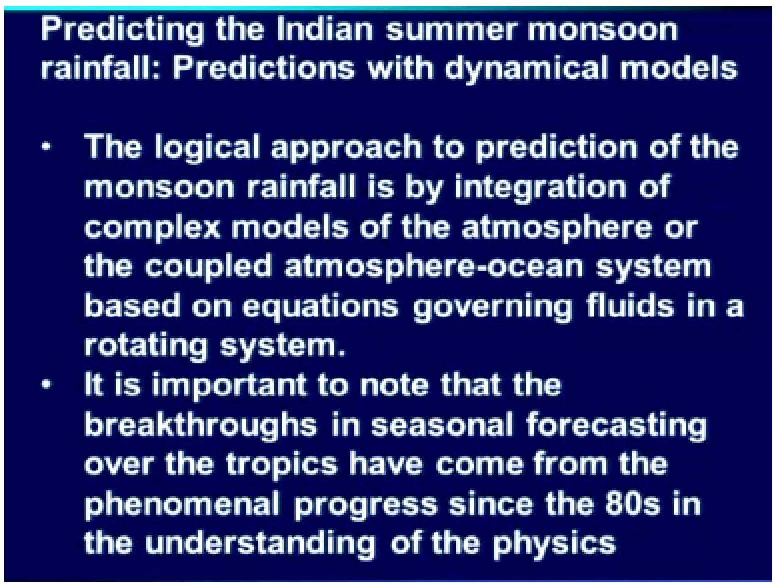

Today, I am going to continue the topic, monsoon prediction, what we are going to focus and today is actually the prediction with dynamical model. So, called dynamical model, these are models based on the laws of physics. So, I am going to talk on predicting the Indian summer monsoon rainfall, so again we focus on the seasonal time scale June to September and the special scale is all India.

So, average Indian rainfall for June to September for that specific season that is what prediction of that is what I am going to talk about today. Now, the logical approach to prediction of the monsoon rainfall is by integration of complex models of the atmosphere or the coupled ocean atmosphere system based on equations governing fluids in a rotating system. It is important to note that the breakthroughs in seasonal forecasting over the tropics have come from the phenomenal progress since the 80s.

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In understanding the physics of the El Nino-Southern oscillation phenomena, ENSO phenomena which is the dominant signal of the inter annual variation of the coupled atmosphere-ocean system over the Pacific. So, there has been phenomenal progress in understanding of ENSO since the 80s, elucidation of the nature of ENSO unravelling of the underlying mechanisms led to the development of models to a level at which they could realistically stimulate the phenomena and its impacts on the climate of different regions, as we have seen already.

It is important to understand ENSO, not only if you are interested about the climate on the Pacific but ENSO does have impact on regional climates over large parts of the tropics other than the Pacific region and so it is very important to understand it and with the kind of insights that were gained in the advances made in understanding of the nature of ENSO, the models could be developed to a level at which not only was it possible to stimulate the phenomena realistically.

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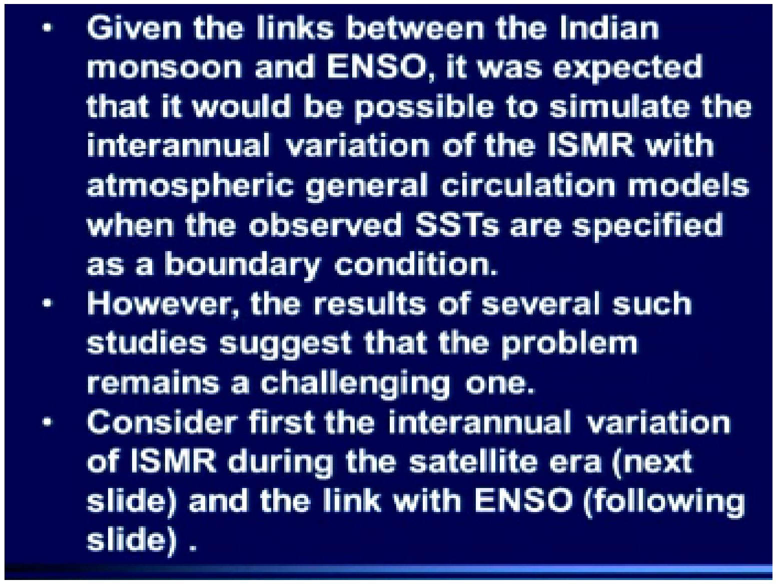

But also its impacts on the climate of different regions, now, we already have seen that the year to year variation of the Indian monsoon, ISMR is related to ENSO. So, given the links between the Indian monsoon and ENSO, it was expected that this revolution that occurred in atmospheric oceanic sciences of being; it being possible to predict ENSO would lead to models giving that predictions of the interannual variation of ISMR.

So, it was expected that it would be possible to simulate the interannual variation of ISMR with atmospheric general circulation models, when the observed SST's are specified as boundary condition. However, the results of several such studies suggest that the problem remains a challenging one, it is not as if solving the ENSO problem has also led to the solution of a monsoon problem there is more to monsoon than ENSO.

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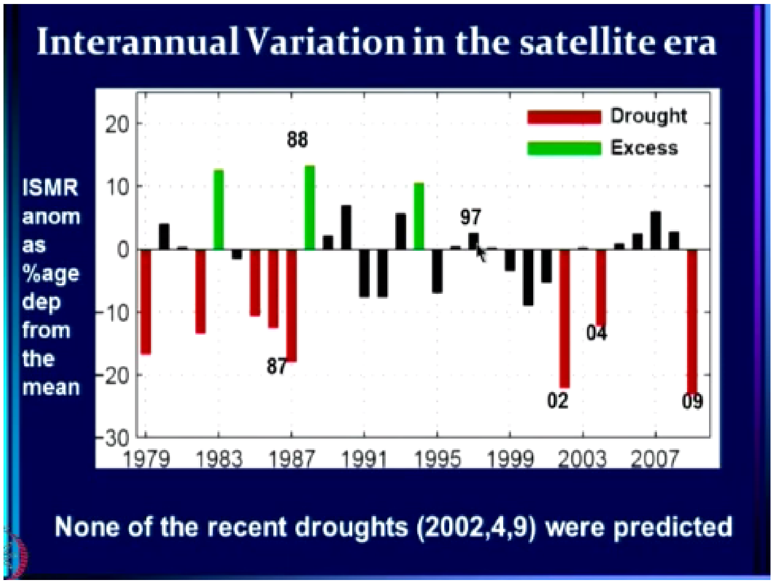

So, consider first the inter annual variation of ISMR during the satellite era and the link with ENSO, so let me just remind you of the inter annual; nature of the inter annual variation of the monsoon, this is only from 79 onwards, remember that droughts, mean deficit more than 10% or one standard deviation is the same thing and excess is above normal rainfall, which is; of which the anomaly is larger than 10% or one standard deviation.

So, during this era, then that I have shown from 79 to 2009, we have seen several droughts, this is 79 itself was a drought, then 82, 85, 86, 87 and then we had a reasonably good period here but it ended with frequent droughts; 2002, 2004 and 2009. The excess rainfall years are in fact, relatively few, there is 83, 88 and also 94. Now, we will see that 94 and 97 as well as 83 are very special years in this stock.

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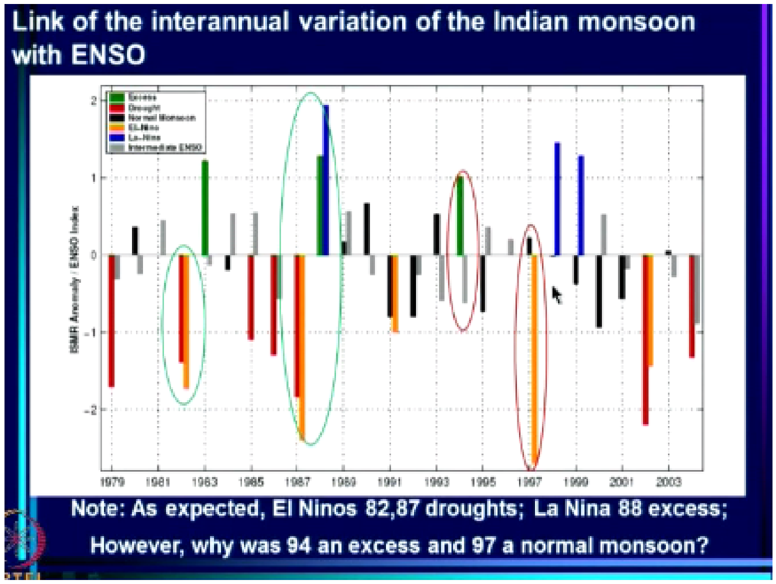

I just want to remind you that 97 was the largest El Nino of the century. So, now what we see here is plotted again the same ISMR, this is the same colour combination used, so red means droughts, green means excess rainfall and in between is a normal rainfall; black is normal rainfall. Now, next to the stick with ISMR, is a stick showing whether ENSO is favourable or not. When it is negative ENSO, it is unfavourable; when it is positive ENSO is very favourable.

And actually, if we have a very highly favourable condition then that is called a La Nina and you see an example here, this blue stick means, it is a La Nina and green means, it is an excess. So, this is an excess associated with the La Nina and El Nino would be orange, this is again departure of the ENSO index beyond one standard deviation deficit, so this is highly unfavourable situation, these are the El Nino's.

Now, the link; let us look at the known link between ISMR and ENSO. Now, actually 79, ENSO was unfavourable but not all that much, 82; you had an El Nino event highly unfavourable ENSO and a drought. So, this as expected, but then 87 also, we had an El Nino but and a strong drought, 88 is a case, where you had excess rain associated with La Nina. So, three years demonstrate the known link between ENSO and monsoon that there is a higher propensity for droughts during El Nino years, high propensity for excess rainfall during the La Nina years.

So, as expected El Nino's of 82, 87 are droughts, La Nina is excess, however, why was 94 an excess, you look at 94, ENSO is unfavourable, it is negative yet we got excess rain and you look at 97, where you have the strongest EL Nino of the century, you can see how large the ENSO signal is and yet the monsoon rainfall was normal. However, then later on what happens is in 2002, with a much weaker El Nino, you are getting large deficit here, big drought here.

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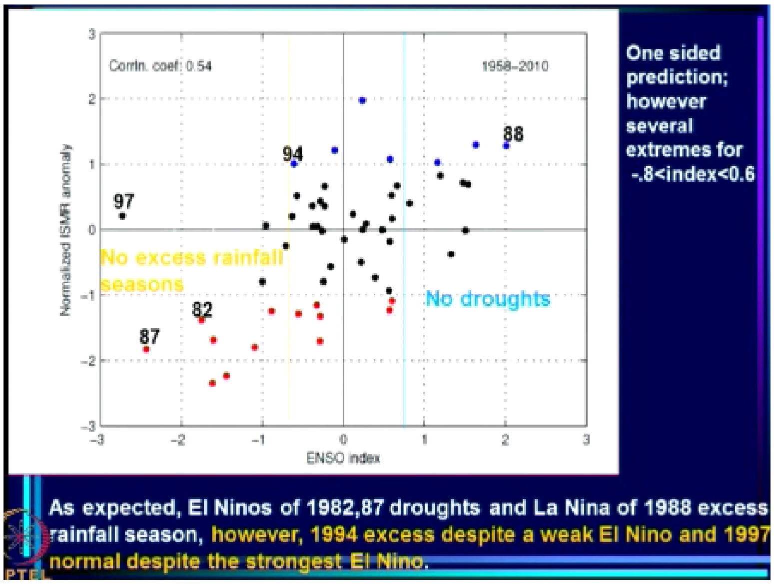

And here also, it is associated with El Nino, so why was 94 an excess? Despite of it being a weak El Nino, it was not a El Nino, the anomaly was not -1, but it was still an excess rainfall season and why was 97, a normal monsoon. If we look at normalised ISMR anomaly verses ENSO index, again this is something we have seen before and what you find is that ENSO index is sufficiently favourable, so this about 0.8, I think.

Then, you have no droughts and when it is sufficiently unfavourable, there are no excess rainfall seasons. So, one can get a one sided prediction provided the ENSO index is beyond this or in this range but in between these 2, there are lots of years, where you have droughts as well as excess rainfall season and with ENSO index alone, you cannot say anything about these extremes here.

Now, as expected El Nino's of 82, 87 and droughts of La Nina, see you see La Nina and excess rainfall season 82, 87 are El Nino's in this but these are the years we want to understand 94, which is an excess despite El Nino being unfavourable and 97 being a normal year despite El

Nino being so strong. Now, I must remind you that we have are going to focus on extremes for reasons I have mentioned in the last lecture.

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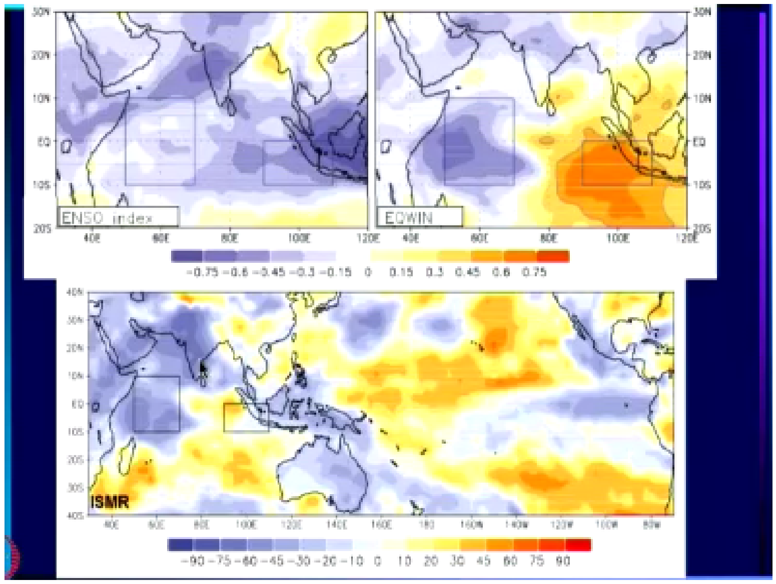

It is most important to predict the extremes of monsoon rainfall much more so, then the fluctuations within the normal range, okay. Now, what you see here is nature of the impact of ENSO of EQUINOO and the relationship of ISMR. We already have seen that 94 and 97, what happened was that there were years with strong EQUINOO; equatorial Indian Ocean oscillation and that is the second mode, which is important in determining ISMR.

This is something we have seen and what is the nature of impact, so if you an ENSO, then this is La Nina case, where the OLR correlation with OLR of ENSO index is shown and what you see is during La Nina, the entire region will have lot of rain except for this head Bay region. Whereas, the impact of EQWIN is different; EQWIN implies excess rainfall here, this is the positive phase of EQWIN corresponding to La Nina.

And separation of convection or rainfall here and this is associated with high rainfall over the Indian region. This is seen here, if you look at correlation of ISMR with OLR, it is highly correlated with rainfall over the western equatorial Indian Ocean and negatively correlated with rainfall over eastern equatorial Indian Ocean and this is of course, the ENSO link, where you have a negative correlation between rainfall over the Central Pacific and rainfall over the Indian region.

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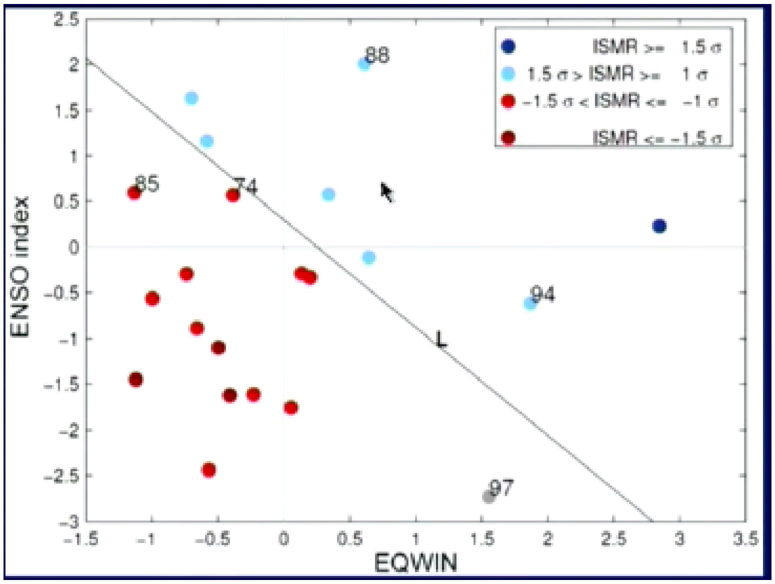

So, if we look at both the indices; EQWIN and ENSO, we have seen already that there is a clean separation and the reason that 94 was an excess is because EQWIN was so large and positive and the reason, 97 in fact, is a normal year again, because EQWIN is large and positive, although, El Nino is so highly unfavourable. We have seen that in the phase, phase of both these indices, the droughts and excess monsoon years are well separated.

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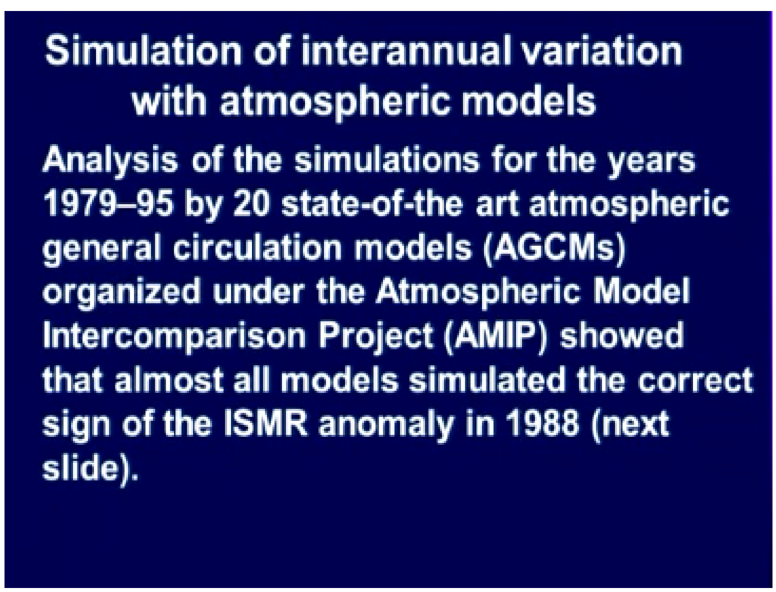

So, if the prediction is for the forthcoming season implies that it is a point somewhere below this line here, then we can say that there is the probability of excess rainfall years is 0; the probability of excess rainfall years is 0, if the point is below the line. Above the line, the probability of droughts is 0; this is from historical records, okay. Now, let us; this is interannual variation as we understand it.

Now, let us look at simulation of inter annual variation with atmospheric models. Analysis of the simulation for the years; 79 to 95 by 20 state of the art atmospheric general circulation model which we called AGCMs was organised under the atmospheric model inter comparison project AMIP, which showed that almost all the models stimulated the correct sign of the ISMR anomaly in 1988.

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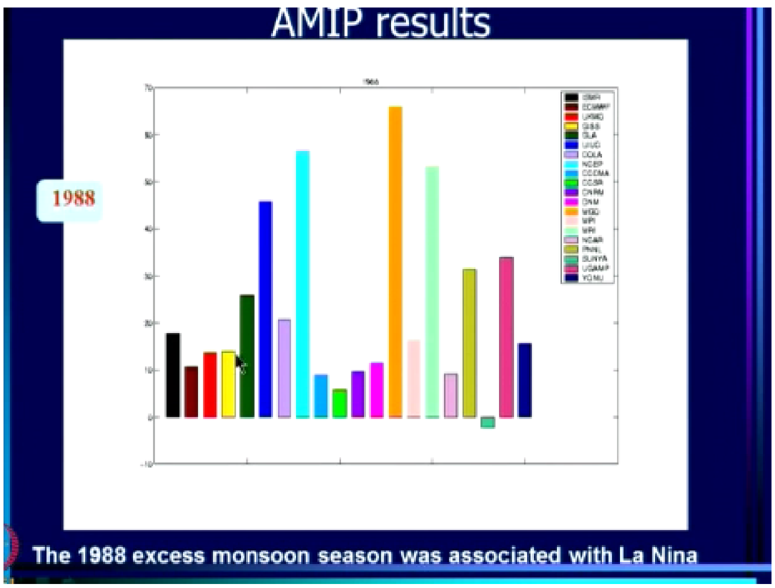

Now, remember the models have still to progress considerably. So, the first question we ask; like we asked of the empirical models I discussed last time is; is at least the sign of the ISMR anomaly captured, when observed ISMR is an extreme. In other words, when the observed ISMR is an excess are the models at least predicting a positive ISMR anomaly. When the observed ISMR is a drought are the models at least predicting a negative ISMR anomaly.

So, this is the question we asked of the AMIP and what we find is that for1988, which I will remind you were a year associated with La Nina, excess rainfall year associated with La Nina.

Black is the observed ISMR anomaly and this is; these are all the different models and you can see but for 1model, all the models have got the anomaly sign right, okay. The amplitude may not be right at all and may be exaggerated in some model.

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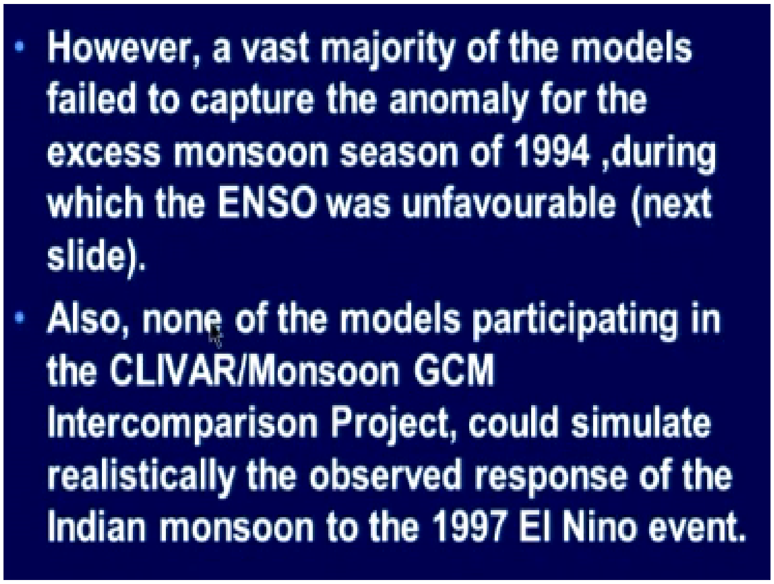

But at least, most of the models; vast majority of the models can get the sign of the ISMR anomaly right, when the AGCMs are forced by observed SST. However, a vast majority of the models failed to capture the anomaly for the excess monsoon rainfall season of 94 during which ENSO was unfavourable as we have seen.

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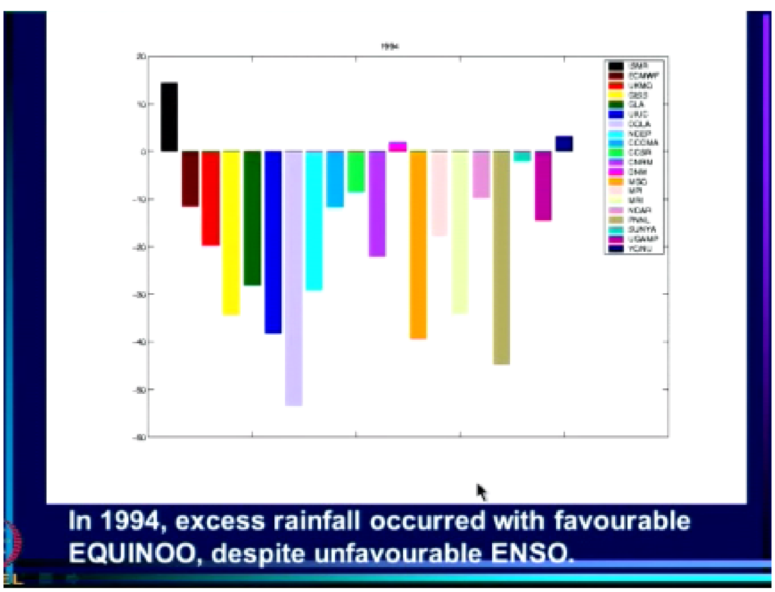

So, this is an excess monsoon season of 94 and you see almost all the models are getting in fact, negative anomalies here; negative ISMR anomalies. So, vast majority of the models have failed to capture the correct sign in this case, also same thing happened for 97. None of the models participating in another experiment which was a CLIVAR monsoon, GCM inter comparison project could stimulate realistically the observed response of the 97 El Nino event.

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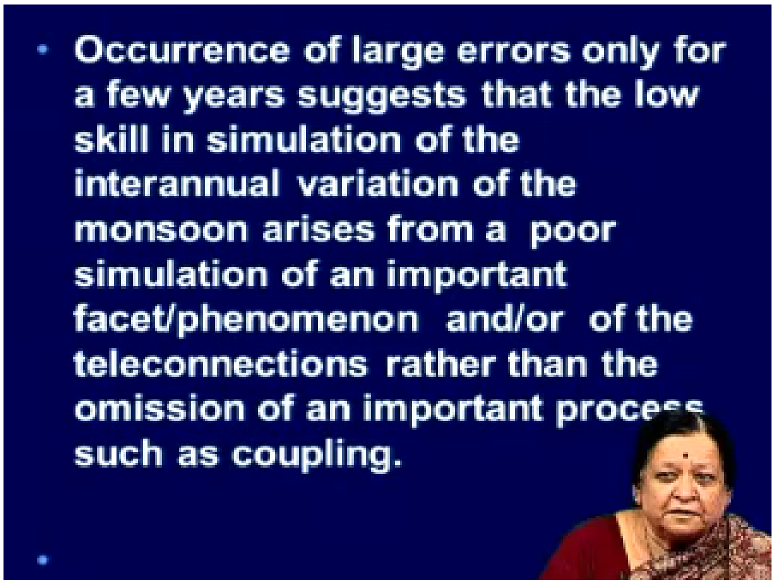

Now, occurrence of large errors, only for a few years, so what are we seeing? For some year, like 82, 87, 88 there are that many large errors, most of the models are at least able to get the sign of the anomaly right but there are huge errors only for some years like 94 and 97. Now, what is this suggest? Occurrence of large errors, only for a few years suggest that the low skill in the simulation of inter annual variation of the monsoon arises from a poor simulation of an important facet of phenomena.

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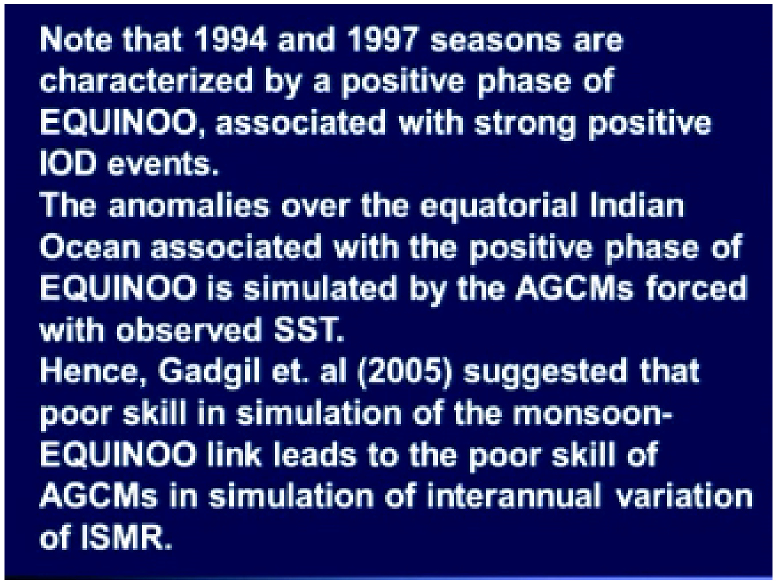

And or the tele-connections rather than omission of an important process such as coupling, because if the models were not good because they had an important process around could be the parameterisation of clouds or boundary layer whatever, then you do not expect this kind of a Bayesian error, where the errors tend to occur only in some years. Note that 94 and 97 seasons are characterised by a positive phase of EQUINOO associated with strong positive IOD events.

The anomalies over equatorial Indian Ocean associated with the positive phase of EQUINOO is stimulated by the AGCMs forced with observed SST. So, actually what happens is, since we have forcing with observed SST, the local response, which is the EQUINOO, equatorial Indian Ocean oscillation is stimulated accurately by the AGCMs, however for some reason, they are not able to get the link with EQUINOO.

So, actually it was suggested by Gadgil et al after looking at this experiment in India called SPIM; seasonal prediction of the Indian monsoon in which 5 models in the country where run for a period; 20-year period beginning with 85. What this project tested was the hypothesis put forth earlier by Gadgil et al, which said that the poor skill in stimulation of monsoon EQUINOO link leads to the poor skill of AGCMs in stimulation of inter annual variation.

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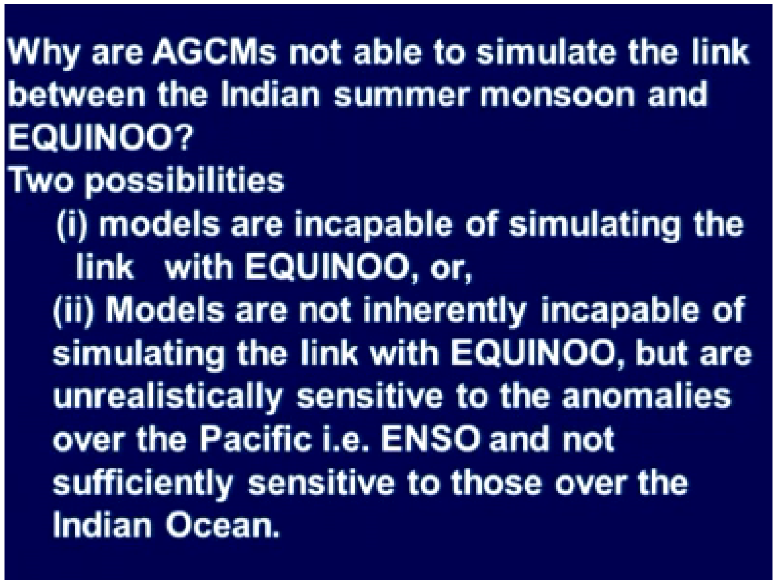

So, this was one thing that somehow the link is not being captured, although the local response is okay. Then the question was why AGCMs are not able to stimulate the link between the Indian summer monsoon and EQUINOO? Now, there are 2 possibilities; one is that models are inherently incapable of stimulating the link with EQUINOO and I must tell you that initially, when people began to look at how good was a monsoon prediction in models with AGCMs; atmospheric general circulation model.

They were not able to stimulate the link with ENSO at all and what happen was under an international project called (()) (16:58) people worked on the models to get the 87 El Nino droughts and 88 La Nina excess monsoon right in the models. So, development was done on the models to get the link with ENSO right. Now, so is it that the models were incapable; inherently incapable of stimulating the link with EQUINOO.

Or that models are not inherently incapable of simulating the link but are unrealistically sensitive to the anomalies over the Pacific that is they has become; in the model, monsoon is much more of a slave of ENSO but in reality, we have seen that the monsoon anomaly can even be of opposite side then that suggested by the ENSO phase, so it is possible that they are not sufficiently sensitive to EQUINOO and or unrealistically sensitive to ENSO.

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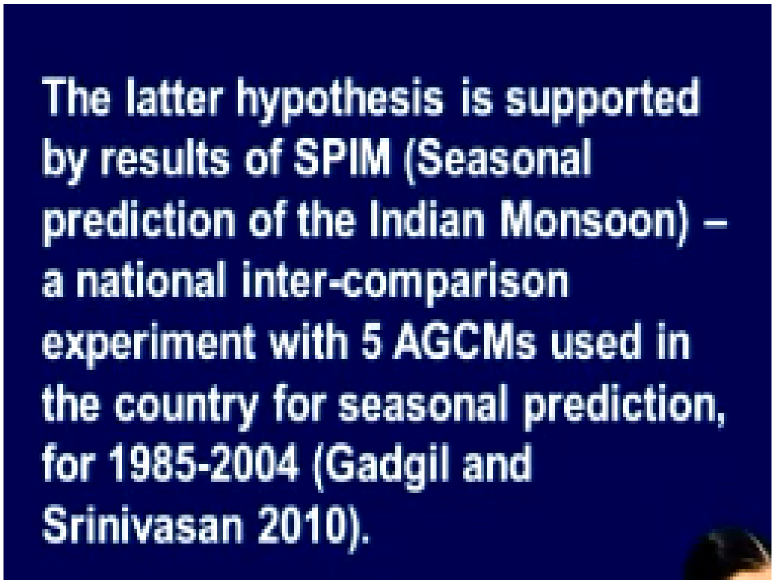

So, these are the 2 possibilities that arise and the latter hypothesis is supported by results of SPIM; this is the project that I mention, this was the Indian project, seasonal prediction of the Indian monsoon and national inter-comparison experiment with 5 AGCMs using the country for seasonal prediction for 84 to 2004.

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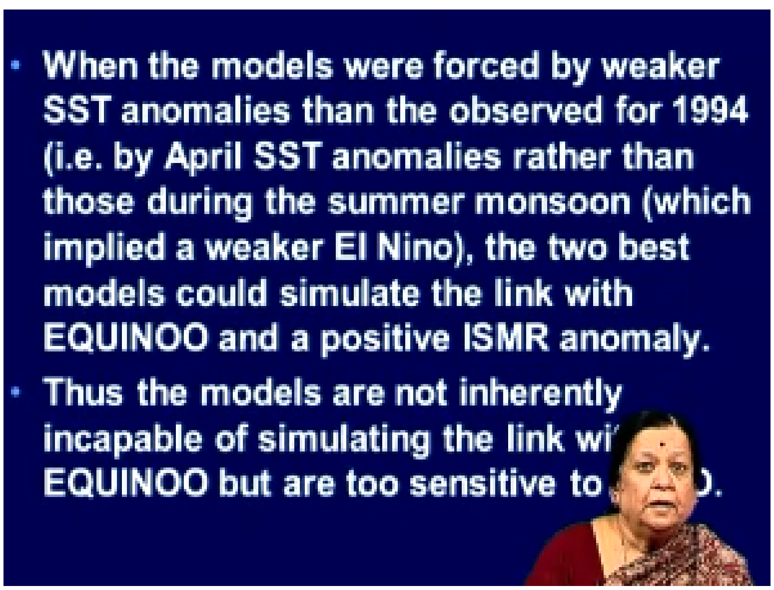

Now, when the models were forced by weaker SST anomalies than observed for 94, so in SPIM, 2 experiments were done. Firstly, for all the 20 years observed SST were specified as the forcing for the AGCMs but there was another experiment done in which for few years, the models were forced by April SST anomalies rather than the real anomalies. Now, for 94 when this was done, what it implied is that it was forced by weaker SST anomalies.

And actually a weaker El Nino over the Pacific and when that was done, the 2 best models could stimulate the link with EQUINOO and a positive ISMR anomaly, so this leads to the conclusion that it is not that models are inherently incapable of actually simulating the link with EQUINOO but rather, they are too sensitive to ENSO. You know, when the effect of ENSO was artificially weakened by replacing the SST anomalies with weaker ones.

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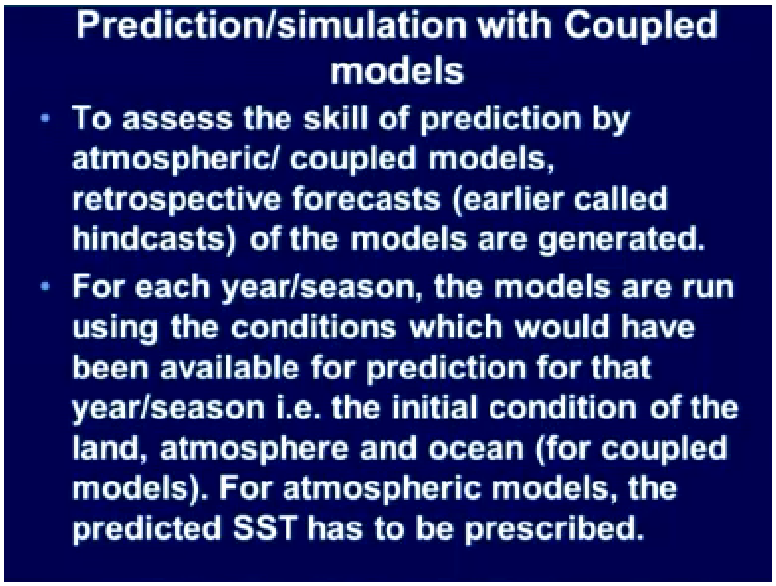

Then the models could actually stimulate the link with EQUINOO. So, so far, we have been talking a prediction with atmospheric general circulation models but as I mentioned before, for prediction with atmospheric general circulation models, you have to specify the boundary conditions in particular, the sea surface temperature, which means that predictions with atmospheric general circulation models involve 2 steps.

These are called 2 tier prediction. One is that you to predict the SST by some way and specify that SST; predicted SST to run the AGCMs, to predict whatever you want to predict in this case the monsoon. Now, of course they may be errors in the prediction of a SST itself and it is to see what would happen to the atmospheric models, if they were no errors in prediction of SST that experiments like AMIP were design, where there was a; if you wish a perfect prediction of SST.

The observed SST was specified to run AGCMs but in real life, if we are going to use AGCMs to predict, then we have to predict SST as well of course, of more natural way of predicting the monsoon with models would be to use coupled ocean atmosphere models were from an initial condition, the ocean evolves and the atmosphere also evolves and the boundary conditions for the atmosphere come from the ocean, which is also evolving in the model.

So, to assess the skill of prediction by atmospheric couple models, what is done is retrospective forecast which used to be called hind casts are generated, let me explain what these are. See for each year or season models, are run using conditions which would have been available for prediction for that year or season. So, even if you are doing the experiment in 2005 as the experiment, I will talk about was done.

What you do is, if you want to make a 30-year kind of run; then 30 years run; then for any specific year, say1994, you take the initial conditions as were available at the time of forecast for 94 season, it could be first May, for example and you take the conditions for the state of the ocean as well as state of the atmosphere and then integrate the model to generate the; what will happen in the forthcoming monsoon season.

So, in a way, these are forecast which are done retrospectively, so there called retrospective forecast somewhat misleading name for them is hind cast. Hind cast seems to suggest the time is going in the reverse direction that is not true at all. In fact, it is that forecast are done long after the season is over but using conditions which were available; would have been available at the time of forecast to assess the model and these are called retrospective forecast, okay.

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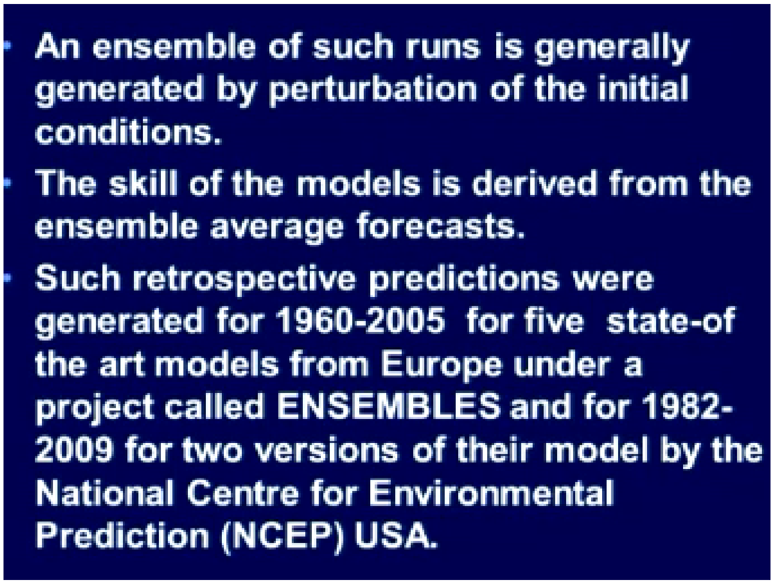

Now, an ensemble of such run is generally generated by perturbations of the initial condition and that is because, we know that atmospheric models are sensitive to initial condition and therefore, one would like to run them for a whole host of initial conditions and average of those initial conditions to remove the chaotic element that comes in because of the sensitivity to initial condition. So, generally, an ensemble of such runs is generated by perturbations of initial condition.

Now, the skill of the model is derived from the ensemble average forecasts, such retrospective predictions were generated for 1960 to 2005, for 5 state of the art models from Europe and I am talking of coupled models; coupled ocean atmosphere models under a project called ensembles and for 82 to 2009, for 2 versions of their model by NCEP; National Centre for environmental prediction, USA.

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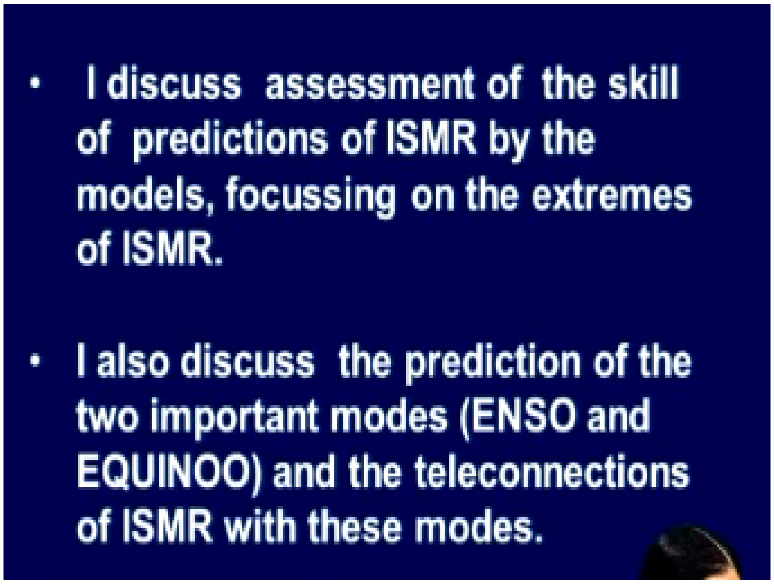

I discuss now, assessment of the skill of predictions of ISMR by the models, again focusing on the extremes to get an idea of how good are the predictions by these models. What is the skill of these models, present state of the art model in predicting the extremes of the monsoon but we have seen that extremes of the monsoon in real life are very much related to 2 phenomena; ENSO and EQUINOO.

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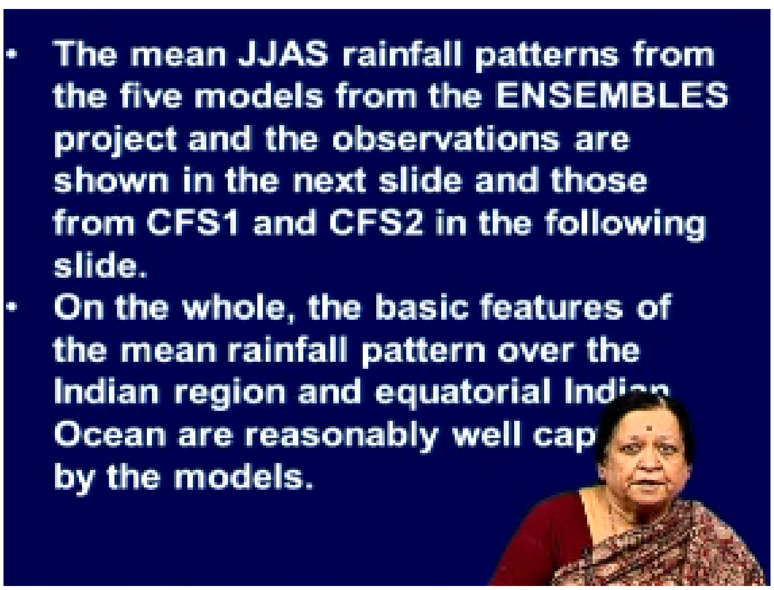

So, I will also discuss the prediction of 2 modes; ENSO and EQUINOO and the tele connection with the ISMR in the models. The mean JJAS rainfall patterns from the 5 models from the ensemble project and the observations are shown in the next slide and from CFS1 and CFS2 in the following slide

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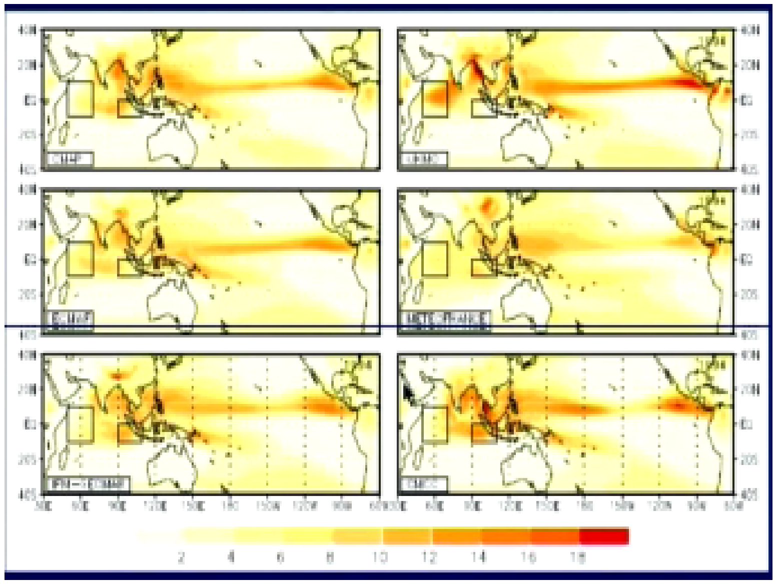

So, these are mean patterns and what you see here is CMAP corresponds to observations, these are the observations and these are 5 models; UK Met office, Meteo-France, CMCC, ECMW, this is the European Centre model and IFM Geomar so, you can see this is reality and in reality, this is the kind of rainfall you get, the scale is given here and this is the kind of rainfall that is stimulated by the model. By and large, the patterns over the Pacific look okay.

But you also see that for some models like, UK Met office and Meteo-France, there is hardly any rain over India, you also see that UK or Met office gets much more rain over western equatorial Indian Ocean than eastern one, whereas reality is the opposite, okay. ECMWF model is not bad, most of the other models do get some rain over India but you can see that in Meteo-France, you will get much more rain here, this is north of the Himalayas.

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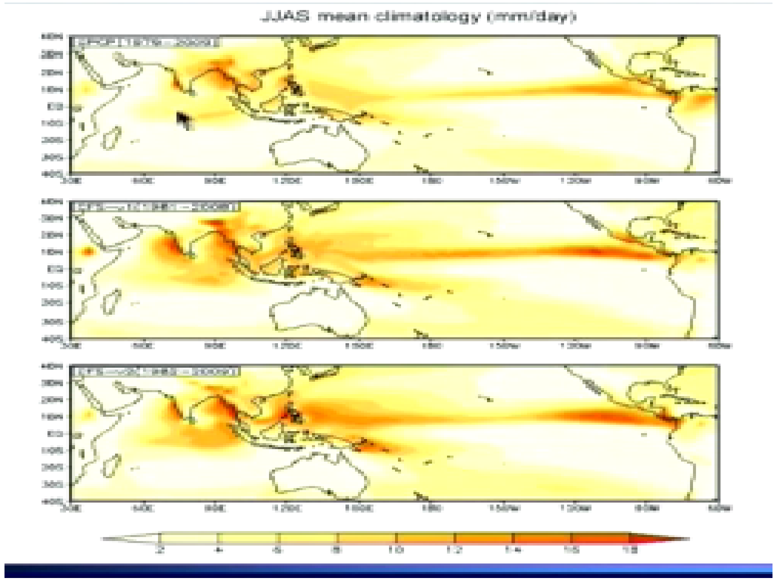

So, there are differences from model to model but on the whole, they are; basic features of the mean rainfall pattern over the Indian region and equatorial Indian Ocean are reasonably well captured by the models. So, those were the ensemble models, these are 2 versions of the NCEP models; CFS1 and CSF2 and these are the observations and again you will see that the second version has a dry bias.

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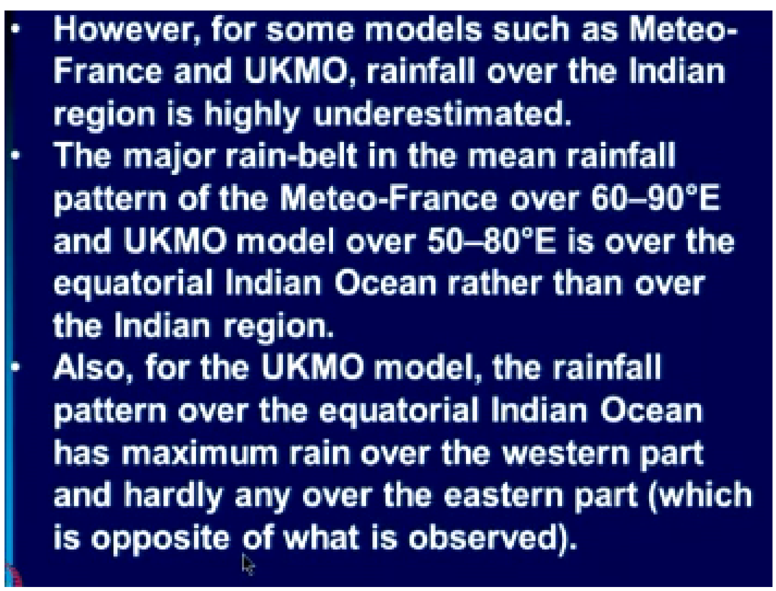

There is very little rain over India in this and it also seems to have in comparison with this, some differences over the Pacific but the major differences over the Indian region, where you have a dry bias here year, which is relative to the observations here. As I mentioned for some models such as Meteo-France and UKMO, there is hardly any rainfall over India. The major rain-belt in the mean rainfall pattern of Meteo-France over 60 to 90 and UKMO Met Office over 50 to 80 is over the equatorial ocean rather than the Indian Ocean region.

So, what you will see here is that the major rain-belt is here and not over Indian region, very much so in Meteo-France also, you see the rain-belt is extending all the way and it is just over the equatorial Indian ocean, it really does not have any rain here, there is some rain over the Himalayas here. So, there is a major shift in the rain-belt okay, also for the UKMO model, the rainfall as I mentioned pattern over the equatorial Indian Ocean as maximum rain over the western part and hardly any over the eastern part which is opposite of what is observed.

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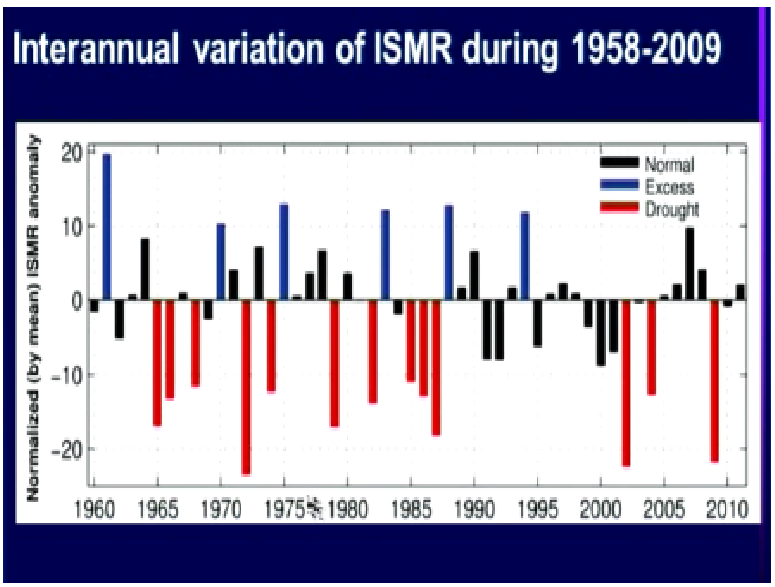

Now, let us again look at observations, this is from 60 onwards because you remember ensemble runs were made from 1960 onwards and these are the excess monsoon years and these are the droughts here. Now, for this we have taken mean rainfall for this same period 60 to 2009, so that what we take with the model is comparable because for model runs, we have from 60 to 2005, so we have taken mean rainfall over a similar period here.

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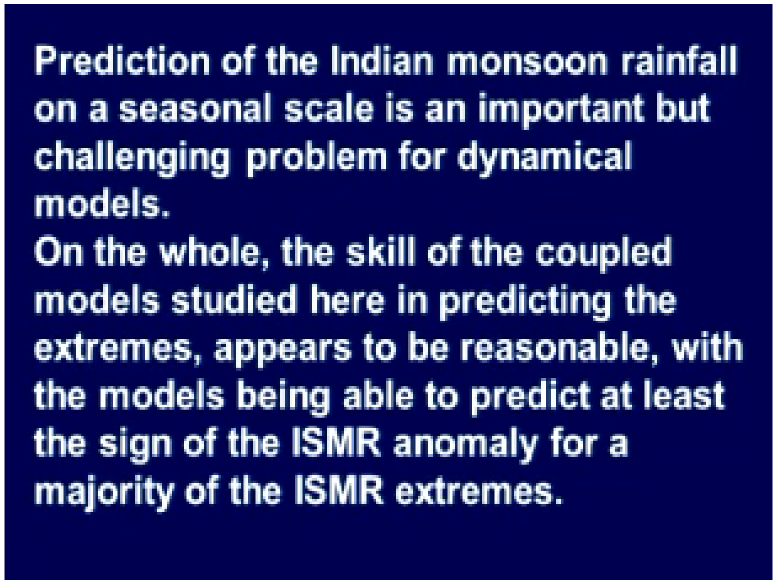

And what you get is; these are the excess monsoon years in fact, 61 is the year with highest rainfall recorded and then we have of course, 70 which is an excess and 75, which was a La Nina in excess, we have 83, which was an excess, 88, which was an excess and 94 which was an excess and then we have a whole lot of droughts as well. So, prediction of the Indian monsoon rainfall on a seasonal scale is important but challenging problem in dynamical models.

On the whole, and the skill of the coupled models studied here in predicting the extremes appears to be reasonable with the models being able to predict at least the sign of the ISMR anomaly for a majority of ISMR extremes. Now, I must mention this was not true about 5 years before this experiment, when models could not even get the sign of most of the extremes right and the statistics is like this.

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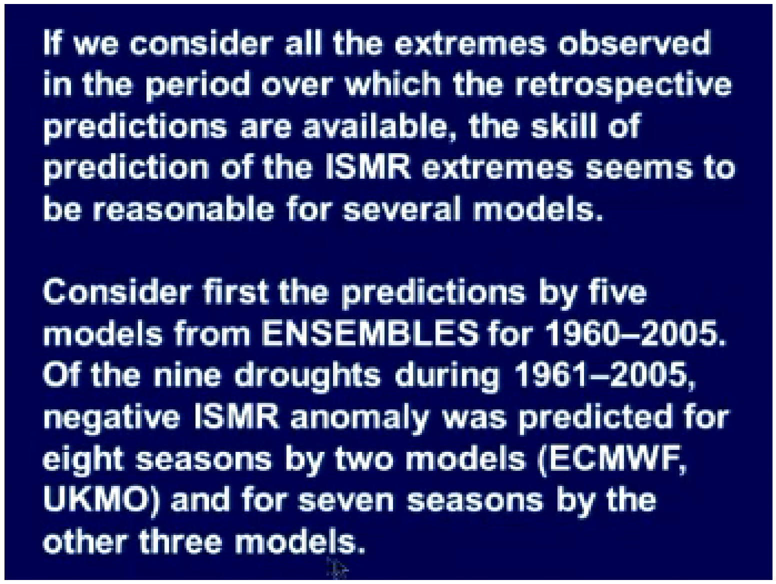

If you consider all the extremes observed over the period in which; in the period over which the retrospective predictions are available, the skill of prediction of ISMR extremes seems to be reasonable for several monsoons. Consider first the predictions by the 5 models from ensembles, this is the set run by the European Centre Project ensembles, of the 9 droughts during 61 to 2005 negative ISMR anomaly was predicted for 8 seasons by 2 models; ECMWF and UK Met office and for 7 seasons by the other 3 models.

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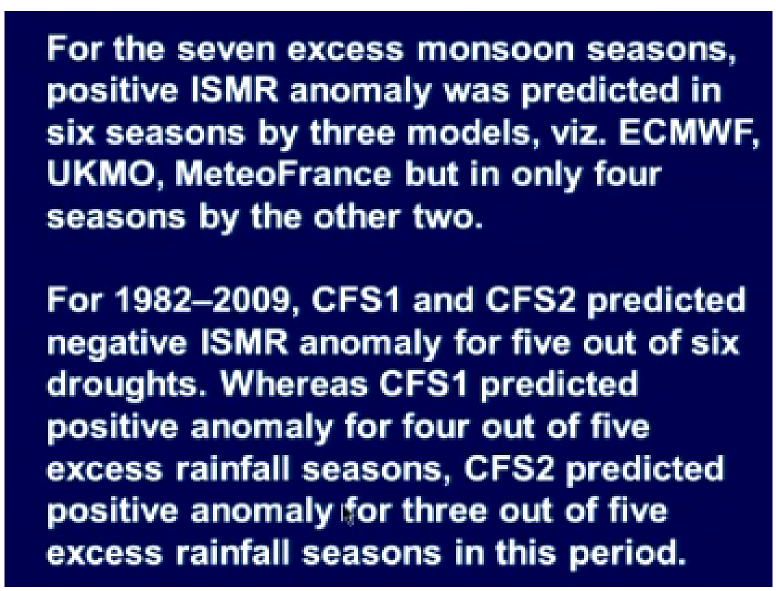

So, this is a pretty good record and for the 7 excess monsoon season, positive ISMR anomaly was predicted in 6 seasons by 3 models and only in 4 seasons by other 2. So, the success rate is not bad for 82 to 2009 from which ensemble model predictions are available, CFS1 and CFS2 predict a negative ISMR anomaly for 5 out of 6 droughts, whereas CFS1 predicted positive anomaly for 4 out of 5 excess rainfall seasons.

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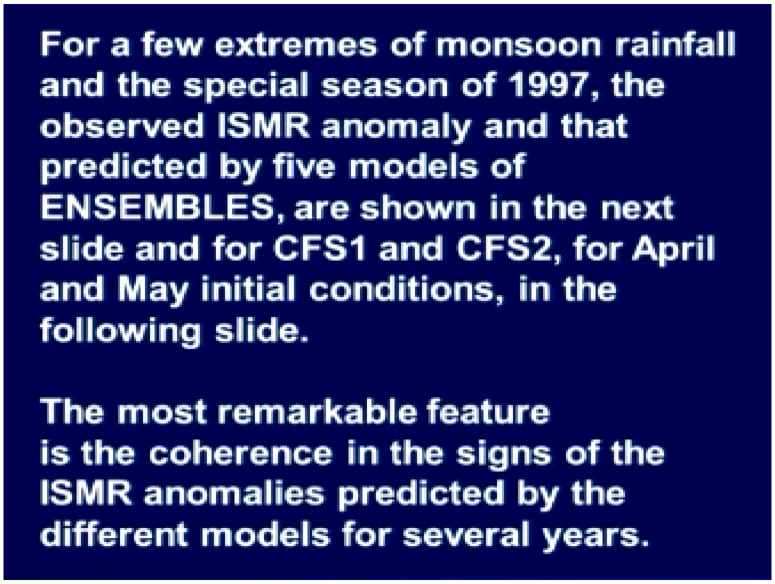

CFS2 predicted positive anomaly only for 3 out of 5, so in this sense CSF2 seems worse, then CSF1, it is also worse in terms of the dry bias. Now for a few extremes of monsoon rainfall and the special case of 97, the observed ISMR anomaly and that predicted by the 5 models of Ensembles.

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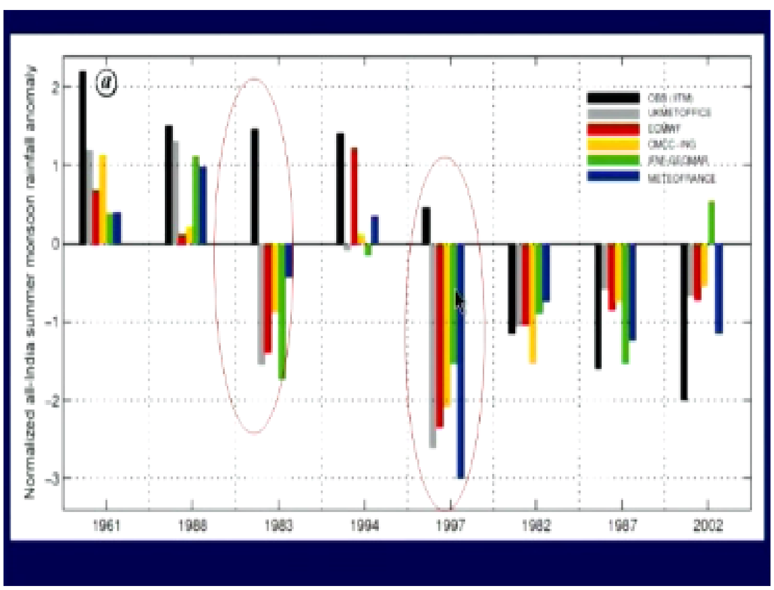

We will see here and see this as 61, this was the year with maximum rain and this is organised; you know with ISMR decreasing as you go, so next was 88, you see in 61 all 5 model got the sign right, in 88 also they all got right but look at 83, in 83, all the models similar to negative ISMR anomaly but actually it was an excess. Now, here most models got it okay, there are 2 models which got the sign wrong but the amplitude is very, very small.

So, 94 has certainly improved from the AGCM experience, 97 on the other hand, you see huge deficits stimulated predicted by the models, whereas actually it was normal. Again, for the other droughts, 82, 87 and 2002 most models seem to be getting the sign right, so there are huge issue discrepancies between model predictions and observations in the year 83 and 97 as far as ensembles is concerned.

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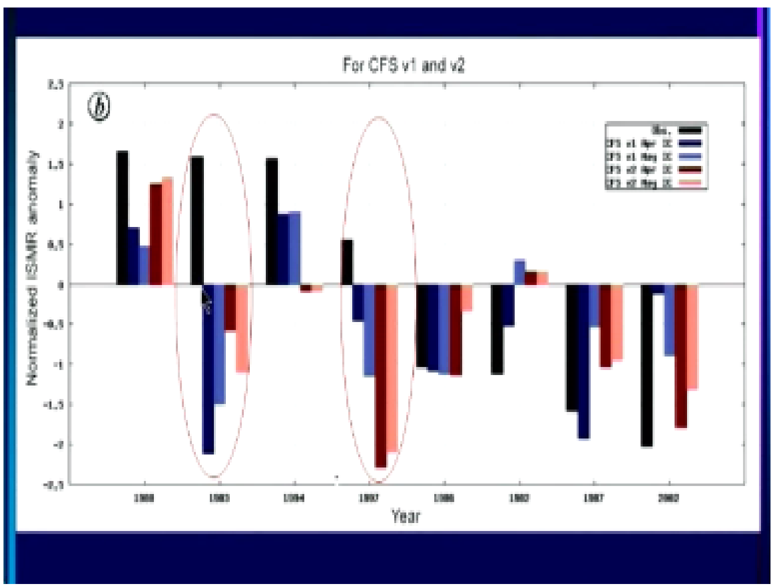

Interestingly, the same years have very large errors, also for CFS1 and CFS2, what you see is CFS1 are blue but with initial conditions in April and May, this is CFS2 and remember the stimulation was from 1980 onwards, so we do not get the earlier excess and so on but again, you see for years such as 94, CFS1 is doing fine but CFS2 is not but again you see, this is a year 88 in which things are actually pretty good as far as CFS1 and 2 are concern in 88. 83 and 97 are again 2 culprits which will completely spoil the skill of the model.

Models are somehow not able to get the skill right, so the most remarkable feature is the coherence in the signs of ISMR anomaly predicted by the different models for several years. So, there is a large coherence and even here, when they get; all get it wrong, there is coherence between the models. So, the only thing is that the sign is wrong when we compare it with reality. So, there is coherence between models, which is an interesting thing to see.

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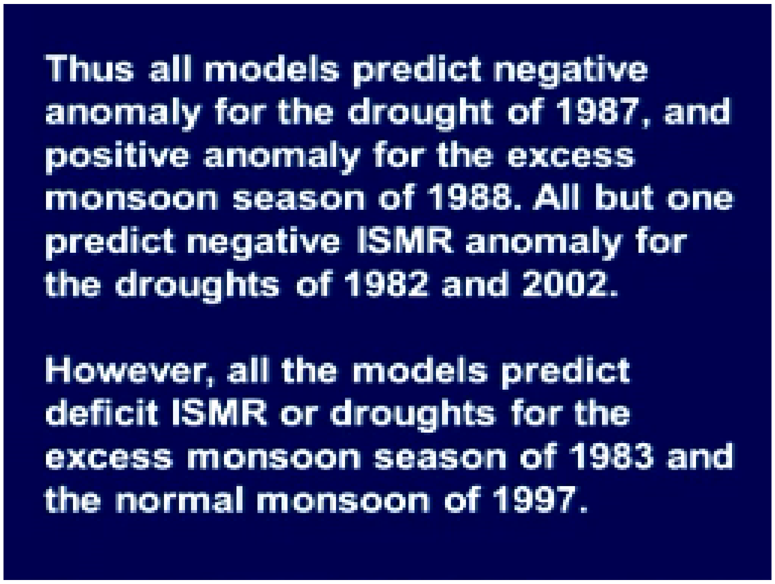

Thus, all models predict negative anomalies, we have already seen this for drought of 87, positive for excess of 88, all but one predicts a negative ISMR anomaly for the droughts of 82 and 2002. However, all the models predict deficit ISMR or droughts for the excess monsoon season of 83 and normal monsoon of 97.

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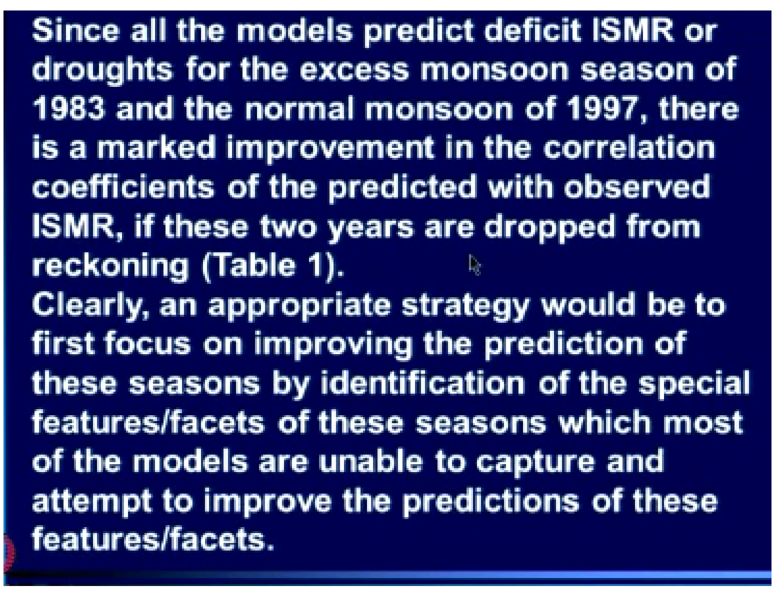

Now, since all the models predict deficit ISMR or droughts for the excess monsoon season of 83 and normal monsoon of 97, there is a marked improvement in the correlation coefficients of the predicted with observed ISMR, if these 2 years are dropped.

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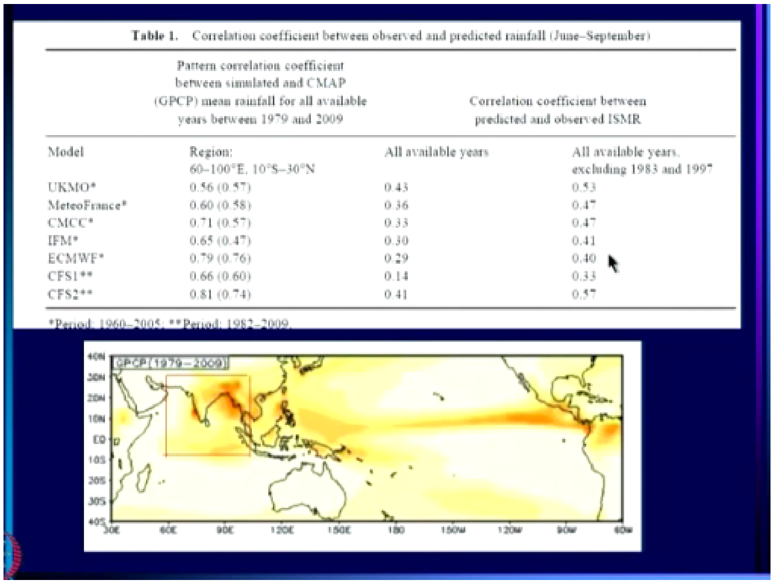

Table 1. Correlation coefficient between observed and predicted rainfall (June–September)

Model	Pattern correlation coefficient between simulated and CMAP (GPCP) mean rainfall for all available years between 1979 and 2009	Correlation coefficient between predicted and observed ISMR	
	Region: 60–100°E, 10°S–30°N	All available years	All available years, excluding 1983 and 1997
UKMO*	0.56 (0.57)	0.43	0.53
MeteoFrance*	0.60 (0.58)	0.36	0.47
CMCC*	0.71 (0.57)	0.33	0.47
IFM*	0.65 (0.47)	0.30	0.41
ECMWF*	0.79 (0.76)	0.29	0.40
CFS1**	0.66 (0.60)	0.14	0.33
CFS2**	0.81 (0.74)	0.41	0.57

*Period: 1960–2005; **Period: 1982–2009.

So, what you see here are two things, one is the pattern correlation coefficient between the stimulated and observed mean rainfall for all the available years and the region we have taken for the comparison is shown here. This is the region over which the actually pattern is compared for the years for which the runs were made with the model stimulated pattern and the correlation is derived.

And what you see here is the correlation between stimulated and CMAP or GPCP mean rainfall for all the available years and what you see is that in fact, the correlation, the mean patterns are very good, the mean patterns turn out to be pretty good for CFS2 and it is pretty bad for UK Met office, where you remember, UK Met Office had very much more rain here, almost no rain here, whereas the opposite is true of the observations, where you get the rain over eastern north west.

And UK Met office also had any hardly rain; any rain over India, so UK Met office has relatively poor pattern correlation; pattern correlation of ECMWF model is pretty good, 79 and CSF2 is also good but you have to remember that CFS2 the sample size is much smaller because the runs have only for 79 to 2009. Now, so; now, what is the correlation coefficient between predicted and observed ISMR, this is where we are trying to test, what is the skill of the model.

And the simplest measure is correlation between predicted and observed ISMR and what you see is, if we take all the available years, then UK Met office has the highest correlation here and CFS2 is coming rather close to it. Now, it is important to see; see, there are many studies which suggest that models that get the mean pattern better are likely to get the year to year variation better.

But actually, this study shows that that is not the case at all, actually the mean correlation is very high relatively speaking for UK Met office but pattern correlation is the lowest. Now, mean correlation is high for CSF2, so is the pattern correlation. So, this is the case and which, I think further studies are required to understand completely, that fidelity in stimulation on the mean pattern is not related to fidelity in stimulation of the year to year variation.

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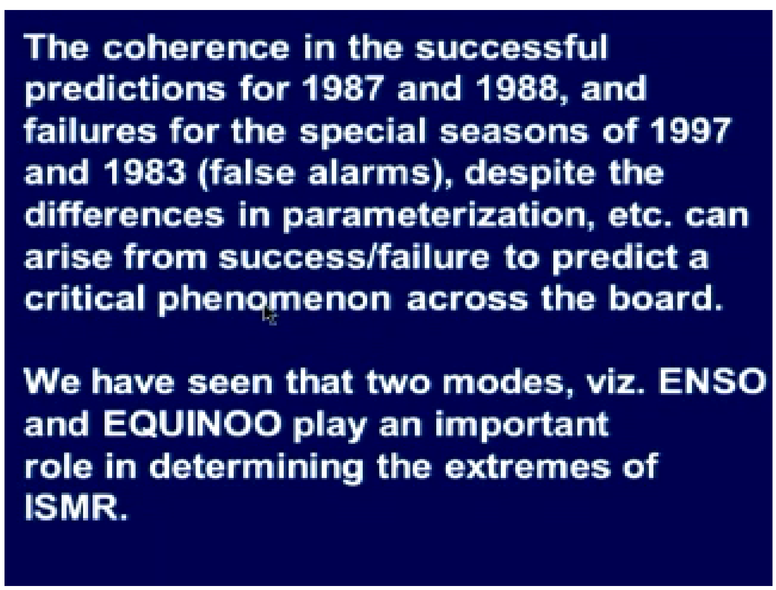

Now, we have seen all the models almost go wrong in fact, why almost, every model gets the sign wrong for 2 years; 83 and 97. Now, suppose we were be able to improve the predictions only for those 2 years, leave the others rest as there are, then what would happen, we will see that correlation will actually increase substantially if 83 and 97 are omitted from the calculation. So, the coherence in the successful predictions for 87, 88 and failures for the special seasons from 97 and 83 which were false alarms.

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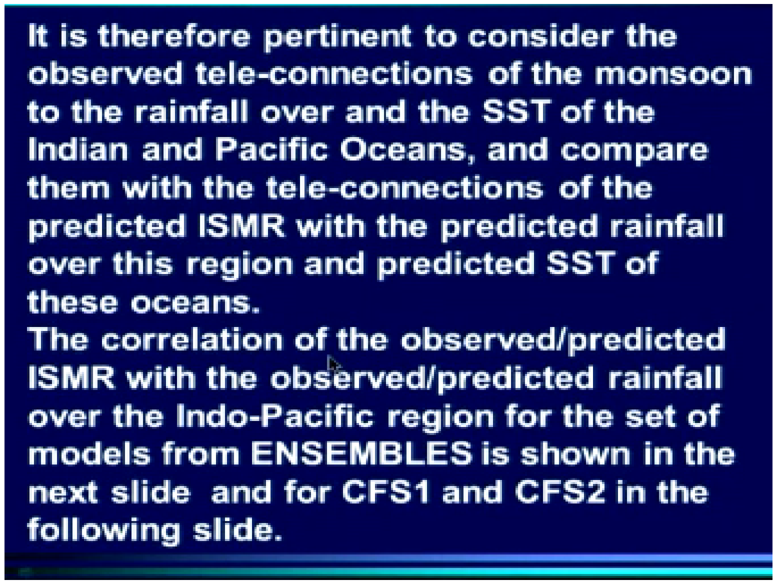

Despite the difference in parameterisation can arise from success or failure to predict a critical phenomenon across the board for all the models. Now, we have seen that 2 modes; ENSO and EQUINOO play an important role in determining ISMR. It is therefore pertinent to consider the observed tele-connections of the monsoon to the rainfall over and the SST of the Indian and Pacific oceans and compared them with the tele-connections of the predicted ISMR with the predicted rainfall over this region and predicted SST of these oceans.

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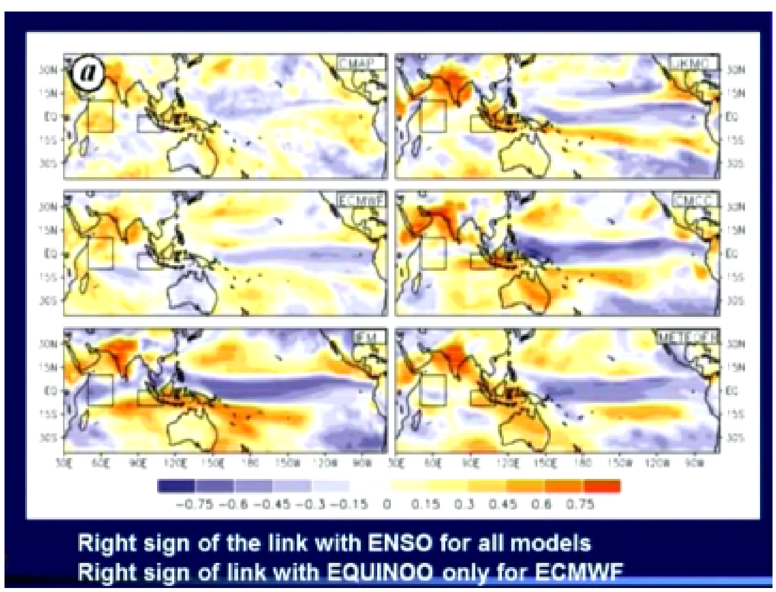

Now, in this lecture I will focus only on the predicted rainfall and not look the predicted SST. The correlation of the observed and predicted ISMR with the observed and predicted rainfall over the Indo Pacific region for all the models and for observations is shown here. This is the correlation for observations, so what is this? This is the correlation between observed and predicted rainfall.

And, so this is the correlation between observed and predicted rainfall over the India for the set of model from ensembles and for CFS1 and CFS2 in the following slides. So, this is just the observed means is the correlation of the observed ISMR with rainfall everywhere else, similar to the slide we have seen earlier. So, this is saying, observed ISMR is highly correlated with west equatorial Indian Ocean rain, negatively correlated with this and this is an EQUINOO link and negatively correlated with rainfall over Central Pacific which is the ENSO link.

Now, let us see how the models are doing, by and large the ENSO link is captured by all the models because remember, the models were tuned were develop to capture the ENSO link properly. So, the ENSO link by and large appears to be captured by the models but if you look at EQUINOO link, just say ECMWF seems to get it right that you have positive correlation with this and negative with this.

But all the other models are getting it wrong, so you have positive correlation with EEIO; rain over EEIO and negative with WEIO, same thing for UK Met office, it is getting it wrong, same thing for CMC and same thing again in fact, for Meteo-France is opposite sign, its negative correlation, large negative with this, very similar to this model here IFM model. So, right sign of the link with ENSO for all models and right sign of the link with EQUINOO only for ECMWF model.

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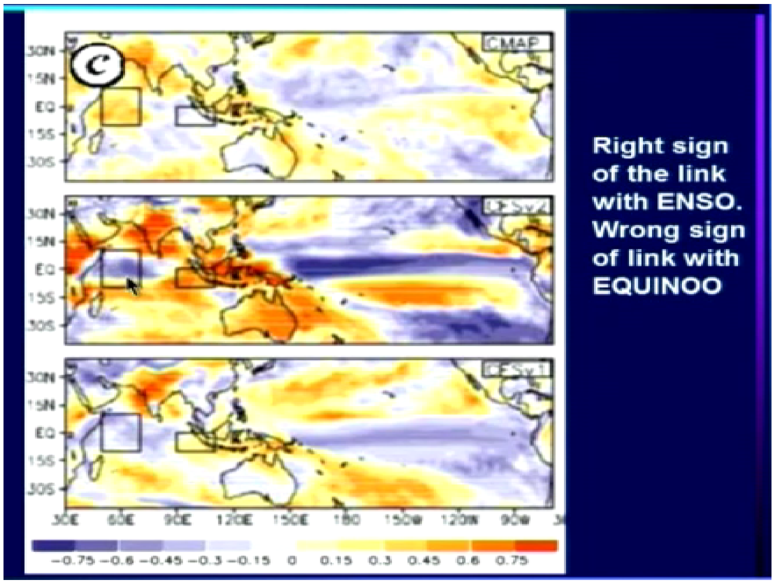

Now, same story again with CFS1 and 2; see CFS2 has very, very strong response to ENSO relative to observations as you can see. CFS1 looks a little bit better but both the models have the wrong sign of response to EQUINOO and CFS2 is much worse than CFS1, both have the wrong sign but the amplitude of the correlations is larger for CFS2.

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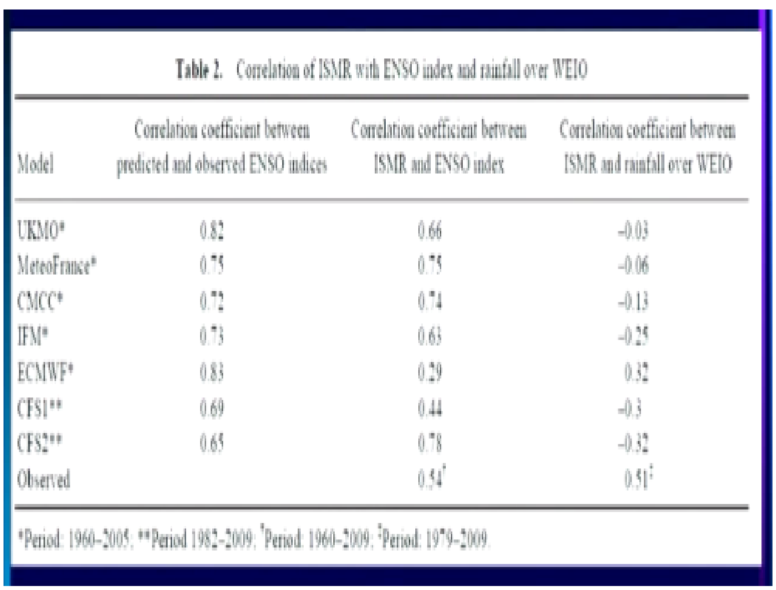

Table 2. Correlation of ISMR with ENSO index and rainfall over WEIO

Model	Correlation coefficient between predicted and observed ENSO indices	Correlation coefficient between ISMR and ENSO index	Correlation coefficient between ISMR and rainfall over WEIO
UKMO*	0.82	0.66	−0.03
MeteoFrance*	0.75	0.75	−0.06
CMCC*	0.72	0.74	−0.13
IFM*	0.73	0.63	−0.25
ECMWF*	0.83	0.29	0.32
CFS1**	0.69	0.44	−0.3
CFS2**	0.65	0.78	−0.32
Observed		0.54†	0.51‡

*Period: 1960–2005; **Period 1982–2009; †Period 1960–2009; ‡Period 1979–2009

So, correlation of ISMR with ENSO index and rainfall over WEIO, this is the correlation coefficient between predicted and observed and this is what you have predicted and observed ENSO indices and what you see is the correlation are ranging from 0.65 to 0.82 pretty high correlation, so the ENSO index is reasonably well captured, correlation coefficient between ISMR and ENSO index, which is the link now.

Now, here is the observed link which is correlation is only 0.54, you remember that is because ISMR is correlated not only with ISMR but also with EQUINOO. Therefore, the observed correlation is 0.54 but actually, many of the models are over estimating the link with ENSO except for ECMWF and CSF1, except for those, all the models overestimate the link with ENSO and now we look at correlation coefficient between ISMR and follow a WEIO, which in the observations.

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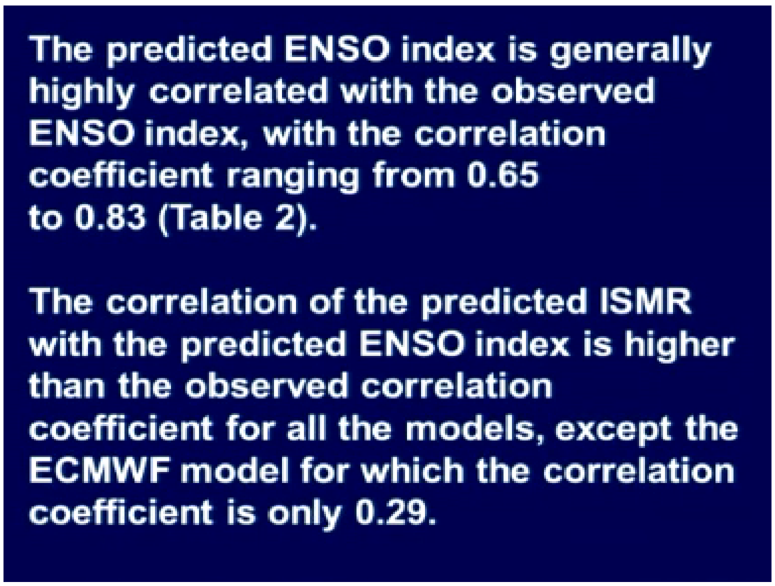

This is the western equatorial Indian Ocean, in observations; it is 0.51, whereas almost all the models are getting it negative except for ECMWF, which is getting it positive. So, ECMWF captures the correct sign of the link with EQUINOO, all the other models stimulate the wrong sign of EQUINOO link with the EQUINOO, so the predicted ENSO index is generally, highly correlated with the observed ENSO index with the correlation coefficient ranging from 0.65 to 0.83.

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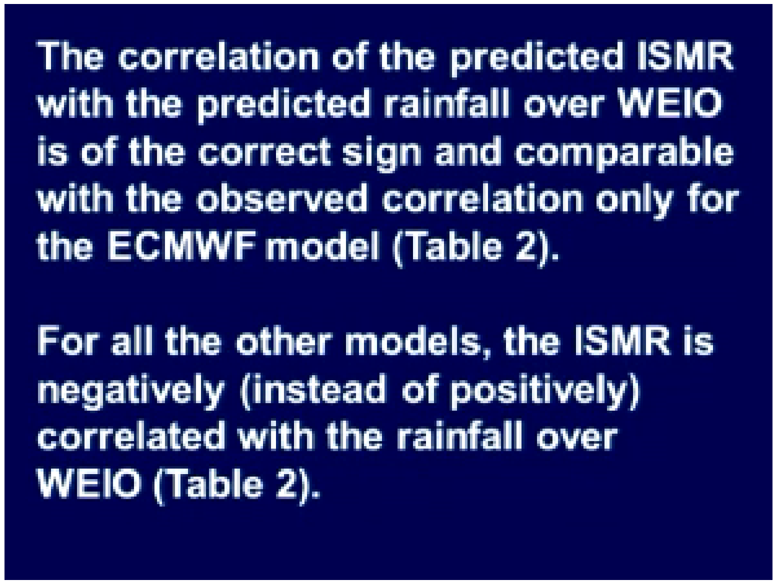

The correlation of the predicted ISMR with the predicted ENSO index is higher than the observed correlation coefficient for all the models except the ECMWF model for which the correlation coefficient is 0.29. The correlation of the predicted ISMR with the predicted rainfall over WEIO is of the correct sign at and compatible with the observed correlation only for ECMWF. So, this is an important point to note.

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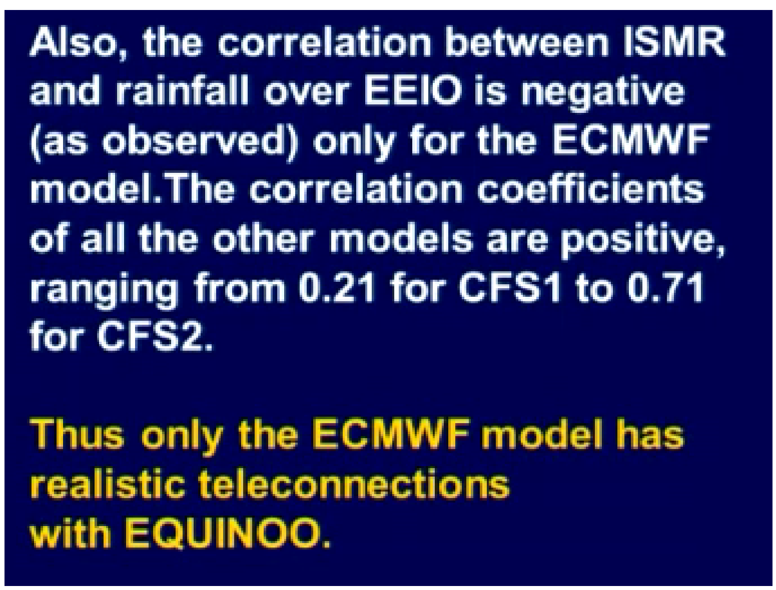

For the other models, the ISMR is negatively instead of positively correlated with the rainfall over WEIO; also the correlation between ISMR and rainfall over EEIO is negative as observed only for ECMWF, correlation coefficient of all the other models are positive ranging from 0.21 for CFS1 to 0.71 for CFS2. Thus, only the ECMWF model has realistic links with EQUINOO.

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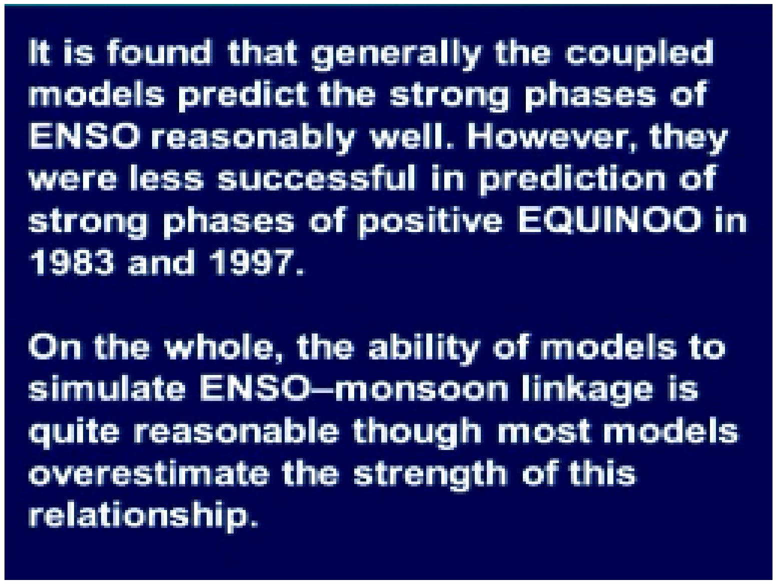

It is found that generally the coupled models predict strong phases of ENSO reasonably well. However, they were less successful in prediction of the strong phases of positive EQUINOO in 83 and 97. On the whole, the ability of models to stimulate ENSO-monsoon linkage is quite reasonable. Though, most models overestimate the strength of this relationship.

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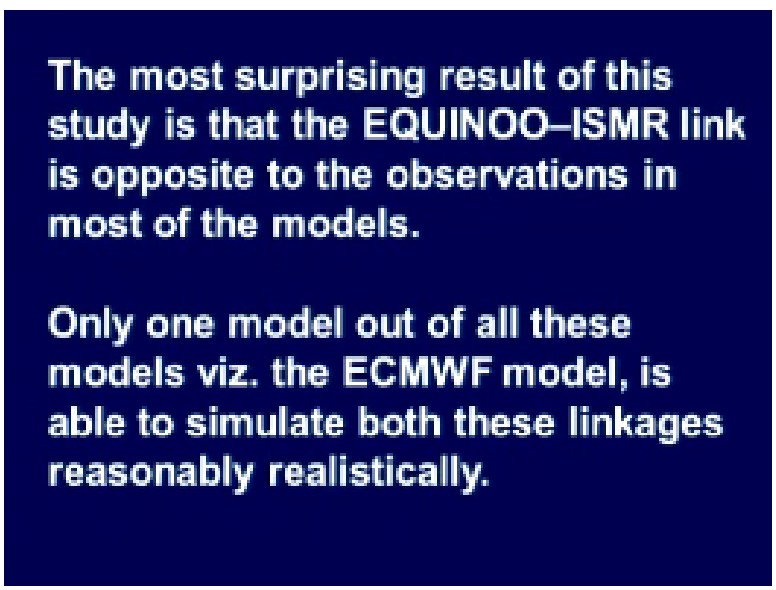

The most surprising result of this study is that EQUINOO-ISMR link is opposite to the observations in most of the models, only one model out of all these models; ECMWF model is able to stimulate both these linkages reasonably realistically.

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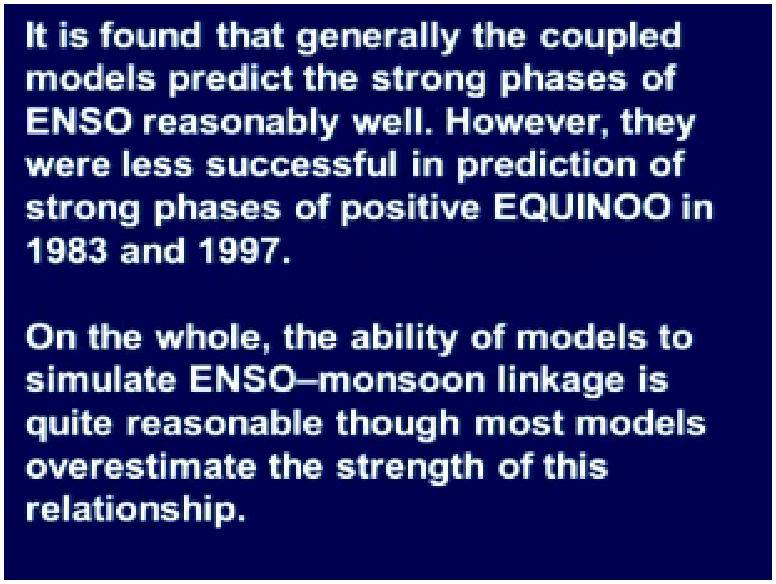

Now, detailed analysis of the cases of 83 and 97, when all the models failed, suggests that improvement of the prediction of the phases of EQUINOO, the stimulation on the monsoon EQUINOO link and of some aspects of ENSO is the prerequisite for better predictions of the Indian monsoon. So, let me say that the; actually, there has been steady improvement in prediction of the monsoon.

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Table 1. Correlation coefficient between observed and predicted rainfall (June–September)

Model	Pattern correlation coefficient between simulated and CMAP (GPCP) mean rainfall for all available years between 1979 and 2009 — Region: 60–100°E, 10°S–30°N	Correlation coefficient between predicted and observed ISMR — All available years	All available years, excluding 1983 and 1997
UKMO*	0.56 (0.57)	0.43	0.53
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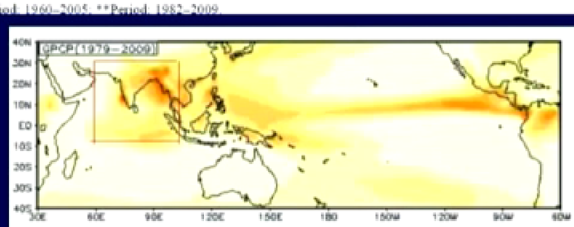
CFS1**	0.66 (0.60)	0.14	0.33
CFS2**	0.81 (0.74)	0.41	0.57

*Period: 1960–2005; **Period: 1982–2009.



In fact, we had seen here that the correlation coefficient between the observed and predicted, you know for ensembles is ranging from about .0.3 to 0.43 and this is significantly higher then, was found in an earlier study with earlier versions of these models and so, there has been a significant improvement in the correlation; over all correlation of the predicted and observed ISMR value in this ensembles related to the Demeter, which was an earlier experiment.

Similar experiment, on retrospective predictions than with European models under the European Centre, so there has been definitely an improvement in the models both in terms of better representation of sub grid skill processes like clouds, boundary layers and so on and also better resolution. In addition, now as opposed to earlier, the models are in fact, assimilating ocean state initial conditions much, much better.

So, there has been marked improvement in data assimilation as well in the models in terms of resolution and their physics as well and this has led to considerable improvement in the skill as measured by the correlation between predicted Indian summer monsoon rainfall and the observed summer monsoon rainfall but we have improved the further that is very clear because we saw that in some years, they give huge false alarms such as 97, which was a normal year.

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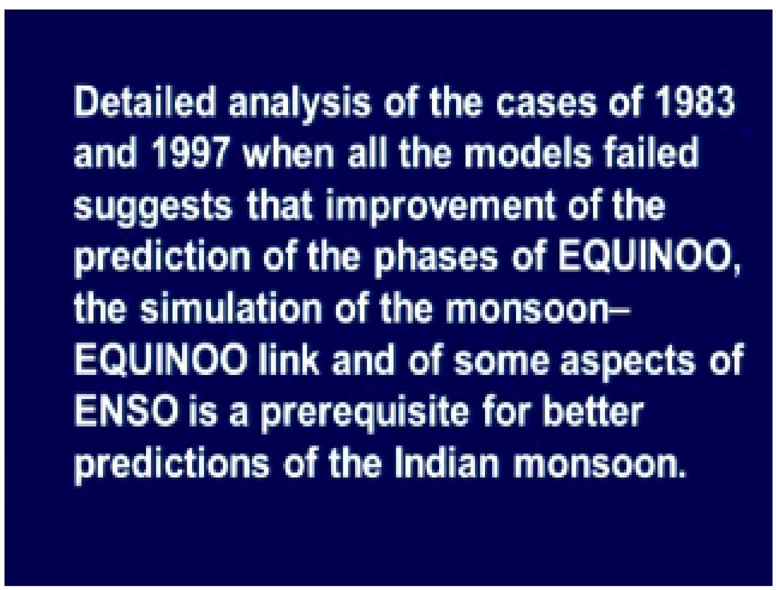

And all the product models predicted a huge drought and 83, which was an excess monsoon year for which also several models predicted drought and all of them predicted deficit rainfall. So, once we can improve these facets of the model, if we can get them to do; you know stimulate EQUINOO better and the link with EQUINOO better and almost all the models fail to stimulate the link with EQUINOO.

Then, we should be able to improve the skill beyond what it is today and avoid this big false alarms, so that would require a systematic study to see why are all the models getting the wrong sign of link with EQUINOO. Now, this is a very important thing to do and it is since EQUINOO has been discovered relatively recently, whereas ENSO, the big advances have come already in the 80s and so on.

It is not surprising that the models are not able to get the EQUINOO-monsoon link right because as I mentioned earlier, models were actually turned or developed to get the ENSO-monsoon link right. So, this is not the surprise but what was surprising part of this study was that even some aspects ENSO need better prediction, if we have to get the monsoon right for example, the evolution of ENSO in 1997 was probably not realistically stimulated.

All the anomalies were there and in 1983, the El Nino retreated half way through or monsoon season, so June, July were very much deficit but August, September we had; the El Nino had retreated, so ENSO and conditions were no longer unfavourable and we had the development of a very strong positive EQUINOO. This combination led to heavy rainfall in August, September and excess monsoon rainfall for the season as a whole in 83.

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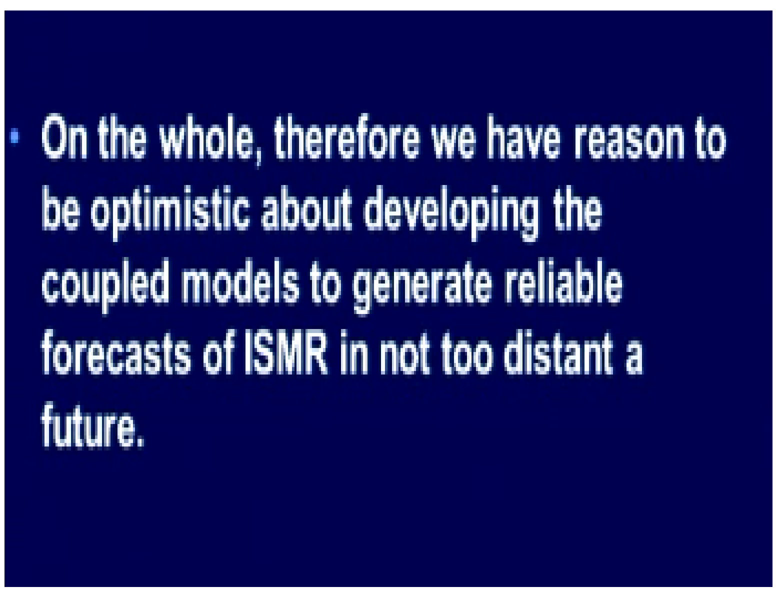

So, it appears that definitely as we had expected the simulation of EQUINOO and the link to EQUINOO of the monsoon have to be improved in the models and these years maybe good years to work on to get the links right but it appears, that more work is also required in stimulating certain facets of ENSO, more realistically. So, on the whole then, we have reason to be optimistic about developing the coupled models to generate reliable forecasts of ISMR in not too distant a future.

Because as I mentioned before from Demeter to ensembles has been only 5 years and considerable progress has been done. If there are concerted efforts, focused on trying to understand why all the models fail in some years and why are they getting the wrong EQUUINOO link, I think we would be able to improve the models to a satisfactory level in the next 5 years.

So, I am very optimistic that very soon our coupled atmosphere-ocean models, the state of the art coupled atmosphere model in the world today would be able to do a good job of generating reliable forecast of the Indian summer monsoon rainfall. Thank you.