The Monsoon and Its Variability
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Lecture - 28
El Nino Southern Oscillation (ENSO) Part 5

Today we continue our discussions about ENSO, the El Nino Southern Oscillation phenomenon try and take stock of the understanding of the phenomenon.

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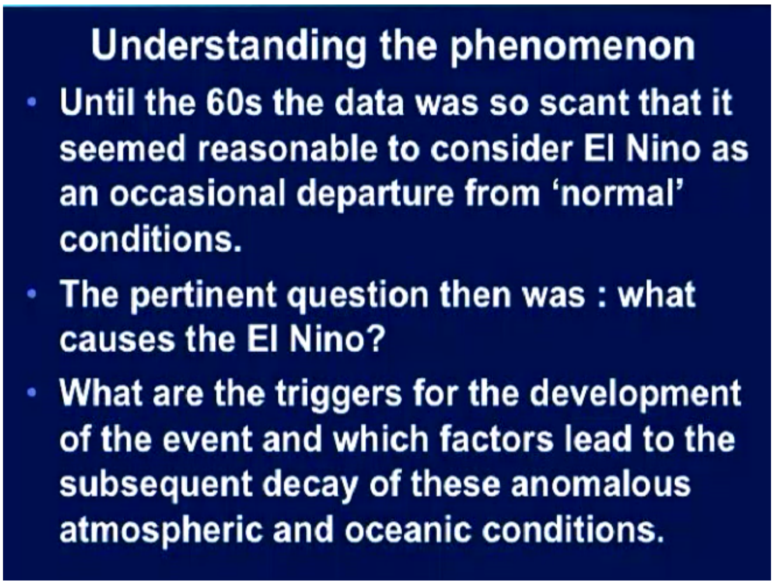

Until the 60s the data was so scant that it seemed reasonable to consider El Nino as an occasional departure from normal conditions, as a special event which occurs now and then you know. So the pertinent question then was, what causes the El Nino? What are the triggers for the development of the event and which factors lead to the subsequent decay of these anomalous atmospheric and oceanic conditions.

So it was okay to consider with the data available then to consider El Nino as an event that occurs and disappears so that conditions return to normal. So this is some kind of anomalous atmospheric oceanic conditions that occur which is called El Nino, this is what was thought.

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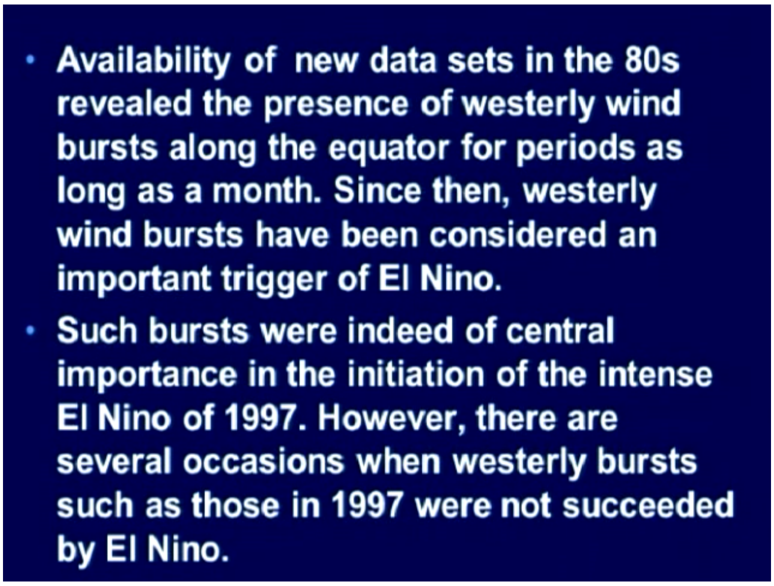

Availability of the new data sets in the 80s revealed the presence of westerly wind bursts along the equator for periods as long as a month. Since then, westerly wind bursts have been considered an important trigger of El Nino. Now such bursts were indeed of central importance in the initiation of the intense El Nino of 1997, we saw this was the intense El Nino of the century.

However, there are several occasions when we westerly burst such as those in 97 were not succeeded by El Nino. So this is the problem, because it appears to be that you may get burst which do not later on lead to an El Nino, on the other hand major El Nino events may be preceded by such bursts.

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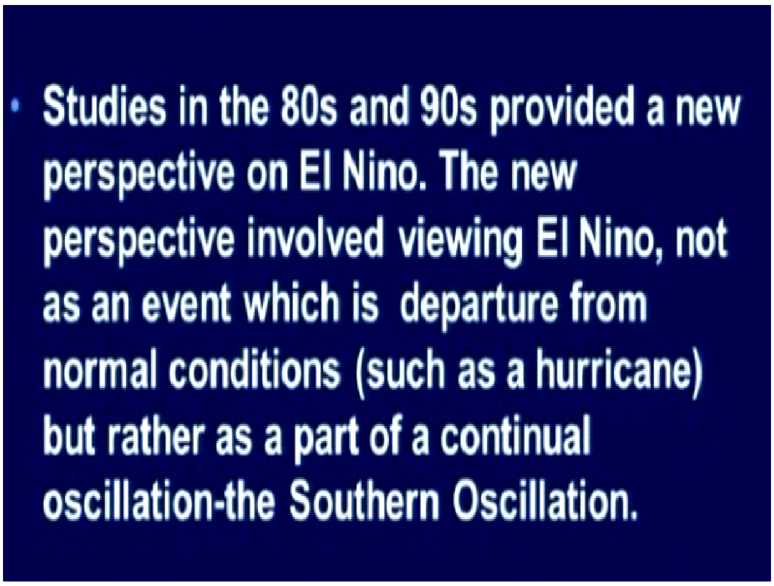

Studies in the 80s and 90s provided a new perspective on El Nino. The new perspective involved viewing El Nino, not as an event which is departure from normal, such as a hurricane. We talk of a hurricane being generated, moving, dieing and then conditions return to normal. So that is the kind of the event which it was considered for as an event which is the departure from normal conditions earlier.

But now the new perspective was to consider El Nino rather as a part of a continual oscillation what they call the southern oscillation. So the southern oscillation comprises oscillation between El Nino and La Nina. So El Nino is a part of this kind of an oscillation, something like a pendulum but it is not regular like a pendulum.

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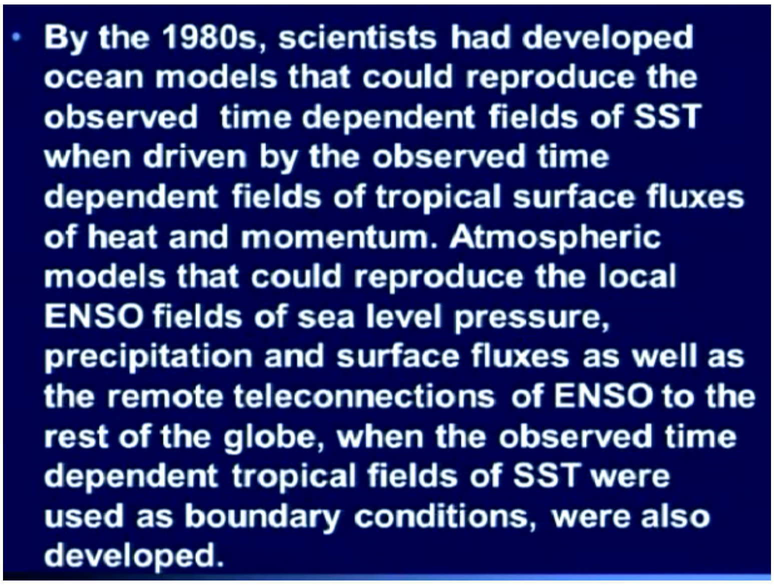

By the 1980s , scientists had developed ocean models that could reproduce the observed time dependent fields of SST when driven by the observed time dependent fields or tropical surface fluxes of heat and momentum. In other words, see when I talk of models and I have not discussed them at any length in this course. But basically models of the ocean or the atmosphere are models which have governing equation which are just the basic laws of physics.

And if it is an ocean model, then conditions have to be specified on the top, the atmosphere, the surface of the ocean. If it is an atmospheric model conditions have to be specified on land or on ocean depending on whether the atmosphere is on land or ocean and then these equations are integrated with time to give a solution of the equation. So when we have ocean models, if the ocean models are driven by the kind of winds that are observed

And by the fluxes you have seen that radiation is one important flux driving the ocean. So by surface fluxes of heat and momentum, momentum being wind. If these are specified realistically from the atmosphere, then ocean models could reproduce the observed fields of sea surface temperature and their evolution with time.

So the models had enough physics in them that ocean models when driven by appropriate condition of the atmosphere could reproduce evolution of SST as observed, in other words also could reproduce El Nino and La Nina which are major anomalies of SST fields. Similarly, atmospheric models could reproduce the local ENSO fields, that is say fields corresponding to oscillation of sea level pressure and precipitation, surface fluxes, etc.

As well as the remote tele-connections, you have seen earlier that ENSO is in fact, has connections with many parts of the tropics, for example El Nino is associated with deficit rain over India, and so on and so forth. So these atmospheric models could reproduce a lot of this if sea surface temperature was specified as a bottom boundary conditions realistically, realistic sea surface temperature was specified as a boundary condition.

So we had a situation in which if we had right boundary condition for the atmosphere, it could reproduce the southern oscillation, if we had right boundary condition for the ocean surface in terms of fluxes of momentum and heat it could produce El Nino and La Nina. But we have seen that the 2 are linked, because sea surface temperature itself determines to a large extends, the pressure distribution in the wind.

We have seen that how water circulation is connected with the sea.

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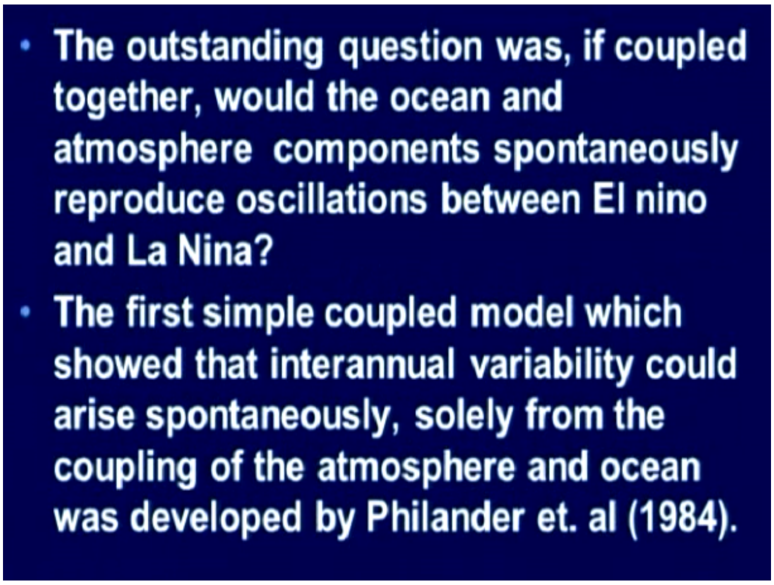

So the outstanding question was if coupled together, would the ocean and atmosphere components spontaneously reproduce oscillations between El Nino and La Nina, because the real atmosphere and ocean are coupled and what we need to start is with an initial condition and let the couple system evolve with time obeying the loss of motion, obeying the dynamical equations.

Now question would they then generate spontaneously an oscillation between El Nino and La Nina the SST anomalies associated with it, and also the oscillation that you see in the atmosphere, between the sea level pressure and so on and so forth. So question is when coupled together can these be generated spontaneously, can the oscillations be generated spontaneously in a run of the coupled model.

In fact, the first simple coupled model which showed that interannual variability could arise spontaneously, solely from the coupling of the atmosphere and the ocean was developed by Philander, who has written 2 excellent books on the theme to which I have referred to before. Now this was in the Philanders book was in, paper was in 1984.

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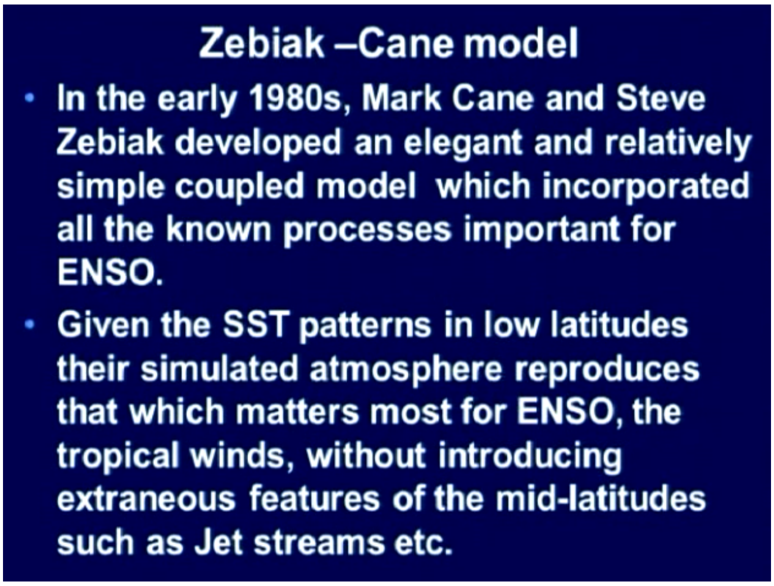

Now in early 80s, Mark Cane and Steve Zebiak developed an elegant and relatively simple coupled model which incorporated all the known processes important for ENSO. So you know the models vary in complexity, coupled models vary in complexity also you can make many simplifying assumptions to make them simpler, but the most realistic coupled model which involve a realistic incorporation of all the physics are extremely complex.

The game is to try and see whether a simple model can generate some of the feature that are important, because it is much easier to analyse and understand simple models than the complex models. So what Mark Cane and Steve Zebiak developed was an elegant and relatively simple coupled model which incorporated all the known process important for ENSO.

So given the SST patterns in low latitudes their simulated atmosphere reproduce that which matters most for ENSO, the tropical winds, without introducing extraneous features of the mid-latitudes such as jet streams, etc., because the general circulation model which is a coupled model has weather, climate and so on for the entire atmosphere over the earth, that is not required to understand in the basic physics of ENSO.

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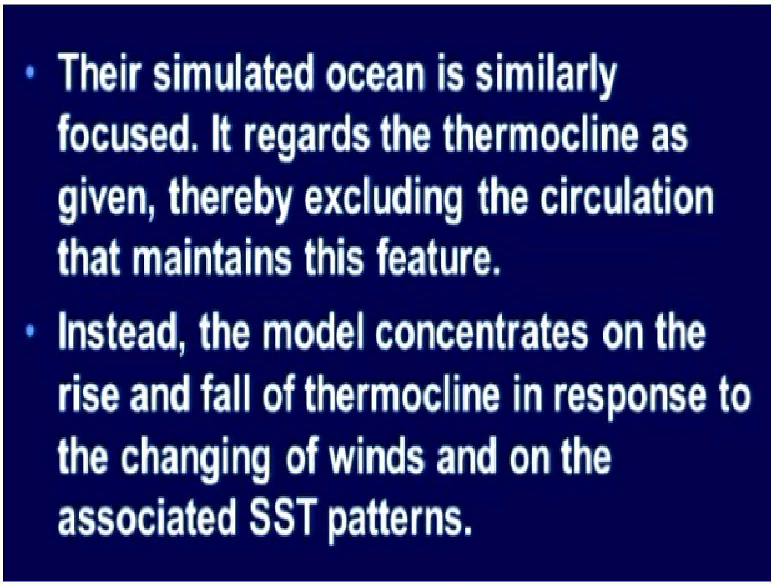

So their model actually could simulate realistic features of the tropics given the SST pattern, their simulated ocean is similarly focused. It regards the thermocline as given, thereby excluding the circulation that maintains this feature. Instead the model concentrates on the rise and fall of thermocline in response to the changing of the winds and on the associated SST patterns.

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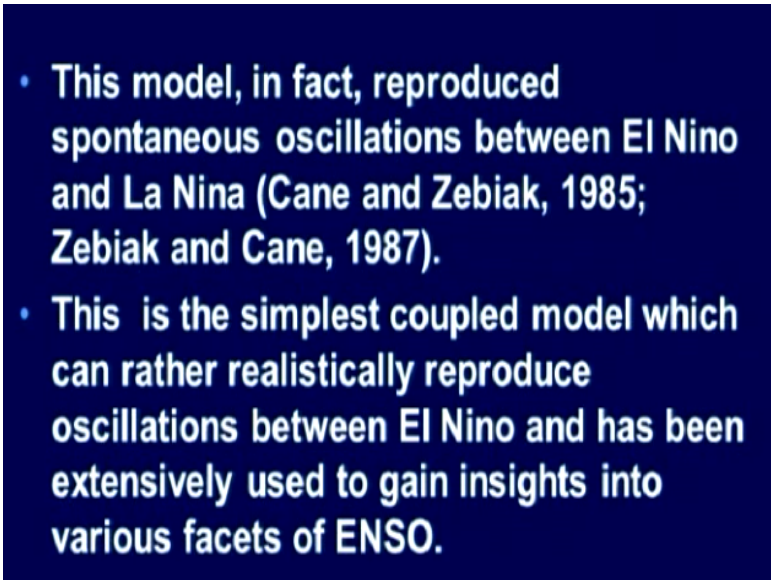

So they were lot of things that were built into the model and this model in fact reproduced spontaneous oscillations between El Nino and La Nina. So this is the simplest coupled model which can rather realistically reproduce oscillations between El Nino and has been extensively used to gain insights into the various facets of ENSO. So it still produces rather realistic oscillations.

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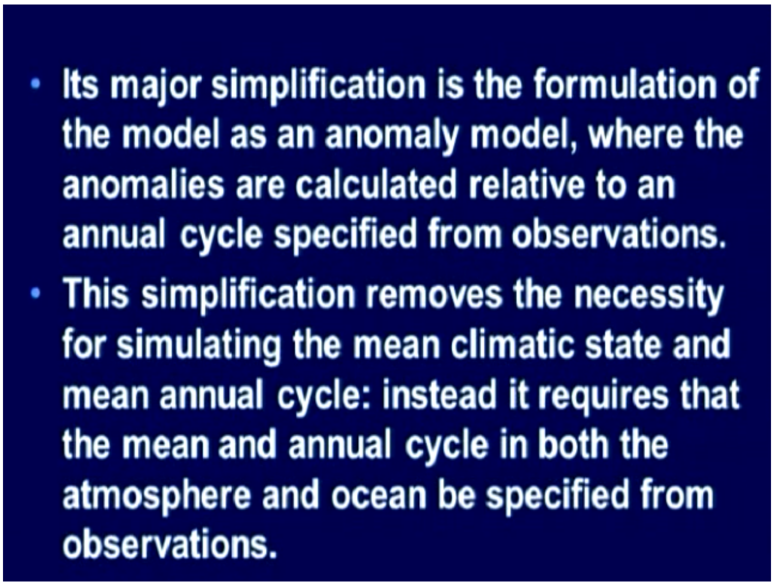

Now when I said given SST fields what did I mean, see the major simplification in this model is that the formulation of the model is an anomaly model, where the anomalies are calculated related to an annual cycles specified from observations. So you have the annual cycle both of the atmosphere and ocean which is specified from observations. And what the model is predicting is the departures from these mean fields.

So it is what is called an anomaly model, it only works with anomalies. Now this simplification removes the necessity for simulating the mean climate state and mean annual cycle. So this whole problem of how to get the mean cycle right and climate right and so on is just wish the way in this model. It does not come into the picture at all.

Instead it requires that the mean and the annual cycle in both the atmosphere and ocean be specified from observations. So mean and annual cycle are specified from observations and the model then simulates the anomalies which are departures from this mean.

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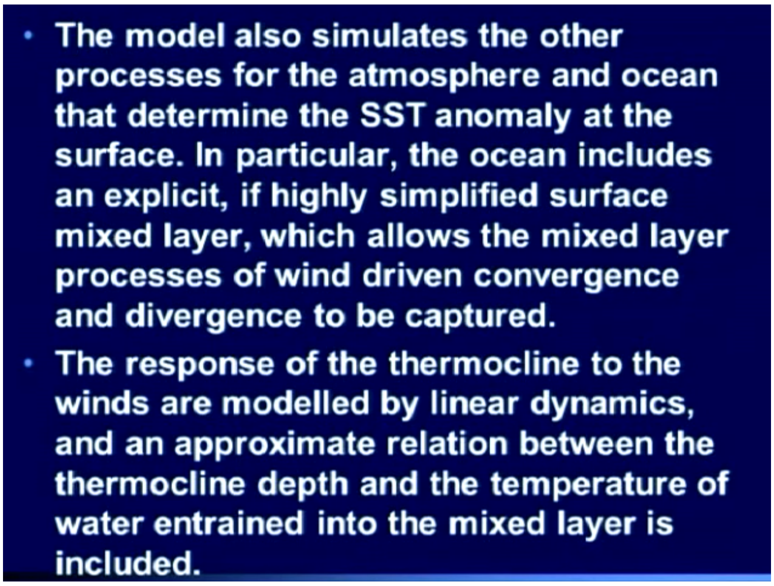

So the model also simulates the other processes for the atmosphere and ocean that determines the SST anomaly at the surface. In particular, the ocean includes an explicit, if highly simplified surface mixed layer, which allows the mixed layer processes of wind driven convergence and divergence to be captured. So although the model is simple, the critical physical processes are included in a reasonable way.

So it includes an explicit boundary layer or a surface mix layer, so that you get an interaction between the atmosphere and the mixed layer and depending on the wind you will get convergence or divergence as we discussed in the lecture before, the one convergence and divergence and so on. So the model has to realistically get the convergence or divergence, now the response of the thermocline to the wind s are modelled by linear dynamics.

And an approximate relation between the thermocline depth and the temperature of the water entrained into the mixed layer is included, because once we have the thermocline there and if the wind is such that upwelling is introduced, then we need to know what is the temperature of water entrained. So that is also specified, the temperature of the water is specified by assuming an approximate relation between the thermocline depth.

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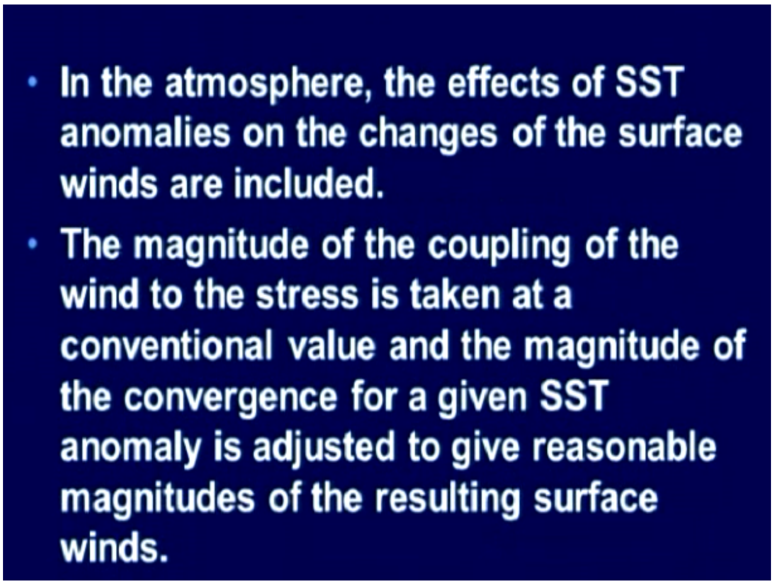

In the atmosphere, the effects of SST anomalies on the changes of the surface winds are included, remember this whole feedback, Bjerknes' feedback implies that differences in the SST gradient which are directly responsible for differences in pressure, surface pressure, will actually have impact on the winds, to which the surface pressure is directly related. So effects of SST anomalies on changes of the surface winds have to be included if the coupling has to be properly incorporated, so that has also been included.

The magnitude of the coupling of the wind to the stress is taken at a conventional value and the magnitude of the convergence for a given SST anomaly is adjusted to give reasonable magnitudes of the resulting surface winds. So here again some parameters have to be brought in and they have just made those are not unreasonable and completely close the links, so the links are as we know them.

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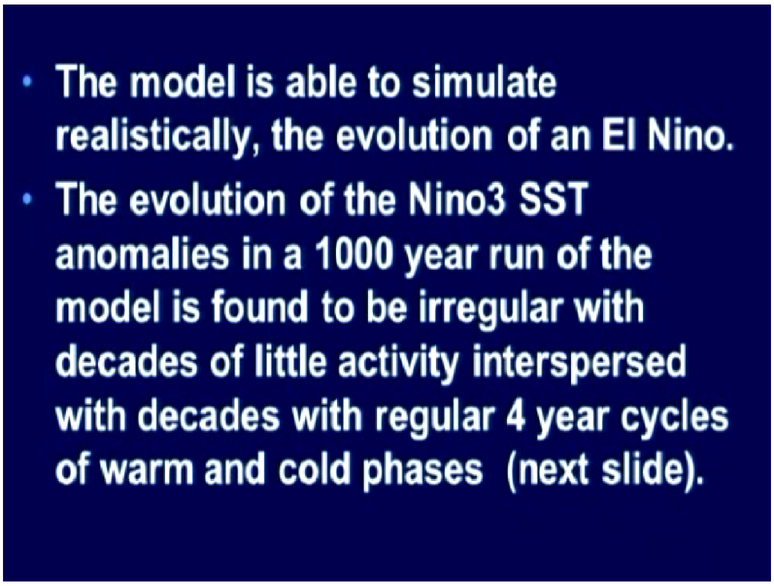

Then the model is able to simulate realistically the evolution of an El Nino, and I will just show you a sample, see the model is simple enough that it was possible even in the 80s, the computer is available even in the 80s, to make runs like 1000 year run, and what did they find.

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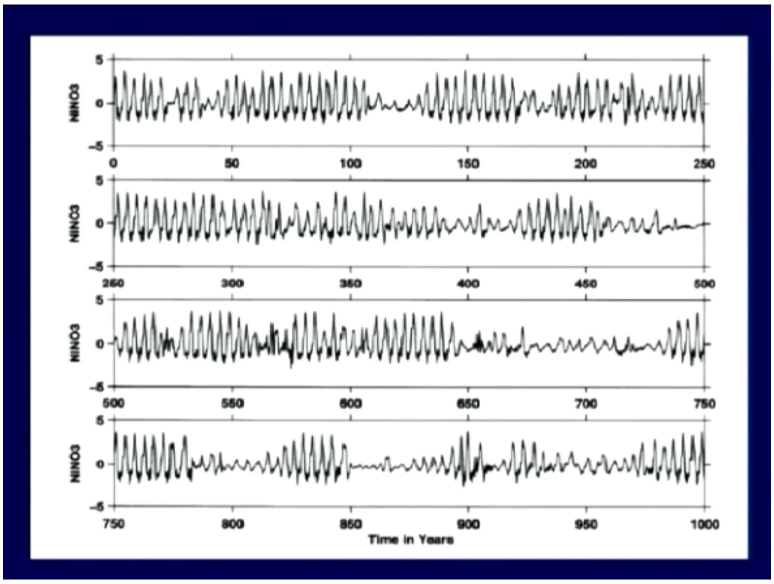

So this is a 1000 year run from the model and this is temperature of the Nino 3 region, remember Nino 3 is the region which goes all the way from Central Pacific to East Pacific. So this is the temperature of the Nino 3 region, SST of the Nino 3 region and what you see is an irregular oscillation, there is definitely oscillation between El Nino and La Nina, and these oscillations occur with certain period up to a point and then simply disappear, not much oscillation.

Again they pickup, again the periods in which there are not much oscillations and this is what is seen. So this is a typical irregular oscillation that the model produced. So what they found was that the oscillation that the model simulates is irregular with decades of little activity interspersed with decades with regular 4 year cycles of warm and cold phase, which is what we saw here regular.

It happens to be 4 year cycles of warm phase cold phase, warm phase cold phase and so on. Now this period is quite regular but the amplitude you can see, there is hardly anything here and then it picks-up and so on and so forth.

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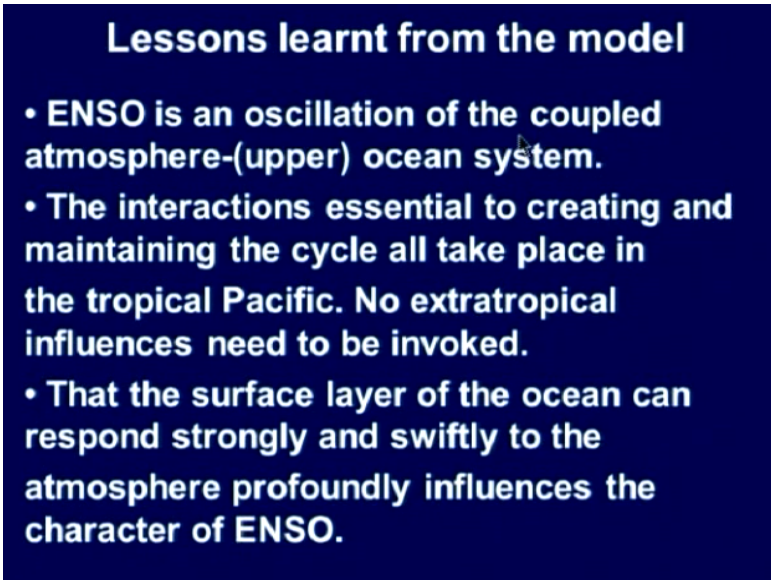

Now this model has started as a great deal, so let us see what are the lessons learnt from the model. First of all ENSO is an oscillation of the coupled atmosphere-upper ocean system. The very fact that the model could produce such realistic ENSO, El Nino, La Nina and oscillations such as that what they did in the model was enough to simulate ENSO. That is to say it is an oscillation of the coupled atmosphere-upper ocean system.

Because that is all the coupling was with. The interactions essential to creating and maintaining the cycle, all take place in the tropical pacific. Now extra tropical influences need to be invoked. Now this is the very important thing to say, that is to say it is entirely tropical phenomenon.

To generate ENSO, we do not need mid latitudes at all, and that the surface layer of the ocean can response strongly and swiftly to the atmosphere profoundly influences the character of

ENSO. So it is important to remember that the surface layer of the ocean can respond very strongly and swiftly to the atmosphere. This is a very important element and which is incorporated in the model and this profoundly influences the character of ENSO.

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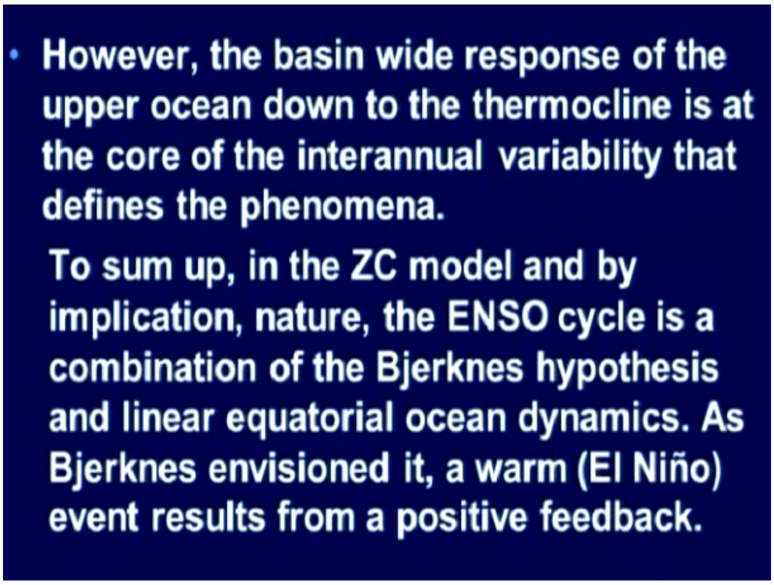

However, the basin wide response of the upper ocean down to the thermocline is at the core of the interannual variability that defines the phenomenon. So it is not enough that you have a quick response of the ocean to the atmospheric forcing. The basin wide response of the upper ocean down to the thermocline is very important to capture, and that is at the core of the interannual variability that defines the phenomenon.

Because you remember during El Nino the thermocline is forced down in the East Pacific during La Nina it is lifted up. And this is the basin wide phenomenon and therefore it is very important to capture this as well. So to sum up in the Zebiak-Cane model and by implication nature the ENSO cycle is a combination of the Bjerknes hypothesis, which you remember involved interaction between SSTs and the winds and so on and so forth, and linear equatorial ocean dynamics.

So as Bjerknes envisioned it, a warm El Nino event results from a positive feedback. So these positive feedbacks are actually incorporated in the model and that is what lead to an El Nino, you remember his positive feedback involved the following.

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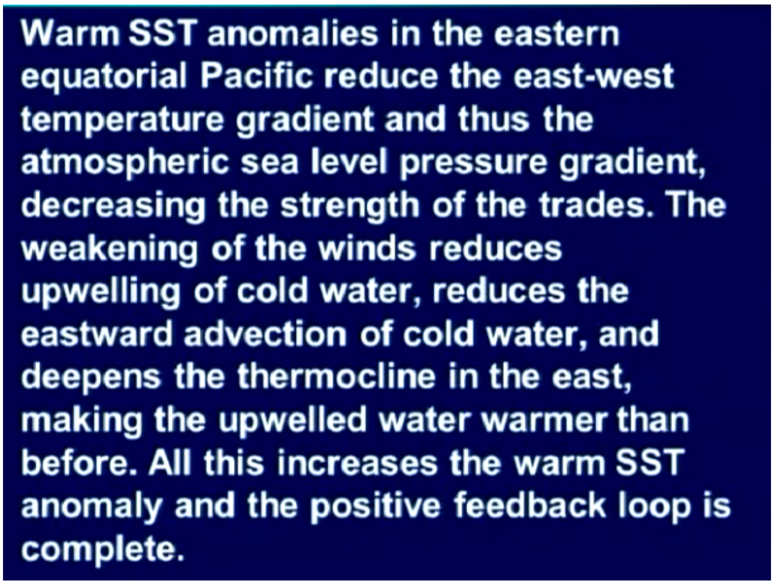

Warm SST anomalies in the eastern equatorial pacific reduce the east-west temperature gradient. And thus the atmospheric sea level pressure gradient, decreasing the strength of the trades. Now weakening of the winds reduces the upwelling of cold water, reduces the eastward advection of cold water, and deepens the thermocline in the east, making the upwelled water warmer than before.

All this increases the warm SST anomaly and the positive feedback loop is complete, so this is the Bjerknes feedback that we had talked of. So you have warm SST anomalies via generating sea level pressure gradients and thereby impacting the wind, actually again have an impact on the upwelling and hence on the SST itself, so the loop is complete, so this is the feedback.

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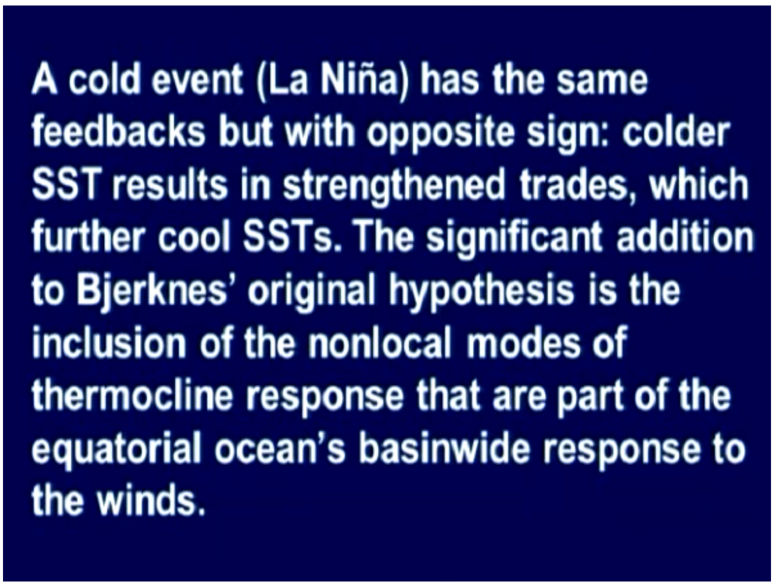

A cold event has the same feedback with the opposite sign. So colder SST results in strengthened trades, because colder SST implies stronger pressure gradient from east to west, which means stronger trade winds which will mean further cooling, right because of stronger upwelling further cooling of the SST that is to say enhancing the negative SST anomalies. So these are the feedbacks that Bjerknes talked about and they are very much in the model.

The significant addition to Bjerknes' original hypothesis is the inclusion of the non local modes of thermocline response that are part of the equatorial ocean's basin wide response to the winds. So this is the new element that had to come in, because you remember Bjerknes, with this feedback could say why an initial anomaly can intensify and lead to an El Nino or lead to a La Nino depending on the sign of the anomaly.

He actually elucidated these feedbacks that lead to it. But what he could not get is the oscillation between the 2, he could not say why once an El Nino system is set up why it does not stay that way forever, why does it decay and then finally lead to a La Nina. To incorporate that part, it is necessary to look at basin wide response of the non local modes of thermocline response that are part of the equatorial oceans basin wide response to the winds.

So that factor has to come in only then can we get an oscillation.

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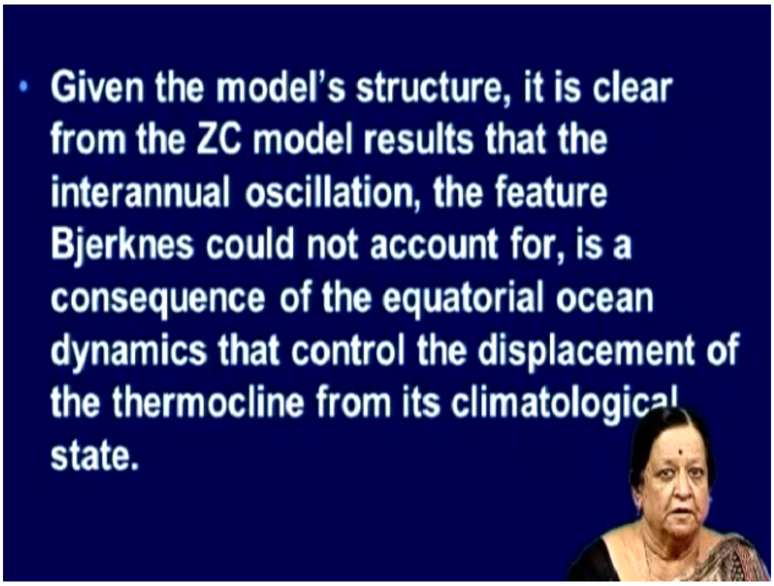

So given the model structure, it is clear from the ZC model results that the interannual oscillation the feature Bjerknes could not account for, is a consequence of the equatorial ocean dynamics that control the displacement of the thermocline from its climatological state.

So this is the element that was not there, and that is why 1 could not get the oscillation, this is the additional factor which leads to the oscillation in the Zebiak-Cane model.

That the feature that Bjerknes could not account for is the consequence of the equatorial ocean dynamics, that control the displacement of the thermocline from its climatological state.

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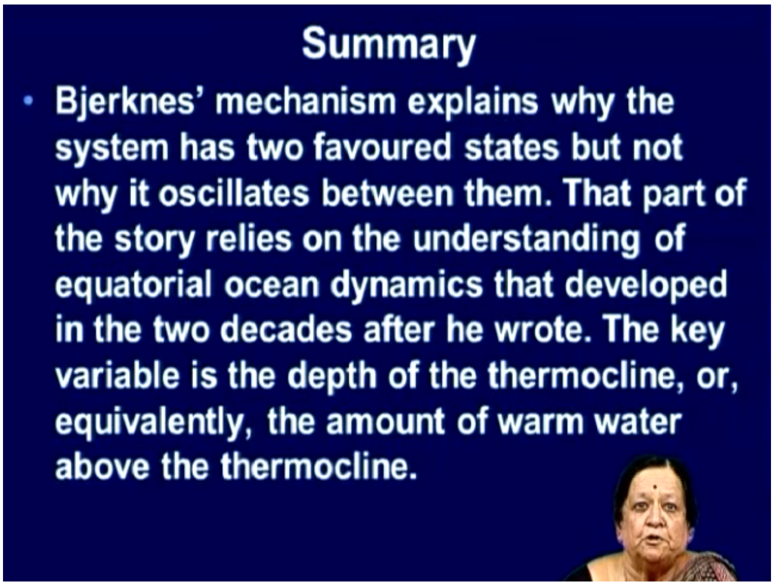

So what is the summary of this, Bjerknes' mechanism explains why the system has 2 favour states, but not why it not oscillates between them. That part of the story relies on the understanding of the equatorial ocean dynamics that developed in the 2 decades since Bjerknes wrote. The key variable is the depth of the thermocline--equivalently the amount of warm water above the thermocline.

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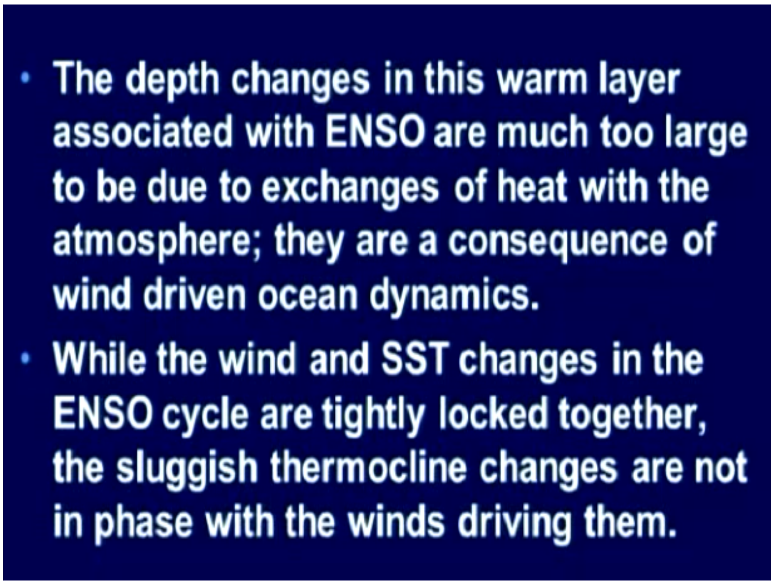

The depth changes in this warm layer associated with ENSO are much too large to be due to exchanges of heat with the atmosphere, they are a consequence of wind driven ocean dynamics. While the wind and SST changes in the ENSO cycle are tightly locked together, the sluggish thermocline changes are not in phase with the winds driving them.

See this is an important point because the ocean dynamics equatorial ocean dynamics which is the new element that has come in to this model, is such while the SST and winds are strongly coupled and SST response immediately to wind, the thermocline responses are sluggish.

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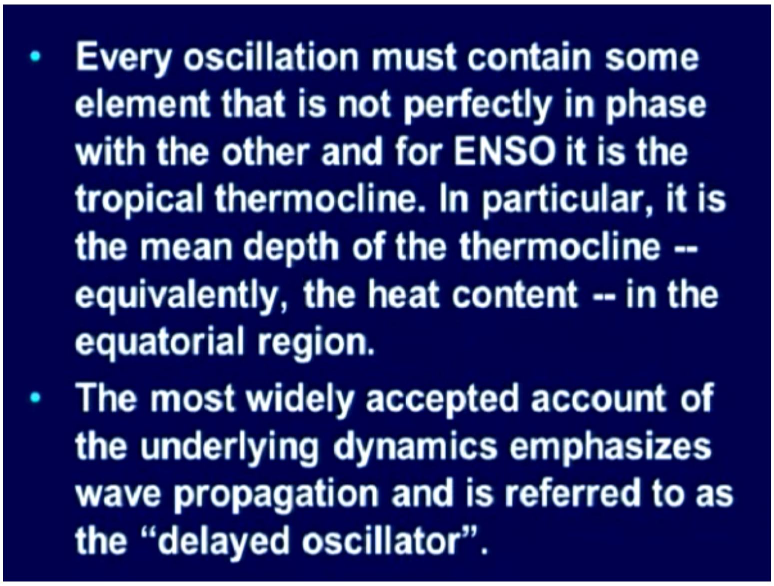

Now every oscillation must contain some element that is not perfectly in phase otherwise everything would occur instantaneously. And so every oscillation must contain some element that is not perfectly in phase with the other, and for ENSO it is the tropical thermocline. In particular, it is the mean depth of the thermocline--equivalently the heat content--in the equatorial region.

So the most widely accepted account of the underlying dynamics emphasizes the wave propagation which is the ocean dynamics I was talking about ocean dynamics of the equatorial ocean, and is referred to as the delayed oscillator.

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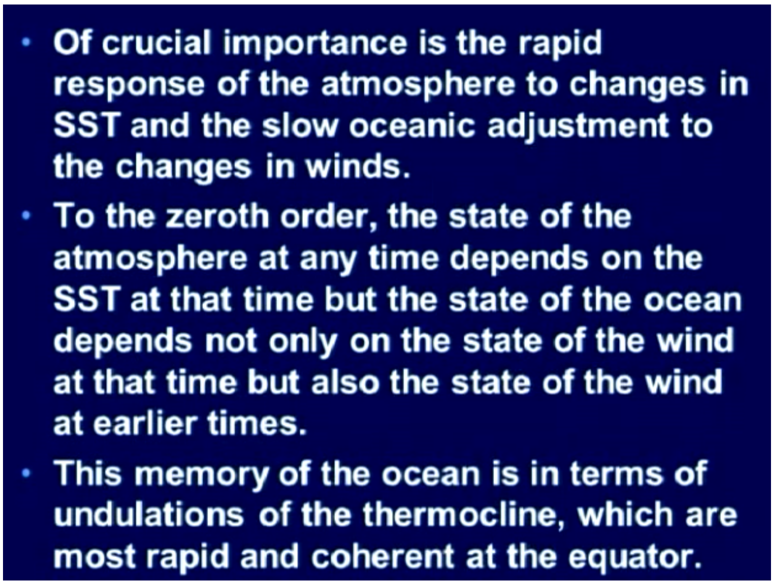

Now of crucial importance is the rapid response of the atmosphere to changes in SST and the slow oceanic adjustment to the changes in winds. To the 0th order the state of the atmosphere at any time depends on the SST at that time, but the state of the ocean depends not only on the state of the wind at the time but also the state of the wind at earlier times, because the ocean means sluggish, it kind of integrates the forcing by wind over time.

This memory of the ocean is in terms of undulations of the thermocline, which are most rapid and coherent at the equator.

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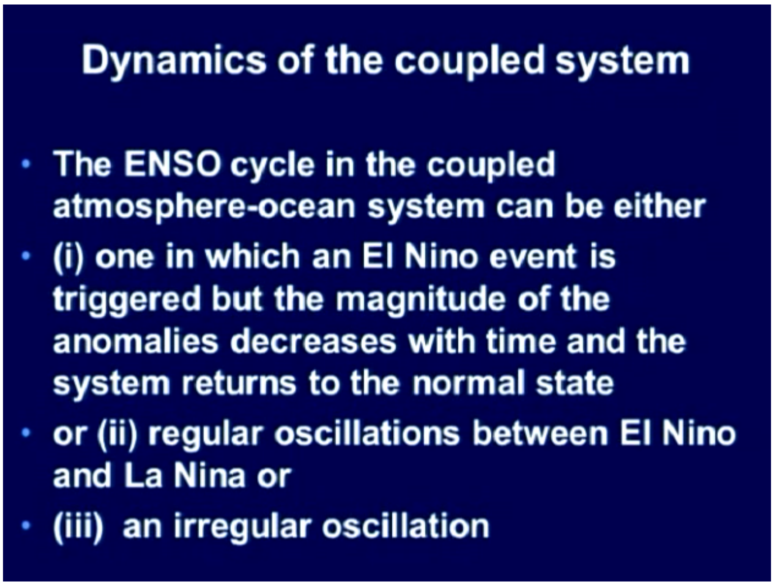

So with Cane and Zebiak model in fact a lot of physics got on the level, it is the 0th order model of ENSO in many ways and it has been used extensively to gain further insight into ENSO into things even like predictability and so on and so forth. I will not dwell on that topic. But now let us consider the dynamics of this coupled ocean-atmosphere system, which gives rise to ENSO.

Now ENSO cycle in the coupled atmosphere-ocean system can be either, 1 in which El Nino event is triggered but the magnitude of the anomalies of decreases with time and the system returns to the normal state. Remember this is what I was talking of earlier the more traditional perspective in which El Nino is considered as an event that is born that lives its life and it dies. And with its death things goes back to “normal.”

That is 1 possibility that ENSO cycle may be a series of events like this of El Nino and La Nina, each of which are individual events which are triggered by some other events and there are processes which lead to their growth, development and eventually to the decay. So this is 1 possibility. Second may be regular oscillations between El Nino and La Nina.

This could be like swings of the pendulum with 1 point where the swing ends being La Nina the other being El Nino and you could have regular oscillations between the 2, if that was the case, then you would get strictly periodic occurrence of El Nino or La Nina, and the third may be an irregular oscillation.

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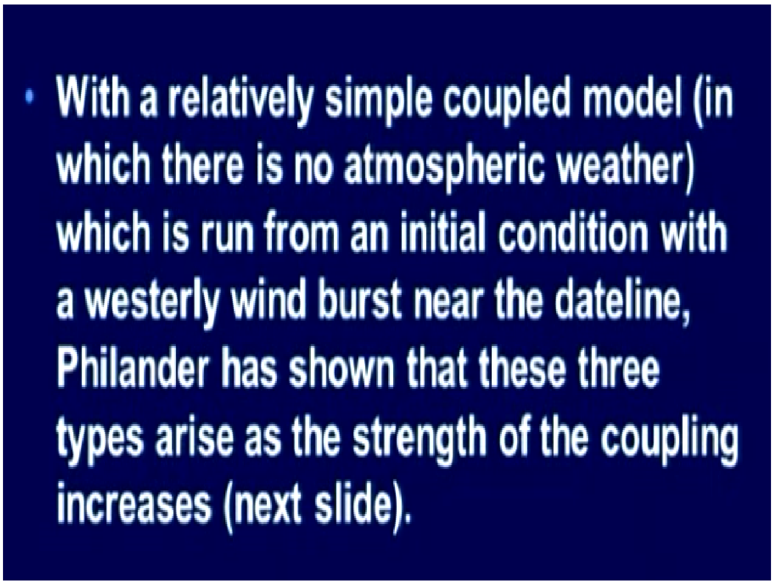

Now with a relatively simple coupled model in which there is no atmospheric weather, which is run from an initial condition with a westerly wind burst near the dateline, Philander has shown that theses 3 types arise as the strength of the coupling increases, this is a very, very study.

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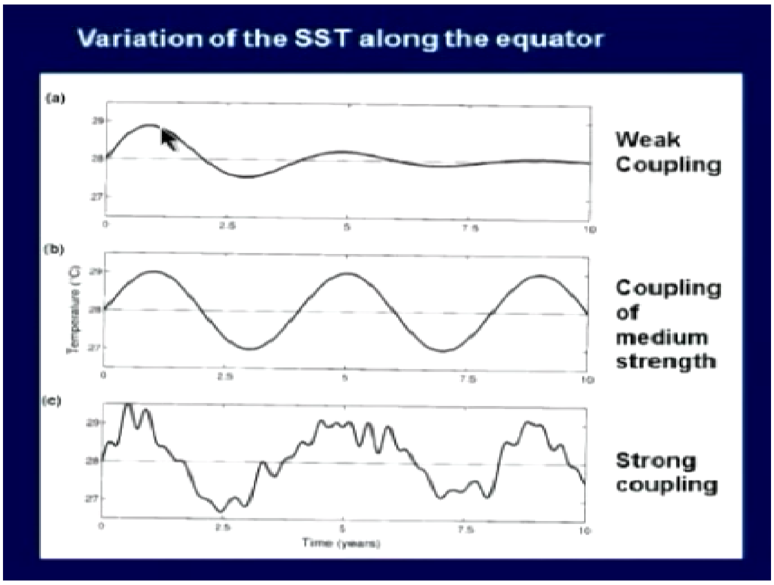

So the same model, it is kicked initially by a westerly wind burst which you know has been thought of as an important trigger for El Nino. So it has been put in there as initial trigger and what happens with varying strength of coupling is shown. This is the case in which you have weak coupling, this is an El Nino which has occurred followed by a La Nina followed by a much weaker El Nino, much, much weaker La Nina and that is the end.

This is the case of weak coupling, so here 1 could think of El Nino as an isolated event or the isolated pair of events. Now is the coupling of medium strength what you get is the nice regular oscillation, but in that case prediction would be trivial and half the fun of the challenge would have gone. So we get weak coupling, coupling of medium thin and if you have a strong coupling then you get an unstable mode which is slightly chaotic.

So you have irregular oscillation, they will not be strictly repeated but you see patterns are somewhat repeated. So this is what you get with strong coupling.

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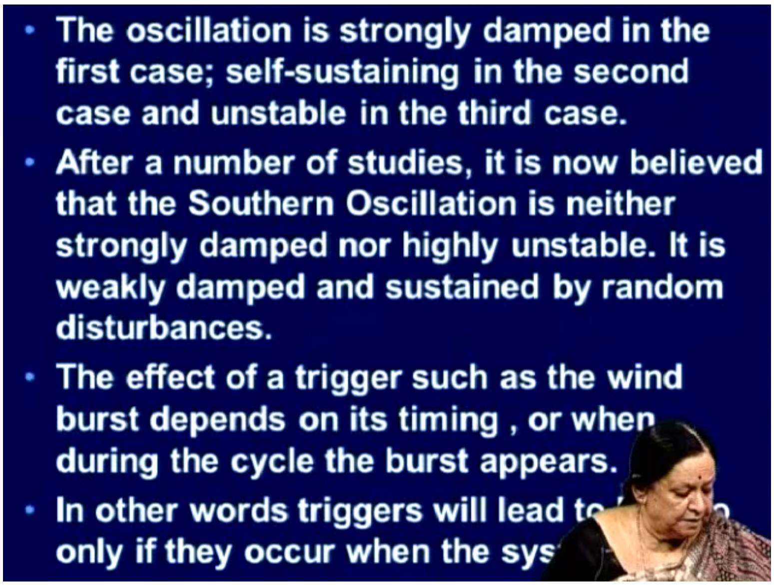

So the oscillation is strongly damped in the first case. In the case of the weak coupling the oscillation is very, very strongly damped, which you can see. This is the amplitude for the first and it is hardly there for the second. So it is a very strongly damped oscillation, it is self-sustaining in the second, this is obviously a self-sustaining oscillation.

So given the trigger of the westerlies after triggers and all are irrelevant for this it just keeps on oscillating in a very regular manner, and unstable in the third case. Now since the study, there have been a lot of studies and I will not go into details of this, what is interesting is the final result. Now it is believed that the southern oscillation is neither strongly damped nor highly unstable.

It is weakly damped and sustained by random disturbances, which is very interesting. So the effect of the trigger such as the wind burst depends on the timing or when during the cycle the burst appears. In other words triggers will lead to El Nino, only if they occur when the system is ready. So this is a very interesting concept and this is why triggers westerly winds like the once that occurred for the 97 El Nino occur at other times too.

But are not succeeded by El Nino, probably because the system is not ready. So this kind of understanding of the dynamical system is very important, of the phenomenon is very important. If we want to use this understanding, translate it in to making reasonable model for predicting this event, because that tells us we have to then monitor and figure when the system is ready and then when a trigger occurs then you expect the thing to happen.

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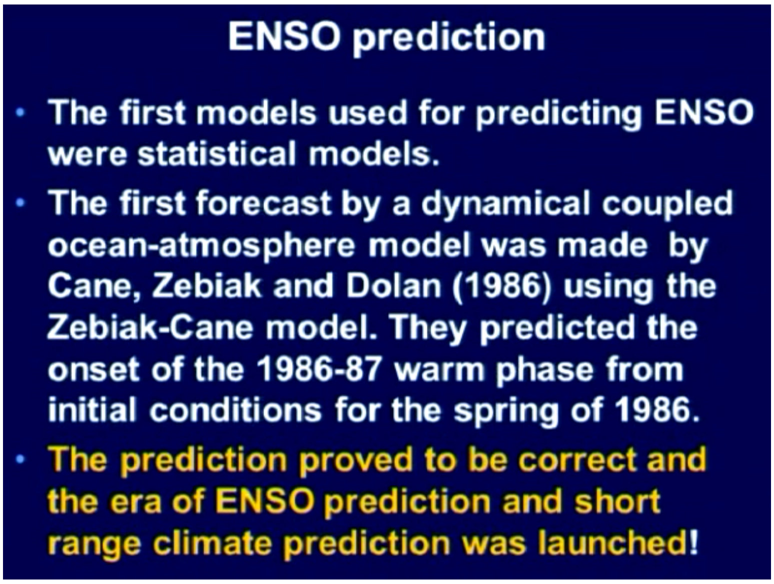

The El Nino are actually to materialize or La Nina are actually to materialize. Now ENSO prediction has been 1 of the major successes on which have been built huge international programs of observation, modelling and so on. I will not dwell on that here, but let me just say that the first models used for predicting ENSO was statistical models, these were in the old times.

The first forecast by a dynamical coupled ocean-atmosphere model was made by Cane, Zebiak and Dolan in 1986 using the Zebiak-Cane model. And what is amazing is they predicted the onset of the 86-87 warm phase from initial conditions for the spring of 86. So they actually predicted that an El Nino would occur during 86-87, and this prediction proved to be correct. And the era of ENSO prediction and short range climate prediction was launched.

This success of this simple elegant model had such a major impact on our field, on the meteorology and oceanography done in the subsequent period in the 90s and 2000s, that it is remarkable that 1 began to think that now we could generate with dynamical models, short range predictions of climate, short range from climate, we point means seasonal predictions could be of the monsoon, could be of the occurrence of the El Nino and so on and so forth.

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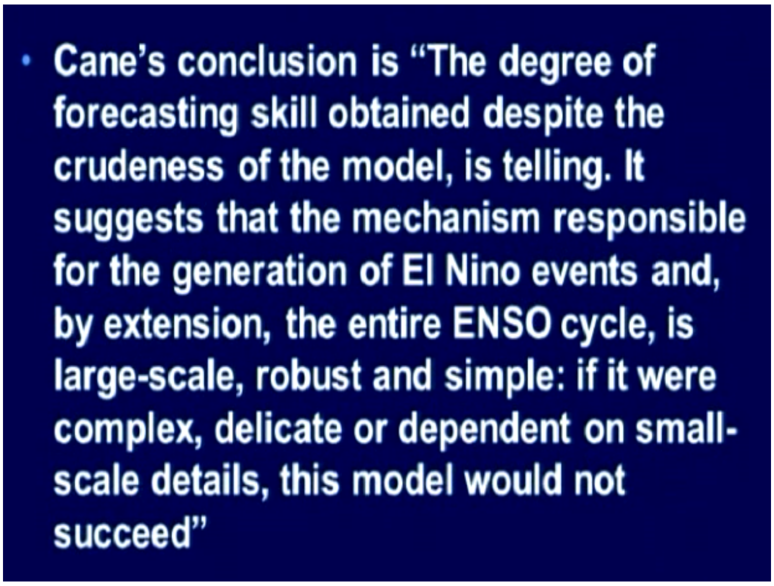

In fact, Cane's concludes that the degree of forecasting skill obtained despite the crudeness of the model, is telling. It suggests that the mechanism responsible for the generation of El Nino events and by extension of the entire ENSO cycle is large-scale, robust and simple. If it were complex, delicate or dependent on small-scale details, this model would not succeed.

So this is a very encouraging that the mechanisms involved are in fact large-scale, robust and simple, and that is why the model has succeeded.

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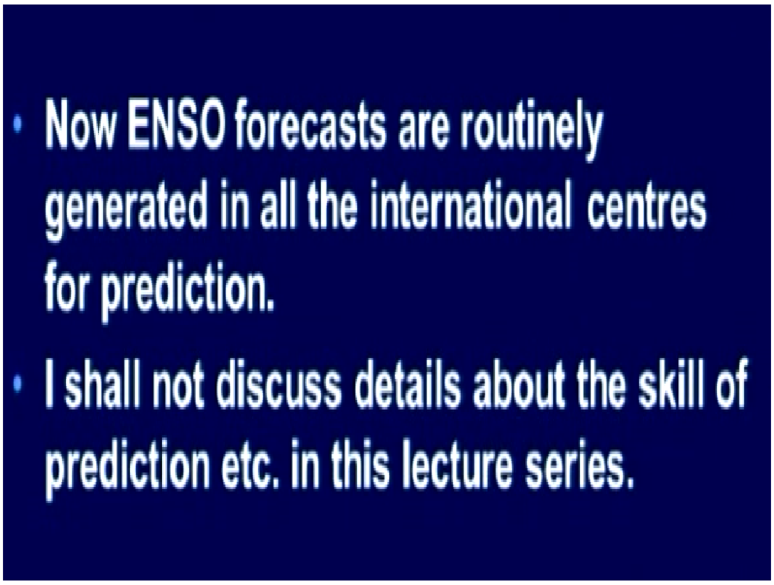

Now, I think there are a lot of lessons to be learned for modelling the monsoon from this. I believe that the monsoon system is also a large-scale robust, not very simple, of course things appears simple only after all the physics has been elucidated, that is not the case of the monsoon as yet. But therefore we should be able to succeed in unravelling this complexity and actually predicting.

Now after the success of the Cane-Zebiak's models, lot a more complex models have been developed. And now at all the international centres ENSO forecasts are routinely generated. I am not going to discuss in detail about ENSO prediction in this set of lectures. But let me just say, that getting an accurate prediction of ENSO is extremely important for our getting reasonable predictions of the monsoon as well, but I will come to that when I talk of monsoon prediction.

Now I would like to shift to a connected but a somewhat different topic. So far we have been looking at what is ENSO, how is it defined, what is the physics of ENSO, what are the basic elements of a model, a model must incorporate if ENSO is to be simulated and so on and so forth. And you can see that right from Bjerknes onwards up to Cane, Zebiak and Philander and others, we have got considerable insight into ENSO.

And are in a situation where we are able to generate predictions with reasonable skill of ENSO with existing models. Now we saw that ENSO has tele-connections with many important phenomenon and 1 of them is the monsoon. So now let me talk about monsoon-ENSO link.

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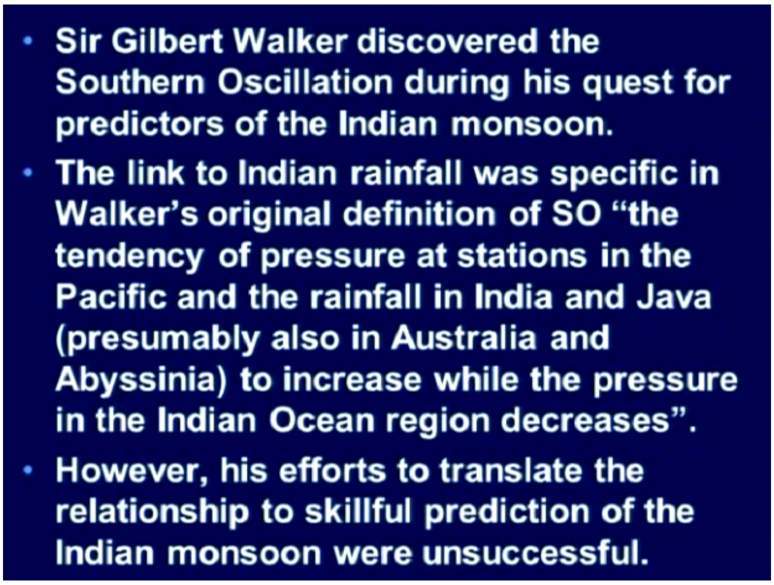

You know Sir Gilbert Walker discovered the southern oscillation during his quest for predictors of the Indian monsoon. He was looking for how to predict Indian monsoon, and for that he has analysed a lot of data and discovered the southern oscillation. Now link to Indian rainfall was specific in Walker's original definition southern oscillation, that is tendency of pressure at stations in the pacific and the rainfall in India and Java and presumably also in Australia and Abyssinia, to increase while the pressure in the Indian Ocean decreases.

This is what he is talking of the southern oscillation. However, Sir Gilbert Walker's efforts to translate the relationship to skilful prediction of the Indian monsoon were unsuccessful.

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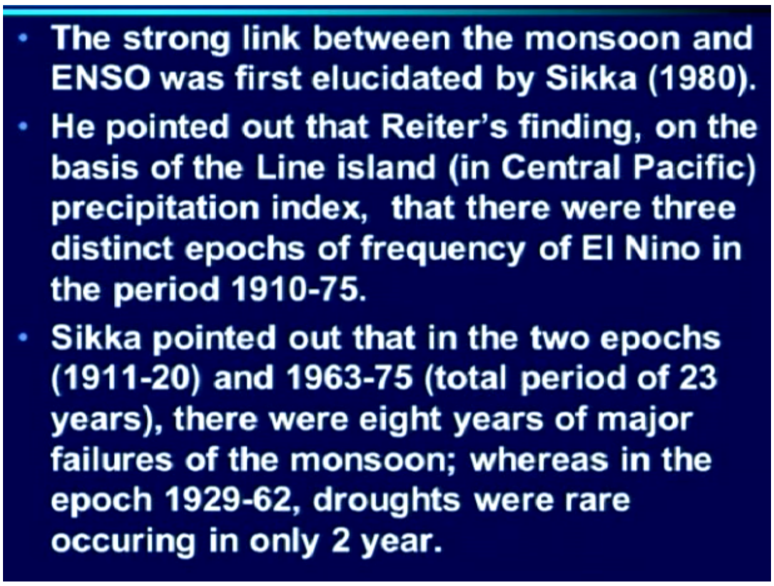

So the subject was kind of dropped, southern oscillation was certainly considered as an extremely interesting phenomena in the atmosphere. But as a useful tool for predicting the monsoon it was dropped. Now this link between monsoon and ENSO was rediscovered by Sikka in 1980, the way it was rediscovered was the following. He pointed out that Reiter's finding, on the basis of the line island precipitation index, that there were 3 distinct epochs of frequency of El Nino in the period 1910-1975.

You remember I talked about how the rainfall over Central Pacific increases during El Nino. So Central Pacific precipitation index, these line islands are 6 islands in the Central Pacific. So this was the index that Reiter used and using it he identified 3 epochs of different, in which the frequency of El Nino differed very much and earlier epoch in which it was frequent, then low frequency than high again.

Now Sikka pointed out that in the 2 epochs 1911-1920 and 63-75, which is a total period of 23 years, there were eight years of major failures of the monsoon, whereas in between that is to say the epoch of 29-62, droughts were rare and occurring only in 2 years. So you had frequent droughts in these 2 epochs, whereas relatively less frequent droughts in the period 29-62.

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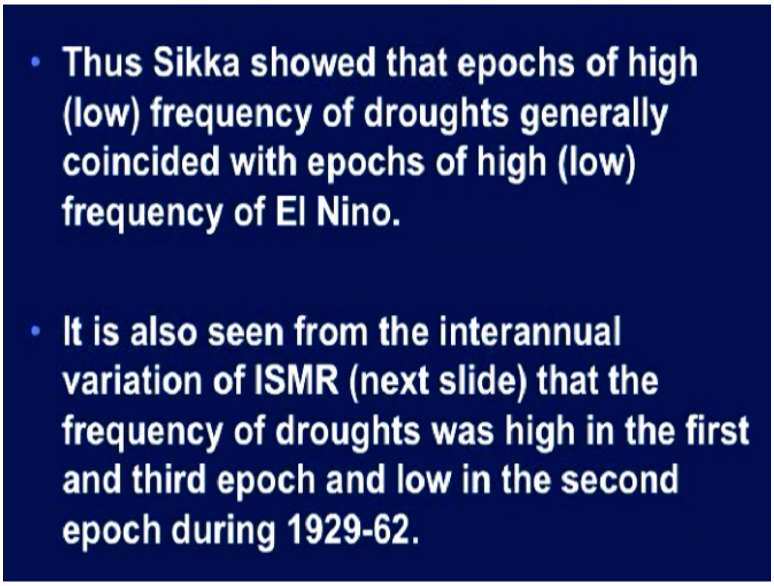

Thus, Sikka showed that epochs of high or low frequency of droughts generally coincided with epochs of high or low frequency of El Nino. Now it is also seen from the interannual variation of the ISMR, that the frequency of droughts was high in the first and third epoch and low in the second epoch, so here you have it.

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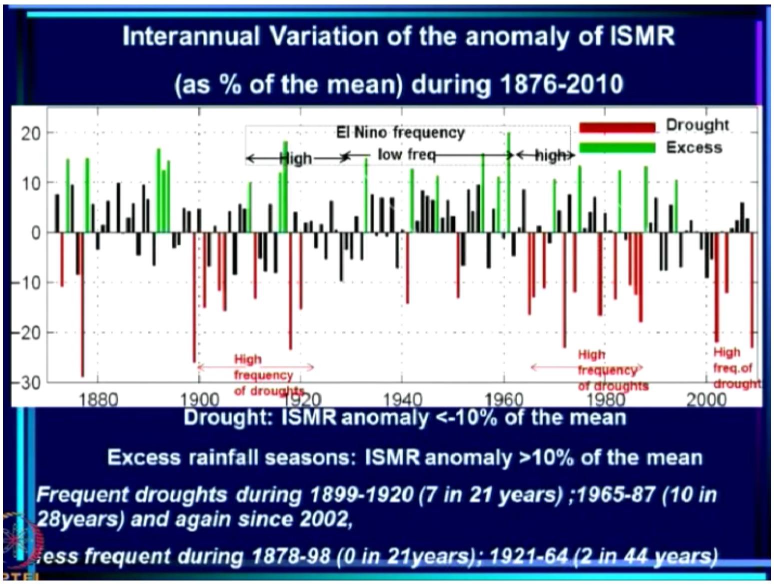

I have drawn here the epochs of El Nino droughts on the top here, which were recognised by Reiter, this is the period in which El Nino epoch, this was the epoch of high frequency of El Nino, then this is the major epoch of low frequency of El Nino, in which you see only 2 droughts have occurred. And again there is a high frequency of El Nino in this period in which you see several droughts have occurred.

Similarly, before this epoch also, before this you see within this high epoch also several droughts have occurred. This is the El Nino frequency and the drought frequency is given here. So there is a correspondence between low frequency of El Nino occurrence and low frequency of droughts and high frequency of El Nino occurrence on high frequency of droughts, in terms of epochs, and this is what Sikka first pointed out.

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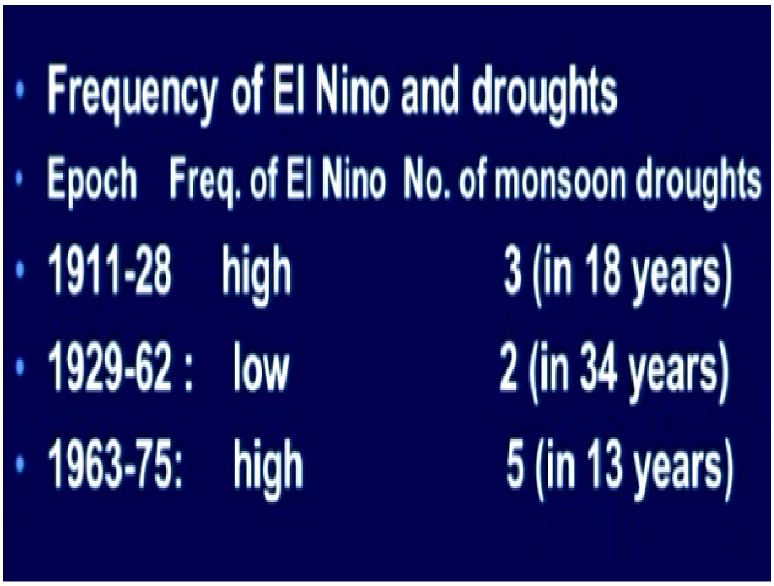

Now so frequency of El Nino and droughts from 1911-28 frequency of El Nino was high, 29-62 it was low and 63-75 it was high. Now droughts if you look at there were 3 in the 18 eight years in this case and in this case 5 in 13 years. So you can see chance of drought is rather high when the frequency of El Nino is high. On the other hand, the frequency of El Nino is low, chance of drought is only 2 in 34.

So indeed there is some correspondence in the frequencies of occurrence of El Nino over the pacific and the droughts over India, this is what Sikka pointed out.

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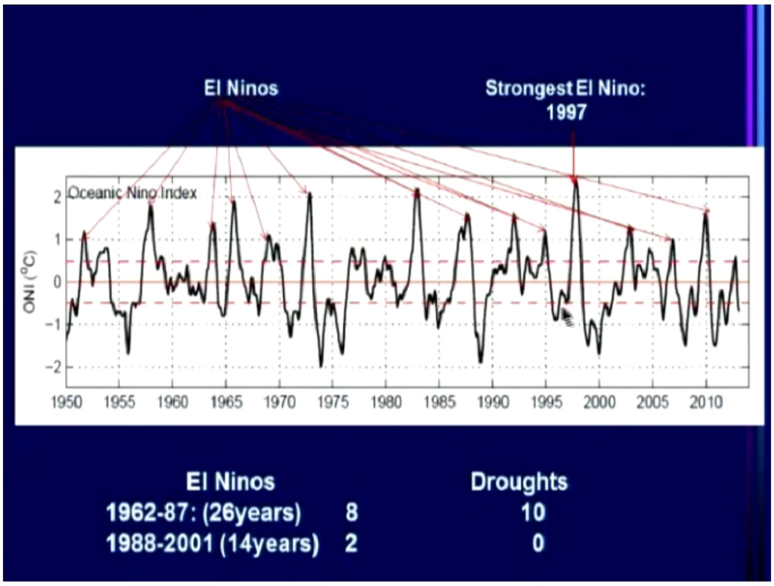

Now you can see this is only up to 62, after that many years have passed. So we can see what happened in the subsequent years. So if we look out, now we know how many El Ninos have occurred because of that ONI index that I showed you. And we can see that from 62-87, there were 8 El Ninos, this is a period of 26 years in which there were 8 El Ninos and 10 droughts.

Whereas 88-2001 which a period of 14 years, slightly over half of this 2 El Ninos occurred and no droughts at all. So Sikka's identification of correspondence between epochs of low frequency of El Nino and low frequency of drought and high frequency of El Nino and high frequency of drought seems to have held in the period subsequent to what he had analysed also.

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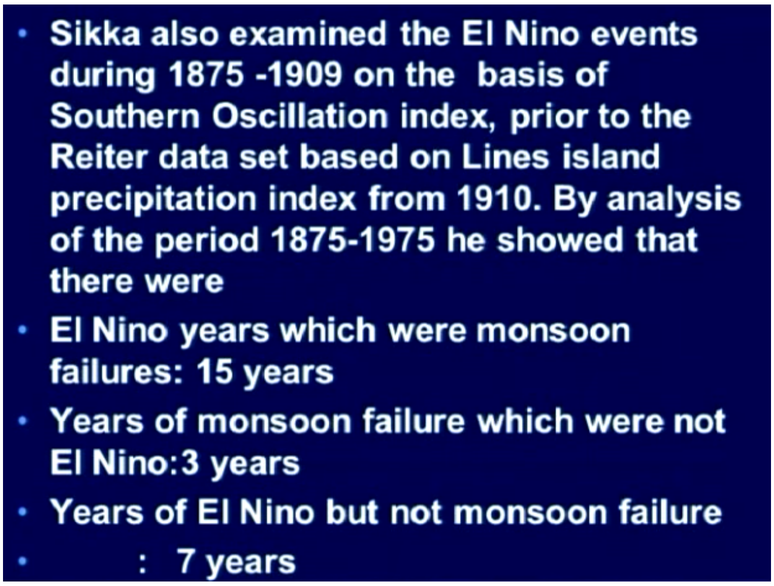

Now in addition to that Sikka also examined the El Nino events during 1875-1909 on the basis of southern oscillation index, prior to the Reiter data set based on the lines island precipitation index of 1910. So he went, actually there was not data on lines island precipitation, so he went to another data set and southern oscillation index and with that he could analyse over the entire period for which monsoon rainfall is available as I said now this was done by IITM scientist.

And 1 could identify monsoon droughts and excess monsoon years on the basis of the data in India of monsoon. So when he examined it for this very long period 1875 onwards, then he found that El Nino years which were monsoon failures were 15 years. Years of monsoon failure which were not El Nino were only 3 years, and years of El Nino which were not monsoon failure were 7 years.

So you could have cases in which you had an El Nino but monsoon did not fail. But out of the years in which monsoon did fail, which is 18 years, 15 were El Nino years. So this was another way in which he showed that the propensity for droughts of the Indian monsoon is very high during El Nino years.

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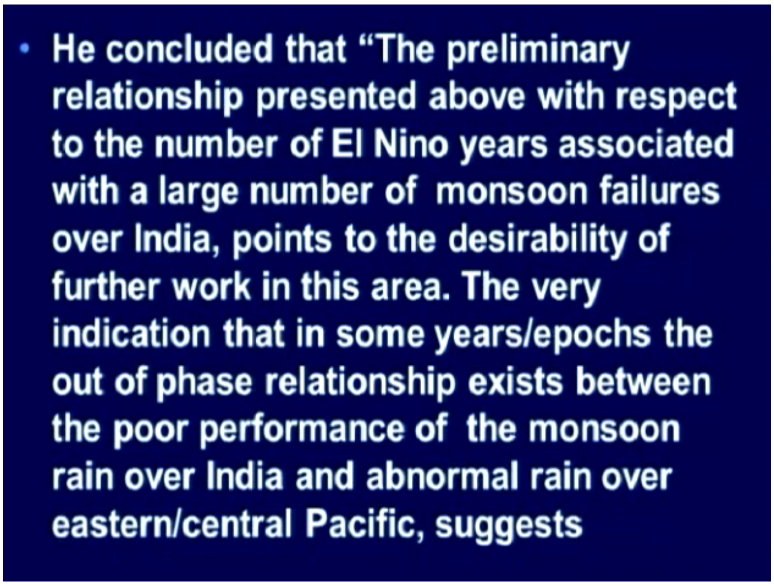

So what did he conclude, he says that the preliminary relationship presented above with respect to the number of El Nino years associated with a large number of monsoon failures over India, points to the desirability of further work in this area. The very indication that in some years or epochs the out of phase relationship exists between the poor performance of the monsoon rain over India and abnormal rain over eastern and central pacific which is the El Nino suggests very large tele-connections.

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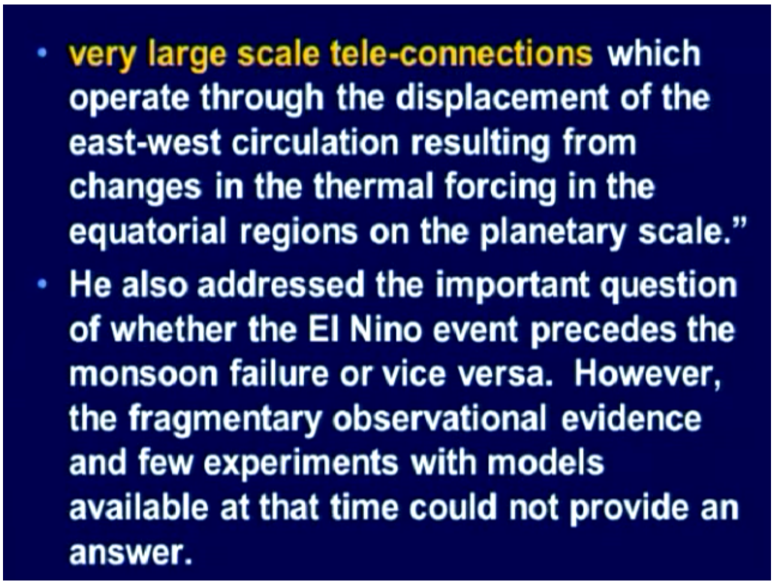

And he used the word tele-connections as early as in 1980, which operate through the displacement of the east-west circulation resulting from the changes in the thermal forcing in the equatorial regions on the planetary scale. He also addressed the important question of whether the El Nino event precedes the monsoon failure or vice versa. However, the fragmentary observational evidence and few experiments with models available at that time could not provide an answer to this.

So the important question okay, monsoon and ENSO seem to be linked. There are no 2 views on it any more. But the question is what leads, which of the event leads the other, does monsoon lead to El Nino or El Nino lead to monsoon, because whether we can use things for prediction of the monsoon depends very much on the answer to this question.

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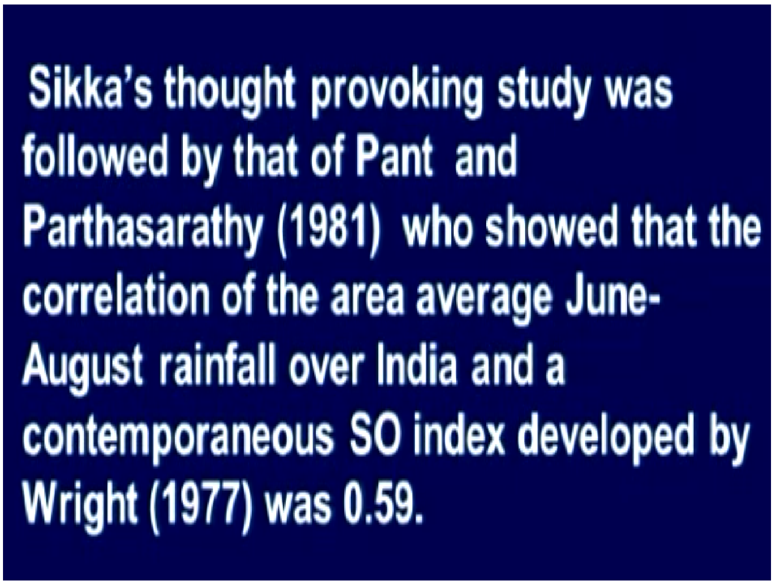

Now Sikka's thought provoking study was followed by that of Pant and Parthasarathy who showed that correlation of the area average June to August rainfall over India and a contemporaneous southern oscillation index developed by Wright in 1977 was 0.59. So this is very interesting that in fact there was a very strong correlation that they showed this was certainly I am sure significant at 90%.

And they showed that what Sikka had shown simply by comparing epochs and comparing number of years actually stood the test of time when we looked at correlations.

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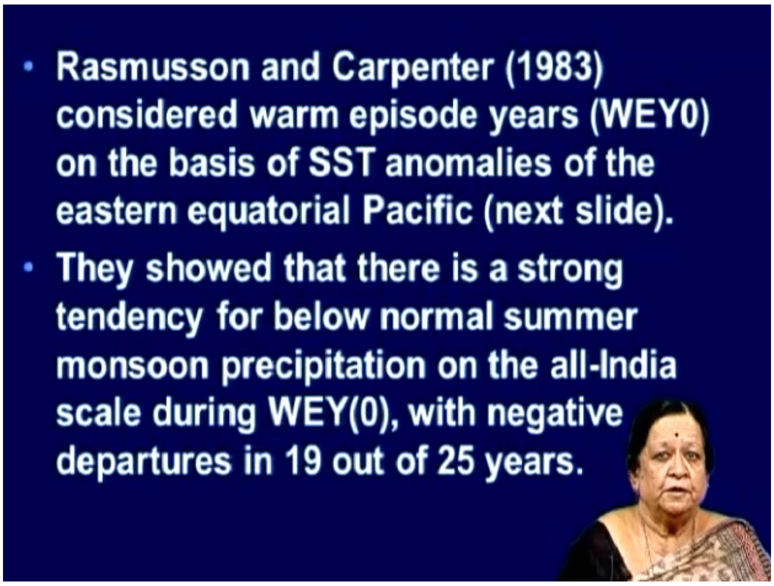

Now as per Sikka's and Pant and Parthasarathy's studies came this paper by Rasmusson and Carpenter, because that came in the paper that I talked about earlier in which a great deal of data about El Nino was synthesised by Rasmusson and Carpenter, that was a paper in 1982. And they followed it up with a paper on impact of El Nino over other regions and particularly Asia.

So Rasmusson and Carpenter as I mentioned before based their definitions of El Nino on SST anomalies of the coast of South America which corresponds to the region Nino 1+2 in the earlier graph. And on the basis of that they identified what can be considered as warm episode years. Now these are given here and they give different sources for this, the last few from 50s onwards are there, in fact even in 23 and so on.

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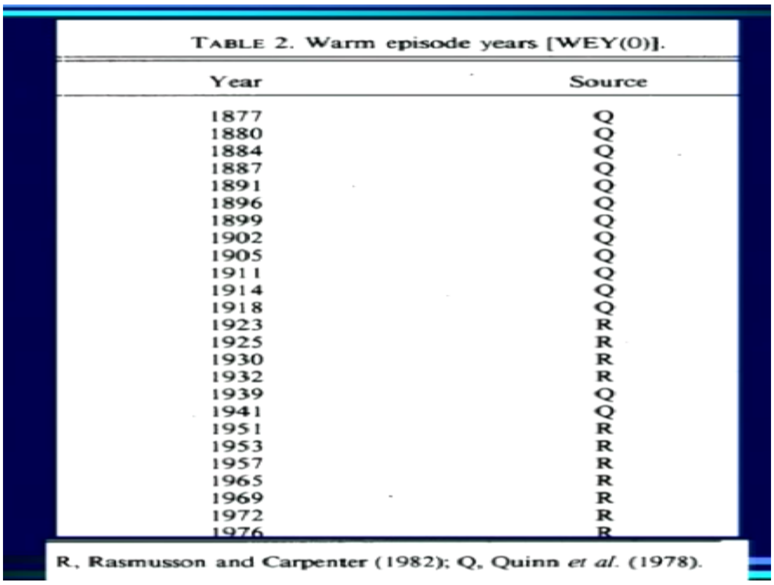

TABLE 2. Warm episode years [WEY(0)].

Year	Source
1877	Q
1880	Q
1884	Q
1887	Q
1891	Q
1896	Q
1899	Q
1902	Q
1905	Q
1911	Q
1914	Q
1918	Q
1923	R
1925	R
1930	R
1932	R
1939	Q
1941	Q
1951	R
1953	R
1957	R
1965	R
1969	R
1972	R
1976	R

R, Rasmusson and Carpenter (1982); Q, Quinn *et al.* (1978).

Quinn is the source for the large number of this identification and these are identified basically from sea surface temperature data of the South American coast. So they have identified all this warm episode years, which are called WEY0 and they show that there is a strong tendency for below normal summer monsoon precipitation on the all India scale during such El Nino years with negative departures in 19 out of 25 years.

So what they are doing is looking at El Nino years and whereas you can see Sikka looked at all years in that period which were monsoon failures. He did not look at only El Nino years but he looked at El Nino years which were monsoon failure, he also looked at years of monsoon failure which were not El Nino years, and he has a El Nino which were not monsoon failure.

Now what Rasmusson and Carpenter did was to focus on El Nino years, that is to say take these 15 years in which there where monsoon failures and 7 years in which it was not monsoon failures. Those 2 categories first and third category only were considered by Rasmusson and Carpenter and what they say is where as Sikka got, I think 15 out of 22 El Ninos were deficits they are getting 19 out of 25 years rather comparable statistics I would say.

Because they are talking about only the negative departures, how large the deficit they are considering is not known.

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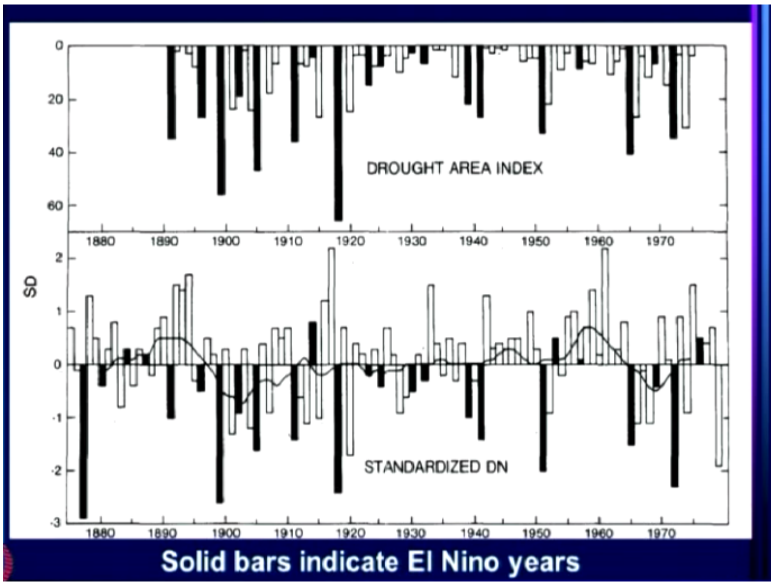

And what they showed was and this is now very clear, solid bars indicate El Nino years. So this is data on all India rainfall here, and this is a drought area index, which is a measure of the how deficit the rainfall is by actually looking at over how much area the deficit is substantive, this is the drought area index. And what you find here, let us look at this one first.

You will find that a large number of deficit years, certainly the major ones, this is the famous 1 of 1876, and then these are in the earlier part of the epoch. So this is where you had quite a few deficits and quite a few El Nino years. This is the epoch where you had relatively less El Ninos as you can see, and relatively less droughts as well, and then of course you have this very big El Nino 65 was an El Nino which was a drought.

66 was a monsoon failure which was not an El Nino, and then the major El Nino 72, major drought in 72 which coincided with an El Nino. So you can see that there is a close correspondence, but a large number of deficit monsoon are not El Nino years at all. So Rasmusson and Carpenter also derived the special pattern of the rainfall anomalies for the El Ninos years.

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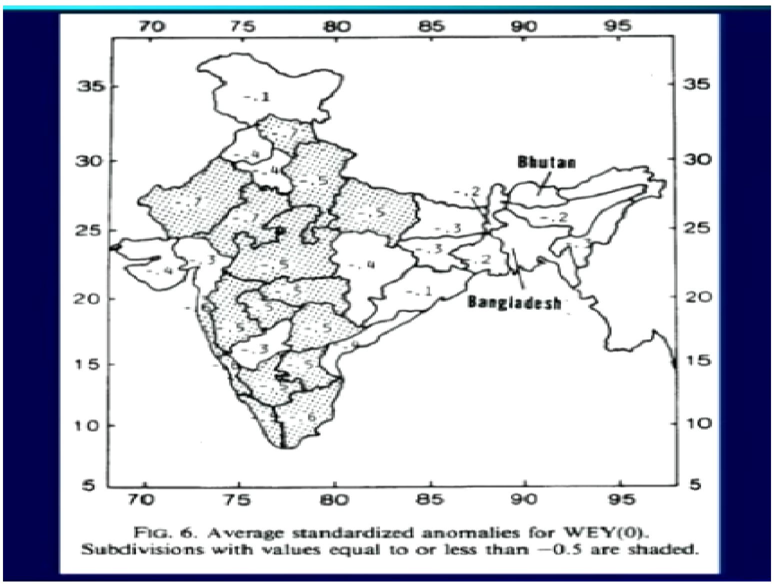

FIG. 6. Average standardized anomalies for WEY(0). Subdivisions with values equal to or less than −0.5 are shaded.

And what they find is that by and law you have very, very large anomalies here, and towards which is really the heart of the monsoon towards Bangladesh and these other regions. There is hardly any impact in fact, but the large impact is on this part. And this is the part particularly here which determines the all India monsoon rainfall, so it is not surprising that you will have a large impact on this.

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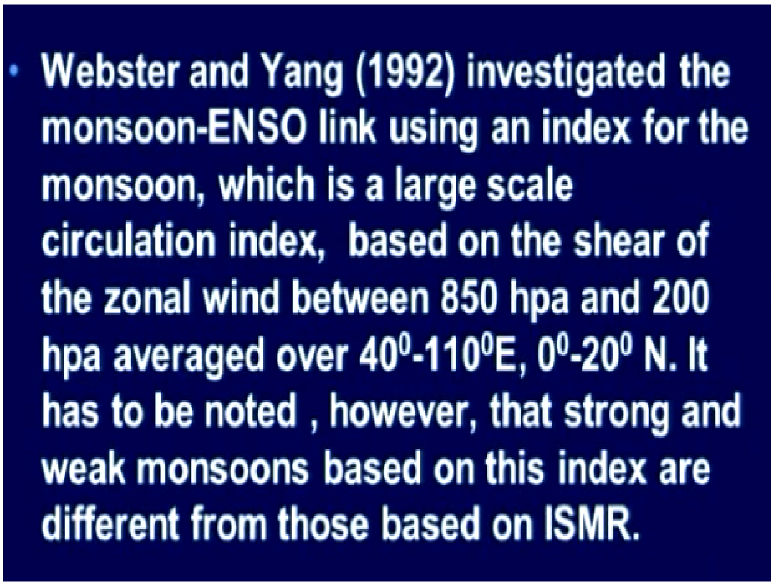

Now this was the second study. Now the question was should we only look at all India rainfall or is there a better index of the monsoon. And I will start discussing that in the next lecture. Now let us just summarize what we have done. Today we have tried to gain an understanding of what people think of as the basic physics of El Nino, what is the ENSO system dynamical system that leads to ENSO.

And we showed that depending on the strength of the coupling you could get a strongly damp system a regular oscillation or an irregular oscillation, and that now people believe that it is not strongly damp but a weakly damp system which is not highly unstable. So whether you get El Nino are not depended on whether the, appropriate triggers occur when the system is ready for it.

So this is the basic understanding of the dynamics that has come in the last decade or so. Then we started looking at the monsoon-ENSO link which actually was first discovered by Sir Gilbert Walker in his search for the predictors of the monsoon. But was rediscovered in 80 by Sikka who started looking at epochs of high and low frequency of El Nino and showed that they are more or less coincided with epochs of high and low frequency of Indian monsoon droughts.

And this was followed by work by Pant and Parthasarathy, and then by Rasmusson and Carpenter who reinforced Sikka's conclusions that droughts over India and El Nino have a tendency to go together. Now we will continue from this to see the links between monsoon and ENSO in the next lecture. Thank you.