Course Name: An Introduction to Climate Dynamics, Variability and Monitoring

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Lecture 46

COUPLED OCEAN - ATMOSPHERE VARIABILITY

Good morning class and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. Today we will discuss one of the most important and also most famous climatic variability that occurs in over the scale of 4 to 5 years to over a decade. This is the El Nino Southern Oscillation or ENSO event. It is one of the most well-known natural variability that occurs in the tropical ocean atmosphere system centered in the Pacific Ocean and affects the global climate throughout. We will discuss this ENSO event in detail today. Let us go back to our surface level currents once.

If you go to your surface level currents and look at the Pacific Ocean, you see that the southern equatorial current and the northern equatorial current flows from east to west in conjunction with northeasterly and southeasterly trade winds. These currents start as the cold currents near the coast of Peru and slowly move through the Pacific and hit the eastern or the, sorry, the western coasts of Australia and Indonesia respectively. And these are driven by the trade wind circulations that are happening in these subtropical regions. So, what is happening here? We are seeing initially cold waters moving from the western coast of the Americas to eventually warm waters hitting the eastern coast of Asia, Indonesia and Australia.

Because the seawater is moving away from the coastline there is upwelling of colder waters along the west coast of America in Peru and in Mexico creating cold high pressure conditions and dry weather in these coasts. So you will have arid dry weather along the western coast of US under natural circumstances and because this water, these ocean currents move along the surface near the equator, they absorb a lot of solar radiation and heat up significantly and become extremely warm by the time they hit the Indonesian and the Australian coastline. So, these warm waters create a lot of evaporation, creating conditional instability and hence precipitation events in the east coast of Australia and Indonesia, which are and hence the warm humid climates of these regions. So, this is the natural situation in the along the subtropical pacific region and this is called the neutral or the default condition. So, let us go over this idea again. Equatorial Pacific strong easterly trade winds move surface waters from east to west along the equatorial region from East Pacific of the coast of West Coast of America to West Pacific of the East Coast of Indonesia and Australia. The surface currents cause upwelling of cold waters of the west coast of America, which is entrained in the surface currents and flow eastwards towards Indonesia. As the water moves along the surface, it absorbs the strong equatorial solar insulation and becomes quite warm. On hitting the coast of Indonesia and eastern Australia, it is forced to sink down. Thus, we have a few important features.

Off the east coast of Australia and Indonesia, we have a layer of deep warm mixed layer caused by the down welling of the warm water that has piled up due to the presence of this easterly trend wind driving them towards the coasts. The warm waters in West Pacific, this region of the coast of Indonesia and Australia, in turn increases the air temperature and evaporation rate. Thus, wet, humid conditions prevail over the western Pacific with vigorous upward convection of evaporating water vapor. Hence, an atmospheric low pressure is generated in the west Pacific. In contrast, cold waters up well in the east capacity along the west coast of America.

So, remember eastern Pacific is adjacent to the west coast of America, western Pacific is adjacent to the east coast of Indonesia, Australia and Asia. So, in the east Pacific, the water cool, the water is cold due to local upwelling and hence the air also becomes cold under the influence of the cold water. So, the air cools and sinks down of the coast of, western coast of the Americas in the East Pacific. Thus, we have a high pressure zone in the East Pacific and a low pressure zone on the West Pacific along the equatorial and the subtropical region. This creates a convective cell in the zonal direction.

So, this is very important. The Hadley cell, for example, is a convective cell in the meridional direction. Here we have a low pressure on the equator on the west. in the West Pacific, high pressure along the equator in the East Pacific creating a convective cell in the zonal direction. So, air moves up in the, in the West Pacific, is transported at high altitudes from West to East and then sinks down in the East Pacific.

From there, the down-moving wing moves along the surface as the easterly tread winds back towards the West Pacific where it rises up again. This convection cell is called the Walker circulation. So here is the normal Walker circulation that we are seeing. This is the East Pacific. This is the West Pacific. Here is the coastline of America. Here is the coastline of Australia and Indonesia. This red region is hot water. This blue region is blue and green region is cold water. And you have a kind of a descending thermocline because you have a big mixed layer of the coast of Indonesia and Australia due to the pile up of the mixed layer water driven by the trade winds.

As a result, you have upwelling in the West Pacific causing cold water to form here and high pressure conditions where the air is sinking down and low pressure conditions in the West Pacific where air is moving up with at water vapor creating precipitation events. And there is a west to east directed air current at the high altitudes and east to west directed tread winds at the low altitudes near the surface. And this is the walker circulation system. Due to the convergence of warm waters, the average sea level may be 40 cm higher in the West Pacific here compared to the East Pacific. The average near surface temperature is also 4 to 8 degree centigrade higher in the West Pacific compared to the East Pacific.

So, you can see here also that this is 40 centimeters higher in altitude, the sea level compared to the East Pacific region because of the movement of mixed layer water from the east to west driven by the normal trade winds. As a result, upwelling is happening and mixed layer is thinner in the East Pacific and is thicker in the West Pacific. So, this is the normal condition, warm ocean waters in the West Pacific, cold ocean waters in the East Pacific. The normal walker circulation air moving up in the West Pacific causing precipitation over Indonesia and Eastern Australia, then eventually moving down over the East Pacific causing dry, cold conditions and arid conditions in the west coast of North and South America and then driven by trade winds, water and air move from the east to west. Now we can define something called the Southern Oscillation Index, SOI, and is defined as the difference in the sea level atmospheric pressure.

The pressure on this side and the pressure on this side. This is high pressure, this is low pressure. The difference between the high pressure in the East Pacific and the low pressure in the West Pacific, the pressure difference is defined in terms of the Southern Oscillation Index. The West Pacific pressure is measured of Darwin in Australia, which is in the west coast of Australia, east coast of Australia and East Pacific pressure is measured of Tahiti. The neutral condition pressure difference is given the value 0. Positive values indicate an intensified pressure difference that is the pressure gradient has increased. So, that is why the delta P has actually increased over the normal value and hence a positive deviation which is an intensification of the walker circulation. So, thread winds are stronger, the movement of ocean waters from the East Pacific to West Pacific is stronger, you have more precipitation. This is called the La Nina event, which is the intensification of the normal conditions. And negative values of delta P indicate a weakening of the pressure difference and the associated weakening of tread winds and wafer circulation.

This weakening where the walker circulation weakens, we have lower trade winds and lower flows of ocean water from the East Pacific to West Pacific is called the El Nino event. So, weakening of walker circulation El Nino event, strengthening of waka circulation is the La Nina event. Another measure of the Southern Oscillation Index is the average sea surface temperature. which is also called the, which is done in the Lino 3.4 region, somewhere here you can see. 120 degree west to 170 degree west, 5 degree north to 5 degree south. Positive deviations of the average value indicate a higher than normal surface temperature. So, if the value here is higher, then you have a higher than normal surface temperature which corresponds to an L Nino event, whereas negative deviations indicate a lower than average surface temperature corresponding to a La Nina event. If the Nino 3.5 average temperature is higher, then you have the El Nino event, the weakening of the walker circulation.

And if it is lower, then you have a La Nina event, a strengthening of the walker circulation. So, we can identify this L nino 3.4 index, the normal range of the temperatures is plus 0.5 to minus 0.5 the average over the average, this is normal oscillations. Anything beyond that you are having a positive deviation you have an L nino event and negative deviations you have a La Nina event. And you can see that the El Nino, La Nina events are spaced over. So, you have these are strong La Nina events, these are strong El Nino events. So, two strong El Nino events for example, happen say twice a decade. So, one La Nina and one, so suppose you look at the 1970, you have an El Nino event.

then La Nina event, El Nino event, La Nina event, El Nino. So, 5, at least 3 and some of these are small. So, these deviations are small. The large deviations are specifically called the El Nino and the La Nina events. So, 3, 2 to 3 El Nino and La Nina events occur every decade. where the oscillations are significantly over the normal range either on the positive side or on the negative side. So, if you see from 1950 to around 2015, which is around the 55 year, 65 year region, you 1, 2, 3, 4, 5, 6, 7, 8, 8 big La Nina events and 1, 2, 3, 4, 5, 6 and maybe 7, 7 big El Nino events, ok, over a 65 year period. So, once a decade you will have a big El Nino event and once a decade you will have a big La Nina event. So what is this El Nino condition? It's the weakening of the normal situation. The trade winds and the walker circulation weaken.

The pressure gradient between the East and West Pacific also weakens. Thus warm waters that have been piled up in the high sea levels of West Pacific begin to flow back eastwards as the sea level anomaly decreases. Because the tread wind has decreased in strength, the ocean currents have also decreased and the strong frictional drag force that was pulling the waters and pulling them in the western Pacific weakened and so that that pool of mixed layer now begin to move back eastwards towards the western Pacific. So you have a reverse flow of warm waters moving from the western Pacific towards the eastern Pacific. So this is a flow reversal and as this warm water moves, the low pressure zone also moves with it. So the low pressure zone migrates from the west coast of Indonesia and Australia, migrates through the Pacific Ocean and eventually this warm water pool hits the west coast of America. And hence the low pressure region now resides on the west coast of America and as a consequence the high pressure region now resides on the west coast of sorry in the east coast of America whereas the high pressure west coast of America whereas the high pressure region now resides on the east coast of Australia and Indonesia. So, during a full reversal, a strong El Nino event, what you will have is a complete reversal of the walker circulation. The warm pool has moved entirely to the west-east Pacific of the west coast of the Americas and the low pressure region is lying over there. Whereas, because the warm waters move to the west coast to the eastern Pacific, you are getting upwelling now in the west Pacific and so cold waters and high pressure conditions begin to form off the coast of Australia and

Indonesia and so you have a high pressure in the west Pacific and low pressure on the east Pacific and the walker circulation reverses itself.

So, this is the full El Nino condition. This warm water has kind of moved then gone in towards the East Pacific region. And so, you have this low pressure region now moving upwards here and going down on both these directions. And eventually, this will move entirely off the course and you have a complete reversal of the Waka circulation. So, because of this, the precipitation region has now moved to the coast of America and so Mexico, Peru, coastal California regions are getting low pressure conditions, warm water is cooling at these regions and you are getting a significantly more rainfall in these traditionally arid regions than average.

Whereas the traditionally humid regions and wet regions of Indonesia and Australia experience drought-like conditions because of the presence of high pressure and cold oceanic waters on the coastline. So, it takes about 4 months for the warm pool of water to travel up to the west coast of America in what is called the equatorial Kelvin wave. On hitting coastal America, majority of this water sloshes back westwards towards Indonesia as the normal ENSO begins to return and the trade winds strengthen. However, part of this warm water travels north and south in the meridional direction along the coastline bringing high sea temperatures and precipitation events along the coast of North America, Californian coast and South America, coast of Peru. The El Nino event ends when the warm water returns to the east coast of Indonesia and Australia.

This entire warm ENSO event lasts around 10 to 14 months, so over a two-year period. Note that the walker circulation also reverses during this peak El Nino condition as warm moisture rises over the pool of warm water in East Equatorial Pacific and sinks of the cold water in the West Equatorial Pacific. The reversal of the walker circulation also has weaker knock-on effects. This maybe has. over the entire sea surface temperature and circulations over the equatorial Atlantic and the equatorial Indian Ocean.

So, what we see in the equator is a series of zonal convection cells forming. And if one cell reverses, the other cells also have to reverse to maintain mass continuity. So the reversal of the worker circulation causes a reversal throughout the equator of all of these zonal convection cells. And this creates deviations of where the low pressures and high pressures are throughout the equatorial and the subtropical regions causing changes in the precipitation behavior.

So this can be seen below. So here is the Walker circulation system under normal conditions, the high pressure here, low pressure here, the precipitation here, dry conditions here. Associated with it, you have seen other zonal convection cells between the high pressure of the west coast of America to low pressure on the east coast of Brazil. Then another low and high pressure region small one between the east coast of Brazil and the central Atlantic where there is a high pressure region. This is remember is the center of the gyre system primarily. Then from this high pressure another low pressure happening near the central regions of Africa and then another high pressure region of the east coast of Africa.

So, here this high pressure creates arid conditions in the eastern horn of Africa and Madagascar. Then this high pressure is this high pressure here goes to the low pressure of Indonesia. So, 1, 2, 3, 4, 5, 6 cells are operating throughout the globe. Now, when you have a reversal, here you have the reversed case of the walker circulation during an El Nino event. So, high pressure is residing over Indonesia, dry conditions. Low pressure over the west coast of America, so wet conditions. So, here high pressure over the east coast of Brazil, so dry conditions in Brazil starts to form in the Amazon rainforest due to the El Nino conditions. Whereas, usually you have a low pressure here, so you have a warm, wet conditions over the Brazilian peninsula. Then you have, instead of a low pressure in the central regions of Africa where you have a tropical rainforest, you have high pressure here, so you get droughts over the central regions of Africa. Then there is a high pressure on the east coast of Africa, so these are usually dry, arid regions.

These now have a lot of precipitation forming here. So, based on this low pressure and high pressure conditions, you can predict where you will get a lot of rainfall and a lot of drought light conditions during the El Nino situations. So, during the El Nino or the reverse situations, you see that drought light conditions extend over the entire Southeast Asia and Indonesian Peninsula as well as coastal Australia as you would expect. Wet conditions prevail over the coasts of Mexico, Central America as well as in the Central Pacific region as well as wet conditions over the south, over the Peru regions here. However, dry conditions occur over the east coast of Central America and Brazil. Similarly, dry conditions occur over the regions of Africa where you have high pressure zone here.

So, you get drought conditions over the east coast. coasts of Africa and southern Africa, but you will have wet conditions in the east coasts of Africa and Madagascar region. And this is true in the winter season, in the January, in the summer season you have also similar conditions happening over the most of these regions. But you will have a weaker monsoon during the El Nino event over the Indian peninsula, which is primarily something that is happening because of the reversal of the circulation systems. So, the monsoon that is coming to India is weaker because of the high pressure conditions existing over the Indian Ocean, you are getting colder Indian Ocean currents which have lower evaporation and hence weaker monsoons. So El Nino causes weaker monsoon over the Indian Peninsula as well as dry conditions over Indonesia, east coast of Brazil, etc. and wet conditions over the west coast of America, east coast of Africa, etc. Now, what is the La Nina event? La Nina event is an intensification of the neutral state. So, the trade winds are even stronger, there is a stronger low pressure zone over the Indonesia in even stronger high pressure zone over the west coast of America, as a result the dry, normally dry regions are even drier and normally wet regions are even wetter. We have extremely wet regions in Indonesia, Indonesia and Australian coastlines, strong wet monsoons, relatively dry winters of India and wet monsoons in summer. You will have wet, large amount of rainfall over the Brazilian coast, etc. More added regions in the eastern Africa and more wet region in the central and western Africa. So, the overall global effect is that during the Ladina case, a normally dry region gets exceedingly dry and a normally wet region becomes exceedingly wet. So, you have the Ladina event and even stronger intensification and a much deeper thermal. So, this is one of the most important natural variability event that we will discuss in this class, the La Nina and the El Nino oscillations caused by the reversal of the walker circulation in the equatorial facet. In the next few classes, we will look at now the impact of the anthropogenic perturbations on the climate of the system. We have now seen the steady state climate in terms of what is happening in the various aspects, what is the vertical gradients of temperature, what are the normal wind directions, normal ocean directions, how heat is being transported, what is atmospheric instability, stability, what are the temperature and the pressure gradients and everything.

what are the natural variabilities one example of that. So, in the next few classes we will about the anthropogenic forcing of the climate due to the creation of the greenhouse gases and how that is affecting the climate in terms of the radiative forcing, the temperature changes and the feedback. So, these terms are very important in terms of understanding the global warming literature. So, the next few classes are very important to this course. So, thank you for listening and see you in the next class.