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

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Week- 7

Lecture 41

SEASONAL SHIFTS - ADVANCED CONCEPTS

Good morning class and welcome to our continuing lectures on climate dynamics, climate modelling and climate variability. In the previous class, we started our discussion of how seasonal shifts of the inter-tropical convergence zone, which is the zone where the equatorial low pressure belt lies and where the southern and the northern Hadley circulation systems converge. shifts towards the north in the summer because of the higher insulation in the 10 degrees to 20 degree north latitudes and shifts to 10 to 20 degree south latitudes in the winter because the southern hemisphere summer there is direct insulation of the sun at those regions. The northward shift in the summer months causes the low pressure belt to lie in the Indian subcontinent, Arabian Peninsula and northern Africa causing the southeast trade winds from the southern hemisphere to move across the equator and become the southwest monsoon winds bringing rain to the Indian subcontinent and regions of Southeast Asia and African Peninsula. in western Africa. A similar situation also happens in the winter when the intertropical convergence zone lies 10 to 20 degree south latitudes over the Australian mainland and in the southern Africa.

Then the northeast trade winds cross the equator and become the northwest monsoon winds that bring rainfall to the Indonesian peninsula here as well as regions of Madagascar and eastern coast of South Africa as the northwest monsoon. So, these two situations have been shown in the figures here. So, this is January, the intertropical convergence zone kind of shift southwards particularly over the Africa, South America and Indonesian continents creating the northwest monsoon circulation system over the Indonesian continent and northern Australia as well as parts of Madagascar and South America. Whereas in the northern hemisphere summer, that is June, July, August, the intertropical convergence zone shifts towards the Indian subcontinent and over Southeast Asian region and creates the southwest monsoon winds that brings rainfall to these areas.

This is more to do with what is happening between 0 to 30 degree north and south latitudes. The mid latitudes have a very different weather system. The ferrule cell is weak and thermally indirect and hence does not contribute significantly to heat transport from the low to high latitudes. Therefore the forward transport of sensible heat is accomplished by deviations from the zonal average. So it's not the zonal means or the meridional means that are transporting heat, mass and momentum from the subtropical high pressure zone to the subpolar low pressure zone.

Instead, deviations from these beads, which are called fluctuations and finally become cyclonic circulation systems, these are what is responsible for the transport of heat, mass as well as momentum from the subtropical high pressure zone to the subpolar low pressure zone. These deviations from zonal average are called eddies. So, we are calling them mid-latitude eddy circulation system. So, what you see in the weather front and you will see this clearly if you see the international weather, the mid-latitude region 30 degrees to 60 degrees is buffeted by repeated cyclonic and anti-cyclonic weather patterns. And these patterns are what are bringing either cold winds from the polar low pressure zone or warm dry winds from the subtropical high pressure zone.

Previously in our discussion, we discussed the idea of time mean of a quantity where we are doing a time average at a given location and zonally averaged quantity where we are doing a meridional average over all the longitude meridians at a given latitude and the zonal average of a time mean. So, we take the time mean over a certain month or a day and then do a meridional average. So these we have done as x bar, x under brackets and x bar within brackets. These are the mean quantities. We can also define the deviations from these mean quantities.

So a temporal fluctuation x prime is the instantaneous value minus the time mean value. Clear? The eddy fluctuation x star and this is what we will discuss here is the instantaneous value minus the zonally averaged value, that is the eddy fluctuation. Similarly, zonally averaged temporal fluctuation is x prime hat, x prime under brackets. So this is the zonal average of this fluctuation here, zonal average of this temporal fluctuation. So we have defined the temporal fluctuation and we do a meridional average of this temporal fluctuation over all meridians in a given latitude and usually over a given isopressure surface.

$$\textit{Temporal Fluctuation} \quad x' = x - \bar{x} \quad (8.1)$$

$$\textit{Eddy Fluctuation} \quad x^* = x - [x] \quad (8.2)$$

$$\textit{Zonally Averaged Temporal Fluctiation}$$
$$[x'] = [x] - [\bar{x}] \quad (8.3)$$

This is basically you take a meridional average here and then you get the the zonal average x under brackets here and this term here which is the zonal average of time. So this minus this becomes a zonally average temporal fluctuation. So eddy fluctuations are defined as deviations from the zonal average for a given latitude and for a given pressure surface. The eddy velocity fluctuations are then given by the zonal eddy velocity u star as the instantaneous zonal velocity minus the zonally averaged velocity across a latitude and a pressure surface. Similarly, the meridional eddy velocity is the instantaneous meridional velocity minus the zonally averaged meridional velocity.

So, this is u star and v star. However, in the mid latitudes, the zonally averaged meridional velocity, this V under brackets is close to 0. Feral cell is very weak. So, the south to north transport and associated average wind velocity is close to 0. So, this V bracket, the zonally averaged meridional velocity is close to 0.

$$\textit{Zonal eddy velocity } u^* = u - [u] \quad (8.4)$$
$$\textit{Meridional eddy velocity } v^* = v - [v] \quad (8.5)$$

If this is close to 0, then the meridional eddy velocity is almost equal to the instantaneous eddy velocity, the actual eddy velocity. That is the entirety of the meridional velocity component is contributed by the eddy fluctuation And the zonally averaged velocity is entirely in the zonal direction. So, the average zonal velocity is given by u under brackets only. So, the entire mean zonal velocity, entire zonally averaged velocity is the zonal mean velocity. zonally averaged zonal velocity, so bracket under e.

So, this is the zonally averaged velocity and the meridional fluctuation is the meridional eddy velocity. The zonally averaged meridional velocity is close to 0, clear? So, now that we understand these aspects, let us see how the eddy circulation system actually works. The full velocity field is given by say this V vector which has two components, the zonal velocity u and the meridional velocity v. So, this is kind of the velocity contour. If you take the zonal mean of this velocity, the zonal mean of the meridional velocity, b under brackets becomes 0.

So, the zonal mean component is just u under brackets, this term here. And the eddy component is whatever is remaining. The u star plus b star and this are looking as circular velocity patterns. Undulating fluctuation is a superposition of a zonal mean velocity, the zonal westerly mean velocity and this circular eddy component of both u star and v star. And how the mean and the eddy components interact with each other gives us the Ferrel's, the eddy circulation system of the midline curves.

How does it work? First we start with a reasonably straight westerly wind structure going from west to east in the Midland coast. This is the polar low pressure belt and this is the subtropical high pressure belt. Now because of certain variations in the insulation, certain regions of the high pressure belt and the low pressure belt intensify. So, you get geographical inhomogeneities in the magnitudes and the extent of this low pressure and the high pressure belt as you move along the globe. So here we have a strong low pressure zone Z developing in the north and two strong high pressure zone developing on two sides of this low pressure zone in the subtropical high pressure region.

Because this is the northern hemisphere, Any wind current around the low pressure will be anti-clockwise and any wind current around the high pressure will be clockwise because of the geostrophic balance as you may recall. So, you see this kind of a circular anti-clockwise circulation becoming prominent in the neighborhood of this low pressure zone and a circular clockwise circulation becoming prominent in the neighborhood of the high pressure zones. As this low pressure and high pressure zones intensify and they begin to move upwards and downwards, the high pressure zone begins to migrate towards the subporal low and the low pressure zone begins to migrate towards the subtropical high. And as they do, the wing patterns become more undulated and more circular in nature as the eddy component around this low and high pressure zone intensifies. clockwise circular motion around this low pressure and the clockwise circular motion around this high pressure.

Eventually these highs and lows pinch off from the main low pressure and the high pressure zones of the polar and the subtropical belts and they become kind of islands of isolated pockets of high pressure and low pressure which are migrating in the opposite direction. Low pressure migrating downwards is an island pocket and high pressure migrating upwards towards the subpolar node. And around this low pressure and high pressure zone you are getting cyclonic and anti-cyclonic circulations developing. And these now move towards the low pressure and the high pressure zones here in the northward and the southward moving direction and are responsible for the transport of heat mass from the subtropical high pressure zone to the subpolar low pressure zone and converts it. So, this entire, once these high pressures hit the subtropical, subpolar low, they dissipate.

These low pressures when they hit the subtropical high pressure zone, they dissipate. So, finally, we are again back, once these cyclonic circulations and the anticyclonic circulations dissipate away, we are again back to a more or less regular westerly circulation. So, initially we have a small undulations due to perturbations the undulations become stronger creating island high and low pressure zones that migrate in opposite directions till they again dissipate away and again the cycle begins. This entire cycle is called an index cycle. Why do these perturbations intensify? They intensify because there is no other way to transport heat from the subtropics to the poles and hence it is these perturbations therefore intensify and intensify and then physically transport heat through this cyclonic and anticyclonic circulations.

Thus, the wind pattern develops wave-like structures, so these are the Rossby waves, with subpolar low pressure migrating southwards and the subtropical high pressure migrating northwards. The amplitude of these waves continues to grow and eventually these high and lows pinch off from the primary pressure belts, creating cut-off cyclonic lows and cut-off anti-cyclonic highs that migrate in the opposite direction. The northward moving highs bring dry warm weather from the subtropics while the southward moving lows bring cold and stormy weathers from the subpolar regions. So, the southward moving low pressures from the subpolar regions bring cold stormy weathers. So, usually snowstorms kind of things that you find often in the winter times in northern hemisphere are created by this subpolar low.

Dry warm spells are created by this anticyclonic highs that are moving northward. The meridional migration of heat, this is causing the meridional migration of heat from the subtropics to the subpolar lows. Eventually the cut-off highs and lows dissipate away and the index cycle begins again. And you can see this structure here, this is the polar vortex and the warm tropical air. And you see these low pressure regions forming and are going downwards and the corresponding high pressure regions forming here.

So, these low pressures go down and high pressures go up creating the cyclonic circulations going towards the subtropics and the anti-cyclonic circulation going towards the poles. Eventually, they become cut up and then slowly dissipate. So this is the schematic of the index cycle. The meridional transport of heat by eddy fluctuations is particularly prominent in winter when large temperature differential exists between the high and the low latitudes. So the January eddy heat flux is strong in the northern hemisphere.

So, this repeated cyclical, cyclonic and anticyclonic circulations are particularly intense in the winter times in the mid latitudes because of the large gradients of insulation between the subtropics and the sub polar regions. So, winter times are, the mid latitudes are particularly susceptible to precipitation and snow events during winter times. Similarly, the southern hemisphere also, the air circulation systems intensify in July when it is winter in the southern hemisphere. But this is mostly confined in the Antarctic Ocean. So, the Antarctic Ocean becomes extremely stormy during the July months because of this.

So, this kind of ends our discussion on the atmospheric circulation system. In the next class we will start with the oceans and the interaction of oceans with the climate which is a part that we have neglected so far. So, the next week we will discuss how the oceans interact with the climate and how that interaction finally creates a lot of important weather events. are inter-annual and decadal in nature like the El Nino-Larina event which we will discuss in detail. So, thank you for listening and see you in the next class.