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

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Lecture 40

ATMOSPHERIC CIRCULATION SYSTEMS - HIGH LEVEL WINDS

Good morning class and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. In the previous lecture we saw the structure of the main surface level winds that characterize the atmospheric circulation system. Today we will discuss the high level winds that is the winds that exist in the upper troposphere of our atmosphere. As we have said in the previous class, both the low level and the high level winds are connected to the three major circulation cells that exist in our planet. Between the equator and the 30 degree north, we have the Hadley cell where we have an upward moving stream from the equatorial low pressure belt to the top of the tropics, then at the top of the tropics this wind moves towards the 30 degree north and 30 degree south latitudes and then descends at the 30 degree north or 30 degree south latitude which is the subtropical high pressure belt and there after that the winds at the surface moves from the subtropics towards back towards the equator. The surface level branch creates the southeast and the northeast trade winds.

So, it follows that the upper levels here are creating the aloft high level global wind pattern between the equator and the subtropics. Similarly, the polar cell, the rising winds from the 60 degree north low pressure belt or the 60 degree south low pressure belt moves towards the poles and becomes an aloft wind circulation system at the polar upper realms of the polar troposphere. And these descend downwards near the north pole and the south pole and become the surface level easterly winds that are moving towards the subpolar low pressure belts. Similarly, in the ferrule cell, the upward moving branch of the winds rising from the 60 degree north low pressure belt and going towards the 30 degree north high pressure belt creates the upper level winds in the mid-latitude troposphere.

So, this set here, this set here and this set here constitute the three upper level wind circulation systems that are found in our planet. So the question now is how do these circulation systems direct it? Clearly, between the equator and the subtropical high pressure belt, the aloft winds are moving from the equator towards the subtropical high pressure belt. These aloft winds are therefore moving from south to north in the northern hemisphere and north to south in the southern hemisphere. Therefore, through Coriolis forces they will be accelerated to their right. That is in the northern hemisphere they will be accelerated in the eastern direction and in the southern hemisphere also they will be accelerated in the eastward direction.

So, you have the southwesterly aloft winds because the wind is coming from the southwest and going towards the northeast. Similarly, in the southern hemisphere, we have the northwesterly aloft winds between the equator and the subtropical high pressure zone. So, we have southwesterly winds in the northern hemisphere between the equator and the subtropics in the upper troposphere and northwesterly winds in the southern hemisphere between the equator and the subtropics in the upper troposphere. Just to remind you, the wind direction is based on the direction from which the winds are coming. So, winds are coming from the southwest, so southwesterly winds, winds are coming from the northwest, northwesterly winds.

In the polar region as well, the winds are moving. Let us go back here. Winds are moving from the polar low pressure zone, subpolar low pressure zone at 60 degrees to the polar high. So, they are moving here primarily south to north and in the southern hemisphere from north to south. As a result, again because of the strong Coriolis force both will be strongly accelerated in the west to east direction that is in the positive zonal direction. And because the Coriolis forces are so high, the wind primarily blows as a west to east wind. So, you have aloft polar westerlies in both in the southern hemisphere and in the northern hemisphere between the subpolar low and the polar high. So, what we see here in these cases if you compare the aloft winds with the surface level winds. So, let us go to the surface level winds once more. At the surface level, we have northeast trade winds and southeast trade winds at the surface. between the equator and the subtropics, while for the upper troposphere we have the south westerly aloft winds and north westerly aloft winds in the northern hemisphere and the southern hemisphere respectively between the equator and the poles.

Similarly, in the poles near the surface we have the polar easterlies, the strong polar easterlies from the poles towards the subpolar lows and strong polar easterlies from the southern south pole to the subpolar lows in the southern hemisphere. On the aloft side, we have the corresponding polar westerlies. So, in the upper or higher altitudes near the top of the troposphere, we have the aloft polar westerlies both in the southern hemisphere and in the northern hemisphere, ok. So, this is more or less clear. between the polar low and the subtropical high the winds are supposed to move from the polar low to the subtropical high in the top of the troposphere.

So, if you think about it you would feel that these winds are moving from north to south and if winds are moving from north to south they should be driven eastwards. in the northern hemisphere and similarly eastwards it is moving from south to north in the southern hemisphere and hence it will be driven eastwards. So, you would have expected that the aloft winds in the mid latitudes would be directed in the eastern direction because the wind direction in the ferrule cell at the top of the troposphere is from 60 degrees to 30 degrees, so north to south in the northern hemisphere and south to north in the southern hemisphere. However, we do not see that. What we see here is mid-latitude aloft westerly.

So, even in the high altitudes of the mid-latitudes, the winds are directed towards the west, though it is also extremely undulated and we will discuss this undulation effect later in the class. So why are these mid-latitude winds at the upper troposphere also westerlies? The reason is our discussion of the thermal wind equations that we derived a few classes ago. Note that in the upper altitudes, there is no surface friction and these winds are moving over regions of hundreds of kilometres long. So, this is the perfect region where geostrophic balance equations work. And when we did the geostrophic balance equations, for the high altitude winds, we saw that the winds will primarily be moving from west to east.

How did we saw see that? So, let us recap that discussion a little bit. Let us go up. What we saw here is that if the gradient of temperature in the meridional direction is strongly negative, and this is extreme, this is true in the mid-latitudes because we are, as we move from the south to north across the mid-latitudes, the temperature falls very quickly because of the differential insulation. Then we will have del u g del z, the gradient of the zonal geostrophic velocity with respect to altitude is greater than 0. That means as we rise up in altitude, you will have a large west to east moving acceleration of the high altitude winds because of the negative temperature gradient in the south to north direction.

As a result, and this is true in the northern hemisphere, in the southern hemisphere, because the Coriolis parameter is negative, we again have the same impact that a positive temperature gradient in the south to north direction because there del t del y is greater than 0 will create and because the f is negative will have the same effect that del u g del z is greater than 0. So, in geostrophic balance as we move up in altitude we will have a stronger and stronger west to east moving acceleration of the zonal component of the geostrophic beam. This effect overwhelms the weak feral cell circulation effect which as we recall is thermally indirect in nature. So, what you get is strong upper level aloft westerlies in the mid-latitudes as well. And these westerlies have a strong undulation pattern to it and we will discuss why these undulation patterns exist.

And we call this kind of undulated westerly wind patterns in the upper troposphere of the mid-latitudes as Rossby waves. So, we observed strong aloft westerlies blowing the mid-latitudes both in the northern and western hemisphere. We can see the structure and the magnitude of the wind directions with altitude for each, for various latitudes in these two contours. This is December, January, February, so northern hemisphere winter. This is June, July, August, that is northern hemisphere summer.

The red are westerly winds, the blue are easterly winds. So, if you see in the surface level, we have reasonably weak polar easterly winds and easterly moving northeast and southeast trade winds at the surface. In the mid latitude, the surface winds are westerly. As we go into the high latitudes, say 10 to 15 kilometres, so this is kind of where the tropopause exists here, you see strong westerly winds are developing, particularly in the 30 degree north and 30 to 60 degree south regions. So, because this is winter and this is summer, these locations where the strongest westerly exists kind of shifts. The mean region where we have very strong westerlies in the near the tropopause is the, is at the subtropical high pressure zone. Why? If you look back again in the feral cell structure, hot winds are coming from the equator towards the 30 degree north high. Whereas cold winds are coming from the subpolar low and going towards 30 degree north or 30 degree south. So at the 30 degree point in general there is a convergence of cold winds coming from the subpolar low and hot winds coming from the equatorial low.

So you have a very strong temperature gradient around the 30 degree north at the top of the troposphere. And a strong temperature gradient in the meridional direction creates strong westerlies due to the thermal gradients, due to geostrophic balance equation that we discussed earlier. So, where the subpolar aloft winds converge with the tropical aloft winds, you will get a very strong westerly circulation developing there. And that happens around the 30 degree north and the 30 degree south latitude on an annual basis. In winter, the convergence zones shift and this is associated with the Hadley cell circulation. So, let us just go back quickly to go back again to the Hadley cell circulation. So, here if you see in the December, January, February, the northern Hadley cell is extremely strong and the southern Hadley cell is weak. And the convergence zone between the northern Hadley cell and the Ferrell cell here kind of shifts a little bit below 30 degree north latitude. So, around 25 degree north. So, it is in this zone here you have a large del t del y.

And therefore, you will have a strong westerly wind associated here in the northern hemisphere in the December, January, February month. Here, in the southern hemisphere, the Hadley cell expands further towards the high latitudes of the southern hemisphere. Because it is summer in the southern hemisphere, the Hadley cell, the southern Hadley cell expands southwards. So, the basically the subtropical high moves southwards to higher latitudes. So, around say 40 degree south latitudes and at 40 degree south latitude you get a convergence between the southern Hadley cell and the feral cell.

So, the in the December, January, February the southern Hadley cell lies at around 40 degree south. The convergence zone lies at around 40 degree south and in the northern hemisphere it rounds around 25 degree north. And this is the region where you will have strong aloft western. The situation reverses in June, July, August, where the southern Hadley cell now moves for northwards. So, the convergence between the southern Ferrell cell and the southern Hadley cell occurs at around 20 degree south.

So, it moves northwards towards the equator, whereas the northern Hadley cell moves further north and goes at around 40 degree north. So, at 25 degree south, you will have a strong westerly and at 40 degree north, you will have a strong westerly in the June, July, August period. And this is what we are seeing here. In the December, January, February, you have the aloft westerlies in this zone and the aloft vessel in southern hemisphere in this zone. See, it has moved further south in the southern hemisphere and is going at around 40 to 50 degree south latitudes where the convergence of the Ferrel cell and the Hadley cell occurs and in the winter hemisphere it has moved, shifted southwards and is now moving at 30 degree to 25 degree north, okay, whereas in June, July, August the peak regions have gone further.

So, this peak has moved now to around 45 degree north and this peak here which was at 50 degree south has moved towards 30 degree south. So, these two are basically shows the convergence zone between the Hadley cell ending and the Ferrell cell beginning and how the shifting of these two cells with the seasons is determining where the strong westerly circulation is going to happen in the aloft region. The other thing is you will have strong, stronger magnitudes of westerly circulation systems near the tropopause in the winter hemisphere because the temperature gradients from the equator towards the poles is much stronger in the winter hemisphere than in the summer hemisphere which gets reasonably uniform solar insulation throughout the hemisphere. So, you have stronger westerlies in the winter hemisphere and weaker westerlies in the summer hemisphere. Here the contour intervals are 5 meters per second.

And you can see the speeds here are like 20, 25, 30 in this westerlies, extremely high speed winds. And these have an impact on airline travel as well. So, these are the main points that have been shown here. The key points are therefore, aloft northwesterly northern hemisphere and aloft southwesterly the southern hemisphere between 0 and 30 degree latitudes. Subtropical westerly jet stream at 30 degree north and 30 degree south where warm winds from the Hadley cell convert with cold winds from the subpolar lows transported by the Ferrel cell.

And the location of the subtropical jet stream, intense zone of westward moving winds kind of shifts with the seasons from around 30 degrees to 50 degrees. Mid-latitude aloft westerlies between 30 degrees and 60 degree latitudes. which are particularly strong as they are driven by strong meridional gradients in temperature, polar aloft westerlies between 60 degrees and 90 degrees. So, what we see is all the aloft winds are westerly in direction and this is because of the thermal gradients. Some places it is stronger, some places it is weaker, but always westerly. Now, we can look a little bit more detail on the seasonal shifts. So, the seasonal shifts can be observed using these contours. So, these contours are contours of the 1000 hectopascal pressure surface. So, the 1000 hectopascal pressure surface altitude has been plotted, the mean is 16 meters. Altitude at which you are getting 1000 hectopascal pressure over the globe is around 16 meters.

But in the high pressure regions, the surface will rise up. So, it will be say 20 meters or 25 meters because the pressure is higher. Whereas in the low pressure region, this 1000 hectopascal surface will dip closer towards the ground. So, high pressure zones where the altitude of this 1000 hecto Pascal surface is higher than 60 meters are given by reds and the low pressure zones where the altitude of this 1000 hecto Pascal surface is lower than 60 meters are given by white and blue. So, the white and blue are low pressure regions, the reds are the high pressure regions. And you can also see the wind circulations figures. Contour intervals is 20 meters. So, there is a, if there is a 20 meter difference in the heights, you get one more contour. And the largest vectors represent winds at around 15 meters per second. So, these large vectors are winds at around 15 meters per second.

So, if you look at the January winds firstly, so this is northern hemisphere winter. As we discussed before, we have a very strong high pressure zone developing. over the interior of Asia along with, so this is firstly what you see here in January is that you have a tropical low pressure belt around this point. And this tropical low pressure belt has shifted somewhat southward because the southern hemisphere is colder and as a result the tropical low pressure belt has moved southwards. Because the southern hemisphere is hotter, sorry in January the southern hemisphere is hotter, so you have strong high temperature and low pressure zones developing in the continents in the southern hemisphere, southern Africa, Latin America and Australia.

As a result, the equatorial low pressure belt shifts southwards and this excursion is very strong especially in the continents. As a result, the subtropical high pressure belt in the northern hemisphere also shifts down because in the winter hemisphere the insolation is lower so the high pressure zone becomes bigger and broader. There is a big and broad high pressure zone is extending much closer to the equator in the winter hemisphere. Whereas the subtropical high pressure zone in the summer hemisphere weakens and is shifting further down towards the, towards high latitudes of the southern hemisphere. Following this you have again the subpolar low pressure belt in the Antarctic Ocean and then the polar high in the Antarctic which has not been seen.

Because the high pressure, subtropical high pressure belt has become stronger and broader, the subpolar low pressure belt kind of becomes discontinuous. This is the subpolar low pressure belt over the Pacific Ocean, the subpolar low pressure belt over the North Atlantic and Greenland and the subpolar low pressure belt over the Southern Pacific, Southern Atlantic and Siberia, ok. these have become discontinuous because the extremely strong subtropical high pressure belt in the winter hemisphere of northern hemisphere has kind of broken the subpolar low into three different segments. And beyond that in the Arctic you will have once more a polar high pressure zone which has not been shown. Because of the circular structure of this high pressure belts, of this low pressure belts in the northern hemisphere particularly, you see this kind of cyclic, anti-cyclonic circulations, cyclonic circulations happening over northern Pacific and northern Atlantic Ocean, alright.

Similarly, because of this low pressure zone. Here, winds are coming from the subtropical high pressure belt in the northern hemisphere and going towards the low pressure zone here. So, winds are going into this low pressure zone both from the northern hemisphere where the high pressure is strong and partly also from the southern hemisphere where the high pressure is somewhat weak. In the July, the situation is reversed. So what you see here in July is a very strong low pressure zone developing over Asian landmass which gets heated up as well as the African landmass.

This section here. Low pressure zones also develop in northern American landmass as well. So, the equatorial low pressure belt now shifts northwards because northern hemisphere is the summer hemisphere which is getting a lot of insulation causing winds to move upwards creating strong low pressure. So, the equatorial low pressure zone moves upwards particularly in the land masses of Asia and Africa. As a result, the subtropical high pressure belt of the northern hemisphere weakens and now breaks up. So, you can see the subtropical high pressure belt has now broken up and has moved and is now where the, where the subpolar low pressure belt was, that is where almost the subtropical high pressure belt has gone in, in the oceans particularly.

Whereas the subpolar low has moved upward and moved further upwards towards the poles. In the winter hemisphere, in southern hemisphere is the winter hemisphere. So, the subtropical high pressure belt has strengthened and extremely strong especially in Australia, South African landmass which are becoming quite cold. So, you have a strong and northward moving subtropical high pressure belt in the southern hemisphere and you get a strong wind circulation system going into the low pressure zone of the Asian landmass from the high pressure zone in the southern hemisphere. So, what are the main features? We will discuss that and we will continue that in the next class. During the northern hemisphere summer, direct vertical solar insulation shifts north to 10 to 20 degree north latitude. Hence, the equatorial low pressure belt also shifts 10 to 20 degree north from 0 degree. So, it is shifting upwards into the northern hemisphere along with the change in the latitude of the direct normal insulation. This shift is particularly prominent over the Asian and the American landmass which experience large heating during summer. As a result, the intertropical convergence zone, the low pressure, equatorial low pressure where the southern and the northern Hadley circulations emerge from lies around 10 to 20 degree north during the northern hemisphere.

And this is where the northeast and the south winds, trade winds will converge and the Hadley circulation will rise up. Okay, this also corresponds to the northward shifting of the subtropical highs and the subpolar lows as the northern half of the circulation moves north and its descending branch migrates to 45 to 50 degree north latitude. So, the entire northern half of the circulation has moved northwards and the southern half of the circulation has extended to 10 to 20 degree north of the equator. So, this is the inter-tropical convergence zone where the Hadley circulations converge in summer. And you can see that in the summer, northern hemisphere summer, June, July, August, these are shifted particularly in the ASEAN continent to around 20 degree north latitude.

As a result, the south, the south, the trade winds from the south, the southeast trade kind of cross over the equator and moves towards the intertropical convergence. This happens also particularly prominently over Africa and the South Asia and Southeast Asian subcontinents. As these winds cross the equator, the Coriolis force parameter shifts its sign. So, the southeast straight winds become the southwest monsoon winds. Because the winds that were moving from east to west, like this, as it moves the equator, the coriolis first shifts and it goes from south to west towards northeast.

So the wind kind of moves like this, crosses the equator and moves from the southwest to northeast direction. And this you can see here particularly prominently. So these are the southeast trade winds crossing the equator heading towards the intertropical convergence zone which is now over the Asian and the African subcontinents and becomes the southwest monsoon winds with rainfall over this entire region. Okay. The winds pick up moisture over the Indian Ocean and hit the south and southeast Asian landmass resulting in heavy precipitation. And this is why you get the strong monsoon rainfall system developing over the Asian and the Southeast Asian continent, land masses. So, we will continue the discussion in the next class. Thank you for listening and see you.