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

Professor Name: Dr. Sayak Banerjee

Department Name: Climate Change Department

Institute Name: Indian Institute of Technology Hyderabad (IITH)

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UNDERSTANDING EARTH'S SEASONS AXIAL TILT, SOLSTICE, AND EQUINOX DYNAMICS

Good morning class and welcome to our continuing discussions on climate dynamics, climate variability and climate monitoring. In this class we will discuss, we will continue our discussion on the previous topic on how angle of inclination between the axis of the earth and the circle of illumination is giving us the seasons as the earth revolves around the sun. As we saw in the previous class the plane of ecliptic is the plane along which the earth rotates around the sun. If you draw a plane along the plane perpendicular to this plane of ecliptic to the center of the earth, that plane will inscribe a circle at the edge of the earth which divides the lighter half which is being illuminated by the sun and the darkened half which is not being illuminated by the sun at any given point of time. The perpendicular line cutting through the center of the earth and perpendicular to the plane of ecliptic, the angle between that and the axis of the earth is the axial tilt or oblique tilt. This is 23 degrees 30 minutes in angle or 23.45 degrees. This axial tilt is a constant value for our case even though it changes by small amount over millions of years. As the earth revolves around the sun, this axis of the earth always remains parallel to itself and this fact is called parallelism. As a result, the effective angle between the circle of illumination and this axis of the earth is changing.

So, when you have the summer solstice, The axis of the earth makes an angle of 23.45 degrees exactly with the circle of illumination and hence earth is rotating such that the northern hemisphere points are having longer daylight period than the southern hemisphere points. Let us look at this situation a little bit more detail. So this is the figure of what is called the summer solstice that happens in June 21st. This is the axis of the earth and the earth is rotating along this axis.

These are all latitudinal circles. So any point on this circle is moving along this circle during a 24-hour day and moving about the axis of the earth. As you can see therefore, suppose you take a point like Repulse Bay which is on the earthic circle, 66 degrees north latitude. This point throughout this 24hour day will be confined to this dotted circle and hence is entirely within the illuminated portion of earth, portion of the earth because the circle of illumination is below the arctic circle. So no point above the arctic circle is ever crossing this circle of illumination and will get 24 hours of daylight.

Even if you consider New York City, so you can draw a line which is perpendicular to the axis and the New York City will always follow this locus, circular locus as it rotates in a 24hour period. And you can see therefore that the New York City will spend a significantly longer fraction of the time of day in the illuminated part of the earth than the darkened part of the earth. So, it will have longer days and shorter nights. On the other side, in the southern hemisphere, if you look at Venus Aries, this is moving to this, along this line here and it will spend a much longer period in the darkened half of the circle of, darkened half compared to the illuminated half. So it will have longer night and shorter days.

And any point in the Antarctic circle and below will lie exclusively in the darkened half of the earth throughout the day and will have 24 hours of night. So, what we see in the summer solstice and in general during the summer period when the axis makes an angle of plus 23.45 degree with respect to the circle of illumination or it will make an angle which is between 0 to plus 23.45 degree, you will have the summer period where northern hemisphere locations will have longer day time and shorter night time and southern hemisphere locations will have longer night times and shorter day time. So, during this period the effective angle between the axis and the circle of illumination will be between 0 degrees and plus 23.45 degrees, ok. So, this continues between September 22, just one second. between March 21 and June 21, ok. So, at March 21 we will see it will be 0, at June 21 plus 23.45 and September 22 it will be 0.

So, between March to September you will have the summer period in general where the axial tilt and the circle of illumination will make an angle of between 0 and 23.45 degree on the positive side. Now if you look at the opposite half of the year between September 22 and March 21 and look, we can look especially on the winter solstice which is December 22 when the angle is minus 23.45 degree. So, basically the angle that the axis of the earth is making with the plane of the circle of illumination at the centre of the earth changes from plus 23.45 to minus 23.45. So, if you can see here this is minus 23, this is plus 23, ok. And 0 to plus 23.45, then plus 23.45 to 0 is between March and September. 0 to minus 23.45 and minus 23.45 back to 0 is between September to March. So, this is the summer half, this is the winter half. What happens in the winter solstice? You can see here that the sun's rays are on this side and the actuarial tilt is minus 23.45. So now every point beyond the Arctic Circle will have 24 hours of night because it lies exclusively in the darkened half of the Earth whereas every point below the Antarctic Circle will have 24 hours of daylight because every point lies in the illuminated half. New York City in this case will have spent a long period of time in the darkened half and will have short days and longer night. we will have longer days and shorter night.

So, in this case southern hemisphere gets the minimum maximum amount of daylight that is possible and the northern hemisphere gets the minimum amount of daylight that is possible ok. Now, what happens in March 21 and September 22? The axis falls on the circle of illumination itself and so there is no effective angle between the circle of illumination and the axis. So, you can see here this is the circle of illumination and the axis points are falling on this circle. So, the axis is falling on this circle. You can see both in March and September 2020.

So, the circle will be like a plane and the axis will be on this plane itself. Because of this every point on the earth surface will have equal times of day and night. So, they will spend exactly 50 percent of its time during the day in the light end half and 50 percent of its time during the day in the dark end half both in the upper northern hemisphere and in the southern hemisphere. This is true for both March 21 equinox and September 22 equinox, which are the spring equinox and the fall equinox respectively. So, let us summarize what we have understood.

Two other points I would also like to know, like to note here. Remember the sun's rays are always along this parallel line. Because the latitude angles are defined between the centre of the earth and the latitude, the surface normal comes much closer to the rays of the sun hitting the surface in the northern hemisphere during the summer period whereas the surface normal is much further away from the sun's rays in the winter hemisphere. So, what is happening is in the summer hemisphere, the sun's rays are much closer to the surface normal than in the winter hemisphere where the sun's rays are much far away from the surface normal. As a result, in winter time the sun is much lower on the horizon even at noon compared to the summer time for in the respective hemisphere.

Beam spreading and attenuation effects are much more accentuated in the winter compared to the summer at high latitudes. As a result, you will get much larger solar flux variations even during the daytime. So, during winter in daytime at high latitudes. Due to beam spreading and attenuation effects, the solar flux will be much smaller even in the limited time of day that is available here at this high latitude. Whereas in the summer not only you are getting more number of daylight hours because the sun is much higher up in the horizon, higher up in the sky and is closer to the surface normal beam spreading and attenuation effects are much lower. So you are getting more solar flux in watt per meter square coming during a summer period as well as longer daylight hours during which the solar flux is coming.

So what this means is winter hemispheres in high latitudes are especially cold because you have shorter daylight hours and more accentuated beam spreading and attenuation effects whereas in summer you have much larger temperature rise because of the longer daylight hours and much less pronounced beam spreading and attenuation effects. Of course during the equinox you have equal daylight hours and the beam splitting and attenuation effects are equally increasing at equal proportion from the equator towards the north pole and the south pole. So, the flux distribution will be symmetric about the equatorial region, ok. Another important point which I have to mention also, every point in the equator will always at any time of the year because if you see in the equator for both the summer solstice and the winter solstice, exactly half of the length of the equatorial circle lies in the illuminated half and half of the length of the equatorial circle lies in the darkened half, ok. So, now that we understand this thing, these are all explained in this note here, let us at the number of hours that you are getting at different latitudes because of this seasonal effect, alright.

So, here is the kind of a plot of the hours. So, this is the 12hour line, ok. This is the 14hour line. So, this region is between 12 to 14 hours of daylight. This is then 14 to 16 hours, 16 to 18 hours, then 24 hours, constant day. Here it falls 12 to 10 hours, 10 to 8 hours, 8 to 6 hours, to 1 hour of daylight, to 0 hours which is constant night. Okay. The days of the year are given from 0 to 360. So 0 is in January, so 1st January is the first day. And 31st December is the last day or the 365th day here. This is the June solstice day. So, this June 21st is this blue line here. Here you can see above 66degree latitude you are getting 24 hours of constant day during the summer solstice. Then throughout the entire northern hemisphere you are getting more daylight hours than night hours. So, 14 hours of day means 10 hours of night, correct. 16 hours of day means 8 hours of night, 18 hours of day means 6 hours of night and so forth.

In the southern hemisphere, the daylight hours are shrinking, 10 hours of daylight, 8 hours of daylight, 6 hours of daylight, 1 hour of daylight, then 0 hours of daylight, ok. So, this is the variation of daylight hours during the June solstice. If you see the December solstice which is here, it is exactly reversed. So, this is 24 hours, 23 hours, 16 hours of daylight, 12 hours of daylight at the equator, then goes down at the northern hemisphere. So you can see in between you have the September equinox and the March equinox where throughout the entire region you are getting 12 hours of daylight and 12 hours of night.

So the green line is extending throughout. And you can see how the daylight hours are changing with the day of the year in between. So, June solstice the high number of daylight hours all start to decrease and the low number of daylight hours in southern hemisphere all also start to decrease till you get the 12 hours of daylight everywhere and then you again start the reversal, ok. That the daylight hours start to increase in the southern hemisphere and daylight hours start to decrease below 12 in the northern hemisphere, ok. Then it again goes down between the December solstice and the March solstice.

So this kind of a plot gives you an idea for a given time of year at which given latitude what is the daylight hour. So for example, suppose you want to find the number of daylight hours at 60 degrees north latitude on 30th January. So you take this line here, 60 degrees north latitude and you get around 8 hours of daylight. Similarly everywhere else. So because of this variation in daylight hours and the variation of the incoming solar flux between winter and summer you are getting this high seasonal disparities in temperature especially in the high latitudes.

So if you think of a high latitude point say 50 degree north latitude for example or 60 degree north latitude. So in 60 degree north latitude the daylight hours throughout the year are changing between say 6 hours for example here to 18 hours here and then back to 6 hours. So, between winter and summer you are getting a 12year hour disparity in daylight hours. Furthermore, because of the because of the changing in the angle of the sun with the surface normal, you are getting much larger beam spreading effect in winter and much lower beam spreading and attenuation effect in the summer. So, a large variation of solar flux between winter and summer is occurring, ok. So, as a result, you will get large variation in temperature. Instead, if you compare in the low latitudes, between 20degree south and 20 degree north, you see that the daylight hours hardly varies between 1 and 2 hours maximum. Okay. And also, beam splitting and attenuation effects are more or less constant because the inclination is not changing that much. So, as a result, the lower latitudes have much smaller seasonal variations compared to the high latitudes.

And this can be seen in the temperature profiles we discussed earlier, where you can see that at high latitudes the temperature variations extend from minus 20, minus 30 or plus 30, plus 40 at the high latitude. Whereas in the equatorial region, here this is the equator, you are getting temperature variations between the winter and the summer season as to lie between 0 and 10 degrees. So, you are getting 30-40degree variation at the high latitude especially on land whereas at low latitude you are getting maximum 10degree variation. Of course, in the oceans that variation is much smaller because water can move very quickly and it has a high latency. We will discuss those things when we discuss ocean currents etc.

And so, oceans respond much slower to any flux variation compared to land. So, I will stop here today. In the next class, we will try to quantify some of the ideas of this mean solar insulation and also discuss a very simple model of greenhouse effect first to kick off the idea of how greenhouse effect can be calculated. In much later classes, we will do a far more complicated models of greenhouse effect as well. So, in the next class, we will look at the mean emission temperature of earth and greenhouse effect related models.

Thank you for listening and see you in the next lecture.