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

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FUNDAMENTALS OF EARTH'S CLIMATE SYSTEM LATITUDE, LONGITUDE, AND TEMPERATURE DYNAMICS

Good morning class and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. In the previous class, we started our discussion on the various astronomical variables or Earth-Cern relationship variables that control the weather and climate of the world. we said that this is because most of the heat and energy that is coming on earth and determining the heat budget of the atmosphere and the oceans and the energy transfer processes that occur there are ultimately coming from the sun and hence how the solar flux in terms of watt per meter square is changing from one location to another location or from day to day within a year or within a month is very important in understanding how the weather patterns and the overall climatic patterns change with location, geography and time We were discussing the geometric factors within the earth how we describe that earth is close to a sphere and we discussed the concept of a latitude and the equator which are basically a series of parallel circles that are going from the North Pole to the South Pole with the equator at the center. Every latitudinal circle is defined in terms of the angle it subtends at the center of the Earth. Similarly, the longitudes are a series of half circles that are inscribed on the surface of the Earth with the center of the Earth as its center that is starting from North Pole to the South Pole. The zero degree meridian passes through the greenwich mean time in England and all other longitudinal half circles are defined in terms of angles that is subtended by those longitudinal circles between the zero degree meridian and the center of the earth. So, for example, a 90degree west longitude is subtending an angle of 90 degree at the center of earth between it and the zero degree meridian.

And this zero degree meridian is called the prime meridian. So we have a series of meridians from 180 degree west and 180 degree east with respect to the prime meridian. The interesting feature of meridional lines is all points along a longitude are in the same local time zone. That is, they are in the same point with respect to the Sun during the course of the Earth's rotation. So, the sun will be at the highest position in the sky at all locations within a single longitudinal half-circle. It will be sunrise and sunset at the same instant at all points in a given longitude. Similarly, the midnight where the sun is the lowest position below the ground will also be at the same local time. The direction along a longitude is the north-south direction, so north-south direction and this is called the meridional direction.

Similarly, the direction along a latitude is the east-west direction, so it is called the latitudinal or zonal direction.

So zonal direction and meridional direction. The east-west along a latitude is zonal, north-south meridional. These terminologies will be very useful when we are discussing wind patterns and ocean current patterns later in the class. So I am just highlighting this point here. Now Latitude has a very important impact on the average temperature at a given location when it is averaged over an entire year and this can be shown in this heat map or the temperature map. So, here the mean temperature has been plotted for any location over a period of an entire year.

The temperature varies from minus 50 degree centigrade to plus 30 degree centigrade. Remember this is the mean temperature throughout when it is averaged over the entire year. And you can see here that the lower the latitude angle that is closer to the equator greater is the mean temperature. And as you go at higher latitude angles either in the north direction or in the south direction the mean temperature falls off quite rapidly. So, from 30 degrees in the near the equator it goes towards in the temperate regions to say 10 degrees, then in the Arctic region it will be 0 minus 10 minus 20 degrees and especially in the ice caps in the Antarctica and Greenland it can go much further down to minus 40 minus 50 degrees.

Now, the question is why does this happen? And there are two reasons why this is happening. So, we will discuss that now. So the two major impacts that is causing this temperature variation is because the latitudes determine how much average solar flux per unit area of the surface is actually hitting the ground. And we can show that the solar flux near the equator is much higher than the solar flux near the poles. That is in terms of energy per meter square that is hitting the ground is much higher in the equator when it is averaged over the entire year compared to solar flux heating the northern and the southern polar regions.

So, even though and we discussed this in the last class, The average solar flux when it is averaged over the entire earth surface at the top of the atmosphere is 340 watts per meter square. So, the mean flux that is coming over a entire 24 hour period when averaged over the entire surface of the earth at the top of the atmosphere it is 340 watt per meter square, but this solar flux is very unevenly distributed. The actual solar flux that is hitting the surface of the earth will depend on which latitude it is in and this is what we will discuss now. So, the first point is what is called attenuation. So let us understand this picture once it becomes clear.

This is the surface of the earth. This is the atmosphere. As you remember, the sunlight is coming as a series of parallel lines from the sun to the earth. These lines are parallel to the lines connecting the center of the earth to the center of the sun. However, the surface of the earth is not perpendicular to this line.

So, here it is perpendicular at the equator, but a parallel line from the axis of the earth to the axis of the sun is not perpendicular to the surface of the earth. So, the surface of the earth kind of moves away from this parallel line and subtends a greater angle as we move towards the pole and at the edge this the surface normal is perpendicular to the line connecting the axis of the earth and the axis of the sun. So let us understand this a little bit more. Suppose the center of the earth, this is the axis of the earth, and somewhere here is the axis of the sun. We are drawing a series of lines perpendicular to both these axes.

And the sun's lights are coming in the form of parallel rays parallel to this to these lines so these are the two axis of the sun axis of the earth and the lines connect a series of perpendicular lines if you think between these two axis then the sun's rays are coming parallel to these lines okay Now, near the equator, the normal to the surface, the surface normal lies along this line. So, the rays of the sun are falling on the surface directly normal at the equator. However, and this is for example the noon time. So that is why in the equator you will find that in the most times at noon the sun is directly overhead. So the sun's rays are falling directly perpendicular to the ground.

However, this is the noon time sun is highest at the equator. If you go at higher latitudes, the surface normal is making an angle to the sun's rays, right. The sun's rays are coming like this, the surface normal is going like this. So, what happens is therefore two things. An attenuation happens in the sense that between the top of the atmosphere and the surface, the sun's rays are traveling over a longer distance.

So here the distance between the top of the atmosphere and the surface of the earth is the shortest because it's the normal. Here the sun's rays are at an angle with respect to the surface normal and hence this distance is much bigger than this distance. And if you go towards the poles where the surface normal is almost perpendicular, the distance between the surface and the top of the atmosphere along the direction in which the sunlight is coming is much longer. So, this is a very basic fact that if the sun is lower on the sky, the distance between the sun's rays and the surface from the top of the atmosphere to the surface, the sun's rays are travelling a much longer distance. Now, atmosphere absorbs part of the solar radiation.

It also has a lot of clouds, a lot of dust which reflects a lot of the solar radiation. So, the longer the distance the sun's rays are travelling between the top of the atmosphere and the surface of the earth, the greater is the amount of energy that is being either lost through reflection by dust and clouds or absorption by the atmosphere. Hence, if a certain energy flux is coming at the top of the atmosphere, a much lower energy flux will be reaching the surface of the earth because the rest is being lost through atmospheric absorption and reflection. and thick longer the distance the sun's rays have to travel from the top of the atmosphere to the surface of the earth greater is this loss due to absorption and reflection on the atmosphere and this is called attenuation that is the solar energy is being attenuated by atmospheric absorption and reflection So what this means is you have much less amount of sun's energy actually hitting the surface of the earth as you move away from the equator even at noon time when the sun is higher up in the sky at all of these longitudinal positions. And of course in any given time of day this is true.

As you move higher up in the latitude, the sun will be lower in the sky compared to the equator and hence the sun's rays will be travelling a longer distance through the atmosphere and its energy will be attenuated by atmospheric absorption and reflection. Hence the incident energy at high latitude decreases compared to the value at the lower latitudes. So that is the first reason why the solar flux hitting the surface of the earth is lower at higher latitudes compared to lower latitudes. The second point is what is called beam spreading. So here again we look at the noon time, it will be the same at other time zones as well.

This is the equator, this is higher up in the latitude. In the equator, the sun is directly overhead or much higher up in the sky, which is why the sun's rays are parallel to the surface normal. What this means here, so if you look at the equator the sun take a beam of sunlight with a certain cross sectional area hitting the surface of the earth. this is the total energy, the total energy is the watt per meter square per the meter square of this say the cylindrical area, so 1 meter square of cylindrical area. So, this will be the wattage that is coming on the surface of the earth at the equator.

However, here if you see Because the surface normal is at an angle with respect to the solar rays, this area 1 meter square of solar beam is falling over a much broader area on the surface of the earth. So, because the surface of the earth is tilted with respect to the solar beam, this is 1 meter square of solar beam area, it is hitting and is spreading over a much longer region of the surface. So, what you are getting here is quite simple. You are getting a triangle like this. So, suppose you take a normal here and you will get this is the length over which the solar light is spreading whereas this is the original length of the solar beam.

So, if this is 1 meter, this is the angle with respect to the solar beam, then you can find the total length over which this beam is spreading on the surface of the earth. So, what we see here, so this is a simple example assuming a flat surface and this is a little bit more complex where we are assuming a spherical surface structure. So, here the beam spreading may be even more under certain conditions. So what is fundamentally true is this 1 meter square of solar beam is spreading over a much larger meter square area on the surface of the earth. So the same amount of incident energy is spread over a larger area of the surface near the poles than at the equator and hence the watt per meter square actually hitting the surface of the earth is much lower at higher latitudes than at the lower latitudes.

So this point is called the beam spreading. So as a result of attenuation and beam spreading due to low sun angles at these high latitudes, the average solar insulation received is much lower at the high latitudes than at the equator. Not only is part of the sunlight getting absorbed more intensely by a thicker region of the atmosphere at high latitudes, whatever sunlight is reaching the surface is being spread over a much larger area. So the watt per meter square solar flux is decreasing. So this explains why high latitudes have colder climate on average than the lower latitudes.

And you can see this in this figure. So this figure basically gives you the total energy per meter square that a certain location on earth is receiving as either a daily average or a yearly sum. So, kilowatt hour is a unit of energy we can discuss this later thinking it is a unit of energy similar to kilo joules or mega joules like that and per meter square of the surface area. So, you can see at low latitudes particularly in the equatorial region, Australia like the subtropical in the equatorial region, Brazil, Argentina, Mexico, Saudi Arabia, India, Indonesia, these are the low latitudes in 30 degree north and 30 degree south. in the subtropical region the energy flux solar energy flux per meter square is much high.

So, it is extremely high between 2000 to 2500 kilowatt hour per meter square on yearly sum and in a daily average it is around 655.5 to 7 kilowatt hour per meter square. Whereas, if you go at high latitudes at the temperate regions, it decreases very quickly to around 1000 kilowatt hour per meter square as a total yearly sum and the daily average as 3 to 3.4 kilowatt hour per meter square. And if you go even further high near the Greenland and the Antarctica, it will be much, much lower even.

So, the solar flux kind of decreases by at least three times between the equator and in the Arctic Circle. So, this is the primary reason why the mean annual temperature is much lower at the high latitudes compared to the low latitudes. So, that is one point where the climatically you are getting colder climates in the high latitudes and hotter climates on the low latitudes as yearly means. And this is dependent on these beam spreading and attenuation effects caused by the spherical surface of the earth over which the sunlight is spreading. The other section is the seasonal variations.

So, seasonal variations are a very important aspect of how the climate and the weather patterns are changing from winter to summer. Why this winter to summer variation is happening at all? So, here is a nice geometric figure that explains what is happening. Fundamentally, the axis of the earth is tilted with respect to the sun. earth-sun plane which is called the plane of ecliptic. So, the plane of ecliptic as you can see here is the imaginary plane that bisects both the earth and the sun.

So, suppose you draw a line between the center of the earth and the center of the sun. The plane of ecliptic is a plane on which this line resides and which bisects The earth into two equals hemispheres and the sun into two equal hemispheres. The revolution of the earth with respect to the sun occurs in this plane of ecliptic. So this purple plane. So the revolution of the sun. So as the earth revolves around the sun. That circle lies on this plane of ecliptic. So both the line connecting the earth sun. This line. And the circle along which the earth is revolving around the sun.

Both of these lie on this plane of ecliptic. That bisects the earth and the sun. into two hemispheres. And the sun's rays are always parallel to this plane of ecliptic as they arrive on earth. So as we said the sun's rays are all parallel to this line connecting the center of the earth and the center of the sun and hence are all parallel to this plane of ecliptic. However the axis of the earth does not lie in this plane of ecliptic. It is tilted with respect to the plane of ecliptic. So, consider a line through the center of the earth that is perpendicular to the plane of ecliptic. So, we can draw a line perpendicular to this plane of ecliptic that is also perpendicular to this line connecting the center of the earth and the center of the sun.

So, this is the 90 degree. So, this is the line. Then the angle between this line and the axis of the earth is called the axial tilt or obliquity. So this is how the tilt of the earth is defined.

You have the plane of the ecliptic, you have the center of the earth here, you draw a perpendicular line from the center of the earth upwards and find the angle between this line and the actual axis of the earth. And this angle is called the axial tilt angle or obliquity and it is currently at 23.45 degree centigrade. 23.45 degrees or 23 degrees 30 minutes. So, remember after degrees you have the minutes. So, 60 minutes is 1 degree. So, 23.45 degree means around 23 degrees 30 minutes. Now, this axial tilt is not strictly fixed. It changes slowly over geological times and has an important impact on the geological variation of the earth's climate. So, ice ages, interglacials, these have an important impact on the slow change of this axial tilt of this earth. However, for our present climatic conditions, we can consider over this human period of say a thousand years, the axial tilt has been more or less constant at 23 degrees 30 minutes and this we can consider as constant for our conditions. So, this axial tilt is fixed and does not change depending on the earth's position relative to the sun. So, the axial tilt will always be fixed. Wherever the earth is, if you draw this line and compare the axial, the axis of the earth around which it is rotating, then this angle will always be 23.45 degrees. Thus the axis of the earth always remains parallel to itself in all its positions along the earth's orbit. So basically if the axis is tilted like this, it always remains tilted like this as it rotates around the earth. So all the positions along a, so if you take the circular line around, circle around which the earth revolves and at each point you draw the axis of the earth, then all of these lines will be parallel to each other.

So, this is called parallelism. The other important point is what is called the circle of illumination. So, let us look at this figure here. So, the earth is rotating. So, this circle is basically the locus of all the centers of the earth. The circle lies on this plane of ecliptic and this is the axis of the earth which is always parallel to itself at each and each of these locations, fine. And is making a angle of 23.45 degrees with this line perpendicular to the plane of the ecliptic, fine. These are all known, okay. Now, the interesting point is This line, the line perpendicular to this plane of ecliptic passing through the center of the earth, is part of a plane. So, if you draw a plane which is perpendicular to the plane of ecliptic and passing through the center of the earth. So, this is the plane of the ecliptic and you have drawn a line, a plane which is perpendicular to this plane of ecliptic passing through the center of the earth, then this line will follow on that plane.

And this plane when it hits the surface of the earth will have will inscribe a circle on the surface of the earth. And this circle is the circle of illumination that is this circle will be separating the all the locations which is receiving sunlight and all the locations which are night, which is not receiving sunlight at that instant of time. So, this is kind of obvious because the sun's rays are parallel to the plane of ecliptic, hence will be perpendicular to this line. So, this circle at the edge of the earth will separate all the locations in the front where sun's rays can hit and all the locations in the back where sun's rays cannot hit and hence it is night. So the circle that this plane subtends on the surface of the earth divides the earth into the illuminated half and the shadowed half and is called the circle of illumination.

So you can see this circle of illumination shown here in these two points. In this point circle is this edge circle. So everything in the back that you cannot see is in the night half and here also this circle is this circle of illumination and everything on the night side you can see on this point. For any location that is on the circle of illumination it is sunrise or sunset at that moment.

So every point here on this circle is sunrise or sunset. So why we are discussing all of this? We are discussing all of this because this helps us to understand why seasons occur. The tilt of the earth with respect to the normal to the ecliptic causes the occurrence of the seasons. So, this tilt respect to the circle of illumination is causing the occurrence of the seasons. It changes the length of day relative to the length of night.

All these points are moving in circles around the tilted axis. So, if you see here and we will see this in a bigger figure in the next class, any point is rotating along this latitudinal circle. So, here the period of night is much lower than the period of day. On this side however, the period of day is much lower than the period of night. So this side is summer with longer days and winter with shorter days. During the March and the September equinoxes, you are seeing something entirely different.

Here the axis, even though it is making an angle with the line connecting the center of the earth and the perpendicular of the ecliptic, both of these lines are falling on this plane or the circle of illumination. So, during the summer and the winter it is like this, when it rotates it kind of becomes parallel to this same plane. So, both of them are lying on the same circle of illumination and hence Throughout all points, you have the same length of day and night during the March and the September equinox. Again in December, the northern hemisphere you have longer periods of day and in the southern hemisphere you have shorter periods of day. So, we will see this in little bit more detail in the next few figures.

So, this is it for today. We will continue this lecture in the next class. Thank you for listening and we will see you in the next lecture.