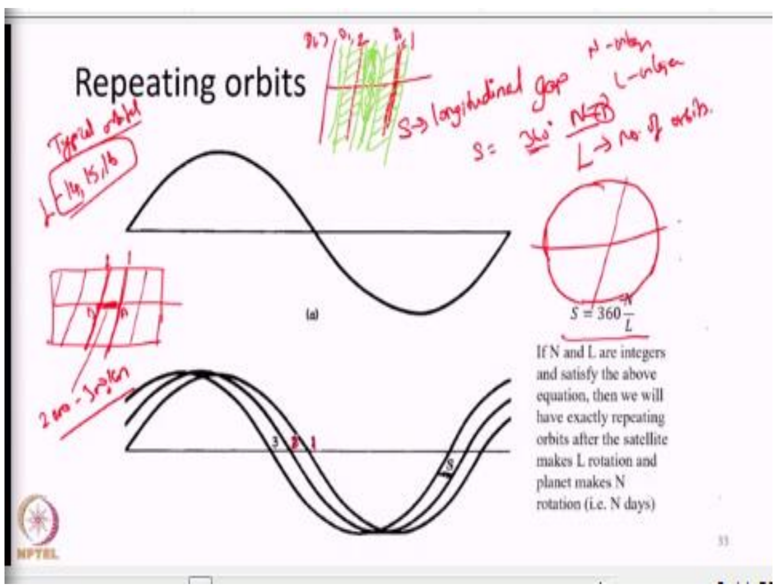
Remote Sensing: Principles and Applications
Prof. R. Eswar
Department of Civil Engineering and Interdisciplinary
Program in Climate Studies
Indian Institute of Technology Bombay

Lecture-55
Platforms for Remote Sensing Observations-Part-6

Hello everyone, welcome back to the next lecture, we are discussing about the topic platform used for remote sensing in which we are specifically talking about the near polar sun synchronous orbits. In the last lecture, I told you concepts related to the equatorial overpass time for different, different latitudes and the typical inclination angles. Also, we started discussing about the repeating nature of orbital cycle.

(Refer Slide Time: 00:50)



I told you that after every given number of days the ground track at which the satellite overpass will repeat**,** say every 16 days once or every 24 days once. And this is actually in order to produce global coverage with meaningful high spatial resolution. This orbital receptivity will be achieved under certain conditions or certain criteria. So, the criteria are given in this particular slide.

$$S = 360\left(\frac{N}{L}\right)$$

where S is the longitudinal gap between 2 orbits. Say this is orbit 1 and orbit 2 on any given day. I told you that when a satellite completes one orbit and when it is going to start its second orbit, it will start from a point that is west of its starting point, it will always happen. So, there is a shift in the longitude at which the satellite is starting its new orbit, that longitudinal shift should be equal to 360 degrees.

This is one full rotation around the earth multiplied by (N/L), where N is the number of days, and L is the number of orbits. That is take for example Landsat series of satellites, the N was around 16 days and L was around 233 orbits. This is day 1, let us say satellite is starting from equator, after completing one orbit, it will come to a new location orbit 2. Again it will come to a new location, this will be keep on proceeding. After 16 days satellite would have made 233 orbits then when it is starting it is 234th orbit, it will start from the same ground point A. So, this is a general condition in order to achieve orbital repeatability $360\times(N/L)$, where N is the number of days, L is the number of rotations or the number of orbits the satellite should make.

Both of them must be integers, N is also an integer, L is also an integer, they cannot be fractions and they should be represented in the smallest forms. That is without a common factor, say 16 by 233 you cannot have a common factor between them. Some satellites may have 18 to 55, there should not be any common factors between them, the numbers should be represented in kind of a lowest possible form.

When that achieves, the numerator will tell what is the number of days once the satellite cycle will repeat, say 16, 18 or 24. And the denominator L represents the number of orbits the satellite should make after doing this. Now, we have seen for a satellite to be launched in sun synchronous orbit naturally, we always have a limitation in orbital height.

Normally whenever a satellite is launched in sun synchronous near polar orbits, we try to keep it between 500 to 1000 kilometers in order to achieve our other mission objectives, that is the normal range. And also the period of rotation will be around in the range of 90 to 110 minutes. So, the range is actually pretty short for us in order to achieve this. In a given day the satellite will not make an exact number of integer orbits, it will always have 14 points some orbits, 15 points some orbits like that, based on its orbital height, it will not be 14 orbits exactly in a day, 15 orbits exactly in a day. The reason is, if it makes integer number of orbits in a given day, then that means the orbital track repeats every day.

So, normally what will happen is for the typical orbital height in which a near polar sun synchronous orbit will be placed, L will be 14 or 15 or 16 it can be in this particular range. That is satellite can make 14 or 15 or 16 orbits. If N = 1 which means the satellite should complete exact integer number of orbits around a earth, when that happens the satellite will overpass the same location on the earth. This is day 1 orbit 1, day 1 orbit 2, day 1 orbit 3 etcetera. In day 2, orbit 1 will again start here in the same point; we can make the orbit to work as like every day we can make the orbit to go back to the same track again and again.

That will be achieved when a satellite is made to have an exact integer number of orbits in one sidereal day 83164 seconds, but normally we will not do that. Because let us say this is the entire globe, equator, Say this is orbit 1 day 1, orbit 1 day 2, like this it will be keep on moving. Say if N = 1, we want the orbit to repeat every day means again the same starting orbit 1 in day 1 will be achieved in day 2, but just see the distance between them. Normally for the time period of our near polar sun synchronous orbit satellite, which will be roughly around 90 to 110 minutes to complete one full orbit. Earth would have moved by a distance of around 2000 to 2500 kilometers that is let us say this is orbit 1 day 1 when it completes one orbit and comes to its orbit 2 day 1, the shift in the distance or the distance in between its starting point A to B along the equator will be in the range of 2000 to 3000 kilometers. This is a large gap actually, so what will happen?

A satellite will have a definite swath width of coverage. The gap in the equator is something around 2000 to 3000 kilometers. Let us say this is the orbit, the swath width the satellite can cover. So, from one overpass, a satellite can cover only a definite swath width, that is fixed by the sensor parameters the scan angle or the push broom geometry whatever. So, this is limited by the sensor characteristics. Now if you want everyday repeat cycle, then let us say the satellite is making 15 number of orbits every day, then after making 15 orbits in day 1 in day 2 the first orbit will be exactly over at the first orbit in day 1 that is possible. But because of the swath width constraint, the central portion will not actually be imaged.

Similarly between orbit 2 and orbit 3 there will be a gap which will not be imaged. There is always a limitation, normally satellites will not have very wide swath. We should make the sensor to scan, like a whisk broom sensor, it has to scan widely, the scan angle should be very wide.

So, that the swath width will be around 2500 to 3000 kilometers. If the scan angle is too wide or too away from the nadir, the GIFOV size will increase, the GSI size will increase everything which will lead to image distortions. So, normally we will not prefer that, we will try to keep the swath width nominal, even if you want to put a push broom type of very long array of sensors again it will be difficult to cover that much swath.

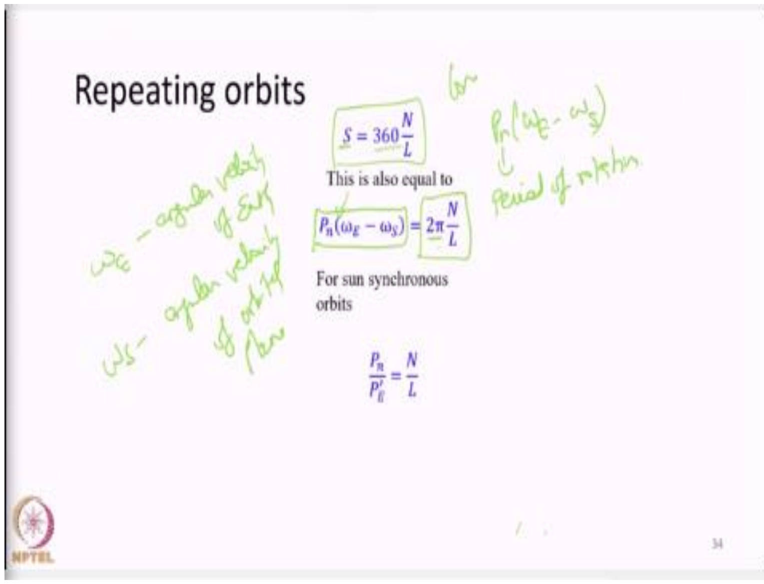
So, except very few satellites like MODIS or VIIRS most of the earth observing satellites in near polar sun synchronous orbit will have a smaller swath in the order of few hundreds of kilometers, not in thousands of kilometers. So, that will actually make orbital gaps, if you want an everyday overpass. That is why I said in the last lecture that, scientists will always make sure the starting point on every day will be at different, different ground points.

Say here orbit 1 day 1 is over point A, orbit 1 on day 2 will be at some other point B, which may be between somewhere here in between location**.** Those things are make sure orbits are designed in such a manner that is these kinds of gaps will not occur. Then by adjusting this N/L parameter, scientist will make sure the satellite again come to its original track again, once after say 16 days, 18 days, 24 days and so on.

So, normally a satellite in sun synchronous near polar orbit will not have repeatability of one day, such orbits are called resonant orbits where N = 1, everyday repetivity will not be provided. Because it will leave us with a very wide gap especially at the equator. From the given orbit we will not be able to cover all the regions on the earth surface, definitely there will be a gap which will stop us or which will prevent us from achieving global coverage.

But still we can put a satellite with 3000 kilometers swath, it is possible but normally we will not do it. Again in order to maintain the geometrical consistency of the image, except very few sensors like MODIS, AVHRR, VIIRS most of the satellites in near polar sun synchronous orbit has a swath width of only hundreds of kilometers.

(Refer Slide Time: 12:56)

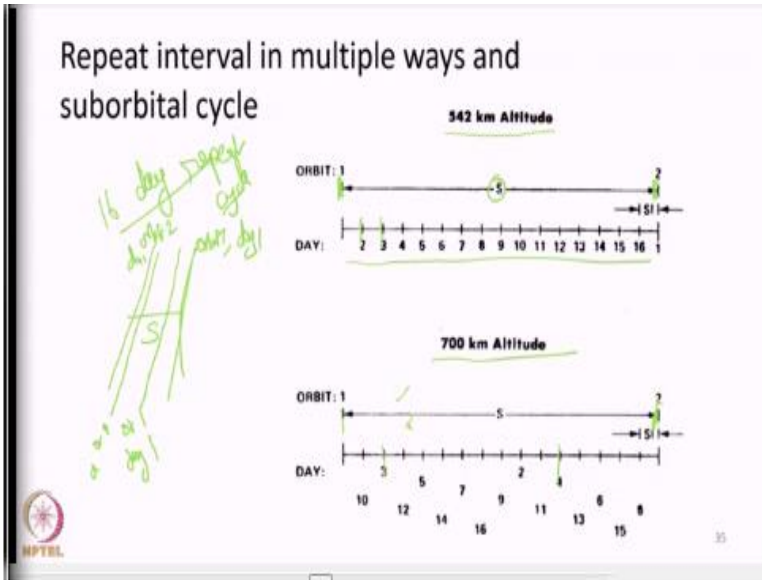


The longitudinal shift is given by 360(N/L), this is also equal to

$$P_n(\omega_E - \omega_s) = 2\,\pi\left(\frac{N}{L}\right)$$

where P_n is the period of rotation of the satellite, ω_E is the angular velocity of earth and ω_S is the angular velocity of the orbital plane. That is when satellite is completing one orbit, earth is moving and that is why the ground trace or the nadir trace of the satellite comes to a new point that we know. But satellite orbit is also precessing in the same direction as that of earth. So, there will be a slight shift out orbit to the east actually. Earth is moving similarly, the orbit track also will move, orbital plane itself will precess, that is the nature of sun synchronous orbit. So, the net effect what we are calculating here is again representing the longitudinal shift in another form. This condition should again be satisfied where instead of writing in 360 degrees, I have written it as 2π radians. Now, I told you the repeat cycle is actually designed or kind of like planned by the scientists and engineers taking care of the mission. It can actually be planned in several ways, a few examples given here. Say, the same satellite with 16 day repeat cycle, we are going to discuss as an example. So, this satellite will repeat its ground track again once every 16 days. Let us say the satellite is placed in an orbit of altitude 542 kilometers above the earth surface. For such a satellite, orbit 1 in day 1, will be like orbit 2 in day 1, this is the longitudinal shift.

(Refer Slide Time: 14:41)



Here for diagrammatic sake they have put it in this direction from left to right. Let us say now, it has completed one full day it is going to start day 2. Say the first orbit in day 2 can be just adjacent to the first orbit in day 1; it can be here somewhere, so this is orbit 1 day 1. The next day, third day the first orbit can be just next of orbit 1 day 3, it can be shifted like this. Every day, the orbital starting will be so planned such that it fills the gap between them. So, this is orbit 1 day 1, orbit 1 day 2, orbit 1 day 3, orbit 1 day 4 like this, everything will be kind of filling the gap in between.

So, after it completes 16 days it will start repeating. So, this is one way in which we can achieve this. At the same time let us say now the satellite is put in a 700 kilometer altitude again with the same 16 day repeat cycle, now how it will be? In second day satellite maybe somewhere in between, on third day satellite maybe here, on fourth day the satellite maybe here. That is the first orbit in the successive days can be planned in many different ways. It is not as we change the orbital height, we have a certain range, we can play with this 500,000 kilometer orbital height, 90 to 110 minutes of orbital period which are interrelated. When we play with it, the repeat cycle can be arranged everyday in between or you can have what is known as a sub cycle.

That is orbit 1 here, orbit 2 can move, the satellite orbits in different, different manners, all these things are planned by mission scientists in order to maximize the ground coverage. Normally, we want to get as much as coverage of earth as possible. And based on the spatial resolution characteristics of the sensor, the swath width of the sensor and everything and the repeated nature that is required for the mission objectives and all these things, the satellite planners will decide in which orbit we should put it. There is always a small leverage or small range of altitude heights in which we can play. So, essentially, the orbit in which the satellite is put 360 N/L can be played within a definite range, the values can be varied. By varying that values between in order to a certain number of degrees, we can try to achieve the repeat cycle we want.

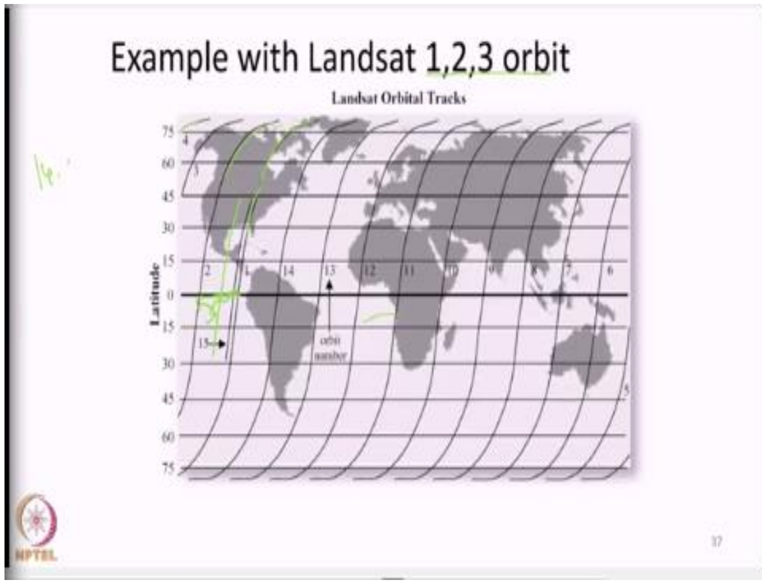
Say certain satellites will have a 16 day repeat cycle; a satellite called ICESat-2 has a repeat cycle close to 90 days. So, the orbit track will repeat only once every 90 days because of its very small swath width. If you want extremely narrow swath width what will happen? You should plan your orbit such that they all fall very close to each other. That is the L should be extremely large, 360 (N/L), the L should be kind of extremely large then only you will get a global coverage. If you make the swaths orbits wide enough you can reduce N or have N as kind of a small number. All fixed by this orbital height the range what we have. Within the repeat cycle itself, there can be several strategies of making the satellite cover the earth entirely. So, normally scientists will try to maximize the ground coverage based on the swath width. Let us say orbit 1 is here on day 1, on day 2 orbit is here, let us say the swath is wide enough to cover 2 orbits say in the order of thousands of kilometers.

So, from day 1 a ground point will be imaged, on day 2 also the same ground point can be imaged because of its very wide swath width, so that is possible. So, normally such tactics will be employed by scientist in order to maximize the ground coverage and a same repeat cycle can be achieved from different, different orbital heights by playing with this numbers. Now, this is an example for orbit track of Landsat 1, 2 and 3. Say day 1 the orbit is starting orbit 1 day 1, day 2 it is like this. So, this is S, the longitudinal shift. So, orbit 3 will be like this, orbit 4 will be here. So, when it comes to second day orbit number 15 will be just next to its orbit number 1.

So, on third day the orbit number 29 will be somewhere here just next to its orbit 15. So, this is how the orbit track was planned, for some other satellites it can be in a definite manner. So, all these things combined together will define the ground coverage of the satellite. Normally for

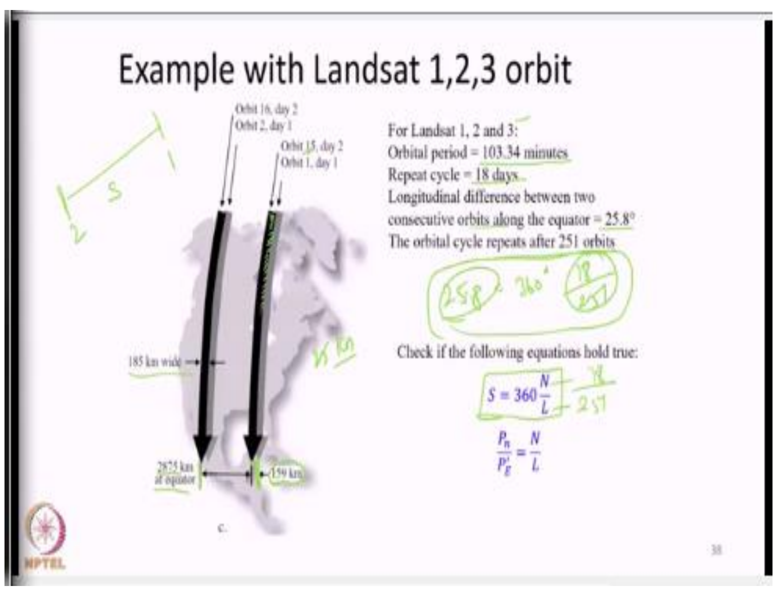
Landsat series of satellites the distance between orbit 1 and day 1, orbit 2 and day 2 will be less than the swath width.

(Refer Slide Time: 21:02)



So, that we will get some sort of side-lap between 2 orbits, say swath width will be around say 180 kilometers, orbital gap maybe in the order of say 130, 150 kilometers. So, that will achieve there a small side-lap between 2 orbits every day. So, that common in between portion will be imaged both and day 1 and on day 2, this is to enhance the ground coverage.

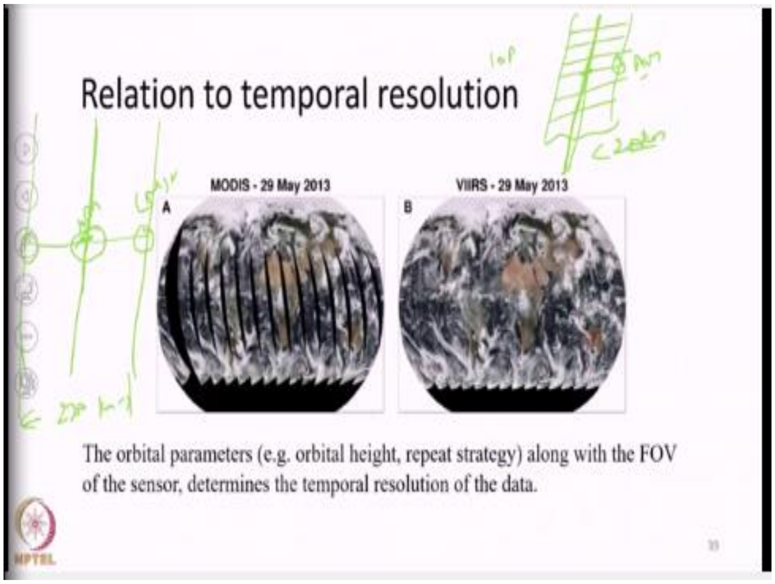
(Refer Slide Time: 22:34)



Say, this is again an example of Landsat 1, 2, 3. The orbital period is 103.34 minutes, repeat cycle is 18 days, longitudinal difference between 2 consecutive orbits along the equator 25.8 degrees, orbital cycle repeats after 251. Maybe with all the data we can check if this is achieved. So, N is 18 days, this is 251 orbits, so the S is 25.8, so we can actually check it. We can play with this in order to arrange this; everything is kind of interrelated.

But the same number, the orbital height, the S or the longitudinal difference between the 2 orbits orbit 1 and orbit 2 on the same day, we can achieve this by playing with this particular number based on our project needs. Say the distance is 2800 kilometers at the equator. So, orbit 1 on day 2 that is labeled here as orbit 15, it is shifted by 159 kilometers where the swath width will be around the range of 180 kilometers. So, this suggest there is some amount of around 25, 26 kilometer overlap in between the 2 orbits. So, that small portion in between will be covered on both the days. This is to further ensure every part on the globe is covered continuously.

(Refer Slide Time: 24:14)



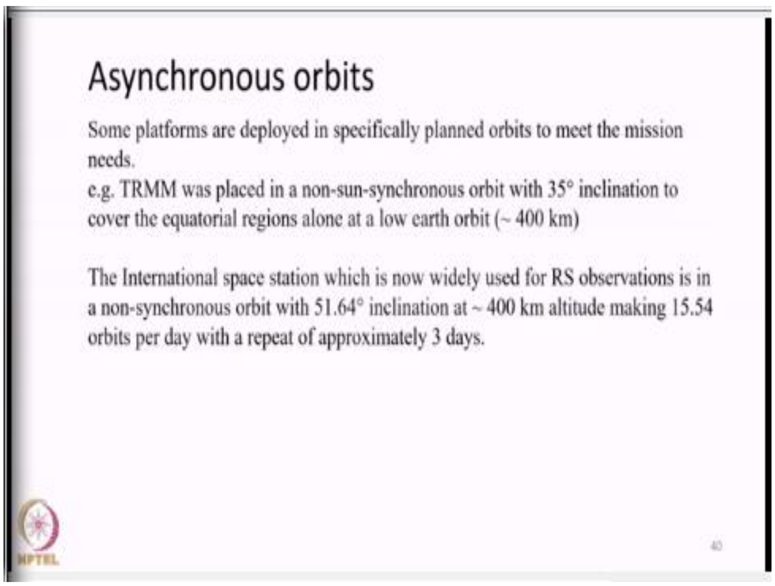
So, with all these long discussions, you would have realized that there is a relationship between the temporal resolution of the satellite and the orbital characteristics. Yes, the temporal resolution is the time period or the time gap between 2 images that we acquired for a same spot. So, the temporal resolution is governed by the orbital characteristics at what repeat cycle orbit will come? What is the ground track that has been planned?

With this swath width, both of them combined together will define temporal resolution. Say, Landsat satellite, Landsat 7 and Landsat 8 has a repeat cycle of 16 days, swath width of 585 kilometers. So, that means the satellite can see only a small region of earth near its nadir, it is not a full scanner it will just scan a small area. So, unless a satellite comes over at the orbit, it will not cover a very large area. So, we have the temporal resolution as16 days, only when it comes over it, we will get an image**,** the swath width is very narrow. Take an example of MODIS sensor or VIIRS sensor, for MODIS sensor the swath width is around 2300 kilometers. That means, from this particular location on orbit, it can cover a very wide swath. It means that from different, different orbits it can image the same point on the earth due to its very wide scan angle.

Similarly VIIRS has a swath width around 3000 kilometers. Again it can cover the same point on earth from different, different orbits. All these things will help us to achieve higher temporal resolution. So, the temporal resolution or the time between the coverage of the same ground point on the earth depends on the orbital characteristics and the swath width. They are related but they are not the same, temporal resolution and the repeat cycle after orbit. So, these are some of the fine details we have to remember in all these things.

Let us think in terms of the overpass time of such satellites. Normally in sun synchronous orbits, we can calculate the satellite overpass time at our particular latitude or longitude. If a satellite has only a very narrow swath, that means the overpass team whatever is there for the orbit we can assume it to be the overpass time for the entire swath width. Like the swath width the center line is the nadir trace of the satellite, this is the exact line the satellite over passing; this is the swath width. If it is very narrow in the order of 200 kilometers, we can achieve the same time, say here the time is like 10 AM, here also we can assume it to be like 10 AM. Let us take example of MODIS, this is the nadir trace of the satellite orbit, swath width will be something like this in the range of 2300 kilometers. So, here the overpass time only we will calculate, let us say this is 10 AM, but due to the very wide scan it will cover several degrees of longitude on either side. Such that the local mean solar time here and here will be totally different from here. Like in the last lecture I told you about this tiny equation, I just wanted to highlight it again here. Because whatever the time we calculated is only for the exact ground point over nadir, not at any other locations. This we should always keep in mind. So, for sensors such as MODIS with its very wide scan angle, we cannot think all the points in the image in a given latitude were at the same local mean solar time. They will be at different, different local mean solar time because of its very wide swath width. A point exactly on the nadir track will be having the overpass time what we calculated. Whereas, if a point is on the extreme of the scan line, it will be at a completely different overpass time, this we have to keep in mind. And finally, apart from all these orbit, we discussed in detail about 2 kinds of orbits geostationary orbit and near polar sun synchronous orbits. There are other types of orbits too MOLNIYA orbits which are put in asynchronous orbits. Asynchronous orbits means they will not maintain the same overpass time, they will overpass a same location at different, different time interval when the sun angle is at different, different angles. A very good example, there was a satellite called TRMM primarily for measuring rainfall in the tropics with inclination of 35 degrees and 400 kilometer orbital height.

(Refer Slide Time: 29:46)



It was an asynchronous satellite. Similarly, the international space station which is now a house of like several remote sensing sensors, GEDI, ECOSTRESS are all like that particular ISS that itself a satellite platform now; it is in an asynchronous orbit. Say today it may overpass over Mumbai at say in the morning, after few days it may overpass at like evening time and so on, such orbits are also possible. But normally for the day to day remote sensing images what we see? All the images, all the satellites will be most likely placed in sun synchronous orbits, but I am just telling you, it need not be, satellites can also be placed in asynchronous orbits. With this we end this particular topic.

Thank you very much.