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

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TYPES OF SATELLITE ORBIT AND ITS REMOTE SENSING APPLICATIONS, VNIR IMAGING THROUGH ELECTRO OPTIC

Good morning class and welcome to our lectures on climate dynamics, climate variability and climate monitoring. Today we will continue our discussion on remote sensing and remote sounding and we will start with a brief introduction to the various types of satellite orbits that are used for remote sensing and sounding applications. Now the satellite orbit types that are used can be classified into two major classes, the geostationary satellites and low earth orbit satellites or LEO satellites. Now geostationary satellites are placed in circular orbits about 36,000 kilometers above the equator. where the angular rotational speed is same as that of the earth about its north-south axis. So, its altitude is quite high 36,000 kilometers above earth surface and they are always placed above the equator and they are placed in the location where the angular rotational speed of the satellite is the same as that of the earth about the north-south axis.

hence the satellite is always directly above the same point on the earth surface in the equator. So, all geospatial satellites have a fixed locus on the earth surface. So, if you drop a perpendicular line from the satellite towards the center of the earth and this line will intersect the earth's surface in certain point and that point is often called the sub-satellite point and that point for all geostrategic satellites will be on the equator number one and they will be stationary constant at all time throughout its operation. Such satellites provide good coverage of the near equatorial region with a viewing angle of up to 55 degree.

So, let us understand this point a little bit. Earth is a sphere and these satellites are seeing the spherical earth from the point of view of a location far above the equator. So, it will have a good near normal resolution around its sub-satellite point over a 55 degree viewing angle surrounding its sub-satellite point. But beyond that its angular resolution will decay because what it is we will see the earth as projected as a circle, correct? And the edges of the circle will cover far will be at a significant its the emissions from the edges of that viewing circle. either towards the north pole, towards the south pole or towards the edges along its east and west viewing angle will be extremely oblique and will have much lower resolution.

So, they provide good coverage near the equatorial region up to an angle of about 55 degrees. But the resolution becomes poor at its edges. Now, the equator can be covered by multiple geostationary satellites. So, you can have good resolution by just changing by putting satellites at different sub-satellite equatorial points, but the polar resolution cannot be increased this way. So, they give good coverage from the equator to around 55 degree latitudes, but beyond that the resolution degrades and hence the data is not very useful.

there is no potential of nadir viewing. So, this is viewing at the line. So, nadir viewing is what is if you have a satellite and you have the ground, if the satellite is directly above the ground locus, the sub-satellite point, then it is viewing that sub-satellite point as a nadir view, ok. connecting the satellite to that ground will be at an angle, oblique angle with respect to the local ground normal. So, those are inclined beams.

Because these satellites are fixed above a certain equatorial point, apart from that point there is no option of nadir beam in any other location. This can be partly elevated through a use of mirrors that we will see, but this is also a significant disadvantage that you cannot have a good narrow viewing satellite at whichever position you choose. Also, the third problem is the high altitude. Because these are placed far above the earth surface, their resolution is significantly coarser than the However, such satellites are still widely used for low-latitude meteorological and climatological sensing. So, above the equator in the subtropical region, these satellites are used to track clouds, weather patterns and lot of other things.

The next class and this class is widely used for climatological and meteorological applications are low earth orbiting satellites or LEOs. As the name suggests, these are satellites orbits at significantly lower altitude than the geostationary satellite orbits. The LEO satellites orbit between 350 kilometer and 2000 kilometer. Compare this with geostationary which is 36,000 kilometer. So, these are 10 like 20 to 40 times slower.

So, if you have 350, this is 100 times slower and 2000 will be around 20 times slower. So, these are far closer to the earth surface compared to geostationary satellites. This region of low earth orbiting satellite is a location between the top of the atmosphere where frictional drag will be too large for satellites to be stable. and the Van Allen belt where high energy charged particles exist at high number density and which can damage the satellite detector and the satellite itself. So, between the top of the atmosphere and the Van Allen belt which captures the energetic solar particles by the magnetic field of the earth.

So, in between there is a region 350 to 2000 kilometers where this LEO's low earth orbiting Now within these orbits also there are certain orbits which are very popular. One type of Leo orbit are called the Sun synchronous orbits which are such that the satellite crosses the same latitude in the same sense that is northwards or southwards at the same local time regardless of the longitude or the date. So what does this mean? These orbits are such that suppose the satellite is crossing 30 degree north latitude once every 5 hours, it will always cross the 30 degree north latitude northward every 5 hours and it will always cross that 30 degree north latitude northward at say 9 am local time corresponding to that longitude. It may not be the same longitude every time, but whichever longitude point above which the satellite crosses the 30 degree north latitude, for that longitude point the local sun time will be 9 am. So, it is crossing the same longitude, the same latitude at the same time of the day.

One other point that you should be aware of that a satellite can orbit the earth multiple times during the day. So, it will cross a 30 degree north latitude once at 9 am northwards, cross it back southwards maybe at 11 am, then cross it back again northwards maybe at 2 pm and then cross back again southwards maybe at 4 pm. Always at local time, again do the same thing at night. So, what this means is the same time of day can be measured for a given latitude and multiple time of days will also be measured for given latitude over its domain. Another advantage of a sun synchronous orbit is that they have inclination close to 90 degrees.

So, a satellite orbiting in the north-south direction in the east west direction has an inclination of 0 degree. So it is always orbiting like this along the direction of earth rotation that will be 0 degree. If it is orbiting on the opposite direction retrograde then it will be 180 degree. If it is orbiting at an inclined position the angle can be between 0 this way or 180 this way it can be anything in between. If it is rotating such that it is crossing the north pole and south pole like this, then the inclination is 90 degrees.

So, sun synchronous satellites orbit at 90 degrees with respect to the latitude circles or the equatorial circles. So, what this means is as the earth rotates and this satellite rotates, so the earth is rotating east west and the satellite is rotating around 90 degrees north south. So, different locations are the, each orbit is covering different parts of the earth's surface, right? Because earth is rotating 90 degrees with respect to the satellite. Hence, these have whole earth covering. If you look at the satellite, sub-satellite points, these sub-satellite points will cover the entire surface of the earth after a set of multiple rotations.

Because the earth is rotating perpendicular to the way the satellite itself is rotating. So the sub-satellite point will move along the earth surface and will eventually be covering the entire earth surface. So these types of satellites can do nadir viewing. of every point on the earth's surface. Unlike a geostationary satellite which can only cover, do an averaging of one point, its sub-satellite point is stuck at a certain point on the equator.

So, these near polar orbits have the greatest coverage of the earth's surface as over time they have the capability to accurately resolve and image all of the earth's surface. Hence, sun-synchronous LEOs are widely used in climatological and meteorological applications. Another popular set of low earth orbits are exactly repeating orbits. So, these orbits have the property that they repeat the same locus on the earth surface called the sub-satellite point after regular intervals. So, the trajectory of the satellites a single rotation around the earth surface repeat after regular interval.

So, repeated observations of certain locations of the earth are possible to exactly repeating video orbit. So, these are of course, these orbits are different types of orbits there are ways to put satellites in these different orbits. We will not go into those. But what we are saying here is we have two or three different ways a satellite can be put and they are useful for different things. A geostationary satellite is good for equatorial coverage and have a wide range but they have poor resolution in the north and the southern in the high latitudes and they have higher have lower spatial resolution.

Low earth orbits especially some synchronous orbit can measure properties at same time at different latitude circles and they cover the entire globe because their trajectories are polar that is near 90 degrees with respect to the latitude of the equatorial circle. Exactly repeating orbit their orbital locus, sub-satellite locus after a state of fixed orbit. So, repeated observations at the same conditions are possible by this satellite. Now that we have looked up briefly on what type of satellites these detectors can go in, let us now look at the various types of detection system that can be used. The first type that we will discuss is VNIR imaging to electro optical system.

Remember VNIR means very near visible and near infrared, visible and near infrared ok. their range is between 0.3 micrometers and 3 micrometers, alright. Now, these are primarily and the detection system is electro optical system and we will discuss what they are as we go along. So, these are primarily imaging systems in that they create a 2D distribution of the radiation intensity across the target field.

So, they create an image of the radiation intensity across the target field. So, in that sense, it is kind of like a photograph or an image, okay. It creates a radiation intensity map. The sensors are used to convert the radiation intense energy into an electronic signal which is amplified and then processed digitally, ok. So, this is what, so this radiation energy that the sensor detects is converted into an electrical signal which is amplified and then processed in a digital manner.

That is why it is called an electro-optical system. An optical energy electromagnetic wave detected and converted into an electrical signal with this process digitally to create a digital map or a digital image. The two most common types of DNI are detectors.

Number one are photodiodes. So, there are specific type of semiconductor diodes that are sensitive to light electromagnetic radiation.

These are used to detect radiation in the near infrared region. It uses a doped semiconductor p-n junction. So, we will not be discussing semiconductor and what they are. Basically semiconductors are certain materials that conduct partially conduct electricity due to presence of donor or acceptor band caused by doping molecules and if you have a p-doped semiconductor you will have a lot of positive charges or holes and if you have n-doped semiconductors you have a lot of free electrons. And a p-doped semiconductor and n-doped semiconductor coming together creates a p-n junction which is the basic system that is working in every diode kind of a system. And these are light sensitive diodes that is these absorb photon of different frequencies and create an electrical signal out of it. So, the p-n junction used for photodiodes are like indium antimonide or lead sulfide. So, it is a p-doped indium antimonide versus n-doped indium antimonide or a p-doped lead sulfide on one side and n-doped lead sulfide on the other side. When electromagnetic radiation of the correct frequency range is incident on the p-n junction of these materials either this or this one, a current is developed across the junction which is proportional to the radiation flux at that frequency band. So, the light energy is converted into a current signal by this p-n junction and this current is basically what is being detected usually an array of photodiodes are used to create a 2D image field from the radiation signal. So, basically a p-n junction sensitive to certain spectra of radiation usually indium antimonyl or lead sulfide is the material which is being used. The current generated is used to convert the light signal into electrical signal at the requested bands. The other type of detector that is used often are called charged cartel devices. So, these are the center of most digital photography ok.

They are common in digital cameras and can also be used in DNIR images. Now, photodiodes are primarily used for near infrared region. So, not the visible spectrum after the point. So, 1 micrometer to 3 micrometer the near infrared region you use photodiodes. In the visible region you are you usually use charged coupled devices CCD.

You can also use CCD in the near infrared region too depending on the material that you are making the charged coupled devices from. So, what are these CCD? It consists of many basically thousands of identical light sensitive elements in a linear or a planar series array. So, either it is a linear series of light sensitive elements or a planar series like going like this ok of light sensitive elements. Each element is quite small about 10 micrometer wide ok. So, even a 1000 cross 1000 element, a series element with 1000 rows and 1000 columns will be less than a centimeter in dimension.

So, these are quite compact devices. What is this light sensitive element? Again, it is a type of semiconductor only. It is a P-doped metal oxide semiconductor capacitor, ok. So, here the novelty is it is a capacitor that is being used, a light sensitive P-doped metal oxide semiconductor capacitor. It is a MOS, metal oxide semiconductor. The semiconductor absorbs photons in the visible or near infrared range depending on the type of material and generates charges at the metal oxide and semiconductor interface which are accumulated by the capacitor.

So, again electric charge is being produced and these are being accumulated by the capacitor. These accumulated charges are eventually converted into a voltage signal. So, the charge is converted into a voltage signal and the intensity is the summation of all of these charges that are being detected over this entire series array up to wavelength of 1.1 micrometer. So, here the idea is CCDs are better in the visible range. So, they are going from 0.3 micrometers to just the edge of the near infrared range of 1.1 micrometer. So, CCDs are used more in the visible range, photodiodes are used more in the near infrared range.

So, that is the main difference. Now, let us briefly look at the methodology by which this imaging is done. So, the main problem of imaging to a satellite system is that the satellite itself and the earth are rotating with respect to each other. If you do not worry about the geostationary satellite, low earth orbit satellite both land is moving and the satellite is moving. So, just like in a traditional camera there is a possibility of image blurring. Why does image blurring occur? You need a certain amount of light emission from the location you are looking at, the detector is looking at for it to properly detect the emission properties.

So, for that the detector must be looking at that location for a certain period of time to get enough photon signals from that region. However, the surface itself is moving during this time. So, what the detector is seeing may be a combination of multiple locations that have moved into the field of view during the time of detection creating a combined signal from multiple locations that is being interpreted as coming from a single location which creates the blurring effect okay and this is basically what is happening when you are looking at the fan also when you look at us at a moving fan the blades are blurring because our eyes cannot are not sensitive enough to detect the individual blade location fast enough to separate out the movement of the blade that is moves along as it moves across the fan axis. So, this is the blurring effect that we are getting. How do we avoid this? Basically what is done is that the detector tracks primarily a certain region till it gets enough information and then does a step switch to the next adjacent location and then share fixedly at that location for a certain amount of time.

So, let us look at how this system kind of works for multiple types of detector systems. We will start today and look into it in the next class as well. So we have a 2D detector, okay. So suppose it is a CCD or a series of photodiodes that is arranged within your detector and each of the detector of the array element is mapped into to a certain location within on the earth surface. So, this square is being mapped to a single say CCD light sensitive array.

This square is mapped into a second adjacent light sensitive array and so on and so forth. Suppose you have a 200 cross 200 CCD array, this will be a 200 cross 200 CCD array. where each square is, photons of each square is being detected by an individual light sensitive array. And these squares which are mapping onto a single light sensitive element which may be a CCD moss or a photodiode is called a razor. A razor is what is being detected The area of the surface is detected by a single light sensitive detector within that detector array that is in the satellite.

So, now detector is staring at the same area defined by this set of results for a long enough period. So, you need to have a control system here. That control system is moving the detector ever so slightly. for us so that it tears into this area over a certain finite time interval adjusting for the relative motion between the satellite and the detector, okay. Then once enough photon information has been obtained from this surface, then this control track the adjacent area which is non-overlapping with this initial result area and this process goes on.

So, from this point to this point it is always looking into this area. Then at this point the control shifts and it suddenly starts to look at a different area just adjacent to it and non-overlapping to it. And this is the satellite platform motion with respect to the ground and this is the nadir point as it is moving. So, this is called step stair imaging technique and this helps to eliminate motion blurring and have high resolution images by the LEO satellite. we will continue this discussion in the next class and thank you for listening and see you in the next one.