Global Navigation Satellite Systems and Applications
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Lecture – 14
GNSS Errors

Hello everyone and welcome to 14th lecture of Global Navigation Satellite Systems and Applications. And in this lecture, we are going to discuss the GNSS Errors. In previous lectures, indirectly or directly sometimes we have touched upon about the errors which are involved but very briefly. But in this particular discussion, we are going to have detailed discussion on how errors are incorporated; how error comes in to our positioning estimations and how we can avoid those errors as well. So, GNSS error sources basically make it difficult for a GNSS receiver to calculate an exact position and no matter how you improve the system, there will be always errors.

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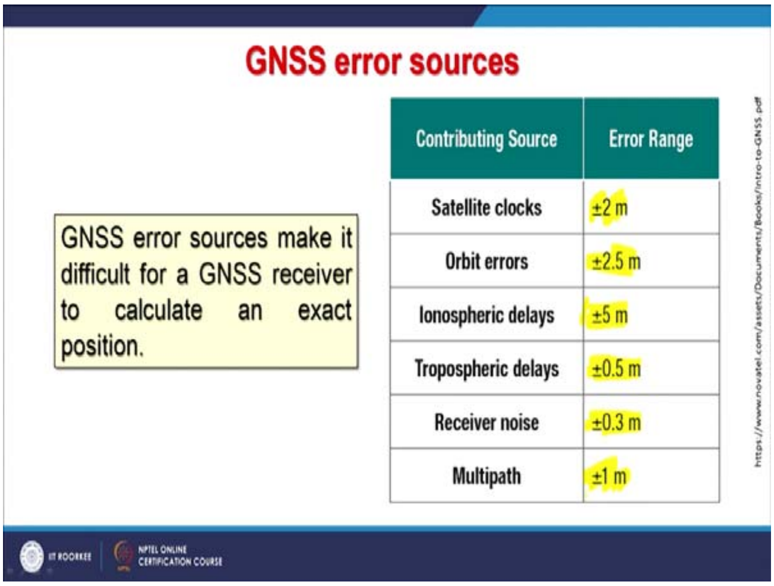

And the problem here is that we do not have anything a sort of standard to compare that how accurate am I. So, only using GDOP concept or any other thing, we say that we are accurate to this range but whatever the standard or reference which we are using that might also be having some errors. So, if you know, say absolute accuracy probably we cannot achieve to that extend as we want but nonetheless we are achieving accuracies nowadays up to millimetre by implying either differential GPS or up to centimetre by SBAS technique.

So, let us look the sources of errors; which are possible sources of errors. Let me first mention here at the outset that it is not necessary that all the errors will come at the same time, not at all. There might be some errors, 2 or 3 errors out of this list may play some role at a particular time but other time, some other errors might be there. If these would have been a permanent or you know regular errors then these can be corrected.

So, the systematic errors can be corrected easily but non-systematic errors, it becomes very difficult to correct or varying errors time to time, location to location, with different geographic areas and different atmospheric condition and then it becomes very difficult to remove those errors nonetheless. You know if there is something wrong with the satellite clock and the receiver clock in our receiver, then the maximum range of errors which can bring in our position estimation is about 2 metre.

And, then this orbital errors because satellites are after all they are moving objects in space. Sometimes they drift from their designed orbit and even a minute drift can bring errors of about plus minus 2.5 metre. Ionospheric delays, tropospheric delays, these will also introduce. Ionospheric delays bring more error which is about plus minus 5 metre but this layer is not uniform throughout the atmosphere or through all along in that envelope of the earth. So, this varies time to time and place to place but the maximum we can have a plus minus 5 metre.

Tropospheric delays are relatively very less compared to ionospheric delays but they play some role in our position estimation. And then receiver noise because after all these are electronic devices and there is a signal to noise ratio and all those electrical or electronic component, they might create some noise and that noise can bring some errors of up to maximum 0.3 metre. These are just estimates but if your receiver is not of very high quality, then these errors can go to a large number. Like in case of mobiles you know, if a mobile is made of from a poor quality electronics then the heating and noise plays larger role but if it is a good quality components though might be expensive but you do not get the heating near the ears and also then less noise is there. So, similarly case with GPS or GNSS receiver.

Multipath errors can also erupt in our position estimation and maximum that can reach to plus minus 1 metre. These are some of the errors, there might be some other errors which may play some important role but not to this significant as these errors are. The maximum as I have mentioned is the created by the ionospheric delays so which plays a very major role in these errors ah.

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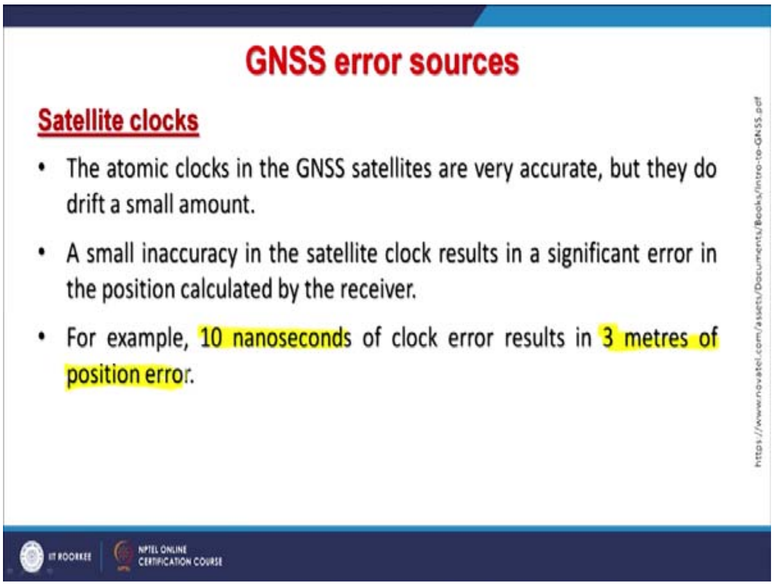

Let us look one by one all these errors in detail like you know that all the satellites of GNSS system, they are having atomic clocks and which are supposed to be very-2 accurate but sometime they also drift a small amount; for example if a small inaccuracy in a satellite clock results in a significant error in the position calculated by receiver because time signal or the signals which are received from these GNSS satellites are time stamped signals and if the stamp itself is stamping in wrong time then definitely receiver will give the wrong position estimation.

For example at a 10 nanoseconds delay or error is there in the atomic clocks which are on board of these GNSS satellites which may results in the 3 metres of position error; 3 metres of position error is a huge error in that sense. But generally the time clocks or atomic clocks on these satellites are kept very much updated and very well maintained; their integrity is maintained, nonetheless. If at all for some time if that clock error is there, it may result of 3 metre accuracy problem.

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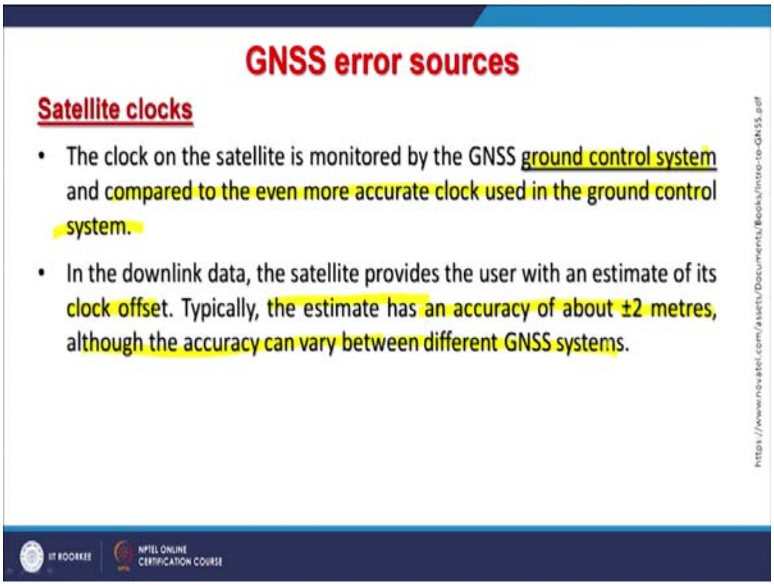

So, the clock on the satellite is monitored by Ground Control Stations of different operators like for GPS in US, they are having Ground Control Stations, for other GNSS systems; every system is having their own Ground Control Station. So, they monitor and if there is a drift, they perform some corrections and then data is transmitted to the users as well. And when they compare the data on the satellite clock and in the Ground Control Systems, they two are having more accurate clock and these highly accurate clocks are there, their timings is matched with the clocks on the satellites. If there is a something drifts change in the satellites clock, those corrections are performed.

Now in the downlink data, the satellite provides the user with an estimate of its clock offset; how much offset is there 10 nanoseconds, plus or minus or whatever or 1 nanosecond. And such estimate has an accuracy of about plus minus 2 metres, although the accuracy can vary between different GNSS system. So, it depends how well these different GNSS system like GPS, GLONASS, BeiDou or GALILEO or our IRNSS are being maintained. If they are very nicely maintained, the clock is getting verified updated very quickly and very frequently then these accuracy problem will not come to that large extent.

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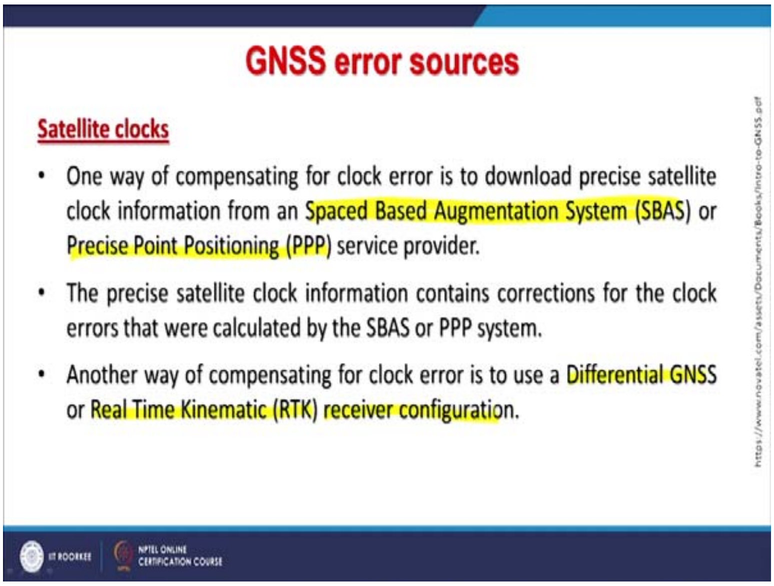

To obtain a more accurate position, the GNSS receiver needs to compensate for the clock error. If it is already known then this can be compensated. Now under again this in satellite clocks, we further look into that the one way of compensating for clock error is to download precise satellite clock information from a Space Based Augmentation System or SBAS.

So, because if a country which is having SBAS or geostationary satellite, then that clock can also be compared or precise point or PPP service provider. So, by which we can compare, we can get the error information and then that information can be used to compensate the position and better accurate position can be achieved, in case if something goes wrong with the clocks onboard of these GNSS satellites.

And, this precise satellite clock information contains corrections for the clock errors that we are calculated for SBAS or PPP system. And another way of compensating for clock error is to use differential GNSS or RTK in the receiver configuration which we have already discussed; these two different approaches or techniques to improve our position estimation. So, there also we compensate for error.

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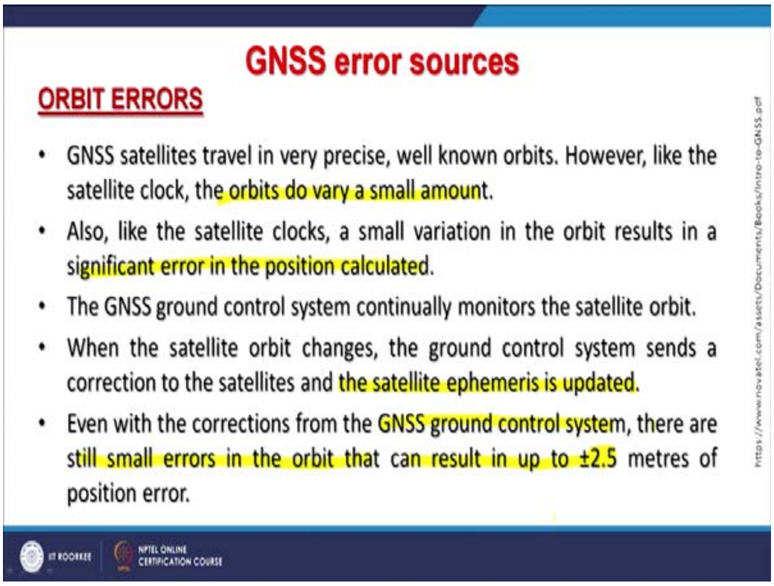

Now, next source of error is the orbit errors. If there is a drift of the satellite itself from its design orbit, then what kind of errors it will bring. So, GNSS satellites as we know travel in a very precise well known orbits, this is what it is expected. However, like the satellite clock, sometimes these satellites also drift from their orbit to a very small amount; orbits do vary for a small amount.

And also like satellite clock, a small variation in orbit results in a significant error in the position calculation. So, that is a very significant here. And this GNSS Ground Control System are continuously monitored by these Ground Stations so that if there is any drift in the orbit of particular satellite, it can be brought back by some space techniques which Ground Control Station can send those corrections to the satellite and then satellite ephemeris are updated. Because these ephemeris are down linked by or they are also received by the user which carries the satellite positions in the space.

And even with the corrections from GNSS Ground Control Systems, there are still small errors in orbit that can result up to 2.5 metre of position errors. So, no matter how accurate these satellites are orbiting in a designed orbit but still some errors can erupt in our position estimation.

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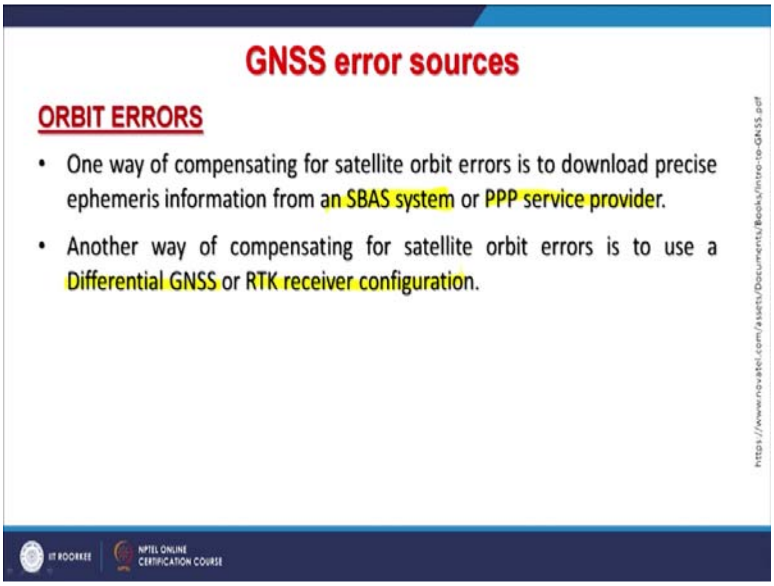

Further one way of a compensating for satellite orbit errors is to download precise ephemeris information from an SBAS system. So, if one is having SBAS system, lot of problems are solved. The problem of clock delay or clocks errors can also be solved by SBAS system or PPP service providers. And the same way the orbit errors problem can also or these errors can be compensated using SBAS system.

And there is another way of compensating for satellite orbit errors is to use differential GNSS or RTK receiver configuration same as in case of clock errors.

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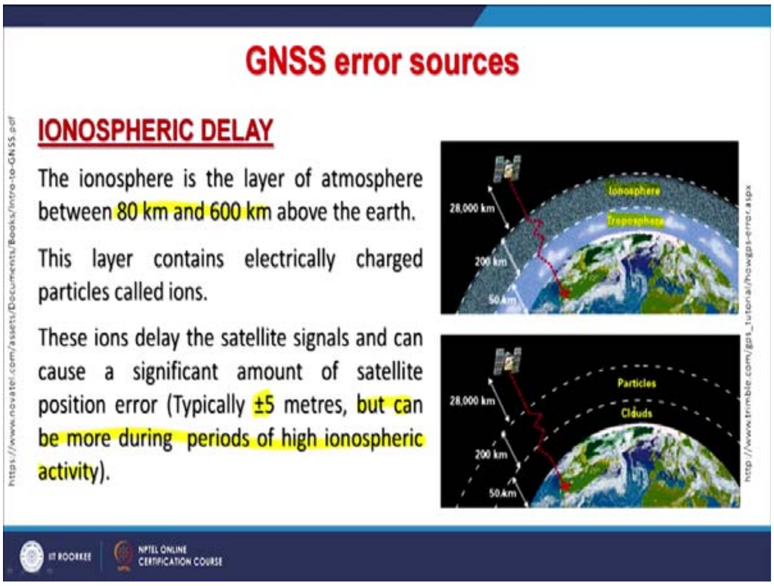

Now, ionospheric delays; so as you know that when we go up in the space from earth towards the space, the first layer one has to encounter is the troposphere and then ionosphere. As in the beginning summary, we have seen that the delays in ionosphere are much larger compared to troposphere but combinedly they can provide and can add the errors into our position estimation. So, there delays have also to be compensated or taken care.

So, then ionospheric layer of atmosphere is between 80 to 600 kilometres above the earth, which is this layer (shown in figure) and then this layer basically contains electrical charge particles called ions. And these ions delay the satellite signals and can cause a significant amount of position errors. We have already mentioned that even plus minus 0.5 metre error it can bring errors in our position estimation.

But, sometimes it can be more during periods of high ionospheric activities because as said that this is not a uniform layer. All the time some ionospheric activity because sun is there and all kinds of reactions and actions are happening within the atmosphere, then these can bring the changes. And therefore, this is not systematic error as mentioned earlier. If it would have been systematic then it becomes much easier. And if there are like here but in the ionosphere, you are having ions or particles, in the troposphere you are having clouds and they create errors in our data.

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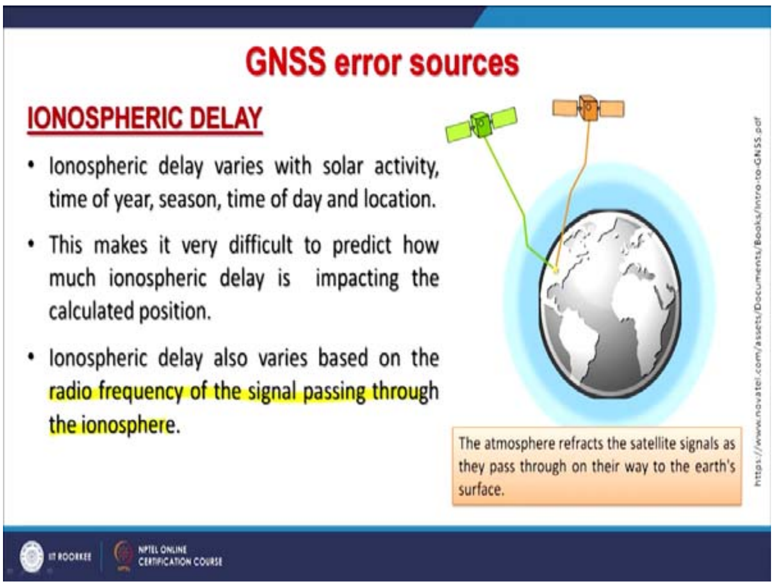

Ionospheric delays varies with solar activity as mentioned and time season of the year and what is the time of the day also, that is also important and location; where it is located, whether on the land or whether on the sea, whether on the northern hemisphere or southern hemisphere because the season varies in these part of the globe.

So, therefore they have to pass through these layers and signals can get delayed and that can add errors to our position estimation. So, this make it a very difficult to predict how much ionospheric delay is impacting the calculate position because we do not know, it changes so frequently and place to place that it is not a systematic error that can be removed quite easily but none the less, their models have been employed to get a minimum effects of ionospheric delay.

And, this is mentioning just a few seconds back that these varies based on radio frequencies of the signal passing through the ionosphere. So, the frequency which is being used for this positions estimation, different frequency also behaves differently with these ionospheric or topospheric layers. So, that is another important component here.

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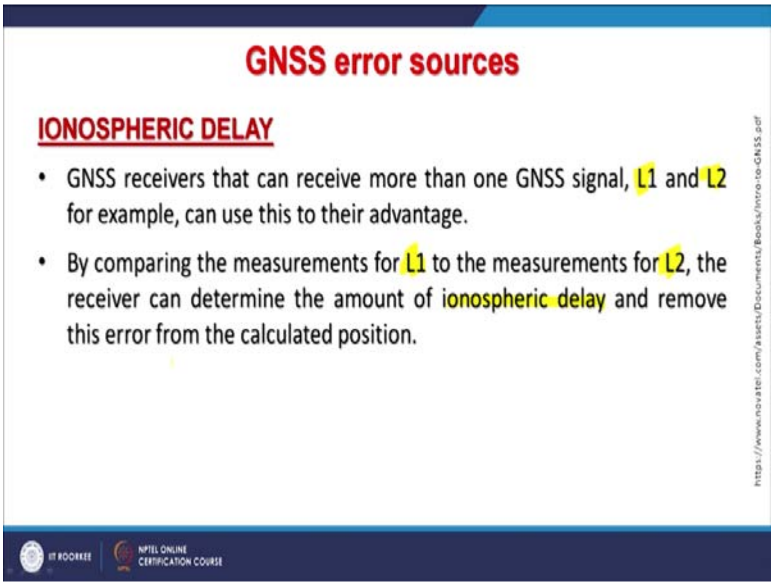

Now GNSS receivers that can receive more than one GNSS signal like L1 and L2 frequency for example can use this to their advantage. So, when you are using dual frequency receivers then these can be compensated. The measurements of L1 to L2 can become compared and then receiver can determine the amount of ionospheric delay and remove this error from the calculated position.

And, a very interesting thing is here that some people are also using these frequency data to map the ionospheric layer because when you know the delays then you can estimate that what is in the ionospher or these ions are there. Also some people are using these differential GNSS permanent or Base Stations and continuously monitoring these ionospheric delays and changes in the ionospheric layer and they have linked with earthquakes. And they have published that before some large earthquake events; they have seen lot of changes in ionospheric layer as well.

So, there are various applications say blessing in disguise. Ionospheric delays for position estimations are bad. But for mapping ionospheric layer or using them these delay signals for as a earthquake precursor can be very-2 useful.

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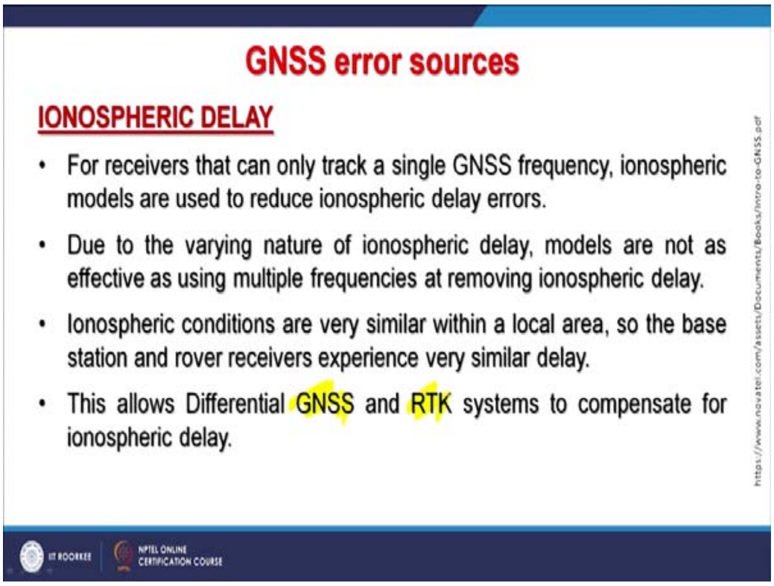

For receivers that can only track a single GNSS frequency, single frequency based receivers ionospheric models are used to reduce ionospheric delay errors. So, dual frequency definitely can compensate but single frequency receivers may use these models to get rid of or minimize these errors due to ionospheric delay.

And as they have been mentioning that due to varying nature of ionospheric delay, models are not as effective as using multiple frequencies at removing ionospheric delay because it is though models are there but it is hard to predict and therefore, may be in future we will have much more reliable model which will compensate for these errors using a single frequency GNSS receivers.

So, ionospheric conditions are very similar within a local area. So, the base station and rover receivers experience very similar delays. This is one assumption if baseline is not very big and therefore, we can utilise these signals in case of differential GPS that is differential GNSS or RTK systems to compensate for ionospheric delays.

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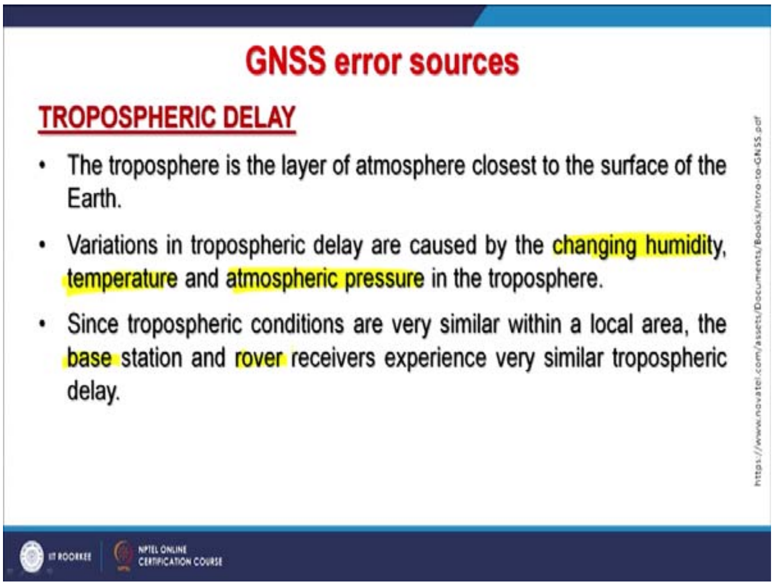

Now, let us discuss about another delays which though it is not that big as ionospheric delays; in ionospheric delays, we have talked about plus minus 5 metre errors where as in tophospheric delay, we have discussed about 0.5 metre errors so one tenth of that one but none the less.

So, it is also a layer but the first layer which is encountered if the signals are going from earth to satellite but in real sense they come back to the satellite. But in case of SBAS, these layers have to be penetrated both ways anyway. So, troposphere is the layer of atmosphere which is closer to the surface of the earth and there are also like, in ionospheric layer there are variations so, in trophosphere layer. And you know these tropospheric delays are influences by humidity, temperature and atmospheric pressure in the troposphere.

So, all these changing temperature or varying temperature within a day during a cycle or within a day or 24 hour cycle, the temperature varies, humidity varies, atmospheric pressure changes and therefore, there are large variations in troposphere as well. Since these tropospheric conditions are very similar within a local area and therefore if somebody is using the differential, then these can be removed quite easily; these delays can be compensated.

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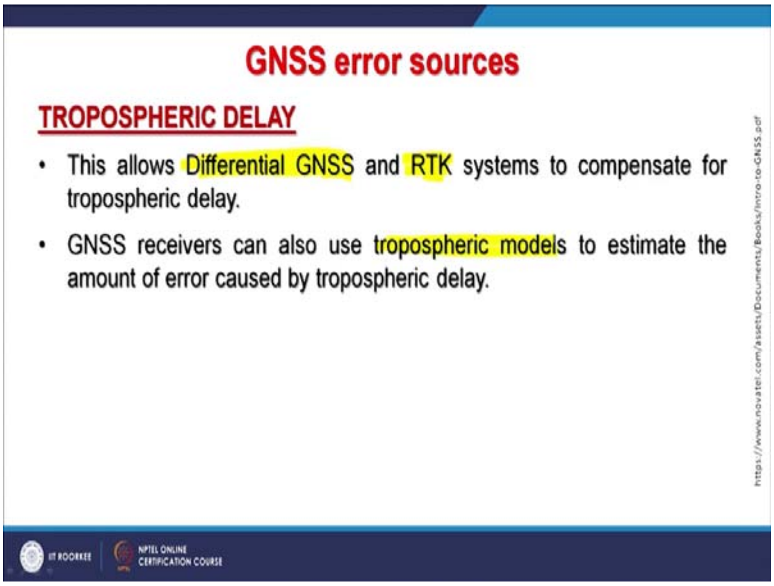

Then these ionospheric delays can also be compensated same way trophospheric delays if differential or RTK systems are employed, then these delays can be compensated. Now GNSS receivers can also used trophospheric models like in case of ionospheric models to estimate the amount of error caused by the trophospheric delay. But same, these models are fixed so, but the phenomena are varying. So, whatever you use, you may get better accuracy if you imply the models but not as is one would expect.

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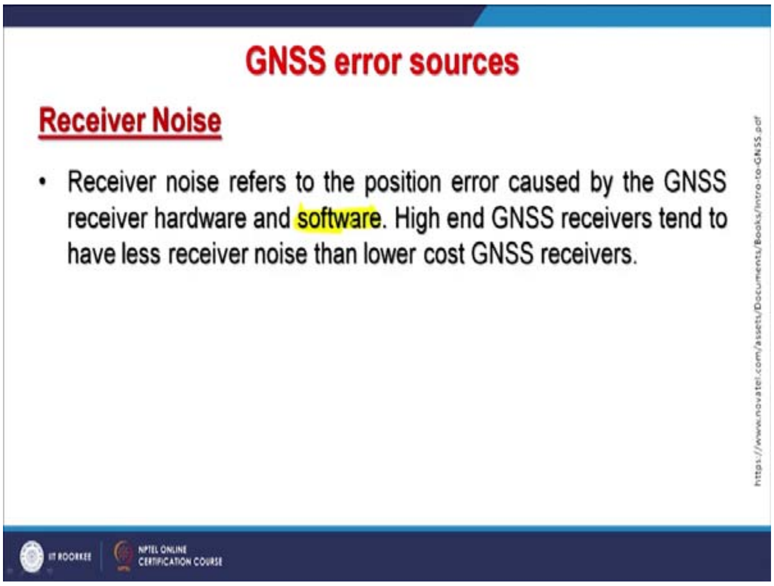

Now, another source of error is the receiver noise. So, within the receiver because of electronic components, there might be some noise and which may bring some errors in our position estimation.

So, noise refers to the position errors caused by the GNSS receiver hardware and software. And this high end GNSS receivers tend to have less receiver noise than lower cost GNSS receivers; say almost the same analogy as I have given in case of a smart mobiles if very cheap smart mobile one buy then there are chances of errors and noise and as well as heating. The same way here if high quality hardware is there then less noise is expected.

And of course, if the software is creating some problem, this is systematic and if it can be detected that can be removed that means basically it's a bug in the software and then position estimations can be improved.

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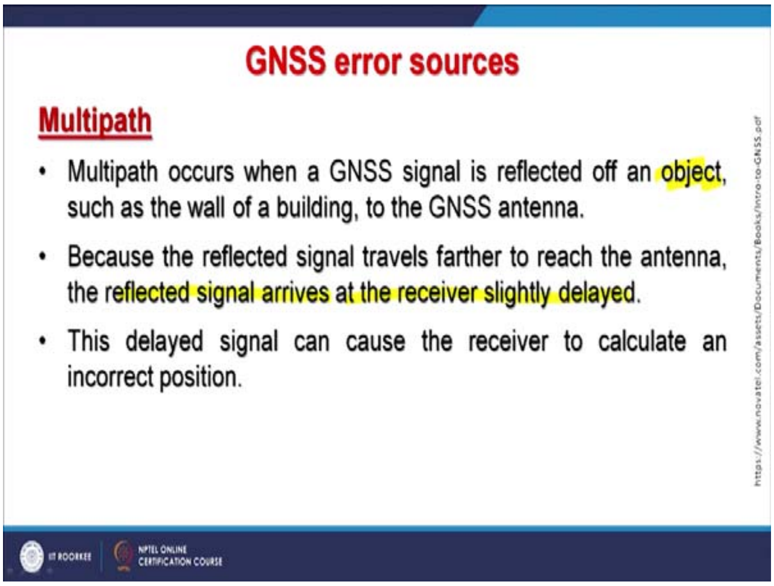

Now, another source of error is the multipath. Multipath occurs when a GNSS signal is reflected of an object. So, somebody if doing some field survey or going or travelling in a hilly terrain, in a valley or in a density area where tall buildings are there, then this multipath error will be there because of different objects which are present for example the wall of a building or other thing.

And, because of these signals are reflected and there is an extended path which is there that means wrong position estimation. So, these reflected signals arrives at the receiver slightly delayed instead of directly signal which are being received by the receiver. So, this extra added path will definitely bring some errors and these delays signals can cause the receiver to calculate an incorrect position.

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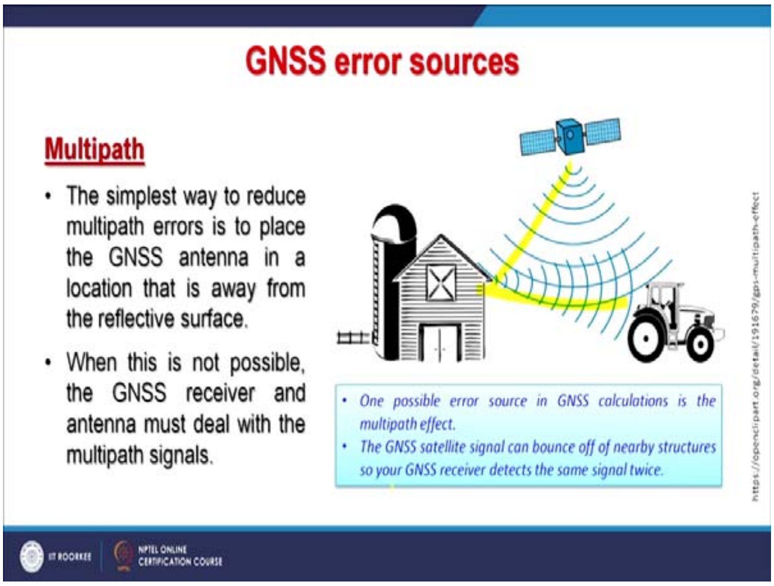

Like example is given here that there is a house and close to the house if receiver is there so, one side is not there but the signals can get reflected like this and then can create a multipath errors. Simplest way to reduce such errors that is multipath error is to place GNSS if possible, this antenna in a location that is away from reflected surface but sometime it is not possible. In a real field scenarios when you have to work in a valley and both sides you are having a mountains, then I need the position there itself not at the top of the mountain. So, we have to live with that kind of scenario or in a city which is surrounded or having tall buildings can create these multipath errors.

So, when it is not possible to shift the location of GNSS receiver and antenna, they must be to deal with the multi path error. One possible error source in GNSS calculation is multipath effect and GNSS signal can bounce off by nearby structures and the GNSS receiver detects the same signal twice. Sometimes this is also an issue that directly it is receiving the signal and reflected signals are also receiving. Now, receiver is confused and that may give you wrong position estimation.

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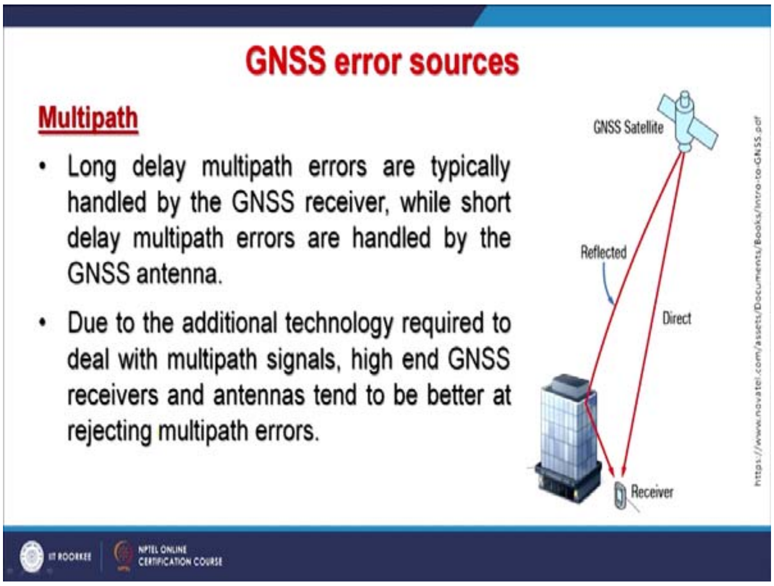

If there are long delays in multipath errors handled by GNSS receiver while short delays multipath errors are handled by GNSS antenna. So, that kind of a situation might be there and due to additional technology required to deal with multipath signals, high end GNSS receivers and antennas tend to be better at rejecting multipath errors.

So, if these reflected signals are there, the signal quality might be relatively poor, the time is added and the receiver self can reject those signals and will not introduce errors in the position estimation while if at all it is getting direct signals as well. So, it compares with direct signals because the satellite ID is the same; if same satellite signals are being received twice, one is direct, one is reflected then a smart receiver can negate the delayed one and the position estimation can be achieved.

So after having this discussion on errors, we come to end of this discussion. Basically there are some other errors; one should also take care because sometimes you are comparing your position estimation which is being received by your GNSS receiver with some map. And, if they are not in same spheroid or same projection system then further errors will be there.

So, one has to be careful that what model or what these spheroid or projection systems are being used by your receiver to display the position estimation. Whether the same your toposheets or map is also having the same spheroid and same projection system or not. If they are two different projection or spheroid system, definitely your position estimations are going to be again different or will have errors.

So, lot of care is required while doing these utilising the position estimation data or doing accurate field service. But in normal day to day; car navigation other things when we do not require very high accuracy then one need not to bother about but for highly accurate service or for construction or automated vehicles or in precise or precision agriculture practices there, all these care should be taken so that we get very highly accurate position estimation. As usual, again I am living with a new cartoon. Just to enjoy.

Thank you very much.