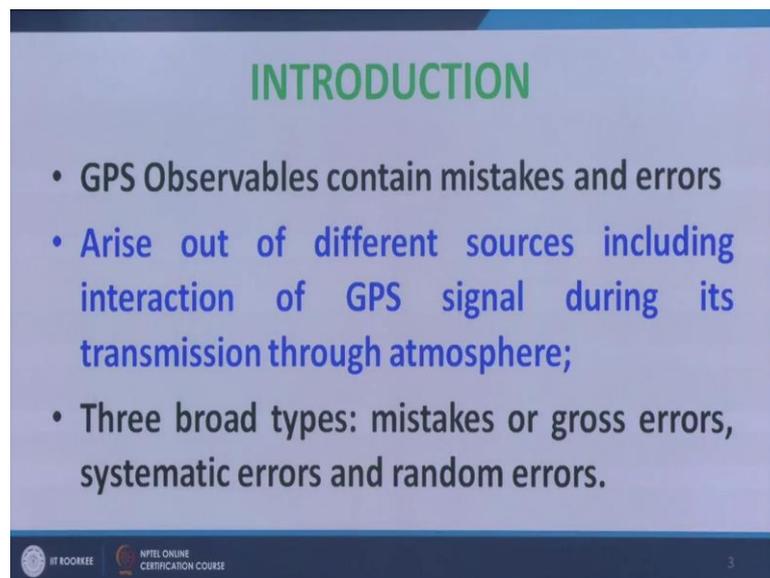


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**Lecture – 11**  
**Errors in GPS Observables**

Welcome students. Lesson number 11; today I will be talking on errors in GPS observables. In the last class we have seen that GPS observables consist of code pseudo range and carrier phase observables. And these observables or fault with errors. In today's class we will discuss on what are the different sources of errors and how those errors have to be taken into consideration. Now the lesson will be discussed under following heads that what are the errors different types of errors than this summary and review question and further reading.

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**INTRODUCTION**

- GPS Observables contain mistakes and errors
- Arise out of different sources including interaction of GPS signal during its transmission through atmosphere;
- Three broad types: mistakes or gross errors, systematic errors and random errors.

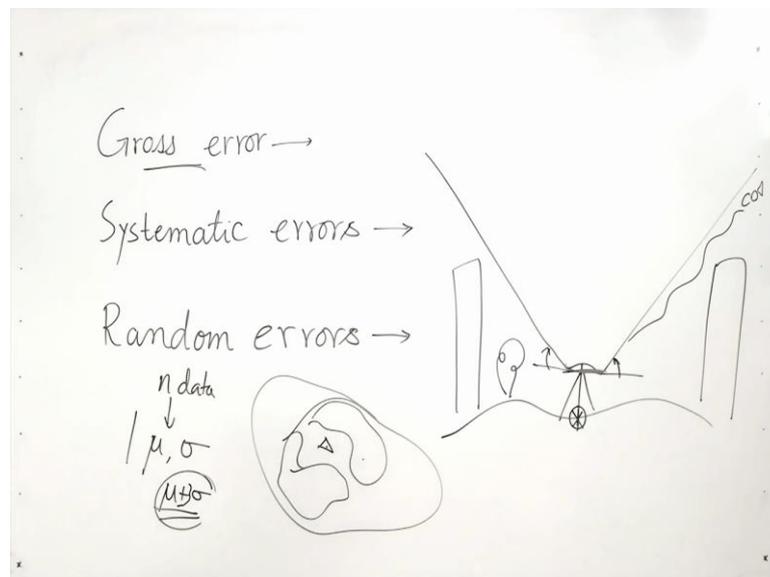
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GPS observables are fault with mistakes as well as errors mistakes means the error which is done inadvertently without knowing it and errors are coming automatically. So, the mistakes actually we can avoid by being a conscious effort, by making conscious effort now these mistakes and errors arising out of different sources. So, we need to know what are the different types of source or different sources from which this error is coming and what is the nature of the error. Depending upon the nature of the error we may take care for further processing. Now depending on the nature of errors actually errors are divided

into 3 broad categories. That is gross error mistakes and systematic error and random error. Now as I told you that in abundant in abundant mistakes; that means, some errors are coming due to undesirable fill condition confusion and carelessness of the observer.

So, we should avoid these conditions to reduce or to avoid gross errors. And these gross errors will be always there with the observation. So, we need to identify those errors and then subsequently we need to remove those error, we need to reduce that error we need to correct those errors and this is done during the preprocessing operation.

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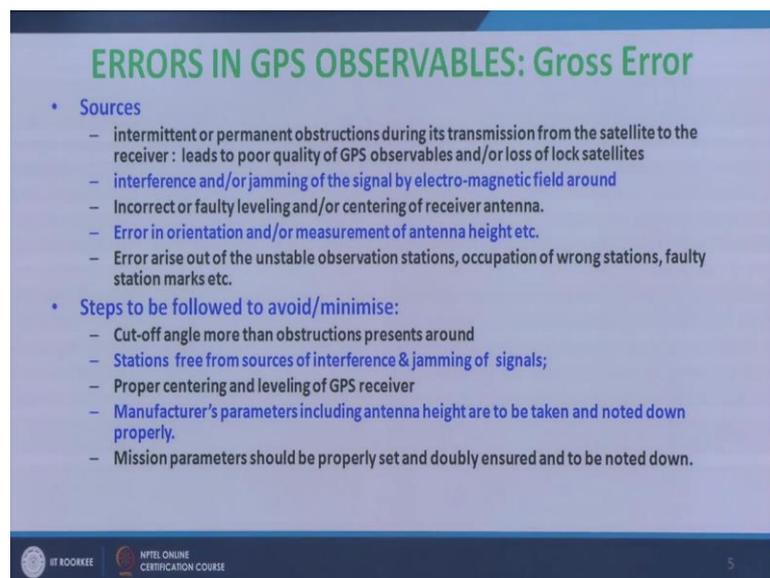
Now, apart from that gross error. So, gross error. So, this is the in advant in abundant mistakes then systematic error. So, from the name itself it can understand that the errors which are related to the system; that means, the GPS system here in our case for the user it is the whole of GPS satellite segment than the signal it is coming through the atmosphere and the GPS receiver.

Now, this systematic errors actually follow certain physical laws which we should look into and we can model those errors and then we can remove it. So, systematic errors are errors which can be model and removed. And these errors actually vary from observation to observation, for each observation the same type of error may be different. And the third one is called random error. From the name itself we can understand that random errors are very random in nature; that means, no one can predict how these errors will come and what will be the nature of the errors. So, again random error can be avoid

should be avoided and can be minimized through some duplication as well as through system analysis.

So, now we should go for the gross error. Now the sources of gross error is primarily the as I told you that some unforeseen conditions in the field or if the signal that is coming from satellite to receiver it may get interrupted or interfered due to some southern phenomena or unfortunate phenomena, or sometimes the person who is carrying out the GPS surveying they may not be efficient or compute enough to carrying out the GPS surveying. So, they may do some mistakes like they may not be able to maintain the receiver in perfectly centered or perfectly level or there may be some mistakes about the antenna is nature. So, many other things. So, that those errors due to negligence or incompetence of the observers or due to unforeseen reason, reasons that may occur in the field this gross error may arise in the GPS observables.

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**ERRORS IN GPS OBSERVABLES: Gross Error**

- Sources
  - intermittent or permanent obstructions during its transmission from the satellite to the receiver : leads to poor quality of GPS observables and/or loss of lock satellites
  - interference and/or jamming of the signal by electro-magnetic field around
  - Incorrect or faulty leveling and/or centering of receiver antenna.
  - Error in orientation and/or measurement of antenna height etc.
  - Error arise out of the unstable observation stations, occupation of wrong stations, faulty station marks etc.
- Steps to be followed to avoid/minimise:
  - Cut-off angle more than obstructions presents around
  - Stations free from sources of interference & jamming of signals;
  - Proper centering and leveling of GPS receiver
  - Manufacturer's parameters including antenna height are to be taken and noted down properly.
  - Mission parameters should be properly set and doubly ensured and to be noted down.

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So, after taking the observations we should need to test the quality of the observables or the content of the observables and we need to identify we should identify whether our observables are associated with gross errors or not. Now some of the steps which we can take before taking any observation like whenever we take the suppose this is the terrain and maybe some buildings are there here or some trees are there. So, we should take the cart of angle in such a way that it does not; that means, signals from GPS suppose GPS

satellite is somewhere here. So, we should not allowed to come here, by making the cut of angle more than the abstraction.

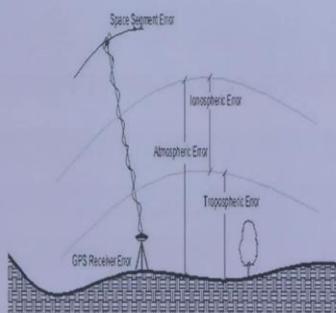
So, by taking cut of angle property by avoiding location where there may be some undesirable reflection from around like her if we say this is the area where we like to go for GPS observables. This is the station we should avoid any water bodies around because this water bodies act as a reflecting surface. So, it provide some undesirable signal. So, that will affect the GPS observation or the observables will be associated with the gross errors. Then the receiver should be properly centered that mean just above the point from which it is for which we want to get the observation location. Or it should be level properly we should make use of the proper instrument. So, all these thing we will help to avoid the amount or nature of gross error. So, the one way we get the GPS observable, the simplest way to identify the gross error is to go for some test call (Refer Time: 08:44) test. So, suppose we are n data. So, should find out the mean and standard deviation and we should see whether all the data is within  $\mu \pm 3\sigma$ .

So, this is the general, generally we this is the very simple way to do; that means, if the observations are within the  $\mu \pm 3\sigma$ , then we can say that the errors that the observable are free from gross error. This is a very simple test and then maybe. So, many about would test beta testical analysis which we will provide us an indication about the presence or absence of gross errors.

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**SYSTEMATIC ERRORS IN GPS OBSERVABLES...**

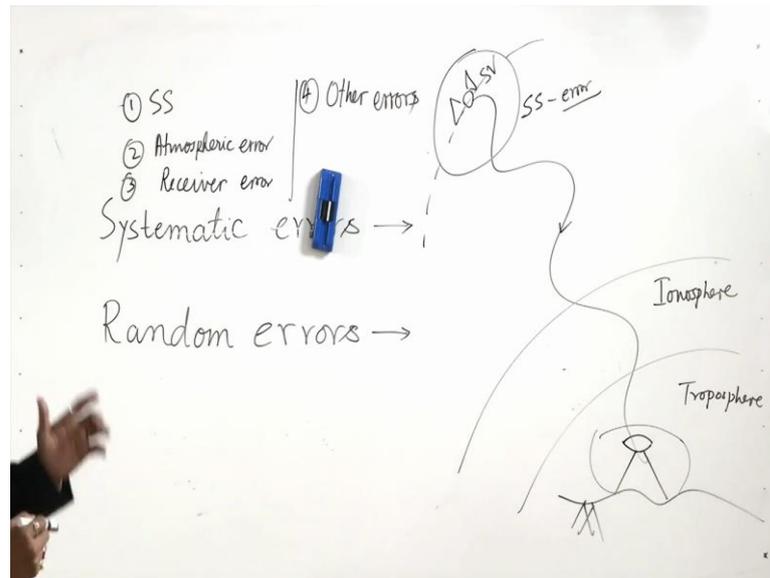
- Four types (Based on their sources): space segment errors, atmospheric errors, receiver errors and others.



The diagram illustrates the various sources of systematic errors in GPS observables. It shows a satellite in space, a signal path through the ionosphere and troposphere, and a GPS receiver on the ground. Labels include Space Segment Error, Ionospheric Error, Atmospheric Error, Tropospheric Error, and GPS Receiver Error.

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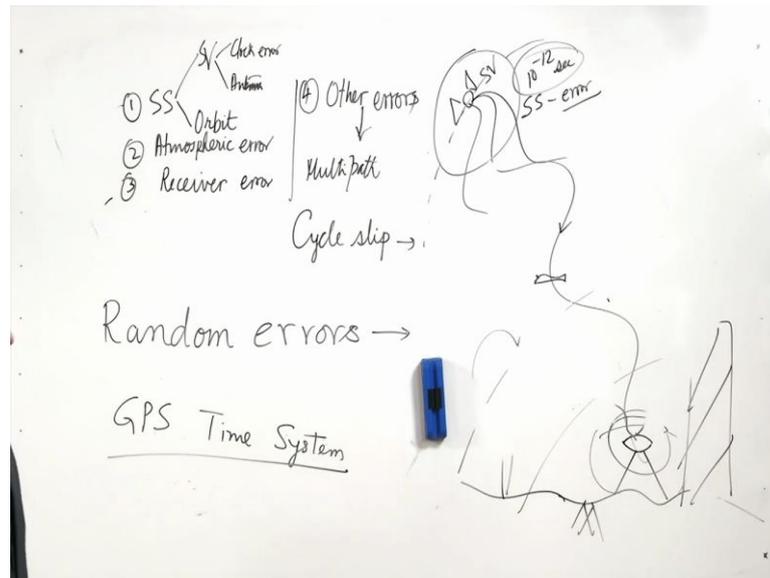


Next type of errors is the systematic error now systematic error actually what we do see is that this is the GPS on satellite vehicle, satellite vehicle and signal is coming. And this is the receiver where the signal is being received, and we can say that this is the atmosphere troposphere and ionosphere. Now we may signal is coming from satellite vehicle to receive it will transmit through that ionosphere.

Now, there may be error associated with this satellite vehicle on orbit. There may that is called space segment error systematic error. Or the signal that is coming from satellite vehicle to the atmosphere to the receiver this signal may not behave or propagate the way it is expected to do because of the presence of ionosphere and troposphere is velocity of propagation as well as direction of propagation we will change as a result there will be some delay incoming the signal to the receiver and that will cause error and that is called atmospheric error. So, there will be some atmospheric error first one is space segment error number 2 atmospheric error, number 3 they the receiver may not function the way which it is expected to do or work.

So, receiver error apart from that there are may be some other error. So, other error. So, under this 4 heads the systematic error may be explained now the first is your space segment error it has 2 type one associated with the satellite vehicles and other with the orbit.

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Now, again in the satellite vehicle there may be 2 types of error one due to satellite clock error and other due to satellite antenna phase error. Now as I told you that the satellite vehicle makes use of atomic clock whereas the and these functions on the basis of GPS time system GPS time system. Now the clock that is being available in the satellite vehicles they may not perfectly synchronized with the GPS time system.

So, there will be error in satellite clock and that error of satellite clock. We do get the information that is model through some functional relation and the parameter of those function are available in the GPS navigational data.

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**SYSTEMATIC SPACE SEGMENT ERRORS**

- Arise out of the satellite system and its motion.
- Include primarily the satellite clock error and the satellite ephemeris error.

**SATELLITE CLOCK ERROR**

- Atomic standards of SVs encounter noises causing deviation in SV time with respect to the reference GPS system time.
- Model coefficients available in navigational message and get updated at an interval of 2 hours.

**SATELLITE ANTENNA OFFSET ERROR**

- Separation between the center of mass of a satellite and that of its antenna phase center
- Values are available at IGS site (<ftp://www.igs.org/pub/station/general/igs05.atx>).

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So, model coefficients are available in navigational messages, and these coefficients we will help us to compute the error or in satellite vehicle clock. Then there is an error in satellite antenna offset error because satellite antenna is the antenna face center of the satellite antenna will be different from the center of mass of the satellite. So, that distance will make an error in the satellite arranging value; that means, in the GPS observables. And these values we can get from this internet site. And the third error that is a ephemerals error which is the orbital error; that means, the satellites are plan to walk around the earth at certain orbit, but it is not possible for satellite to know as per the desired or width there will be some variation and that variations are known as a ephemerals error.

So, ephemerals error may be minimized are avoided by making use of precise ephemerical rights. So, for long baseline or for very accurate GPS point positioning, we should go for very precise ephemerical rights. Then the signal as it comes out from the satellite vehicle we will transmit through the atmosphere and switch to the receiver, but well it will come it will interact with the ionosphere as well as with the troposphere. Now in case of ionosphere; that means, ions are there. So, and electromagnetic signal is also electromagnetic in nature. So, they will be much influenced or there will be a lots of (Refer Time: 16:28) in the signal propagation through ionosphere depending upon the intensity of ions available. And the error associated with that is called ionosphere error. And that is electrical in nature whereas the troposphere contains the many physical

particles like water bubbles than other particles. And physically that will hinder or abstract the transmission of GPS signal as well as it is as a result of which the velocity of propagation as well as direction of propagation will change which we will make these signal propagation time delete.

So, this will make the errors in GPS observables. And these errors can be actually for atmospheric error we generally go for modeling and then we reduce the errors through modeling.

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**SYSTEMTIC RECEIVER ERRORS**

- Types: Antenna Offset Error, Receiver Hardware Error AND Receiver Clock Error

**ANTENNA OFFSET ERROR**

- affects maximum in elevation.
- Steps to remove or minimization:
  - Observations involving similar types of antenna.
  - Maintaining proper orientation of antennas during observation.

**RECEIVER HARDWARE ERROR**

- random influences from unwanted disturbances in antenna, amplifiers, cables and the receiver electronics.

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Now, the third type of error that is arise around the GPS receiver. And as I told you that GPS receiver will be having an antenna. And always there is a problem with the antenna phase center. Because the different components of the GPS signal will have different location of antenna phase centers. So, different types of observable will have different errors. So, the best way to minimize the antenna offset error is to make use of the same type of antenna for different types of different receiver used in project. Receiver hardware error; that means, that receiver is an electronic instrument. So, it may not function the way it has been design they to define field condition temperature pressure (Refer Time: 19:09) something like that.

So, if he does not work the way it is being design then there will be some error that is called receiver hardware error. So, to minimize receiver hardware error we need to take

the receiver which is very robust in nature and we should make use of full condition for which it is being designed.

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**SYSTEMIC RECEIVER ERRORS**

**RECEIVER CLOCK ERROR**

- Large deviation of receiver time from GPS system time is receiver clock error.
- As it contributes significantly high error in range measurement, the error due to receiver clock gets computed as an independent unknown in GPS surveying.

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And the most important and most dangerous or most significant error that is associated with this GPS system is the receiver clock error. Already we have discussed in our class of GPS positioning that the clock in the satellite vehicle is the atomic clock which is having the position of the order of  $10$  to the power minus  $12$  second  $10$  to the power  $13$  second  $10$  to the power  $11$  second where as the clock we use in GPS receiver quartz nature having the position of the order of  $10$  to the power minus  $6$  seconds.

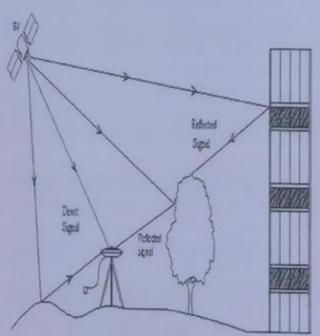
So, there is an error called synchronization error between the satellite vehicle and the receiver vehicle receiver. And that makes a very large error in GPS observable that is the reason why the GPS observables is not the range, but the pseudo range. And it is being taken as an independent error and is being used to find during GPS processing. Under the other types of error there are 2 errors which are very prominent which is called multi path error.

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**OTHER ERRORS**

**MULTIPATH ERROR**

- Signal reflected from surrounding objects and/or ground
- causes reduction in signal strength and reverses the polarity of the signal. affects both the carrier-phase and pseudo-range observables but differently.
- C/A code observations suffers maximum due to multipath
- Steps for reduction of multipath :
  - through observation design, station calibration, proper choice of receiver and processing techniques etc.
  - avoid possible reflector in the vicinity of observations
  - taking observations over longer period
  - Select multi-path resistant antenna such as choke ring antenna



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And now what is multipath error. So, sometimes if we set up the instrument near some building or some tree signals from GPS we will not only come directly to the receiver, but also it will get reflected from adjoining building or trees. This is this phenomenon is known as multi path. Now due to multipath because it is coming from the GPS same GPS signal GPS satellite. And they are leaving the satellite at the same instant of time, but it will reach at different times because of the different path it took as a result of which the signal will be corrupted undesirable errors will come.

So, this is error this type of error is known as multipath error. And this type of error is more prominent in ca code observation and the step for reduction of multipath is that we should avoid a place where the there are some add objects around and from which the signal may get reflected to come to the receiver. Or we must avoid areas like in a crowded building trees or some adjoining water bodies water bodies also reflect on x is the reflected. And one another way to take care because all are it will it may not be possible to choose that type of ground or that type of station. So, now, a day there are some specific type of antenna available called choke ring antenna. This type of antenna actually rejects multipath the idea behind multipath is that it gets polarized and that polarity of the signal direct signal and the multipath signal is different. So, whenever it receives signals of different polarity they reject and that is the concept of multipath based on antenna and that type of antenna if we use then we will be able to minimize the multipath error.

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## OTHER ERRORS....

### CYCLE SLIP

- abrupt change in the integer value of the phase observable
- Causes :
  - observation dependent : obstructions from trees, buildings and other infrastructure; due to signal noise (low SNR ratio, multi path, radio interference and ionosphere scintillation) or low satellite elevation
  - receiver dependent: quality of receiver, receiver kinematics, antenna inclination, erroneous signal processing etc.
- During preprocessing, cycle slip gets removed from the GPS phase observables. In order to its removal, cycle slip is required to be detected and then repaired
- Commercial GPS data processing software usually developed having in-built capabilities to free phase observables from cycle slips.

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The next type of error other error is that cycle slip. Cycle slip errors occur suddenly suppose the signals are coming from GPS satellite vehicle and in between some abstraction may come suppose there is an airplane. So, for some time this airplane we will abstract the signal, and once it will leave again the signal will be coming to this as a result of which that integer ambiguity will be restarted need a new integer ambiguity will come.

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① SS  
 Clock error  
 Antenna  
 Orbit

② Atmospheric error

③ Receiver error

④ Other errors  
 Multi path  
 Cycle slip →

Random errors →

① Receiver Clock error  
 ② Ionospheric  
 ③ Multipath →

So, if we plot phase observable phase observable number of phase number of cycle by time how you will see we will find it is increasing. Suddenly it may decrease and then again it will increase so; that means, corresponding to this time there is a slip of cycle or discontinuity in observation. Sometimes it may be like this sometimes it may be like this it may increase like that.

So, corresponding to that time we can say that there was a disturbance in single section and so there is a sudden increase or sudden decrease in number of cycles in the GPS phase observable this phenomenon is known as cycle slip now during GPS data preprocessing in the we can identify and remove the observation corresponding to this time. Now these are the differential now of the different types of systematic error the most dangerous error is that receiver, receiver clock error receiver clock error is the most dangerous.

So, this error is being considered independently receiver clock error is the most significant and it is. So, high that we do take this error as an independent error and independent unknown and we do resolve it before we go for any GPS point positioning among the other errors it is the ionosphere error which is ionosphere error which is most prominent and to be avoided and can be avoided by modeling then it is the multipath error and ionosphere error is of different nature from code and career phase then multipath error is the dangerous most third most dangerous.

So, this is the sequence of it is errors and the third kind or the last kind of error that we that the GPS observable may have that is called random error. Now from the name itself we can understand that the errors which does not follow every rule the errors for which the observer has no control those errors are random errors. And random errors can be avoided or minimized by proper planning and execution of GPS surveying. Also we do take care of random survey by statistical analysis. So, statistical analysis what we do the errors random errors associated is distributed to different parameter. So, that. So, that the each of the parameter computed parameters have some error which is very insignificant does we can say that the pseudo range does the GPS observable pseudo range of any range from is satellite  $i$  to receiver  $r$  is equal to geometric range plus the error due to receiver clock error  $c$  into  $\Delta t_r$  plus.

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$$PR_r^i = \rho_r^i + c \cdot \delta t_r - c \cdot \delta t_i + I_r^i + T_r^i + d_r^i + dt^i + d_r^i + E_r^i$$

$$L_r^i = \phi_r^i \cdot \lambda_0 = \rho_r^i + \lambda_0 \cdot N_r^i(1) + c \cdot \delta t_r - c \cdot \delta t_i + I_r^i + T_r^i + d_r^i + dt^i + d_r^i + E_r^i$$

Random errors  $\rightarrow$

- ① Receiver Clock error
- ② Ionospheric
- ③ Multipath  $\rightarrow$

Or I have it is anyway it depends upon the condition, but c into del t i that is the satellite clock error then your ionosphere error and tropospheric error ionosphere error plus tropospheric error than receiver hardware error, then your satellite vehicle hardware error than your multipath error and random error.

So, this expression provides us; that means, this the pseudo range observable which we get from GPS observation, we get this number, but this number we will consist of all these components. Similarly, if we say about the we this is the carrier phase pseudo range; that means, carrier phase observable multiplied by the wavelength, that is the carrier phase observable. So, we can again this is geometric range and this is the integer ambiguity. So, number of integer ambiguity multiplied by the wavelength will give you the error due to integer ambiguity that is the total number of cycles in the first (Refer Time: 30:33) of observation then you will have c into del t r c into del t i. Now here you can see the ionosphere error is opposite in nature that is here it is plus, but here it is minus. So, tropospheric error plus d t r d t i d t r.

Now, one thing you should remember that they had written the same symbol, here it is geometric distance is same this is that satellite clock error is same as this, but these values I should written as dash because the amount of other error will be defined from your in the code and career these errors will be defined. So, we should better write some other symbol like dash the amount of other errors are different for code, and career as it

is written here code error associated with code in phase are defined and also between the type of codes as well as well as on the type of carrier.

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**Observable Equations**

Pseudorange observable equation

$$PR_r^i = \hat{\rho}_r^i + c\delta t_r - c\delta t_t + I_r^i + T_r^i + dt_r + dt_t + d_r^i + \varepsilon_r^i$$

Carrier phase pseudorange observable equation

$$L_r^i = \hat{\rho}_r^i + \lambda_0 N_r^i(1) + c\delta t_r - c\delta t_t - I_r^i + T_r^i + dt_r + dt_t + d_r^i + \varepsilon_r^i$$

where,  $N_r^i(1)$  is initial ambiguity;  $c\delta t_r$ , receiver clock error;  $c\delta t_t$  error is satellite atomic standard; ionosphere error is  $I_r^i$ ; tropospheric error,  $T_r^i$ ; receiver hardware error,  $dt_r$ ; satellite hardware error,  $dt_t$ ; multipath error is  $d_r^i$  and random error is  $\varepsilon_r^i$ .

• Errors associated with code and phase observables differs and also between the types of codes as well as on the type of carrier.

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So, with this I like to conclude this class. Now let me summarize about this class that GPS observables are fault with errors, errors all of different types depending upon the sources from which it is being alone. And we do divide into 3 types gross error systematic error and random error gross error are the errors or mistakes, which we can avoid by taking duplication systematic error are always there. So, we have to make use of some model or methods to minimize or to remove this, and random errors are the errors which can be avoided through particulars planning and execution of surveying and as well as lexical analysis.

And with this let me conclude this class some review questions and for your further reading this is the book. And in the next class I like to take GPS data preprocessing in which we will see some very simple methods through which we can minimize the errors that is associated with GPS observable.

Thank you.