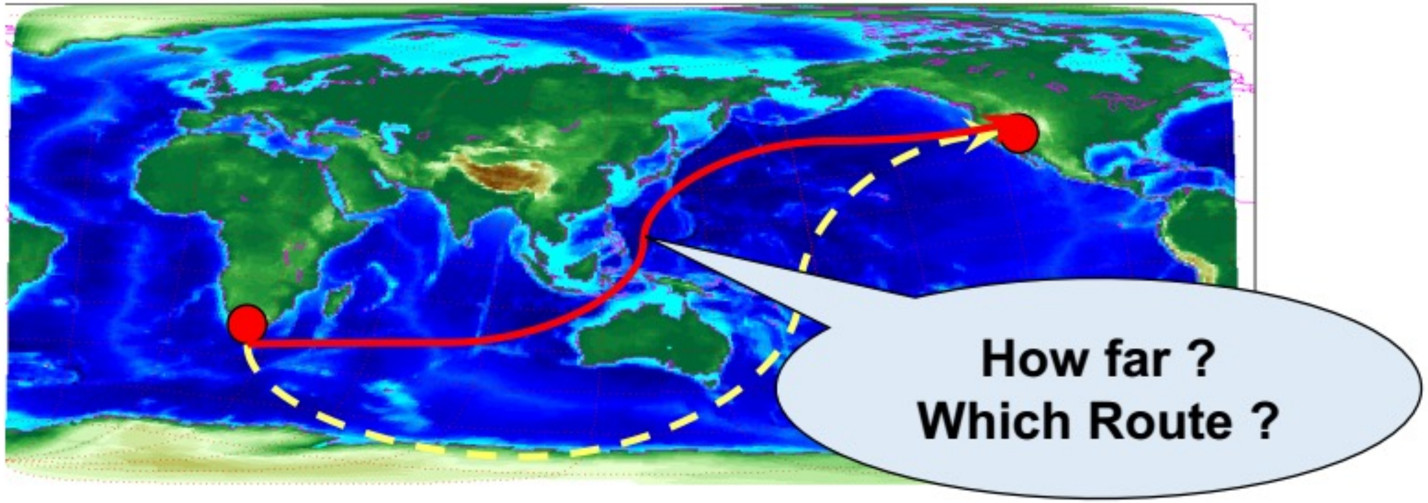
GNSS Remote Sensing
&
Its Applications

Outline

- ❑ Part-A
- ✓ Global Navigation Satellite System (GNSS)
  - ❖ Principle of GNSS
  - ❖ Components of GNSS
  - ❖ Data collection methods
  - ❖ Errors in Observations and Corrections
- ❑ Part-B
- ✓ Basics of GNSS Remote Sensing and its configurations
- ✓ GNSS Remote Sensing Applications

Fundamental Problem

- **How to know my location precisely?**
  - ❑ In any conditions
  - ❑ In any time
  - ❑ Everywhere on earth (Outdoors)
- **How to navigate to the destination?**
  - ❑ Guidance or navigation



Navigation Types

- Landmark-based Navigation
  - Stones, Trees, Monuments
    - Limited Local use
- Celestial-based Navigation
  - Stars, Moon
    - Complicated, Works only at Clear Night
- Sensors-based Navigation
  - Dead Reckoning
    - Gyroscope, Accelerometer, Compass, Odometer
    - Complicated, Errors accumulate quickly
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT, GPS, GLONASS, GALILEO, QZSS, BEIDOU (COMPASS), IRNSS
    - Global, Difficult to Interfere or Jam, High Accuracy & Reliability

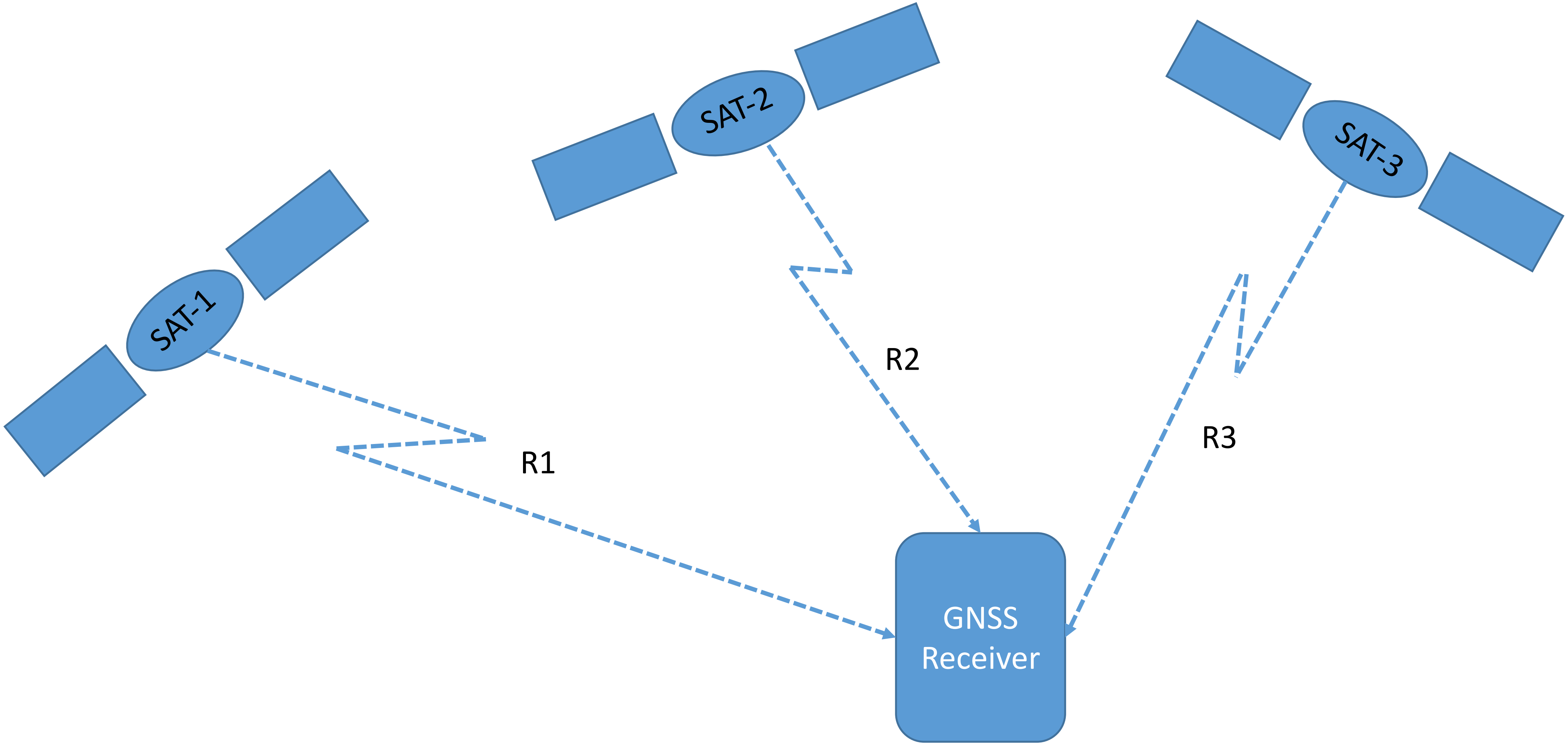
What is GNSS?

Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC.

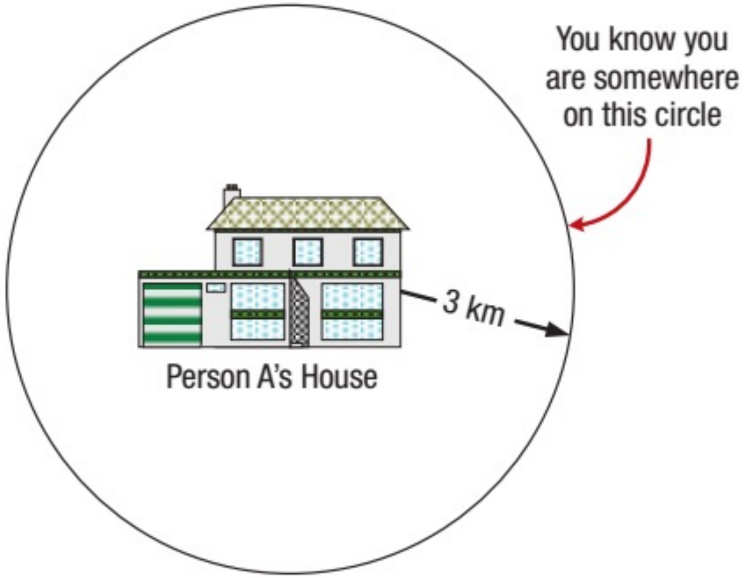
- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS), China

- Regional Constellation
  - QZSS, Japan
  - NAVIC (IRNSS), India

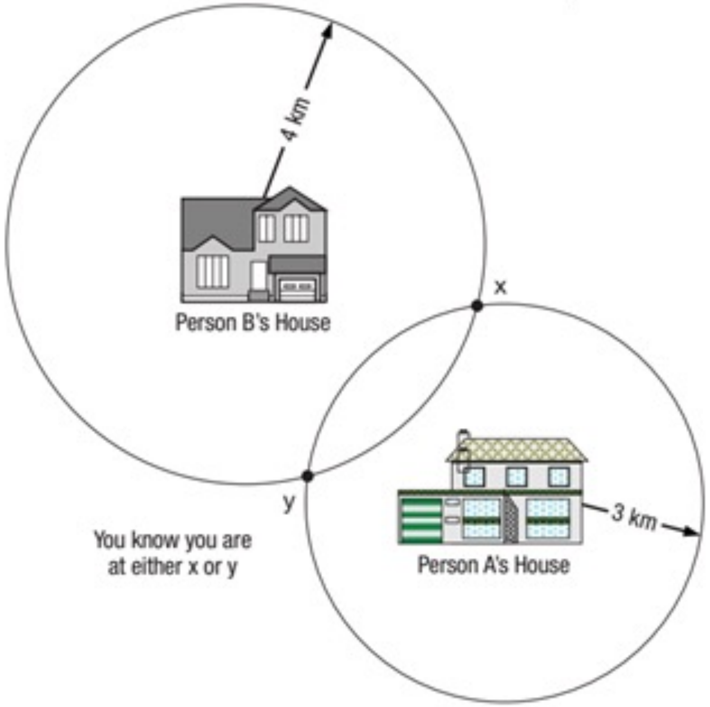
How to find the locations using GNSS?
Basic Principle



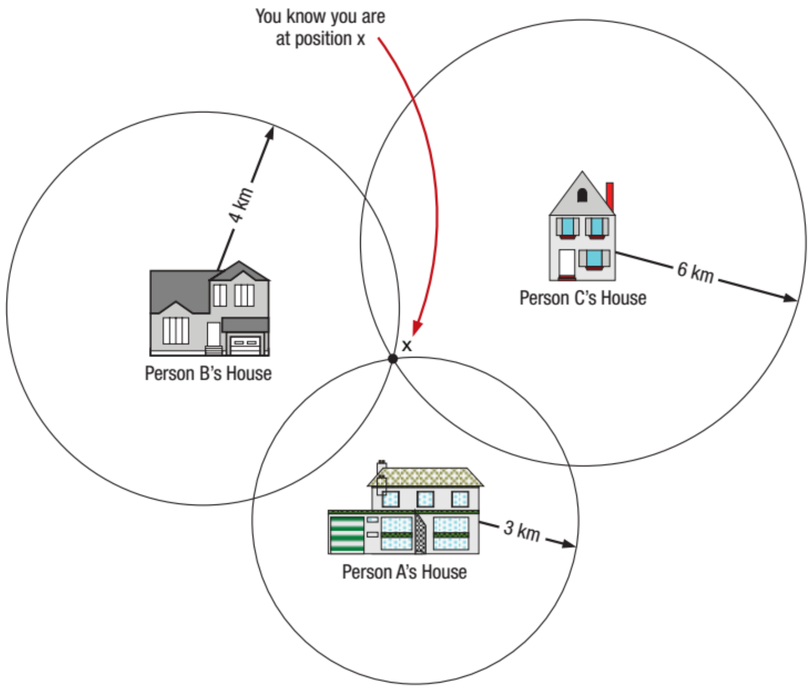
Basic Principles of Finding Precise Locations
"Trilateration"



Knowing One Distance

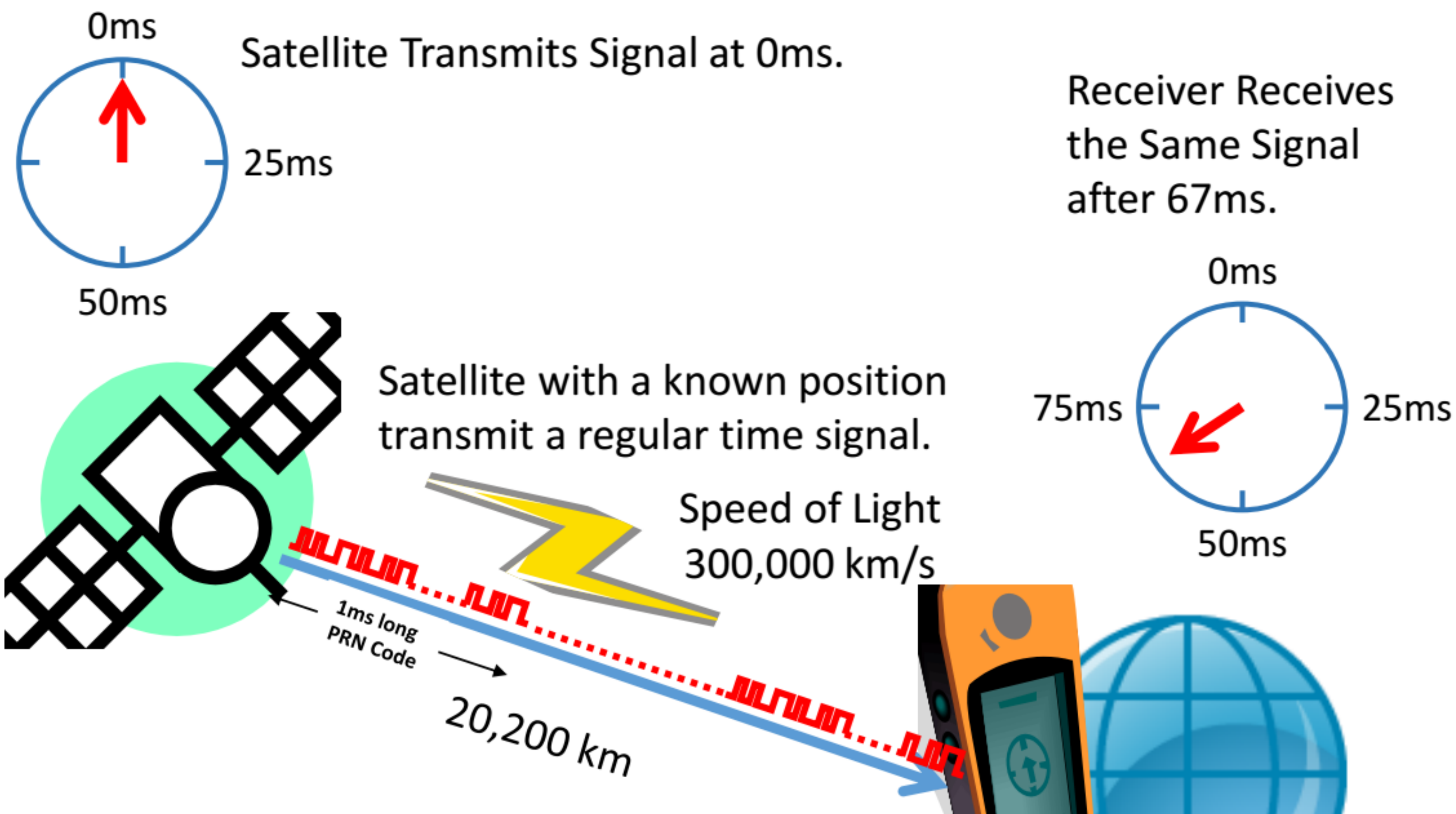


Knowing Two Distance



Knowing Three Distance

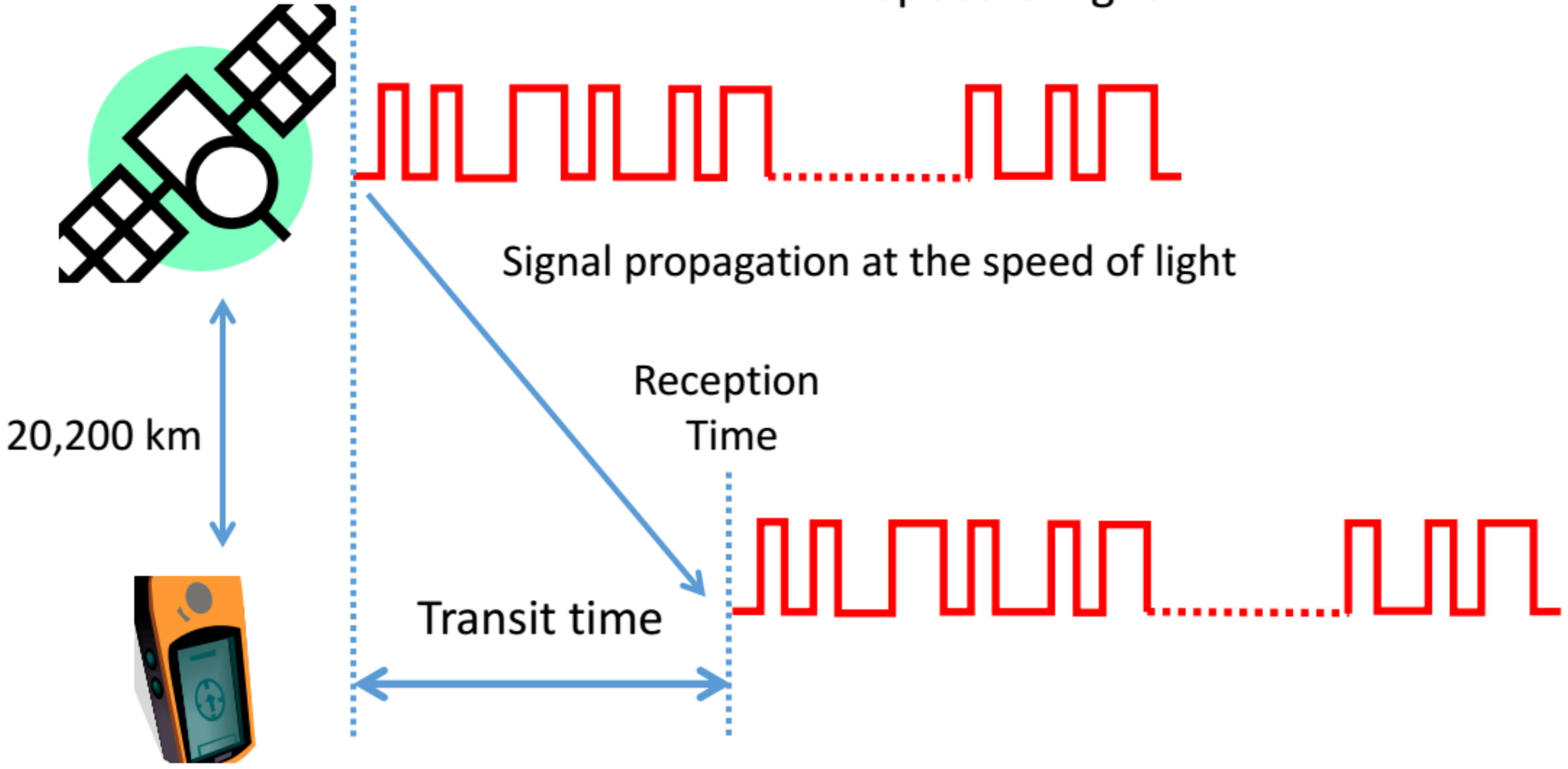
How to measure distance using EM waves?



Distance = (Transmission time – Reception time)
× Speed of light

Pseudorange

Pseudorange = (Transmission time – Reception time) × Speed of light



A GNSS receiver measures the signal transmission time from the code phase at signal reception time.

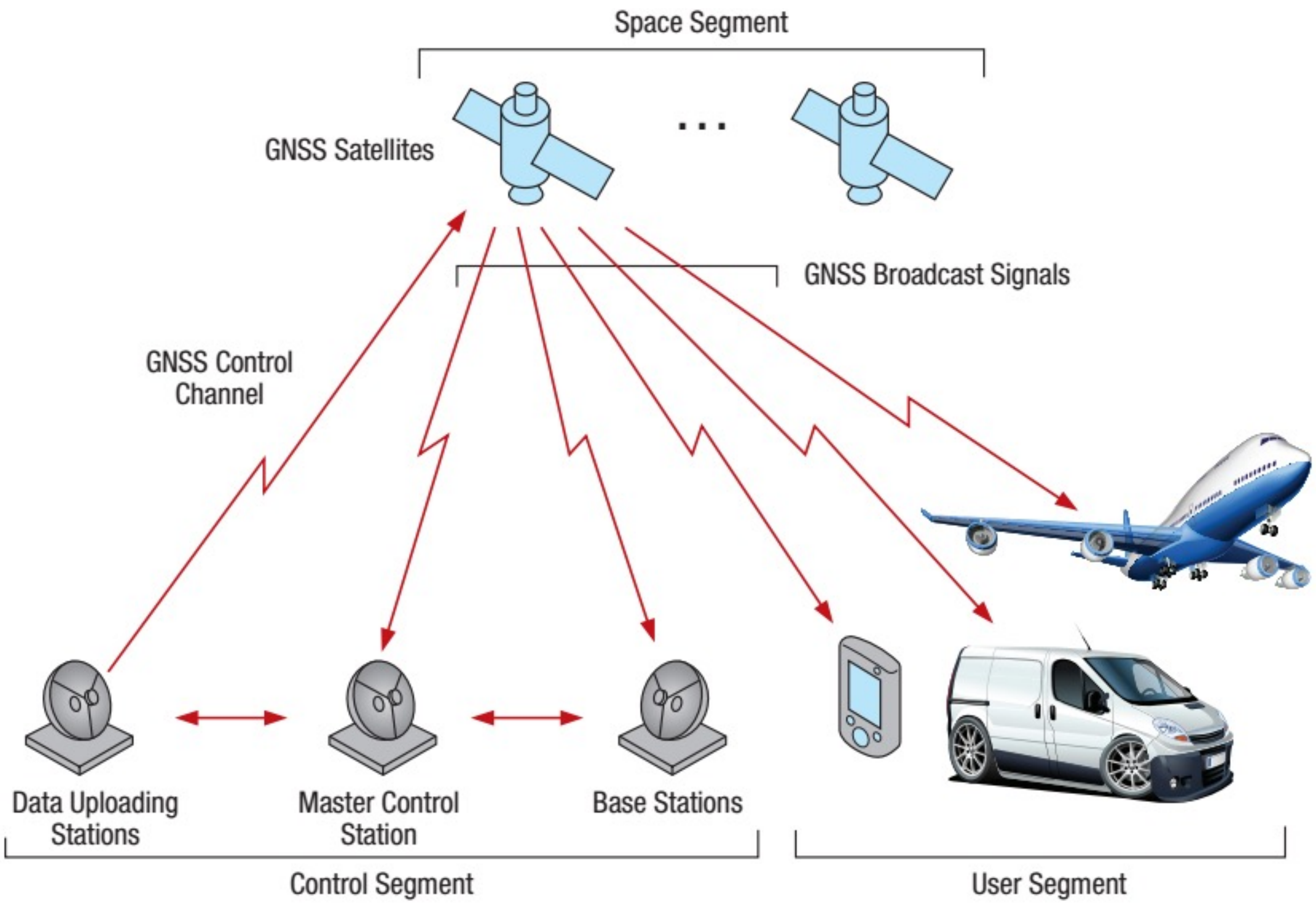
Basic Requirements for GNSS

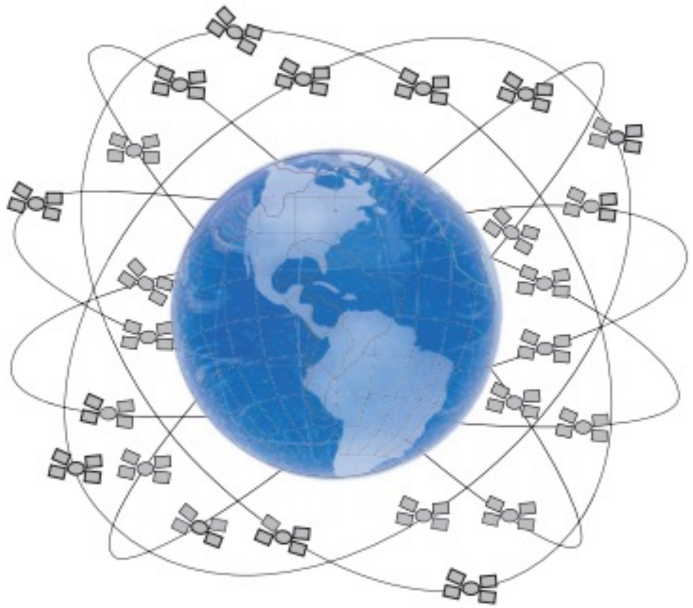
- GNSS needs a common time system.
  - ✓ Each GNSS satellite has atomic clocks.
  - ✓ How about user receivers?
- The signal transmission time has to be measurable.
  - ✓ Each GNSS satellite transmits a unique digital signature, which consists an apparent random sequence
  - ✓ A Time Reference is transmitted using the Navigation Message
- Each signal source has to be distinguishable.
  - ✓ GNSS utilizes code division multiple access (CDMA) or frequency division multiple access (FDMA).
- The position of each signal source must be known.
  - ✓ Each satellite sends its orbit data using the Navigation Message
  - ✓ Orbit Data: Almanac and Ephemeris

GNSS Signal Characteristics

- GNSS Signals have basically three types of signals
  - Carrier Signal
  - PRN Code (C/A Code)
    - PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
    - Each GPS satellite transmits a unique PRN Code.
    - GPS receiver identifies satellites by its unique PRN code or ID.
  - Navigation Data
    - Navigation Data or Message is a continuous stream of digital data transmitted at 50 bit per second. Each satellite broadcasts the following information to users.
      - Its own highly accurate orbit and clock correction (**ephemeris**)
      - Approximate orbital correction for all other satellites (**almanac**)
      - System health, etc.

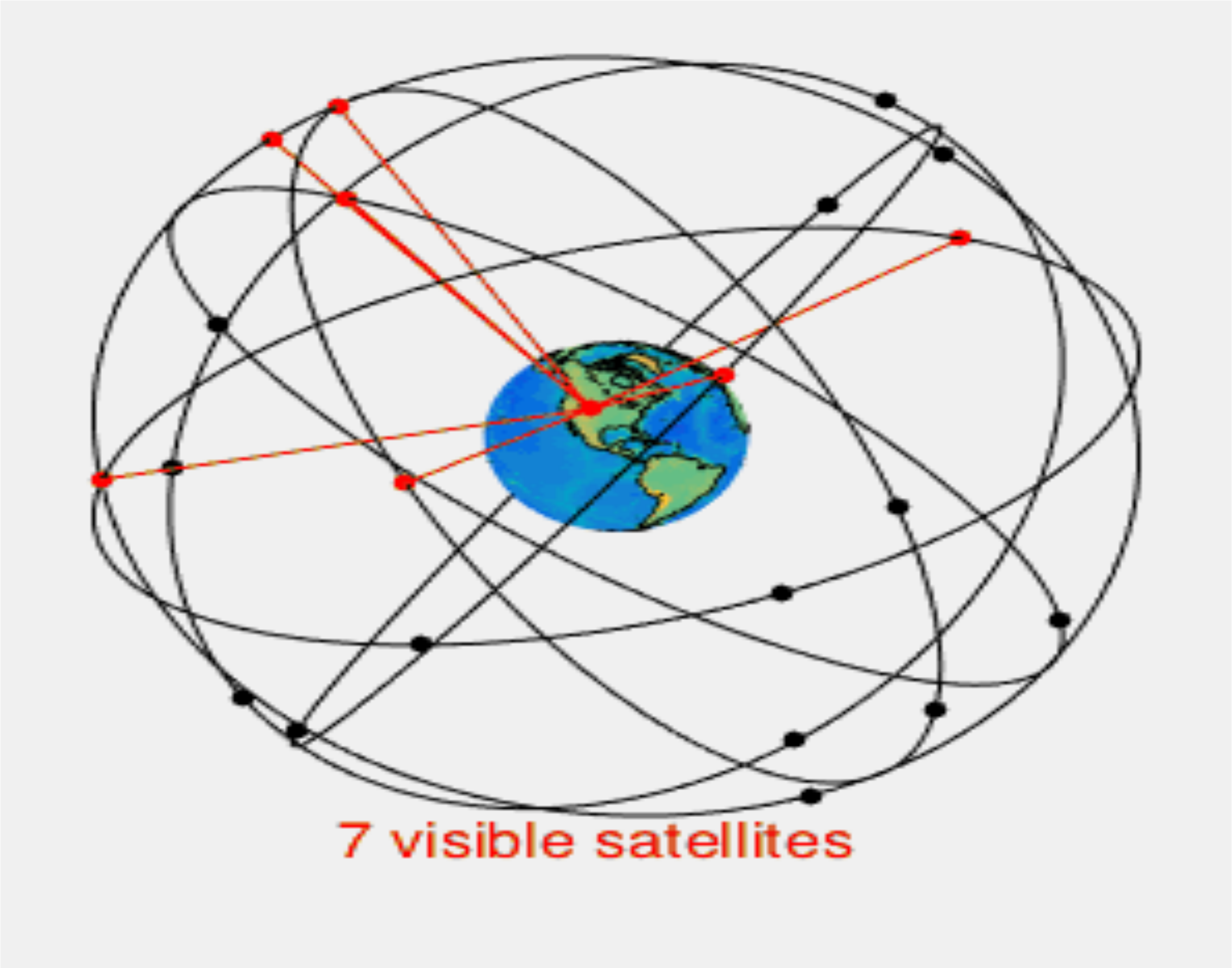
Navigation System: GNSS Segments



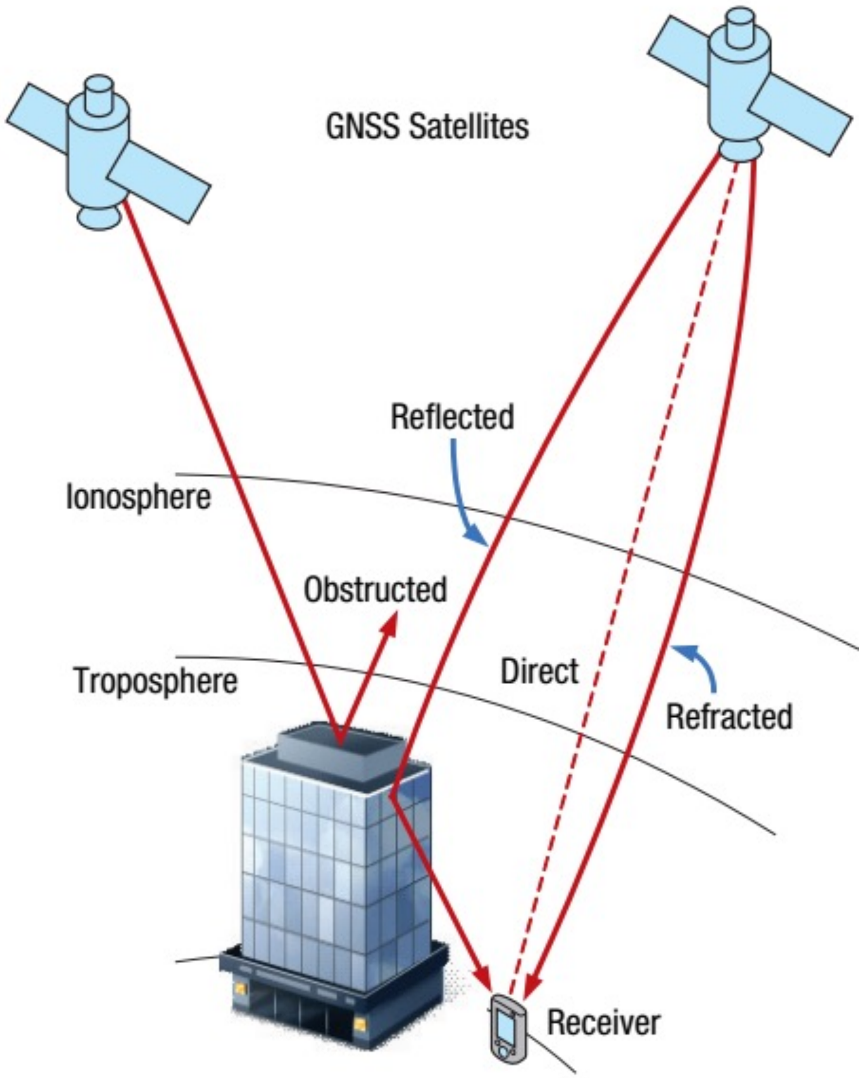


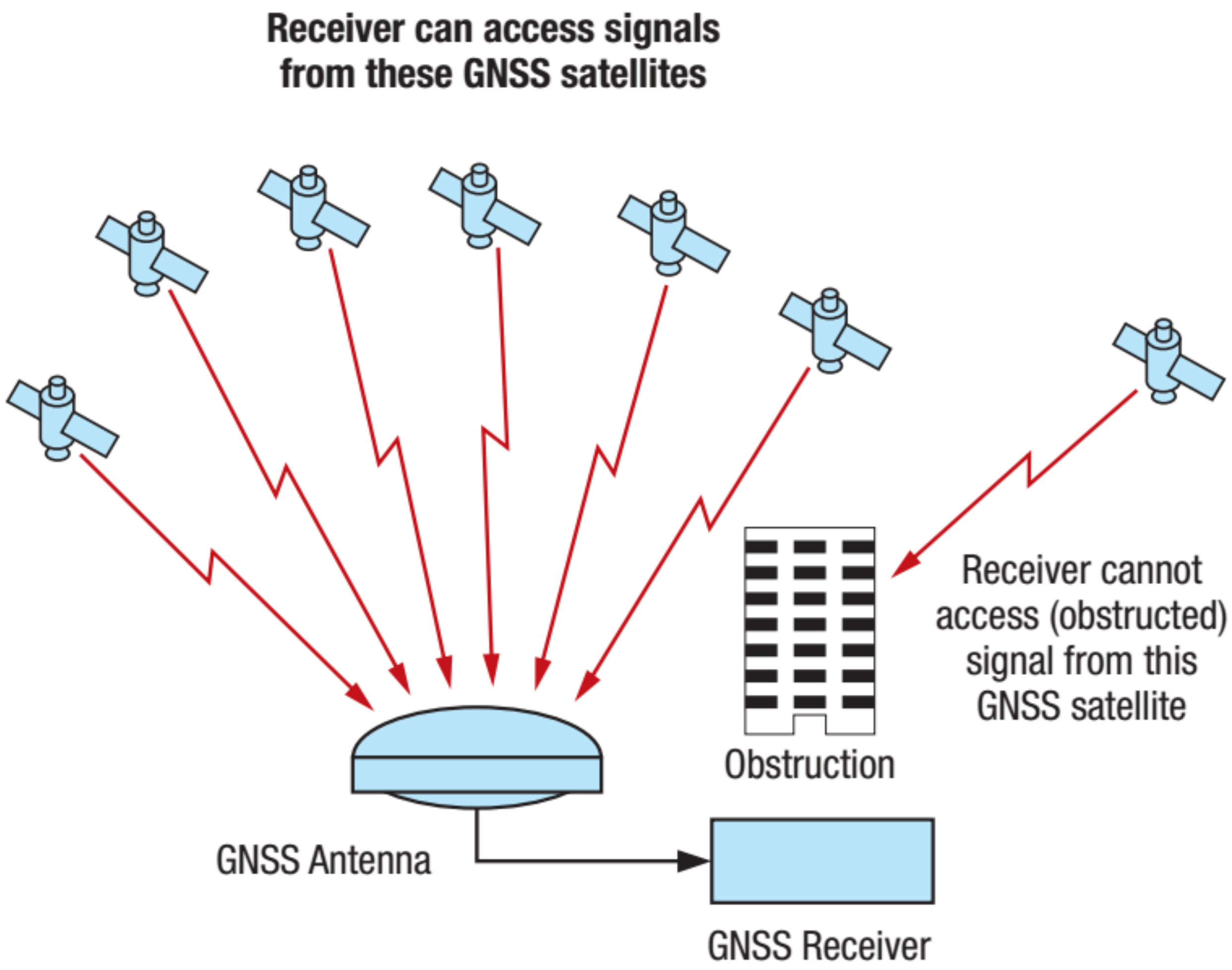
GNSS Satellite Orbits

GPS Space & User Segment



GNSS Signal Propagation and Reception

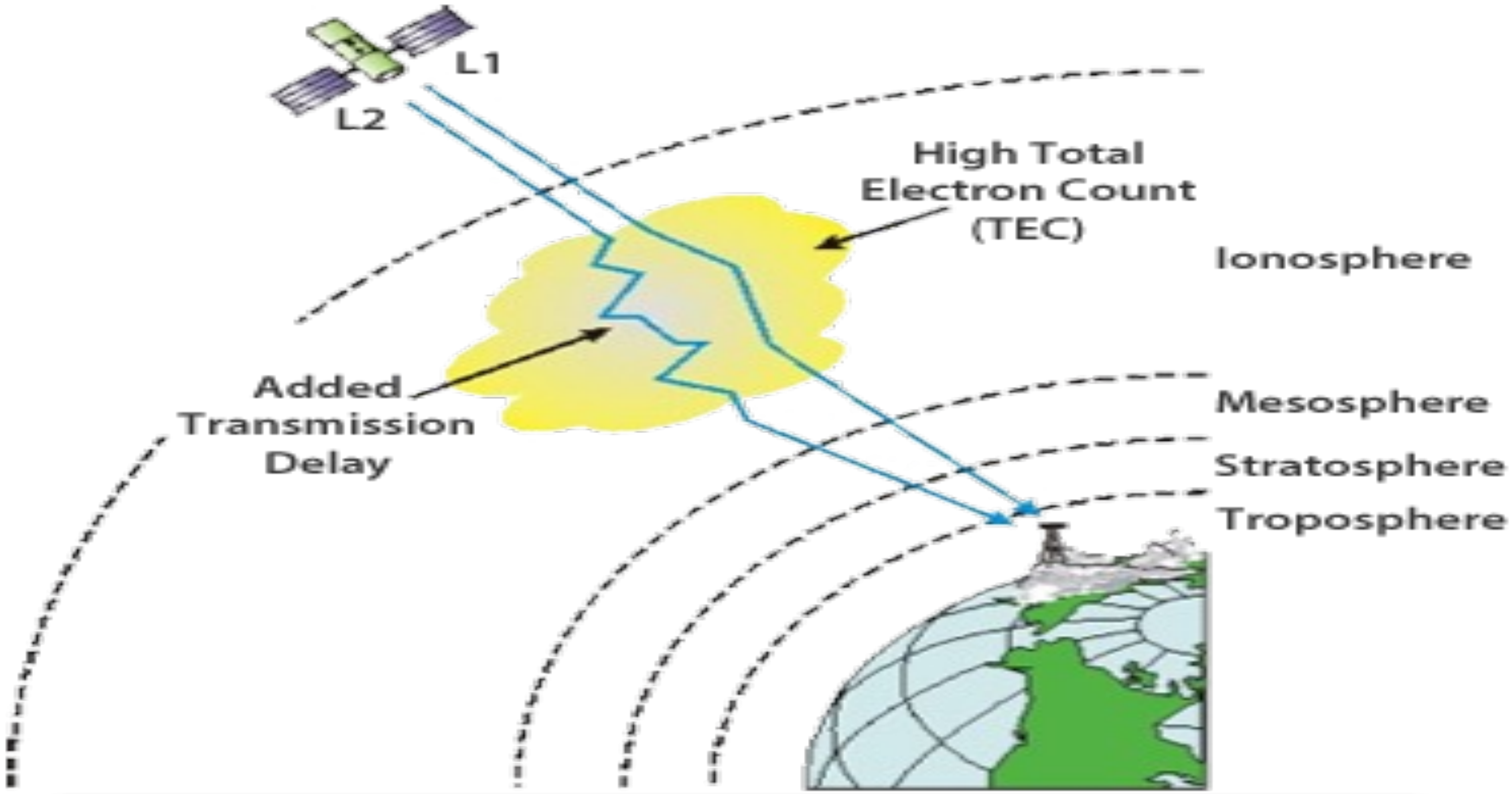




GNSS Error Sources

Contributing Source	Error Range
Satellite clocks	±2 m
Orbit errors	±2.5 m
Ionospheric delays	±5 m
Tropospheric delays	±0.5 m
Receiver noise	±0.3 m
Multipath	±1 m

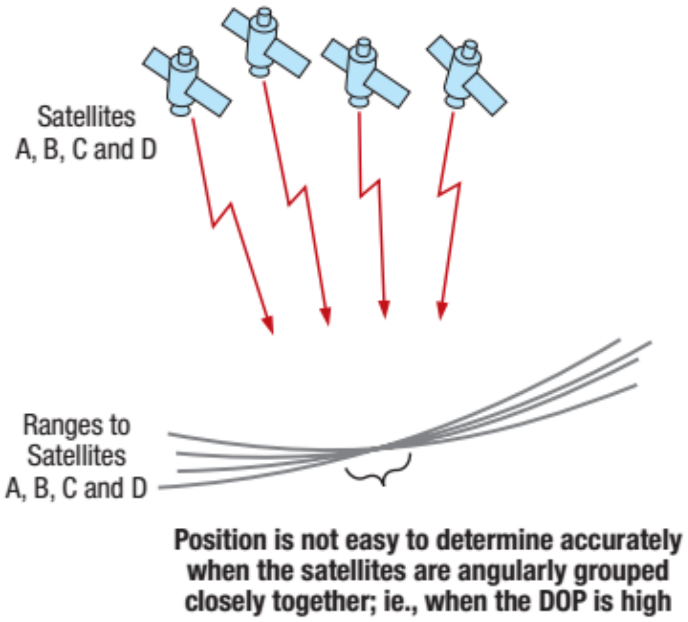
Propagation Delay Experienced by GNSS signals



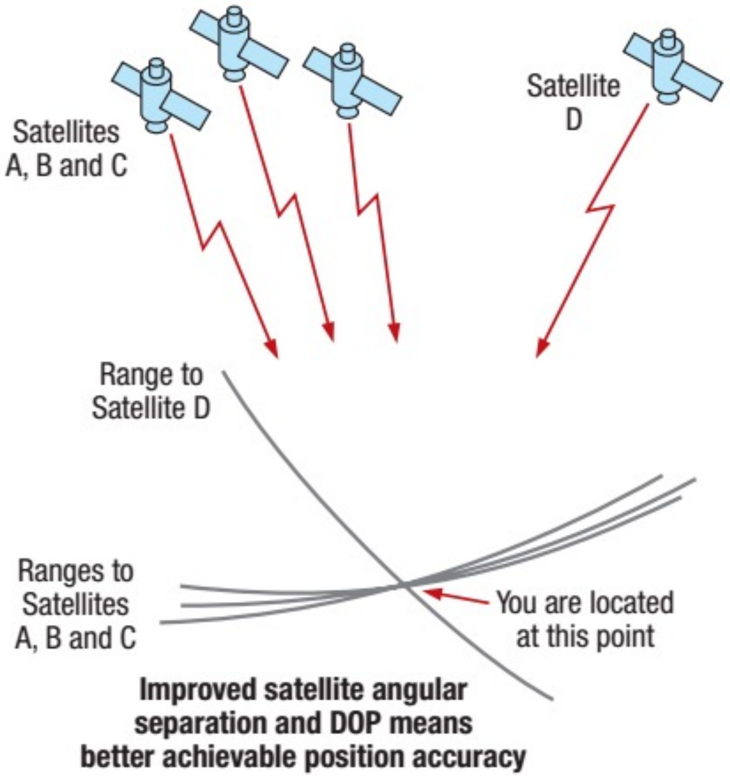
Effect of ionospheric refraction. The GPS signal are affected in different ways, depending on whether it is a question of codes or phases.

GNSS Error Sources

Dilution of Precision (DOP)



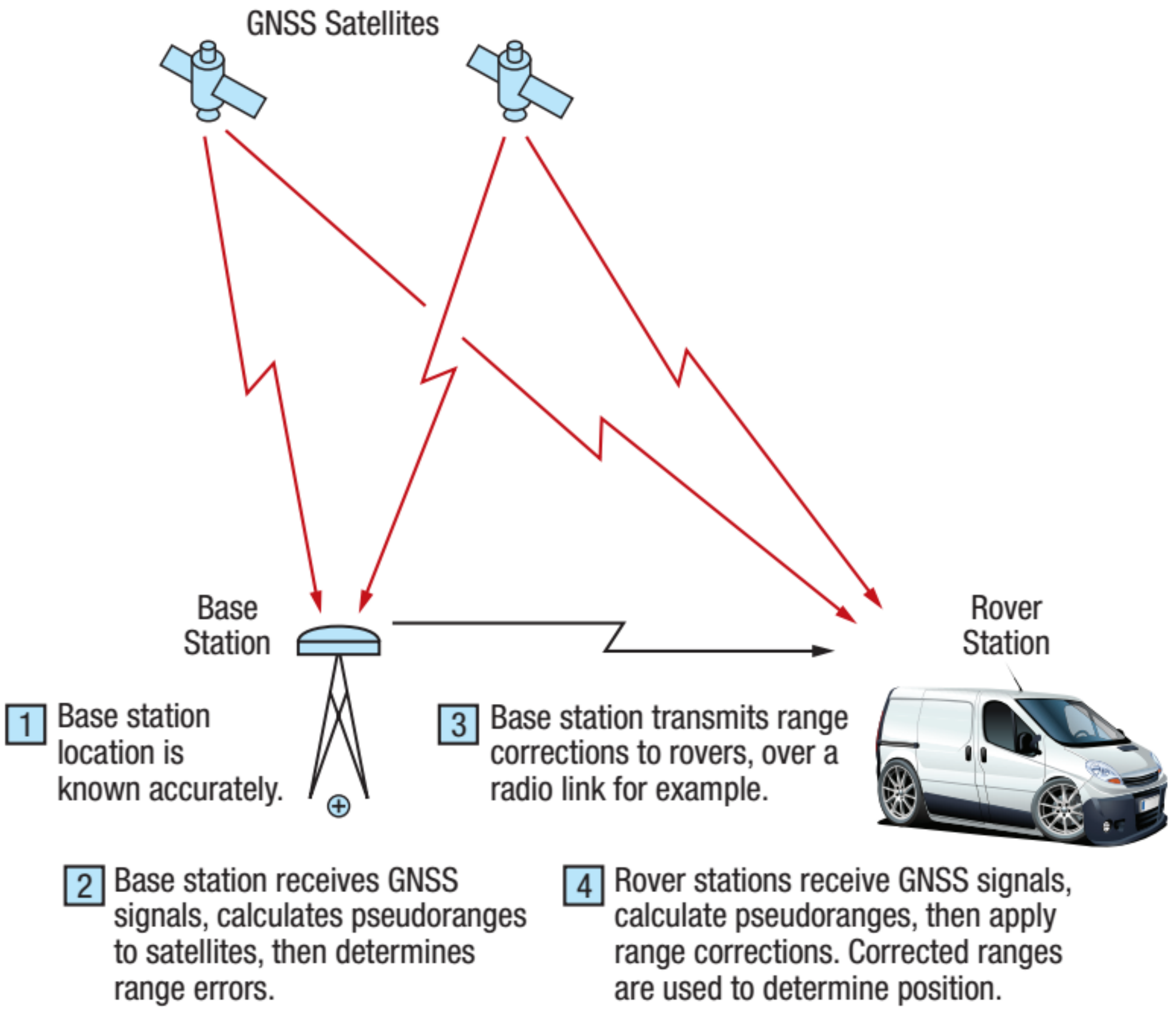
Dilution of Precision (poor satellite geometry)



Dilution of Precision (improved geometry)

GNSS Error Mitigation Techniques

1. Multi-constellation
2. Multi-Frequency
3. **Code and Carrier Phase Based Techniques**
   - ✓ Real-Time Kinematic (RTK)
   - ✓ Precise Point Positioning (PPP)
4. Differential GNSS



Differential GNSS (DGPS)

Why Indian Navigation System, NavIC?

Kargil War Memorial

Necessity - Mother of Invention

NavIC (IRNSS): Indian Navigation System

Objectives of NavIC

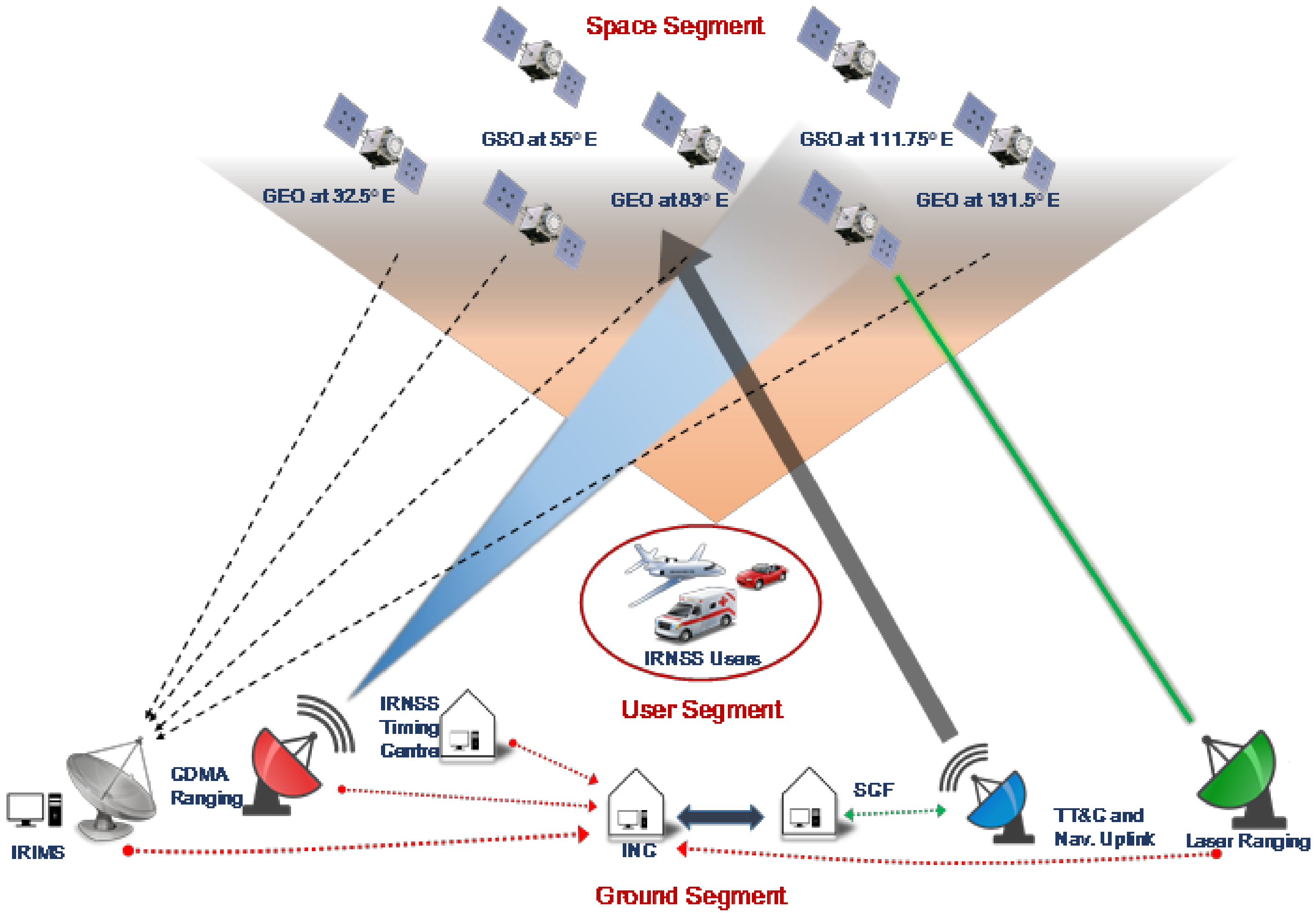
- Indigenous, Independent, Regional Navigational System under Indian Control
- Provides Accurate Position, Velocity and Time to User

•Better than 20 m (Target:10 m) in Horizontal and Vertical position

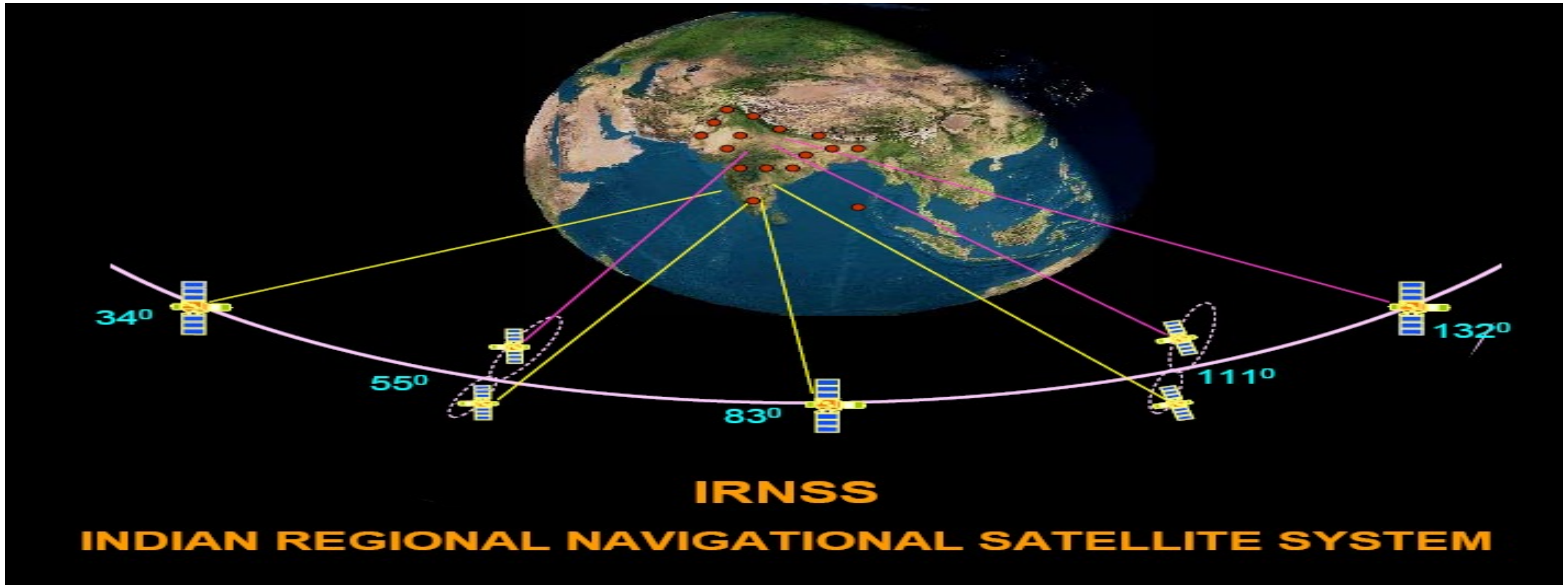
•Better than 20 nano secs in Time

- Provides Navigation Services to
    - •Indian Landmass extending 1500 Kms beyond the geopolitical boundary
    - •Extended Service, in future to a service area bounded by 30° S to 50 ° N latitude ; 40 ° to 140 ° E longitude
- All Weather 24/7 Operations with high availability (99.99 %)

•Better accuracy for a single frequency user with Grid based Ionospheric corrections



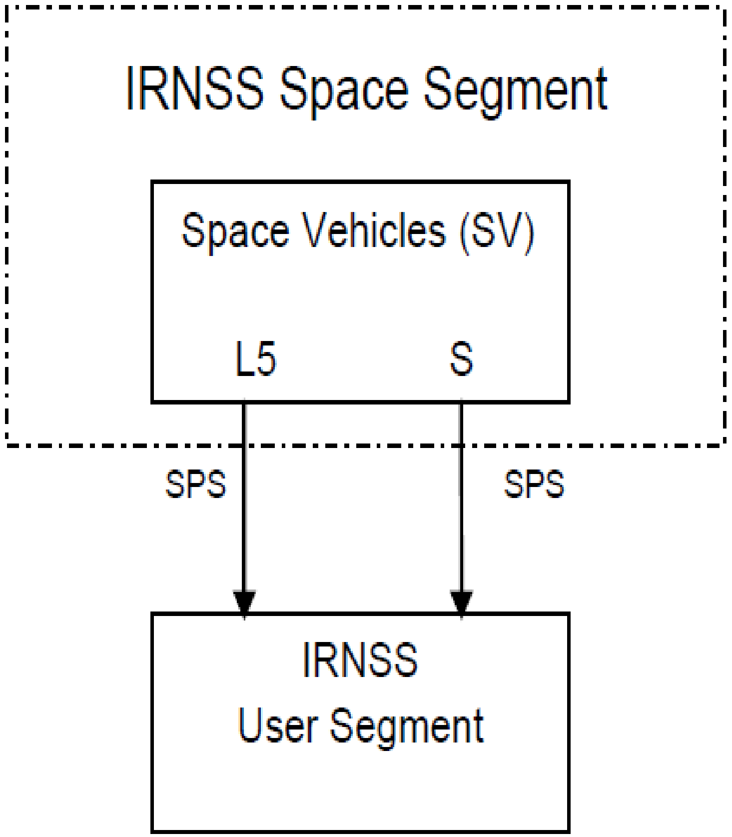
IRNSS – Indian Regional Navigation Satellite System



- Indian Regional Navigation Satellite System (IRNSS) is now called
  - NavIC (Navigation with Indian Constellation)
- NavIC/IRNSS consists of 7 Satellites
  - 4 Geo Synchronous Orbit (GSO) satellites at 55° E and 111.75° E at an inclination of 27°
  - 3 Geo Stationary Satellites (GEO) at 32.5° E, 83° E and 129.5° E at an inclination of 5°
- Transmits signals in L5 band (1176.45 MHz) and S band (2492.028 MHz)

NavIC or IRNSS Architecture

- NavIC architecture mainly consists of:
  - Space Segment
  - Ground Segment
  - User Segment



NavIC Ground Segment

NavIC ground segment is responsible for the maintenance and operation of the IRNSS constellation.

The ground segment comprises of:

- ISRO Navigation Centre
- IRNSS Spacecraft Control Facility
- IRNSS Range & Integrity Monitoring Stations
- IRNSS Network Timing Centre
- IRNSS CDMA Ranging Stations
- Laser Ranging Stations
- Data Communication Network

GNSS Ground Segment Objectives

- Carry out house-keeping and station-keeping of the GNSS satellites
- Carry out precise orbit determination of all GNSS Satellites one-way , two way CDMA and Laser ranging of the satellites
- Generate maintain and disseminate GNSS network time using an ensemble of highly stable atomic clocks
- Estimate the onboard satellite clock bias and drift rate and ionospheric delay using one way range measurement data and generate parameters that will be broadcast by the GNSS satellites for user community
- Have dedicated uplink facility for each satellite for housekeeping and navigation uplinks
- Enable 24X7 automated operation of the GNSS Ground Segment

Ground Segment

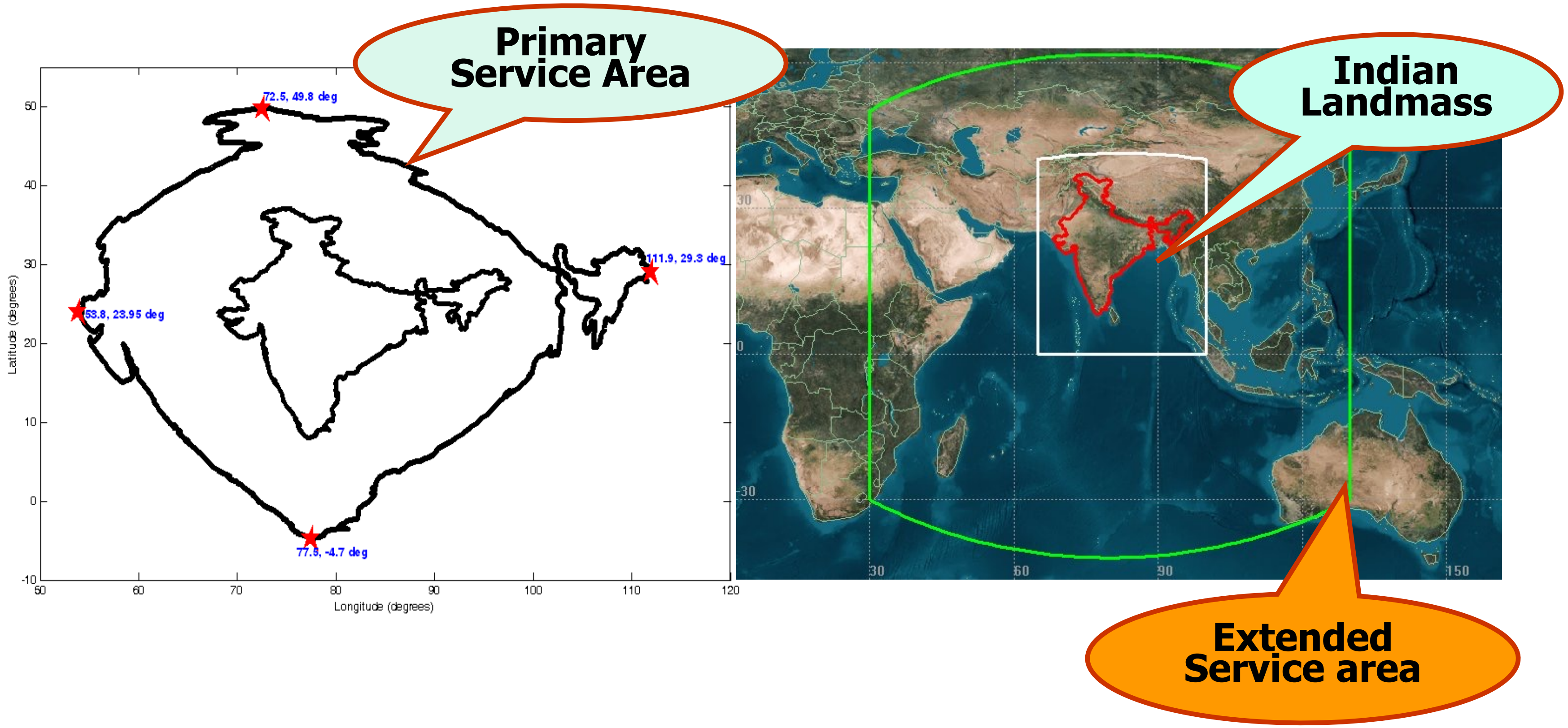
INC at Byalalu
Central processing facility of IRNSS for generation of Navigation Broadcast Data

IRCDR at Hassan
Two way CDMA ranging for
Orbit determination

IRNWT
IRNSS network timing center maintains
timing accuracy < 20nsec with respect to UTC

IRIMS
One way ranging with
integrity monitoring

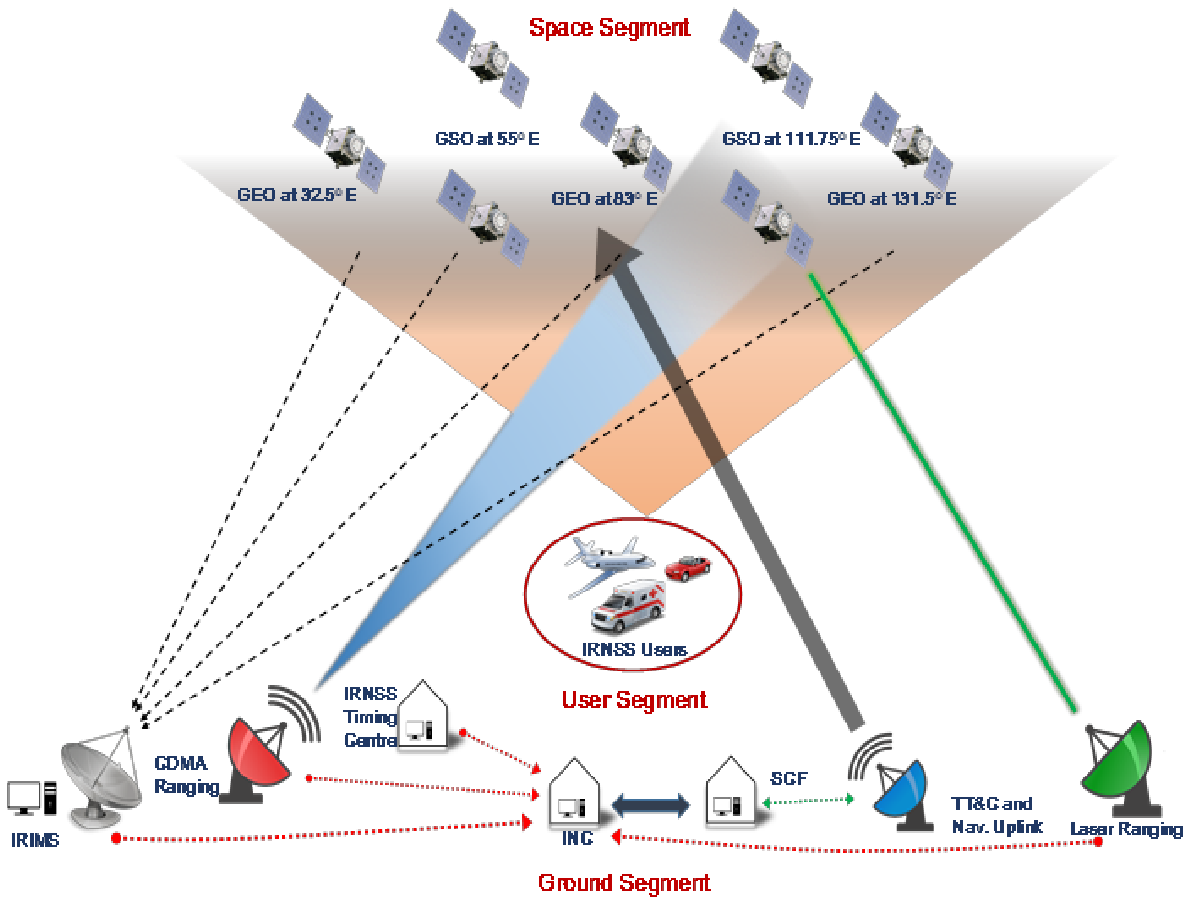
IRNSS - Service Area Definition

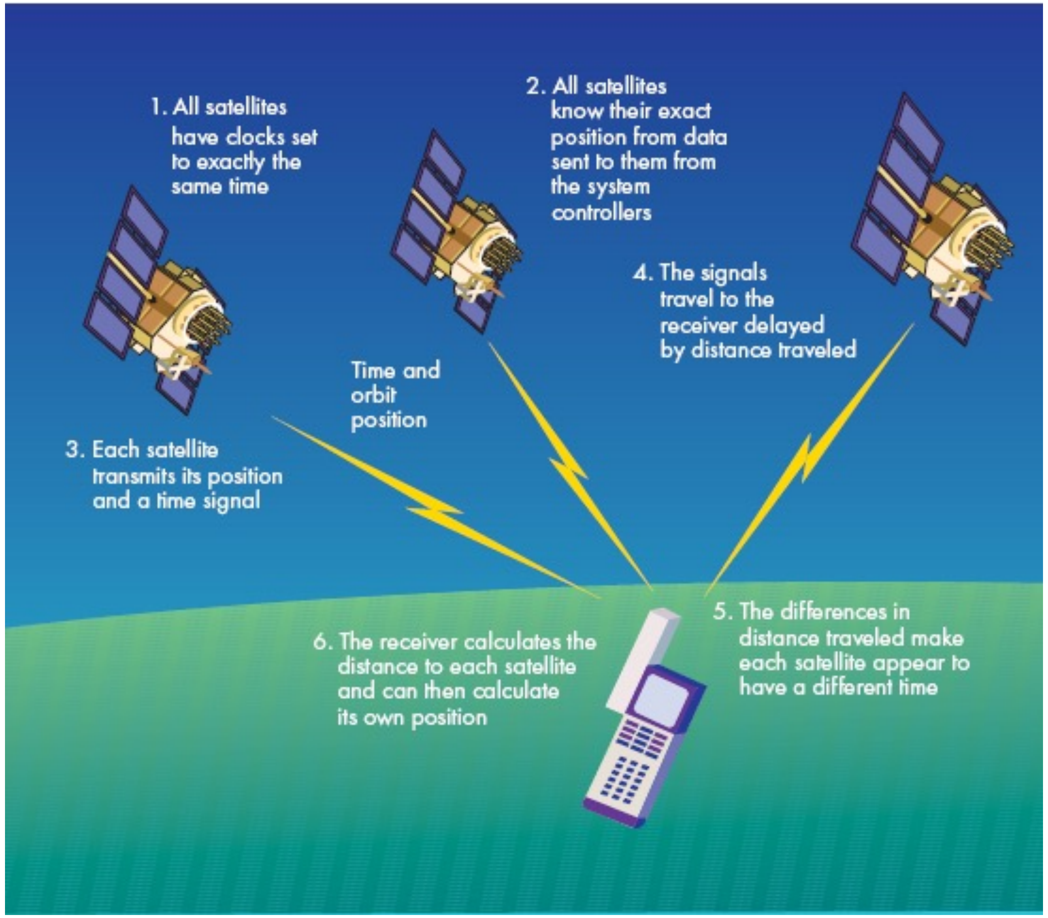


IRNSS service area is divided into three regions:

- ❑ Indian Land Mass : The area encompasses the Indian Geo-Political boundary.
- ❑ Primary Service Area: The area covered by 1500 km contour from Indian geopolitical
- ❑ boundary inclusive of the Indian Land Mass.
- ❑ Extended Service Area: The area between primary service area and area enclosed by
- ❑ the rectangle of Lat 30^0S to 50^0N, Long 30^0E to 130^0E.

NavIC System & Positioning





IRNSS Services

❖IRNSS will provide following services:

Standard Positioning Services (SPS)

➢ Open access service for all
➢ 20 m positioning accuracy in Primary Service Area

❖ Restricted Service (RS)

➢ Provide better position accuracies than SPS
➢ For Restricted Users only

NavIC Frequency Band & Transmit Polarization

Parameter	L5 band	S Band
Centre Frquency	1176.45 MHz	2492.028 MHz
Frequency Band	1164.45 – 1188.45 MHz	2483.778 – 2500.278 MHz
Polarization	RHCP (Right Hand Circular Polarization)	
Services	SPS (Standard Positioning Service) & RS (Restricted Service)	

Frequency Selection

The frequency selection is governed by

- Signal Compatibility
- Interoperability
- ITU regulation issues

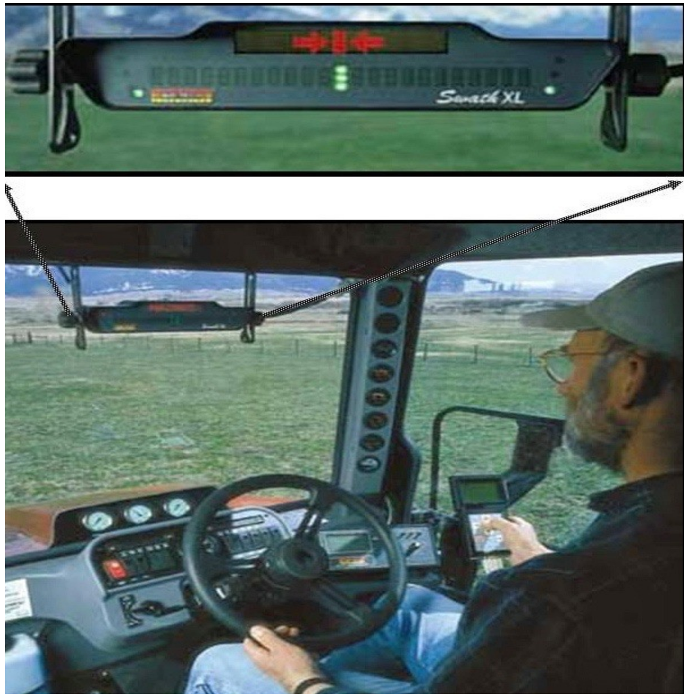
- ❑ L band is selected to provide interoperability with other systems like GPS, Galileo etc.
- ❑ S-band to enable dual frequency reception for Ionospheric correction.
- ❑ S-band will experience much less Ionospheric delay and Ionospheric scintillation than L5 band.

Satellite Navigation Data

IRNSS Navigation data

- Satellite Ephemeris
- Clock correction parameters
- Time of Week (TOW) and Week Number (WN)
- Ionospheric Correction Data
- Ionospheric Grid points data
- Alert Flag
- Almanac
- User Range Accuracy (URA)
- Autonav Flag
- IRNSS Time Offsets w.r.t. UTC & GNSS
- Text Message

Satellite Navigation Applications



Precision Agriculture or Smart Farming

Precision, Optimization & Automation in Agriculture with GNSS

- Precision agriculture is a comprehensive information based efficient farm management system of resources through location specific high tech interventions to identify, analyze and manage variability within fields for optimum profitability, sustainability and protection of land resources.
- GNSS guidance systems lay the ground for new levels of automation in Agriculture moving towards autonomous applications.

GNSS Technology in Ola & Uber Cab Services

- OLA & Uber use GPS technology to let users book a cab.

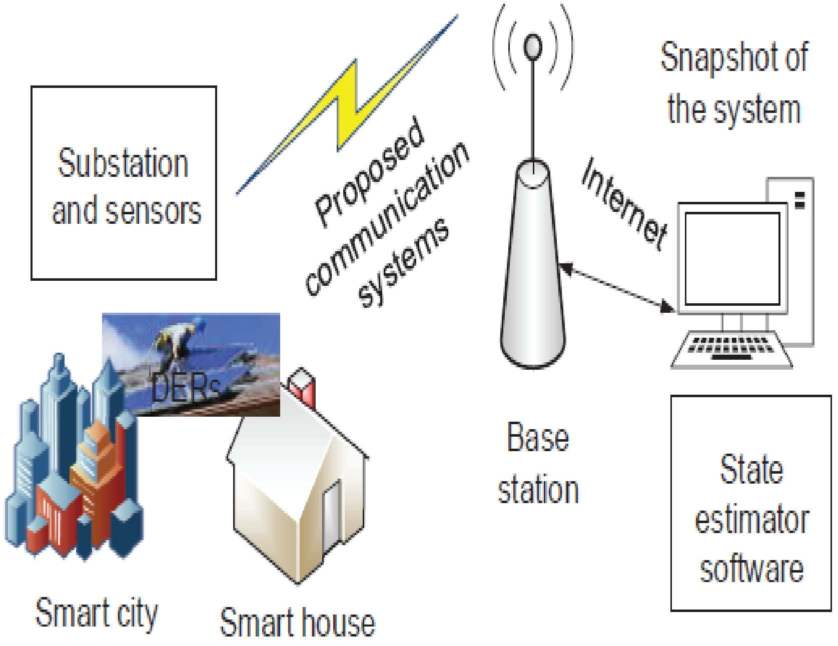
- Cab booking is done through mobile app equipped with the Mapping & Geolocation features using folloowing steps:

  - User makes request to server for a prticular destination
  - User location is required by app & is sent to the server
  - Server sends back information of available cabs
  - Server tries to contact all available drivers
  - Ones the driver accepts booking then driver ID & Geolocation is sent to the user
  - User then can track driver in real time display map along with location information through GPS.

➢ Optimum route planning is done using Artificial Intelligence (AI) based algorithms

GNSS Technology for Time Synchronization in Smart Grids: Com-Nav

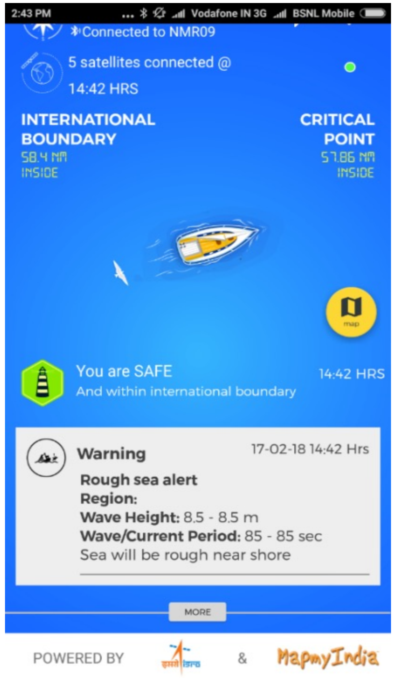
- GNSS Receivers are being used by National Power grid sites for time synchronization & stamping of power grid phasor measurements for Power grid control, measurements and monitoring applications.
- Renewable Distributed Energy Resources (DERs) are going to be integrated in smart grids.
- The observation from the multiple DERs is transmitted to a control center via the Internet of things (IoT) based fifth generation (5G) communication network.
- Based on this innovative ICT based communication infrastructure voltage regulation challenge is address by offering the two-way communication links for microgrid state information collection, estimation and control.
- Also NTP server with NavIC Time reference disseminating precise time in railways (CRIS) through ICT-based infrastructure.



A typical 5G & IoT communication system for DERs

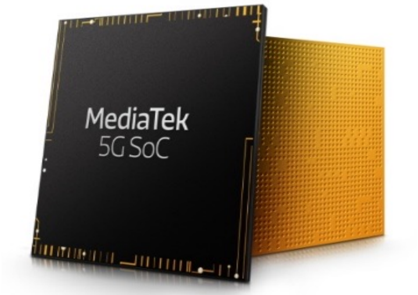
NavIC Messaging and Positioning Application

- NavIC Messaging receiver are capable of receiving Messages from satellite.
- Messaging units are being used by state fishery department.
- If fishermen are in any kind of distress, a rescue team may be sent to reported location.
- This is done through amalgamation of communication & navigation technologies.



NavIC Chips in Mobile Phones

- ❑ More than 6 GNSS modules are available in market supporting NavIC constellation
- ❑ NavIC is integrated in Qualcomm Snapdragon 720G, MediaTek Helio M70 and Broadcom BCM47765 mobile chipsets
- ❑ GPS chipsets are already available in mobile phones
- ❑ Raw GNSS measurements are also now available in mobile phones



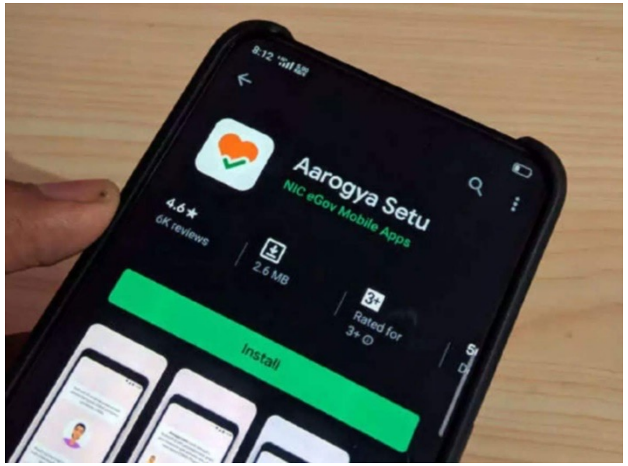
GNSS Technology for Survey & Land Records Digitization

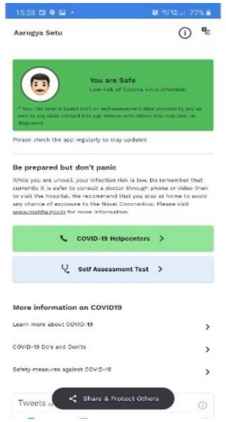
High Precision Applications

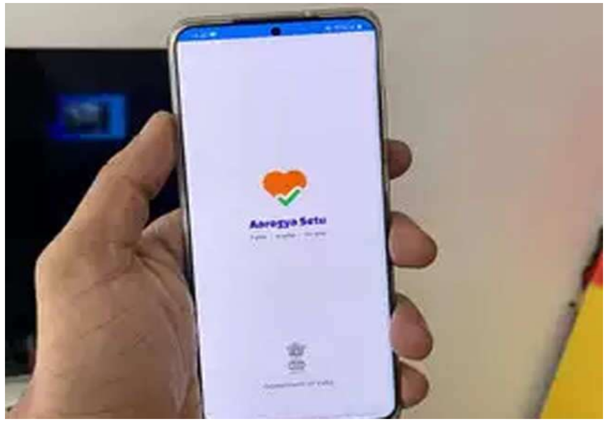
- As part of modernization, it is decided by the Government that further survey work should be done with the help of modern systems such as GPS & GAGAN & NavIC.
- Based on the government order the survey and land records department started survey with modern survey instruments.
- Many states have already ditized the records using GNSS Technology & made them available on websites under Digital India initiatives .

Contact Tracing: Aroygya Setu App for Covid-19

- One of the easiest way to control the spread of a Corona virus is to immediately inform the persons who recently had close contact with the diagnosed patients.
- However, to achieve this, a centralized authority (e.g., a health authority) needs detailed location information from both healthy individuals and diagnosed patients.
- “Arogya Setu” mobile app uses Bluetooth and algorithms based on Artificial Intelligence (AI) and will provide as innovation solution based on location information to protect the people from Covid-19.
- If a Corona patient comes into contact of somebody, he will be alerted.
- Also user’s location is tracked to see if he is in high risk zones of Corona infected people.







Navigation Applications Contd…

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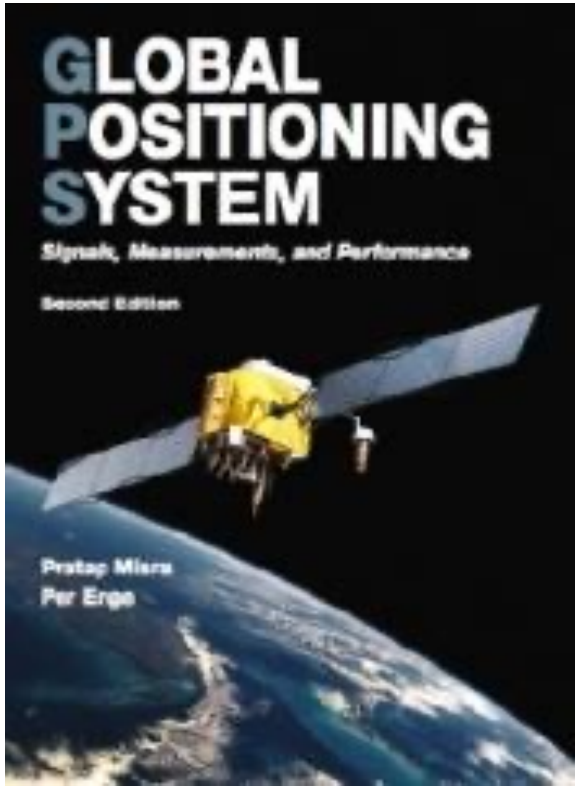
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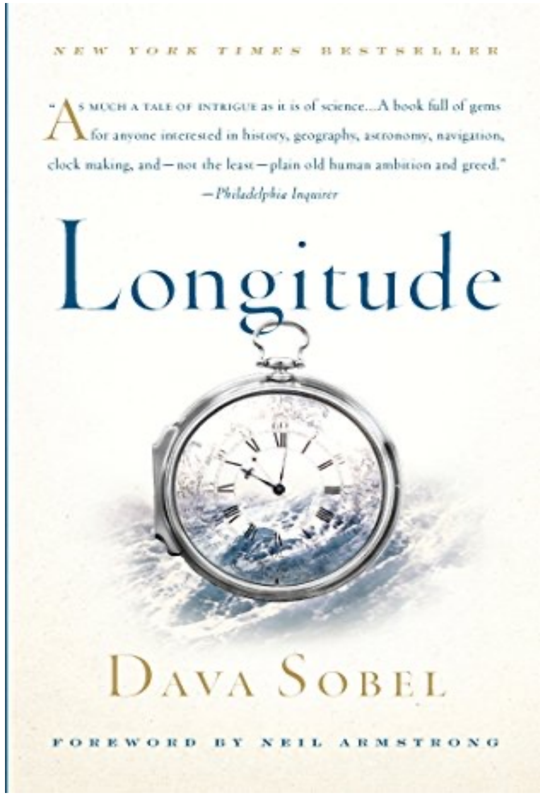
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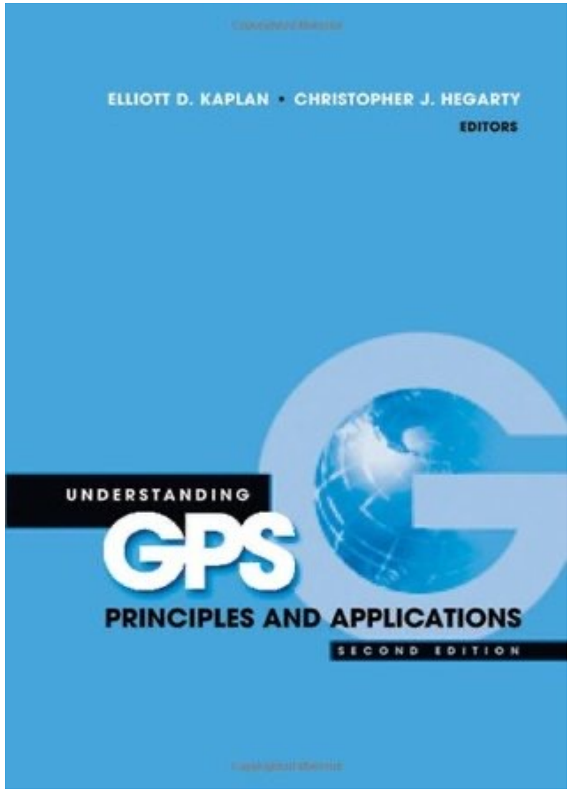
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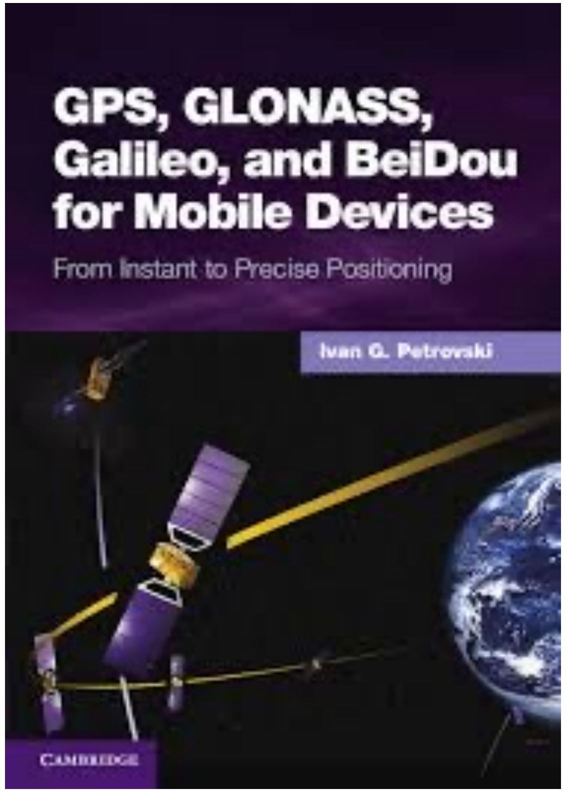
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From Instant to Precise Positioning
Ivan G. Petrovski
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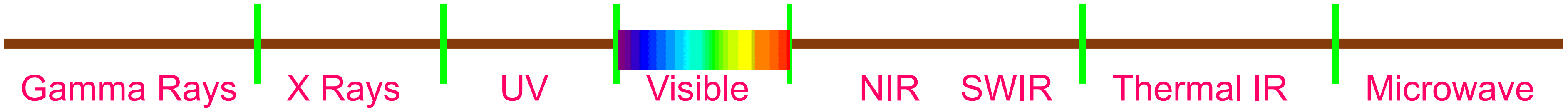
Part-B
GNSS Remote Sensing and its Applications

REMOTE SENSING AND EM SPECTRA

Optical Infrared (OIR) Region

Visible	0.4-0.7µm
Near infrared (NIR)	0.7-1.5µm
Shortwave infrared (SWIR)	1.5-3.0µm
Mid-wave infrared (MWIR)	3.0-8.0µm
Longwave IR(LWIR)/Thermal IR(TIR)	8.0-15µm
Far infrared (FIR)	Beyond15µm

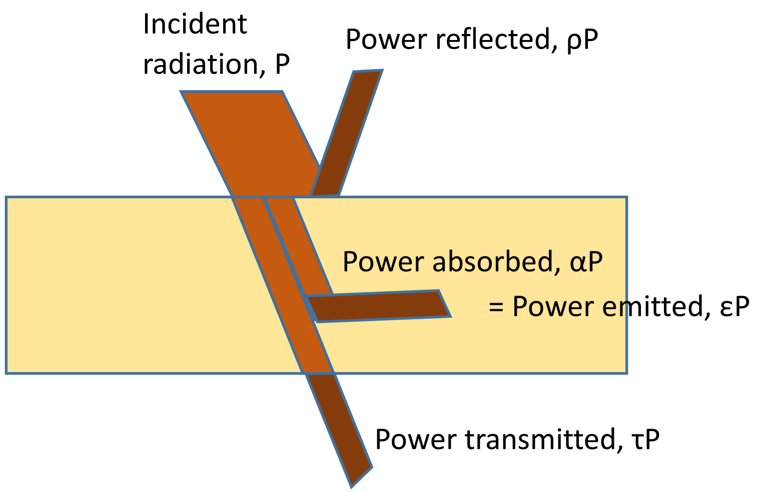


Microwave Region

P-band:	~0.25 – 1 GHz
L-band:	1 -2 GHz
S-band:	2-4 GHz
C-band:	4-8 GHz
X-band:	8-12 GHz
Ku-band:	12-18 GHz
K-band:	18-26 GHz
Ka-band:	26-40 GHz
V-band:	40 - 75 GHz
W-band:	75-110 GHz
mm-wave:	110 – 300GHz

- ***Sensors are 24x365***
- ***Signal data characteristics unique to the microwave region of the EM spectrum***
- ***Response is primarily governed by geometric structures and hence complementary to optical imaging***

DOMINANT MECHANISMS MEASURED BY SENSORS



$P = P_r + P_t + P_a$

$$\frac{P_r}{P} + \frac{P_t}{P} + \frac{P_a}{P} = 1$$

$\rho + \tau + \alpha = 1$

At thermal equilibrium, absorption and emission are the same.

1) Reflection

Optical cameras
LIDARs
RADARs

2) Emission

Radiometers

What are passive and active sensors?

Sensors which carry their own source of illumination to measure reflection / scattering are called active sensors (LIDARs and RADARs)

And, those which do not require are passive sensors (Cameras & Radiometers)

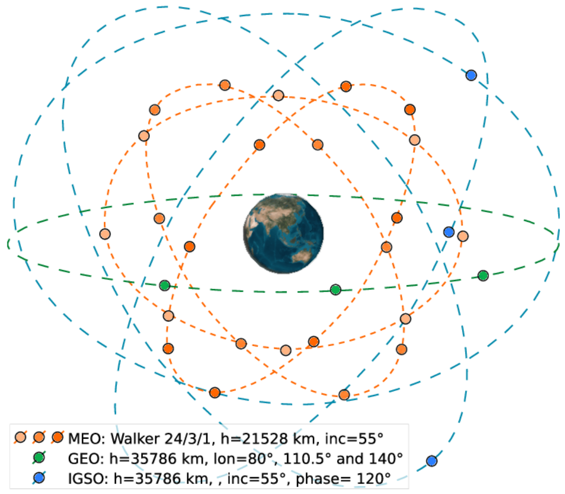
GNSS/RNSS CONSTELLATIONS

GPS
- 6 Orbital planes
- 24 Satellites + Spare
- 55° Inclination Angle
- Altitude 20,200km

Galileo
- 3 Orbital planes
- 27 Satellites + 3 Spares
- 56° Inclination Angle
- Altitude 23,616km

GLONASS
- 3 Orbital planes
- 21 Satellites + 3 Spares
- 64.8° Inclination Angle
- Altitude 19,100km

7 Satellites Covering INDIA for IRNSS / NAVIC



Beidou

So many microwave transmitters around the world…!!!
Need some receivers to make best use of it!!

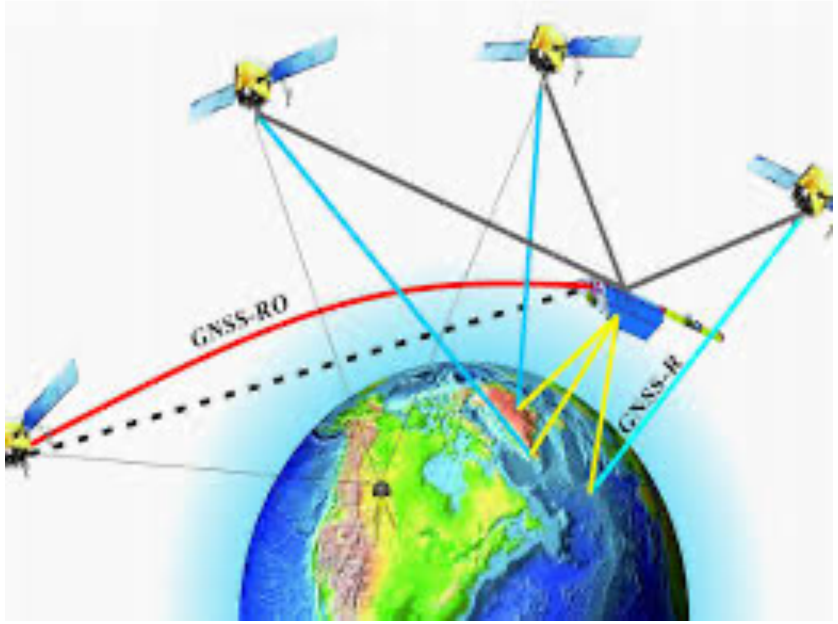
GNSS REMOTE SENSING

GNSS Remote Sensing can be divided in two categories :

- Depending on the way the signals (Direct or Reflected)materials are used:-

    (1) GNSS Reflectometry (GNSS-R)
    (2) GNSS Refractometry (known as GNSS Radio Occultation or GNSS-RO)

- GNSS-R involves analysing measurement of GNSS signals reflected from the earth surface.
- GNSS-RO utilises measurement of GNSS signals refracted by the atmosphere when the slanted propagation path is close to the earth's limb.



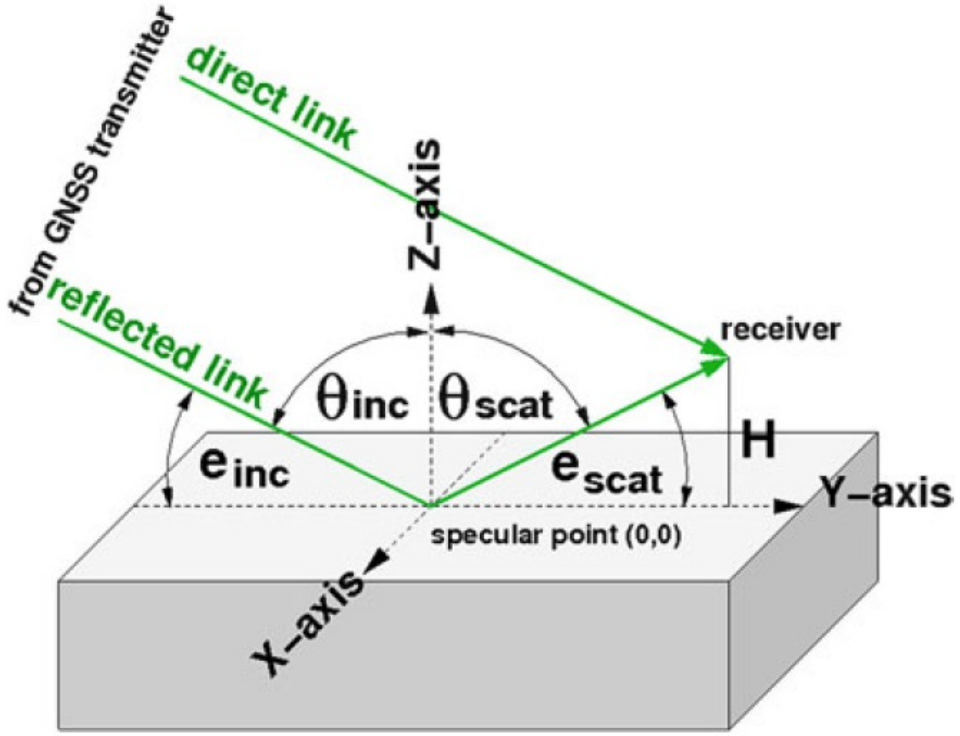
GNSS REFLECTOMETRY

- GNSS-R works as a bi-static/multi-static radar
- Received signal has contributions from different GNSS sources which can be separated by making use of their respective modulation.

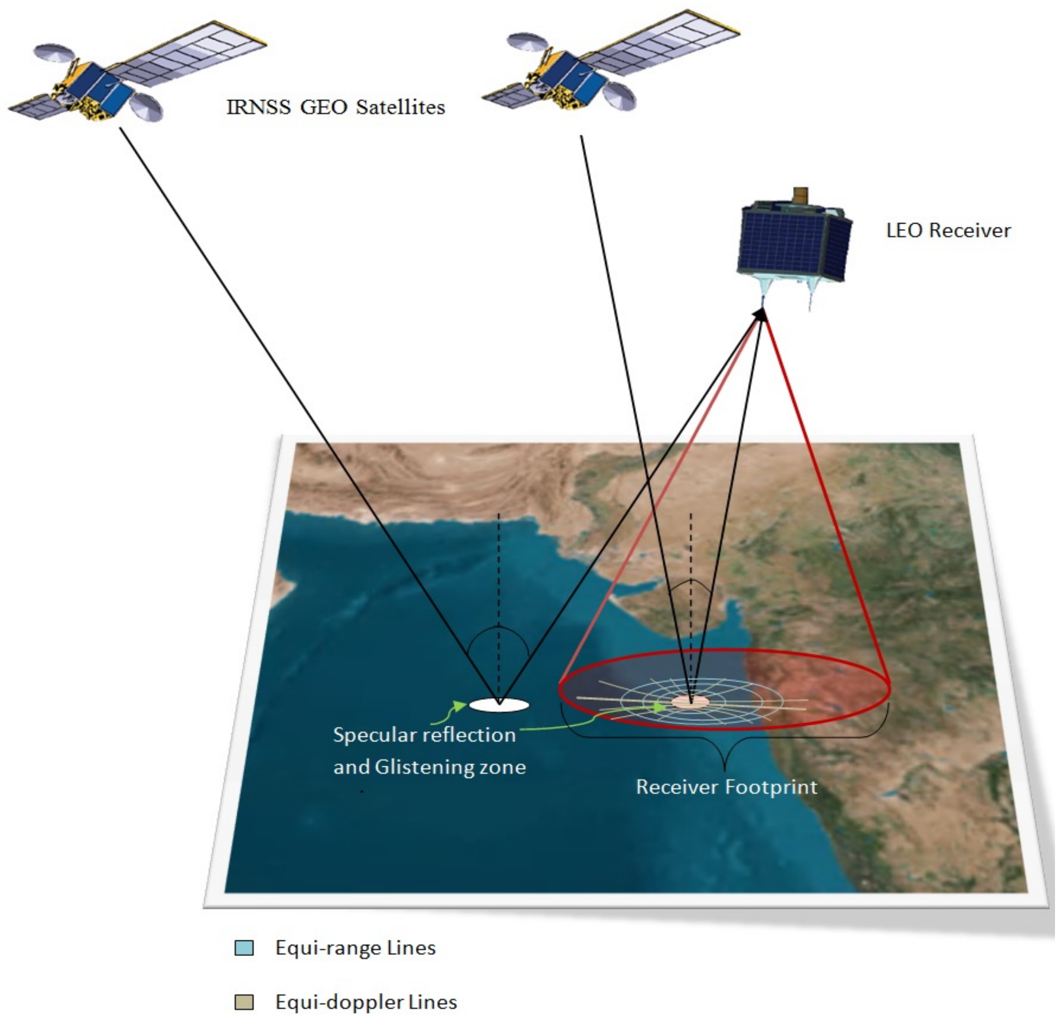
- **Direct rays will be RHCP polarization and reflected signals will be LHCP.**

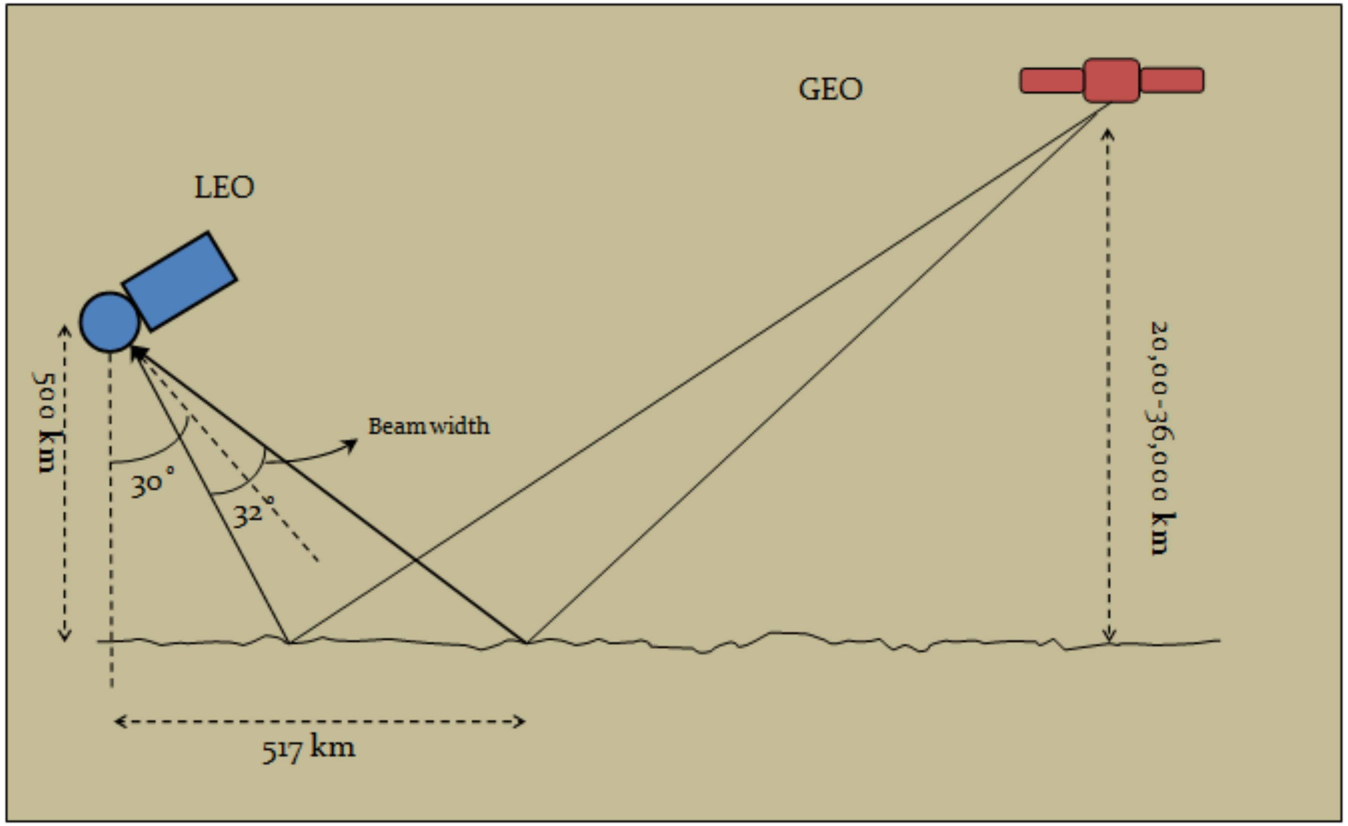
❑ Two ways by which reflectometry can be done:

1. By measuring interference caused due to net of direct and reflected signals, using receiver with RHCP antenna
2. By measuring the reflected signals separately, using receiver with LHCP antenna.



TYPICAL IMAGING GEOMETRY





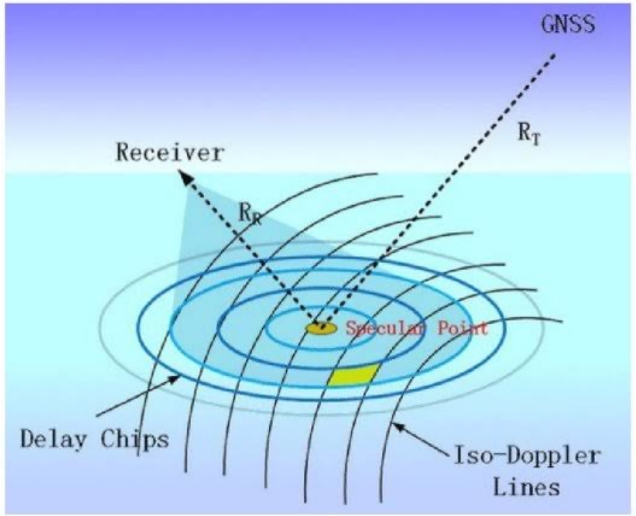
indicative geometry of the LEO-GEO satellite duo

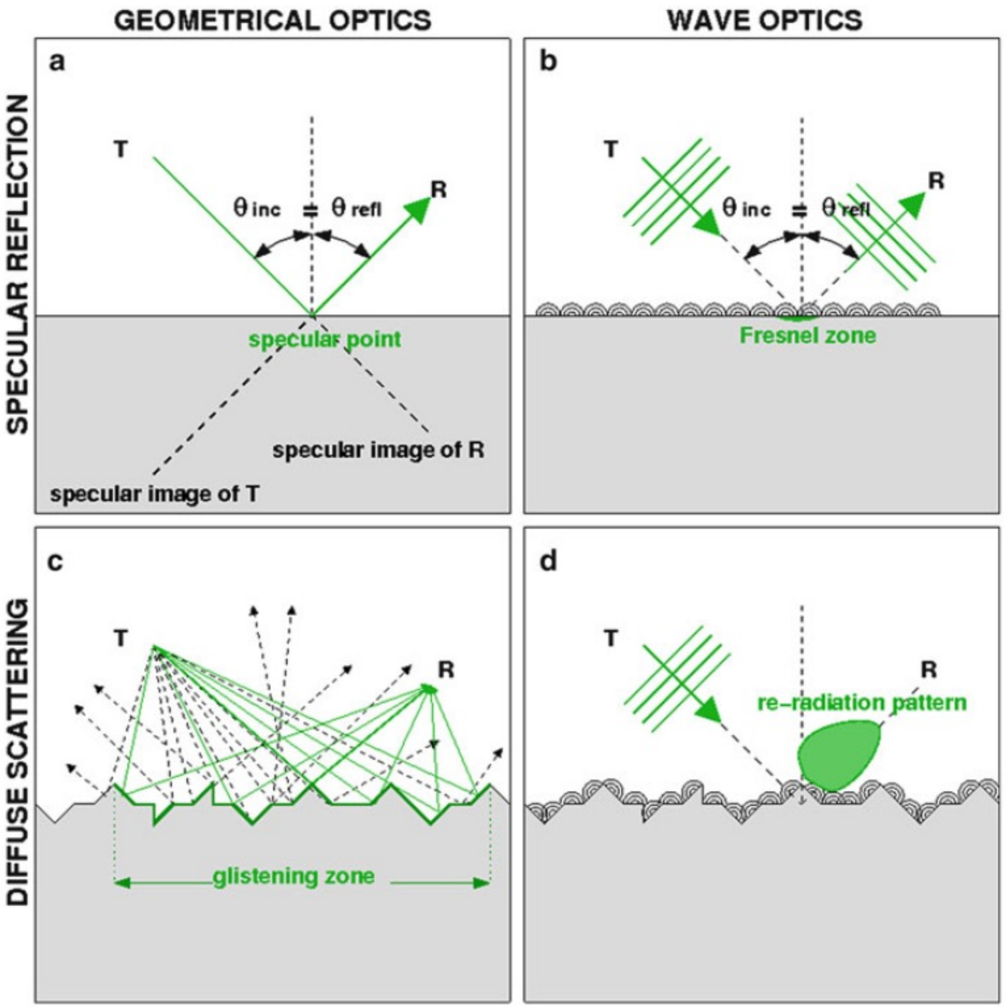
GNSS signals of opportunity are relatively weak, the scattered signal is received only from the area around the nominal specular point on the surface called a ***glistening zone.***

BISTATIC REFLECTIVITY

- Bi-static reflectivity is complementary to Radar backscatter.

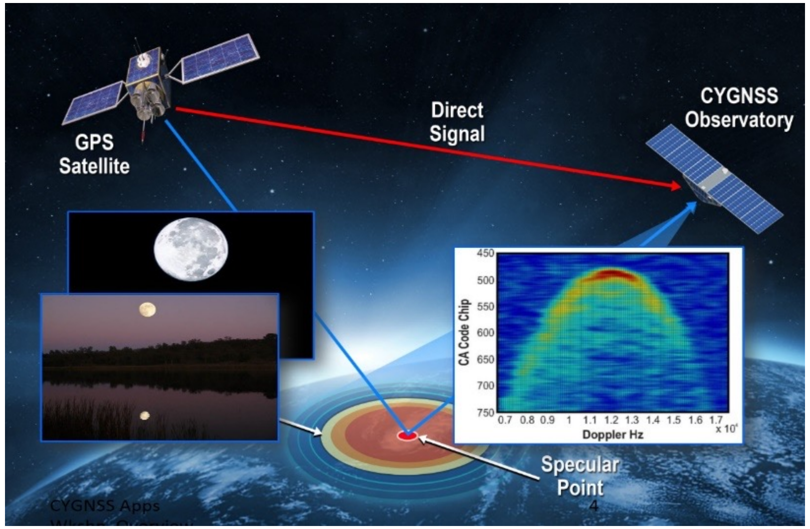
- If surface is smooth, bistatic reflectivity will be max at specular angle (refl angle = inci angle), but backscatter will be minimum
- Vice-versa for rough surface





CYGNSS MISSION

- Mission aims to study of ocean winds and waves in tropical cyclones
- Constellation of eight Low-Earth orbit micro-satellites in an equatorial orbit at an inclination angle of 35°.
- Each micro-satellite is capable to receive four reflections at a time so total 32 signals can be recorded corresponding to different locations on the earth.



- Delay Doppler Mapping instrument is used to receive the direct signal from GPS and the reflected signal from the land as well as ocean surface.

GNSS-R BASED APPLICATIONS

There are Different types of Application of Global Navigation Satellite System Reflections Technique

Remote Sensing

Ocean
- ❑ Altimetry
- ❑ Sea State

Land
- ❑ Soil moisture
- ❑ Vegetation height
- ❑ Surface topography

Sea Ice
- ❑ Altimetry
- ❑ Age

Snow
- ❑ Snow thickness

SOIL MOISTURE RETRIEVAL USING GNSS-R

- **In-situ measurements:** Extensive measurements not possible frequently
- **Using Spaceborne radar (SAR)**: Temporal Resolution: few weeks,
  Spatial resolution : sub-kilometre
- **Using Spaceborne Radiometer**: Spatial Resolution ~40 km,
  Temporal Resolution 2-3 days

- **Using GNSS-R (Eg. Cyclone GNSS : CYGNSS) :**
  Less expensive
  Temporal Resolution : Everyday
  Spatial Resolution: few kilometres

ADVANTAGES OF SOIL MOISTURE ESTIMATION USING GNSS-R

- GNSS signals are at L-band, which is optimal for SM remote sensing due to the increased ability to penetrate vegetation relative to shorter wavelengths.
- Constellation of receivers ***shortens revisit time*** compared to a single satellite.
- Simplicity and ***low-cost*** passive instrumentation, which enables smaller instruments, smaller satellites, and larger constellations.
- Constellation can compensate for a sparse swath of a single satellite and will increase the ***global coverage*** by decreasing the repeat time compared to a single satellite. global coverage achieved with an average revisit time of less than two hours globally.

CYGNSS DERIVED RADAR REFLECTIVITY

- Surface reflectivity (SR) is derived from Delay Doppler Maps (DDMs) corresponding to each specular point,
- DDMs represent the relation between the surface reflected signal power and the replica signal which is stored in the receiver
- The peak intensity of the DDM at specular point can be translated into surface characteristics which include the dielectric constant and surface roughness.

$$P_{rl}^{r} = \frac{(P_r^t * G^t)}{4\pi(R_{ts} + R_{sr})^2} \frac{(G^r * \lambda^2)}{4\pi} \Gamma_{rl}$$

Where,

P_r^t transmitted RHCP power,

G^t gain of the transmitting antenna,

R_{ts} distance between the transmitter and the specular refection point,

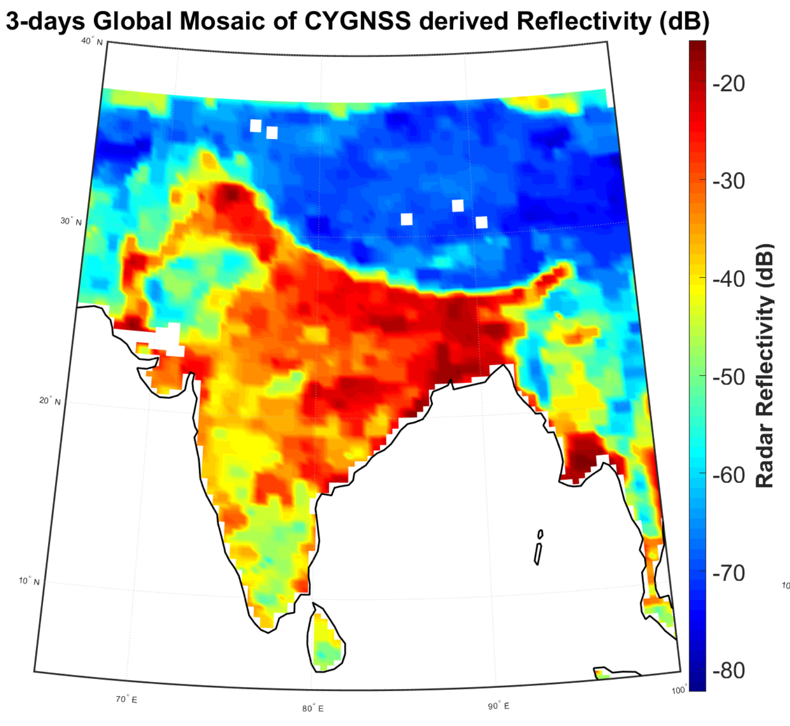
R_{sr} distance between the specular refection point and the receiver,

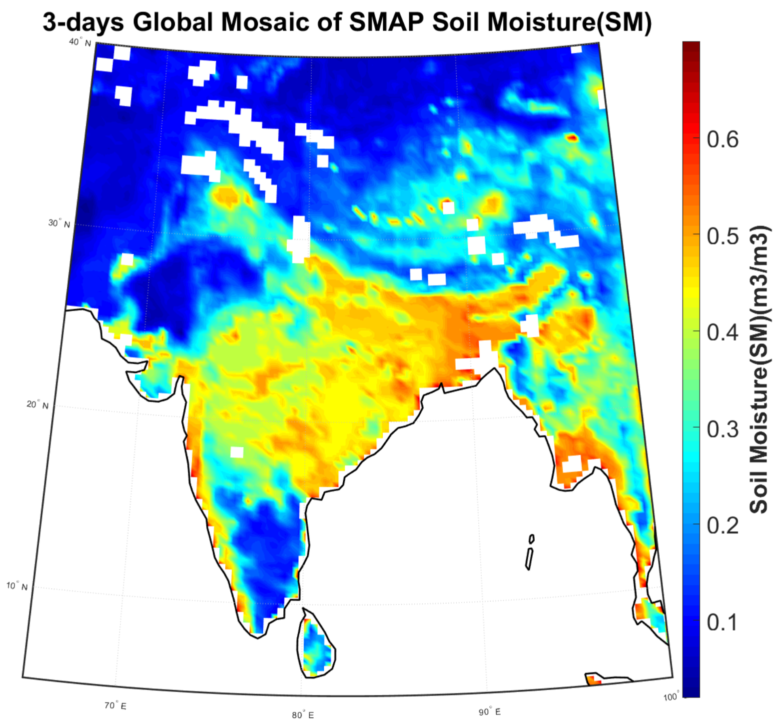
G^r gain of the receiving antenna,

λ GPS wavelength(0.19 m),

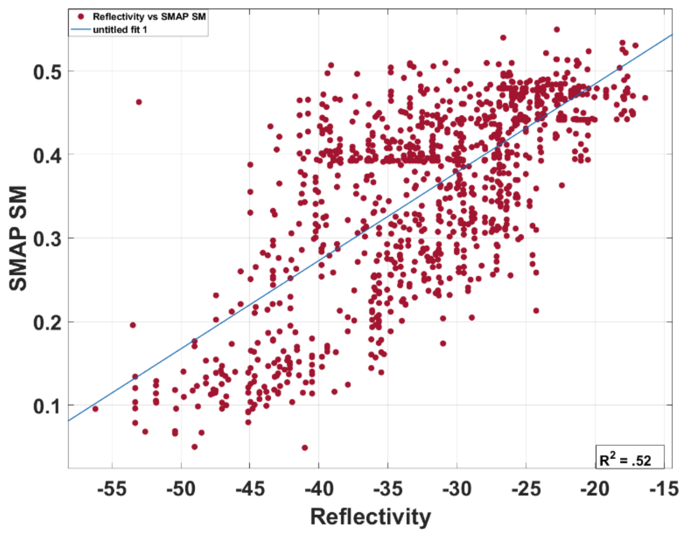
Γ_{rl} surface reflectivity

CYGNSS DERIVED REFLECTIVITY





CYGNSS derived Reflectivity and SMAP SM 3-days mosaic map over India from 22/08/2018 to 24/08/2018



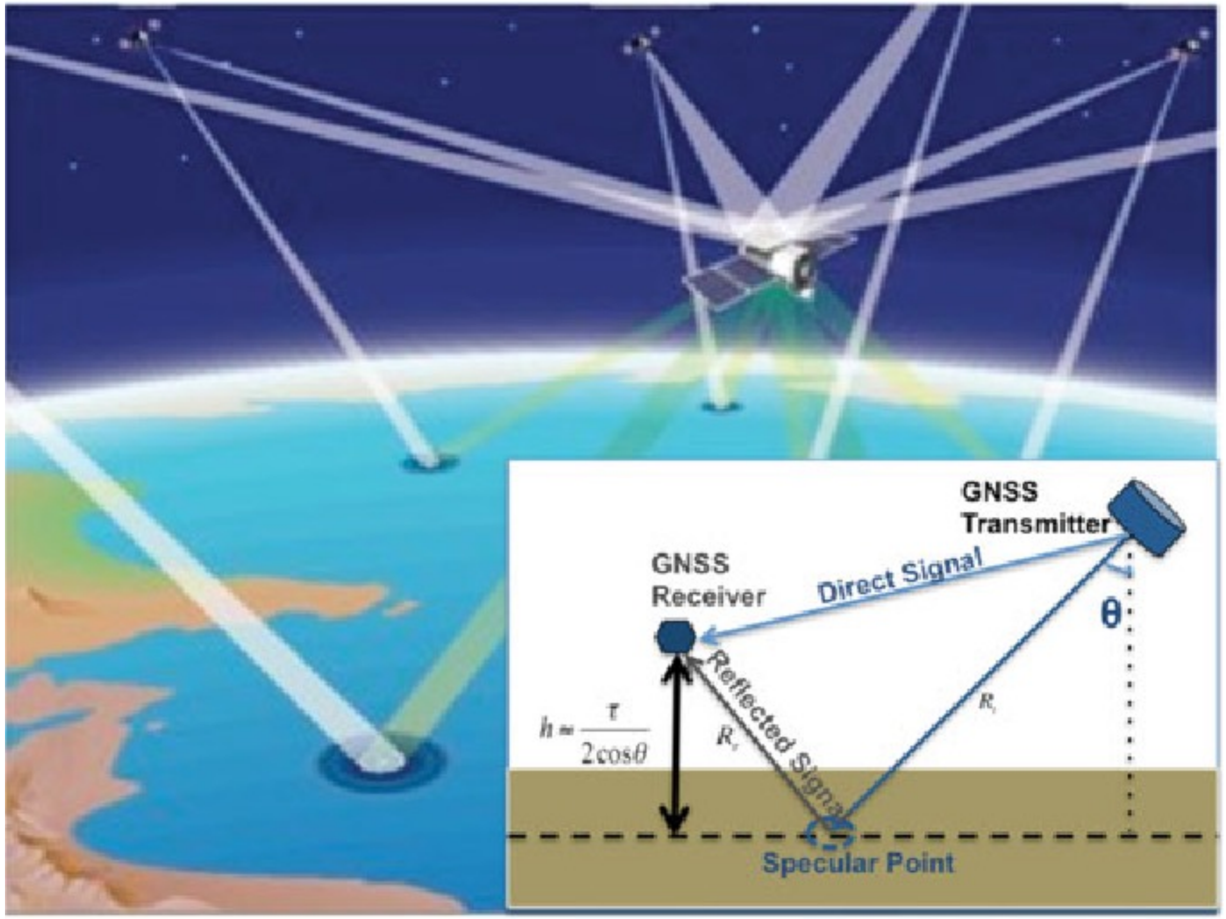
Scatter plot of SMAP SM and CYGNSS derived reflectivity

Ocean Based Application
Altimetry

The altimetry technique is used for determination of the sea surface height and its also valid for altimetry over any other surface that can reflect enough power to enable precise observables.

The altimetric techniques can be applied to reflections off any surface, but their performance will depend on the signal-to-noise ratio of the scattering.

Therefore, GNSS-R altimetry has been only conducted on strongly reflecting surfaces and geometries, such as waters and smooth ice, or land at near-surface receiver altitudes.



Sea State Information

As shown this images. This sensor will provide very useful altimetry and sea state information from at least, low altitude applications (e.g.,coasts or aircraft).

To apply algorithms for operational code and phase tracking of the reflected field and extraction of geophysical parameters.

So reflected signals carry significant information on sea state and topography, and both experimental work and simulations have demonstrated the potential of this concept for coastal and airborne altimetry and sea state monitoring.

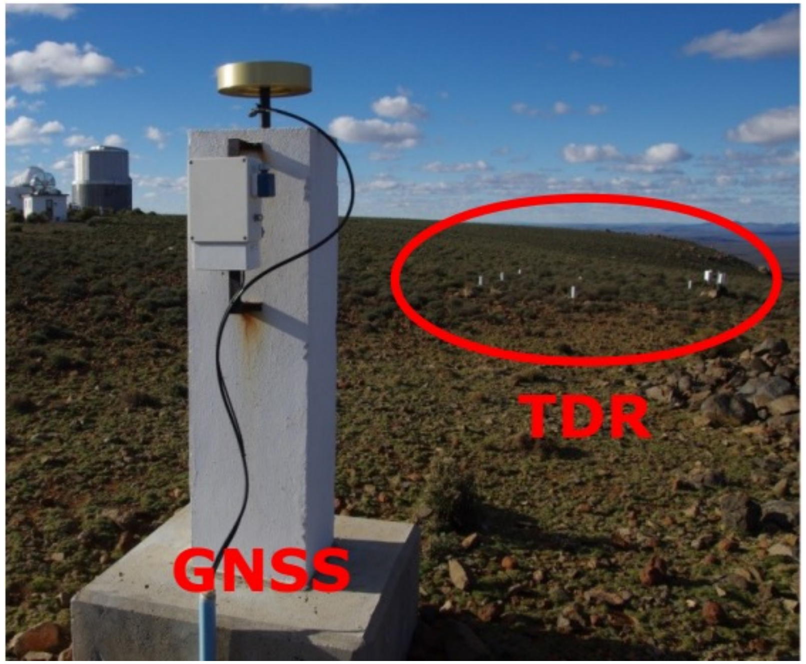
Kiruna,sweden

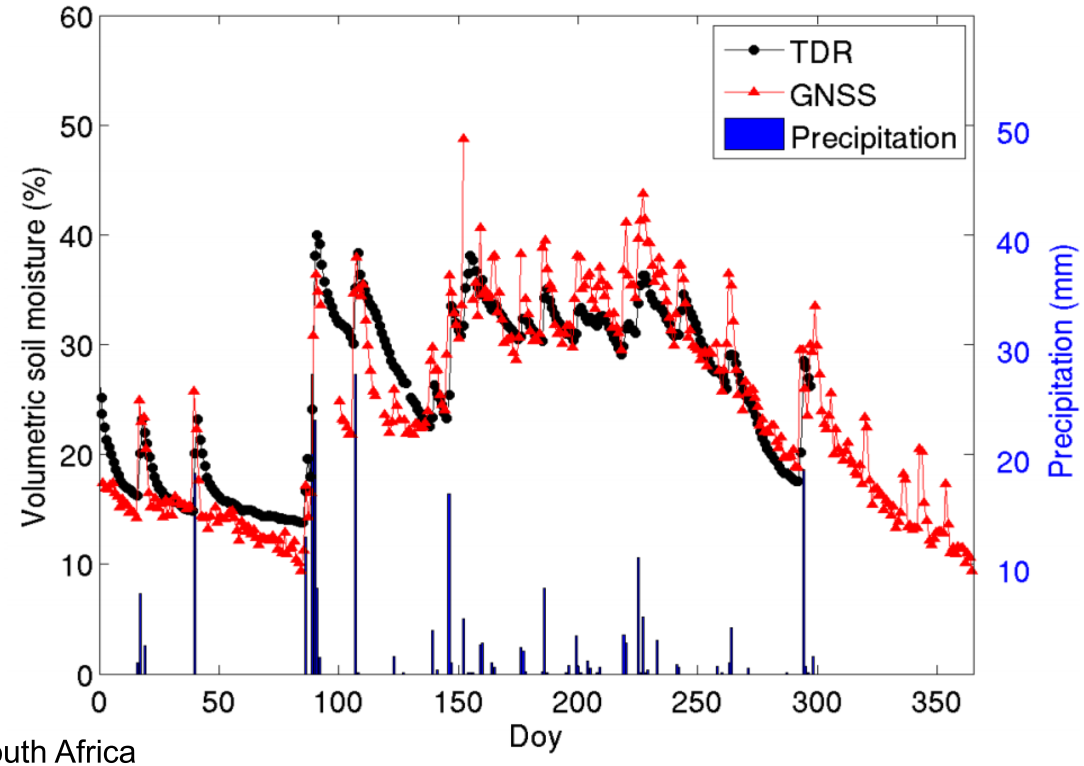
Land based Applications
Soil moisture

GNSS-R could be also applied for land applications such as the retrieval of ground vegetation condition and soil moisture.

Soil moisture remote sensing is based on the large contrast of the dielectric properties of wet and dry soils throughout most of the electromagnetic spectrum. Active and passive sensors have been used from airborne and spaceborne platforms for the estimation of the scattering properties of soil, which can then be used to estimate soil moisture.

Among the active sensors used for this purpose, one could essentially identify microwave radars, while on the passive side, optical spectrometers and microwave radiometers are the most important ones.





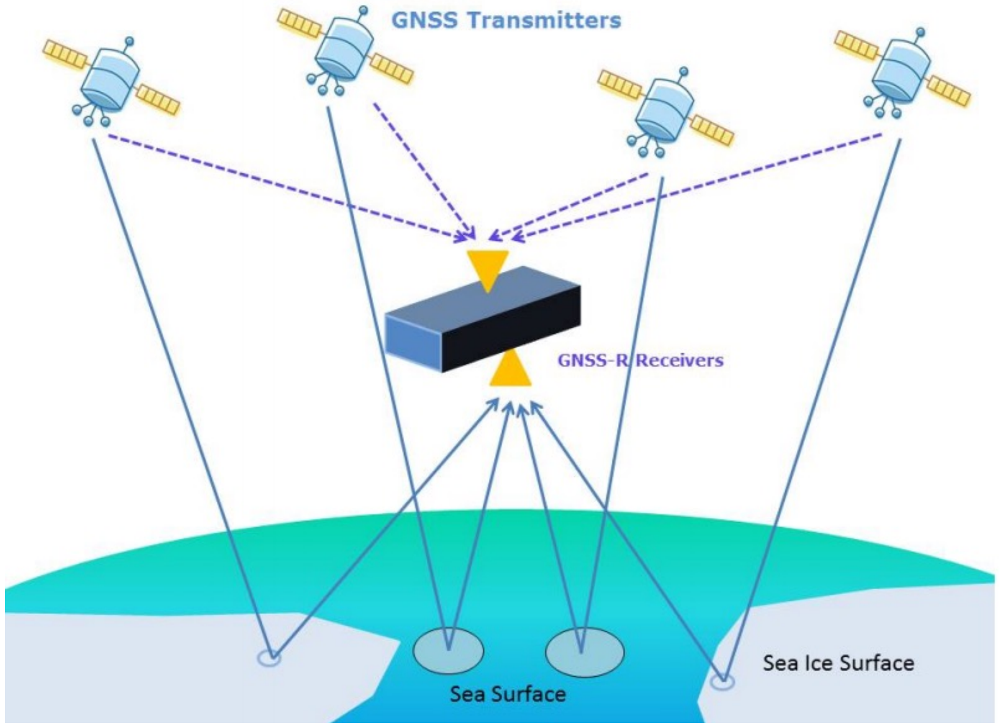
Soil moisture at Sutherland,South Africa

Sea Ice

GNSS-R can be used to retrieve main parameters of sea ice i.e. thickness,concentration, surface roughness and ice permittivity.

These parameters can be combined to help characterize different ice types including new ice, young ice,thin first-year ice, first-year ice, and multiyear ice.

Sea ice thickness is a key parameter for classification and characterization of sea ice masses, which influence the temperature and circulation pattern of both the ocean and atmosphere and thus can be used for analyses of the Earth’s climate.



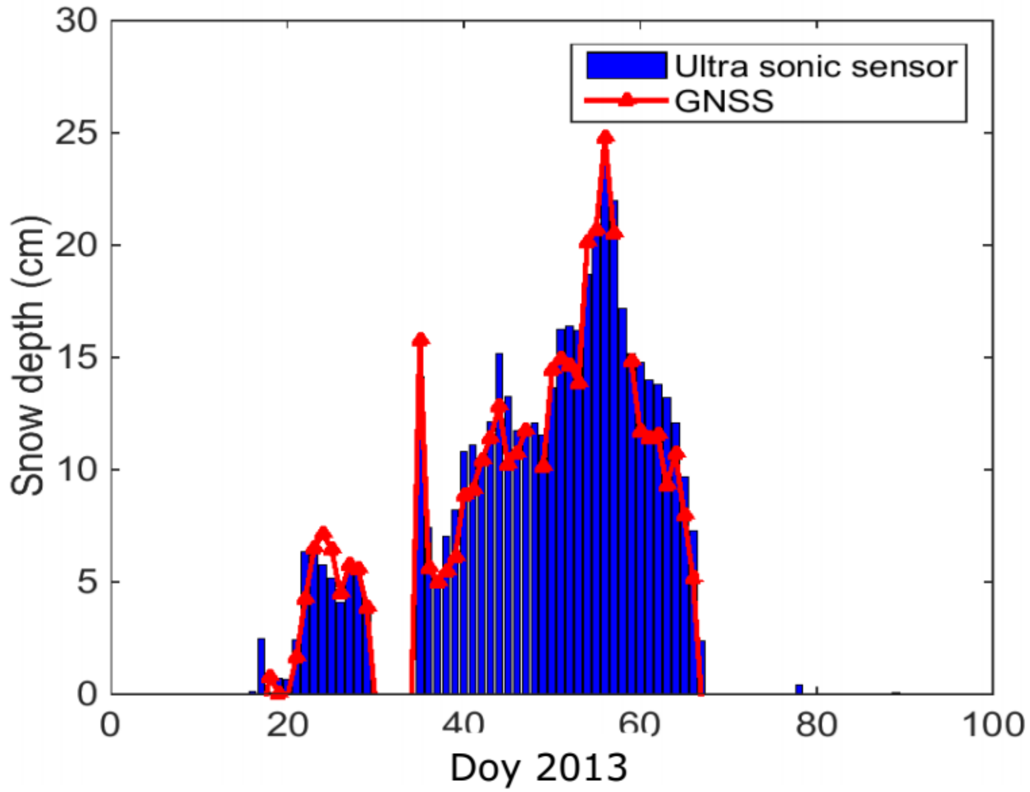
Snow Depth

Continental snow is currently being monitored with GNSS reflectometry as it occurs in geodetic GNSS stations.

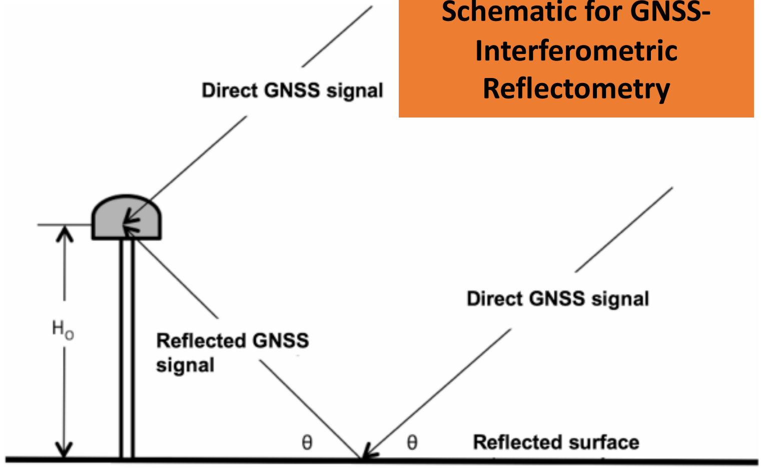
The multi-path reflectometry technique analyses the interferometric pattern to infer the depth of the snow.

The measurement principle is based on the frequency of the interference to measure snow depth variations or on both its frequency and amplitude to solve for snow thickness and equivalent water content.

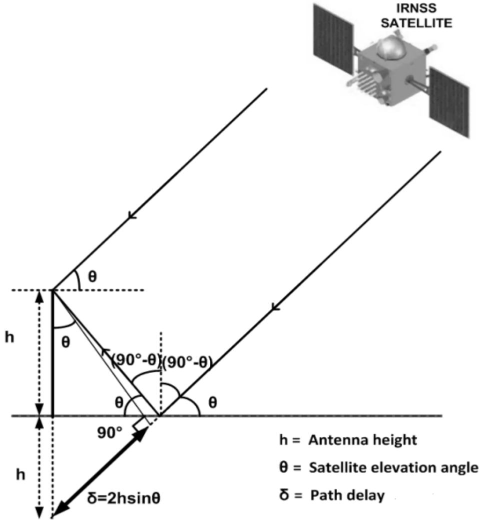
GNSS derived snow depths correspond very well to in-situ observations by an ultra sonic sensor (RMSE 1.7 cm)



Basic Principles of GNSS-IR using NavIC



Schematic for GNSS-Interferometric Reflectometry



Geometry of Multipath Reception

- Path difference causes interference at receiver.
- Multipath C/N_o is given as.

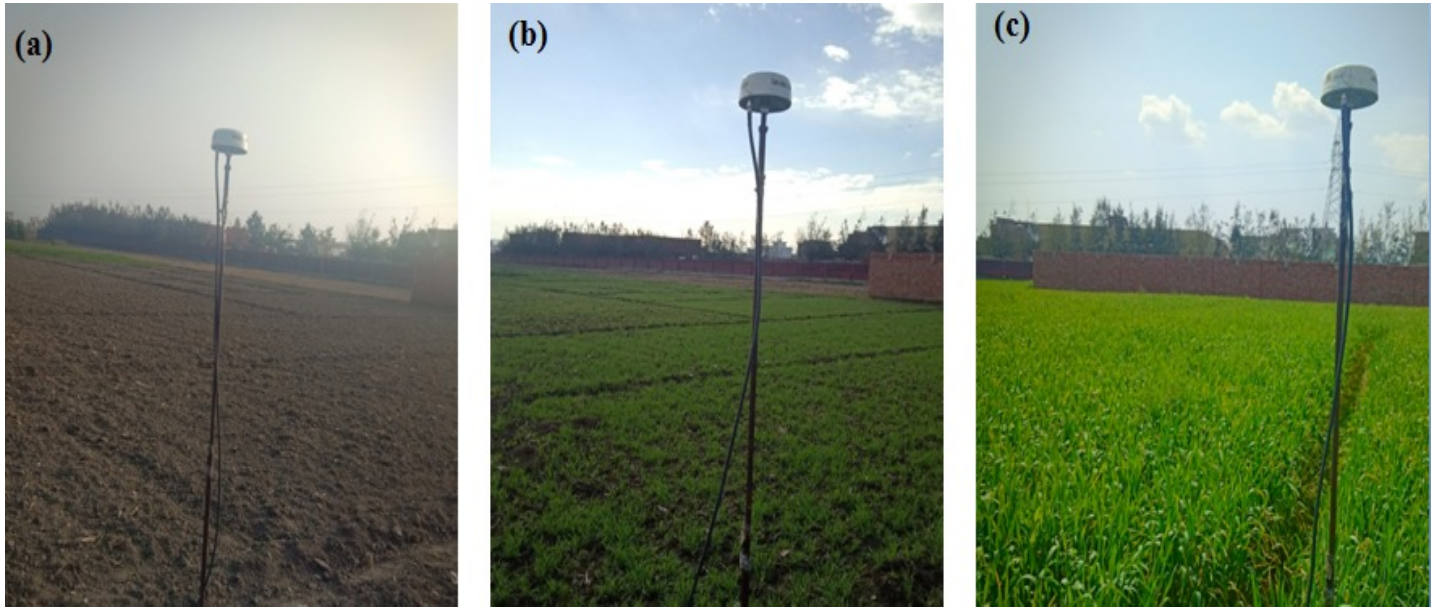
$$C/N_{\circ\, mpi} = A\cos\left(\frac{4\pi h}{\lambda}\sin\theta + \phi_{mpi}\right)$$

Where A is multipath Amplitude

ϕ_{mpi} **is the multipath phase**

Study Area and Data Used for Field Experiments

- NavIC L5 band data utilized for Field experiments.
- Observations were carried out at Dehradun, Uttarakhand, India:



Field Photographs of NavIC Receiver deployment

- **The in situ soil moisture was collected three times a day and reported soil moisture value is average of 20 samples.**

Soil Moisture Retrieval under Crops Using GNSS Interferometric Reflectometry Technique:

Potential of NavIC data for Agriculture Applications

Developed a vegetation correction schemes using ***NavIC SNR derived Multipath Phase*** as observables for Soil Moisture retrieval over crop covered (winter wheat) soil with improved accuracy (ubRMSE < 0.04 m^3/m^3).

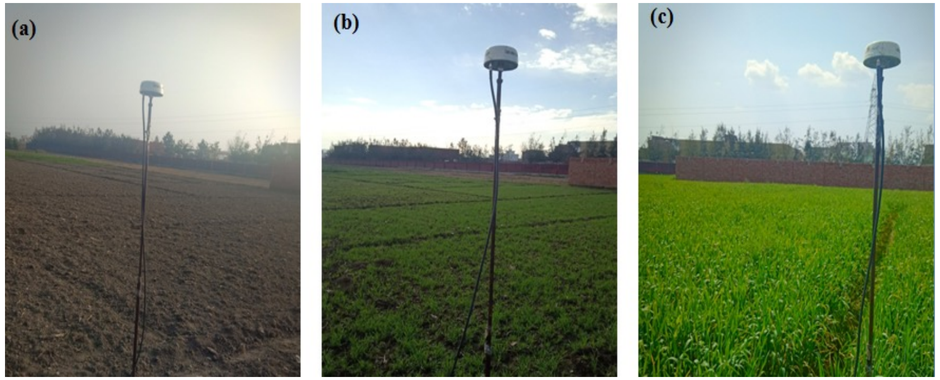
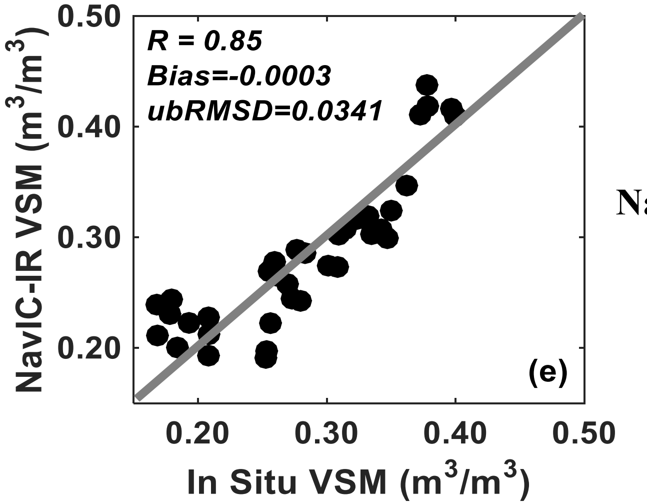


Fig. 1: Geodetic antenna installed at height of 2.1 m at winter wheat agricultural field. Figure shows different stages of crop growth such as (a) seed sowing (b) sparse vegetation at crop height of 10 cm and (c) grown wheat crop at 72 cm.



***Scatter plot between NavIC-IR VSM and *in-situ* VSM**

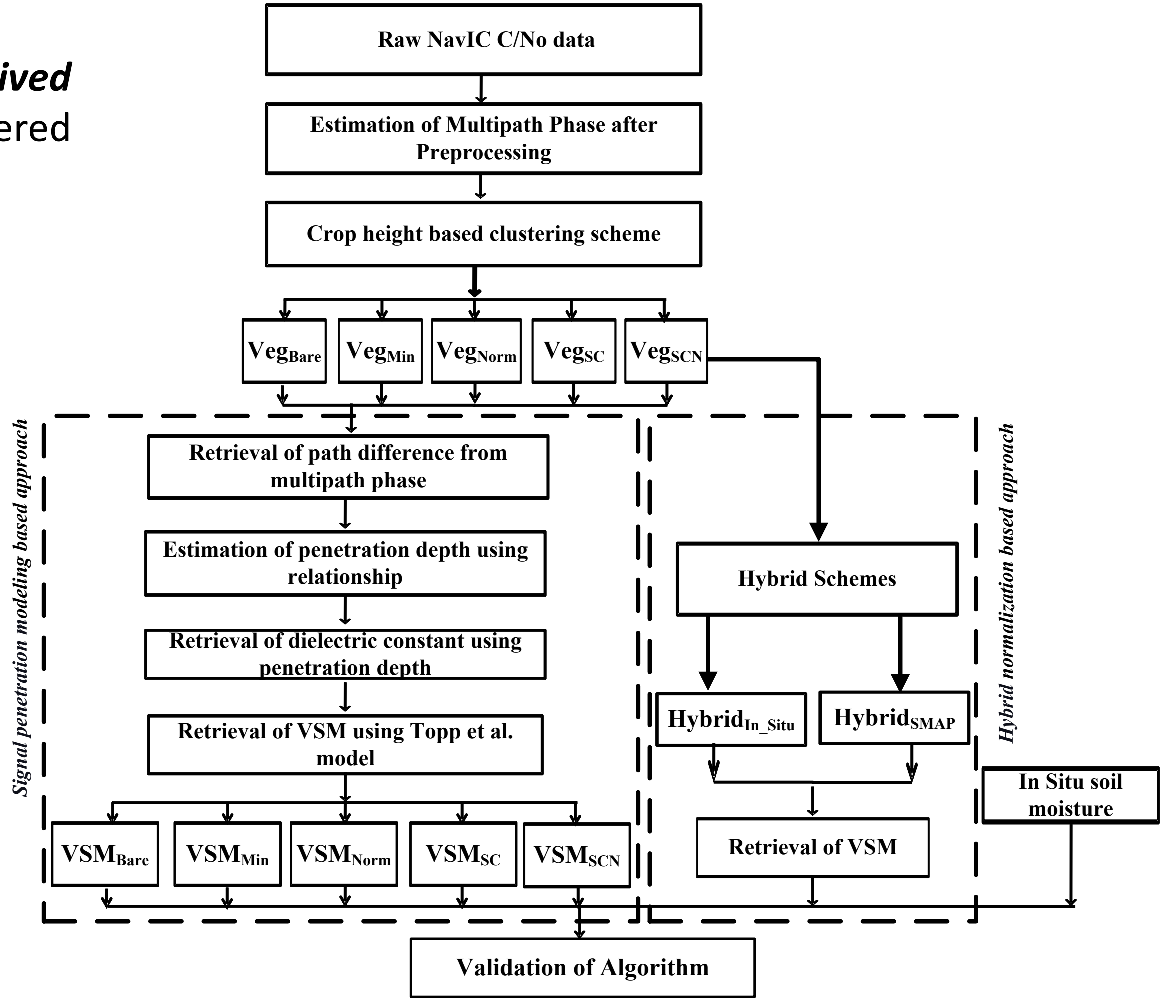


Fig. 2: Flowchart for field scale VSM inversion scheme with adaptive vegetation correction Scheme

Thank You!!!