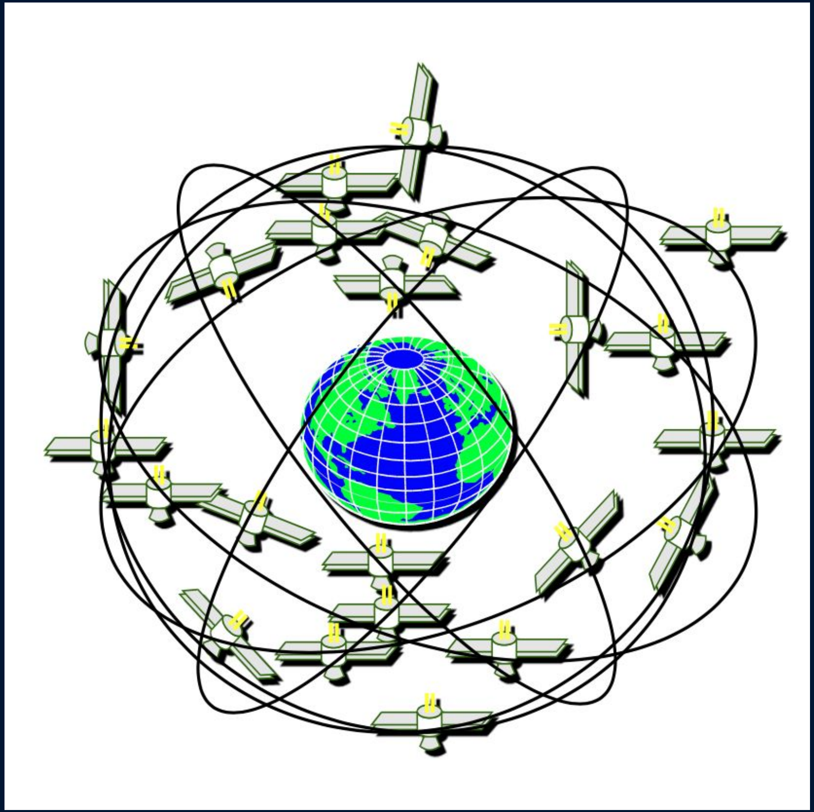
# GNSS Errors

By Halmat Atta Ali

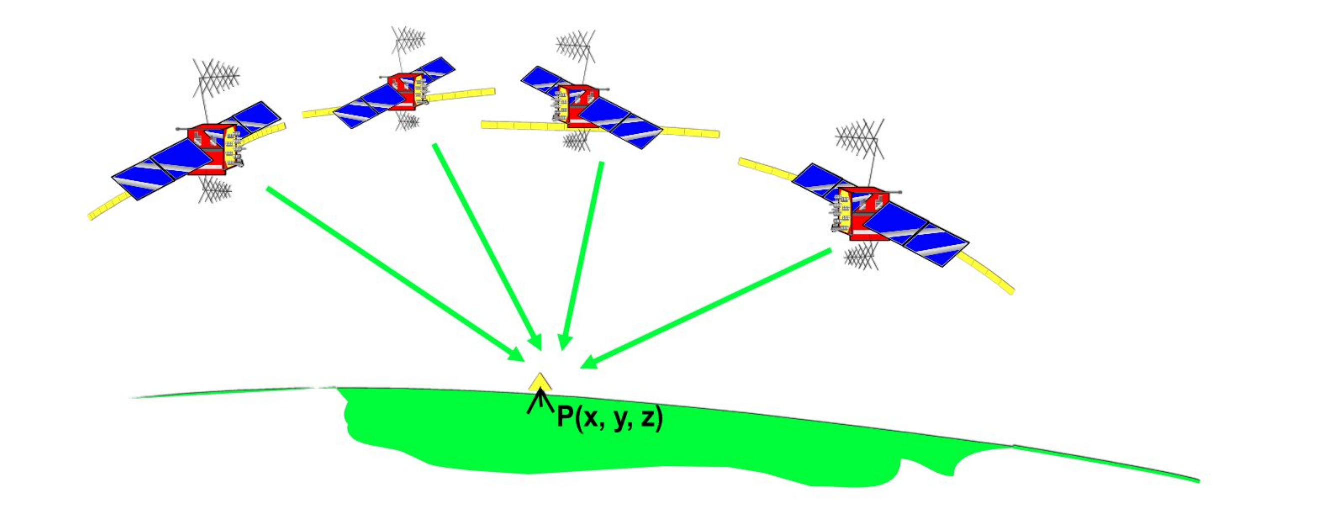
BRGTC

# GPS constellation



- 24 Satellites
- 6 Orbital planes
- 55° Inclination
- 20200 km above the Earth
- 11h 58m orbits

# GNSS Concept

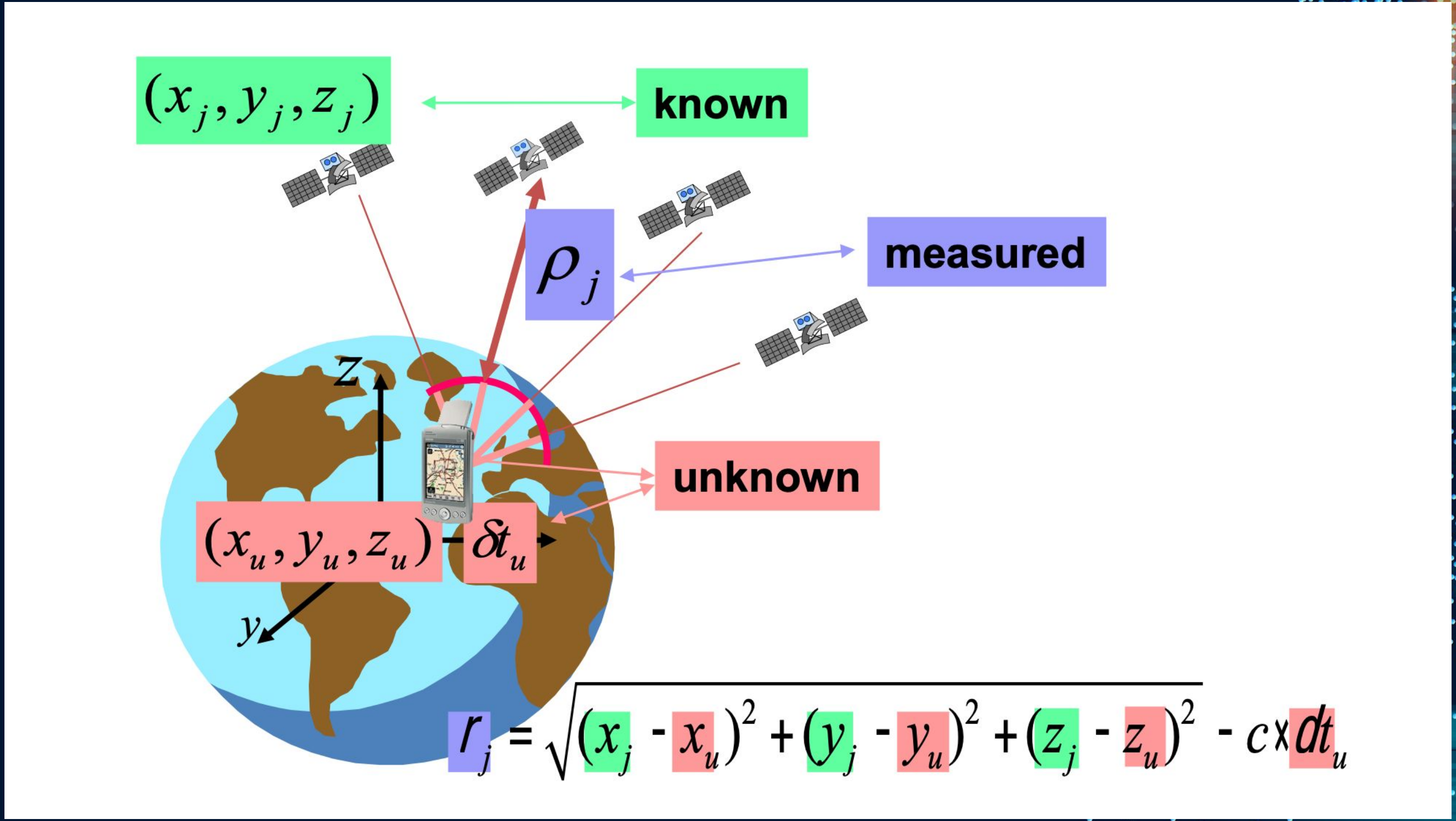



User measures distance to four satellites

Satellites transmit their positions in orbit

User solves for position (X,Y,Z or Φ, λ, h) and clock error Δt

# Pseudorange measurement

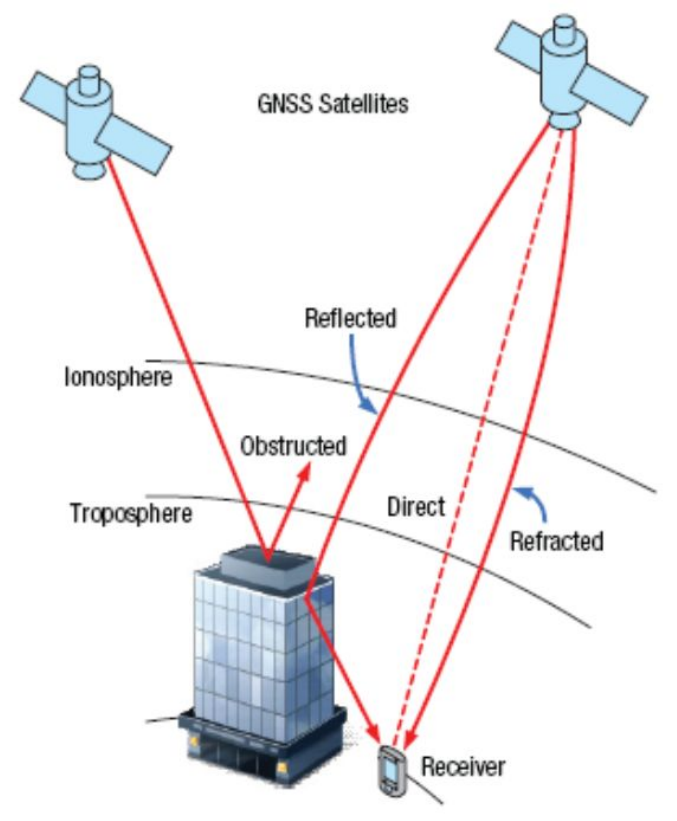


# Review

- In order to estimate its position a receiver must have at least four satellites in view
- The satellite must be in Line-of-sight (Not 100% true, depends what quality of position you need)
- If a larger number of satellites is in view a better estimation is possible. In the past the combination of four satellites giving the best performance was chosen
- Modern receivers use multiple channels in order to perform the position estimation (From multiple constellations)

# Propagation

- GNSS signals pass through the near-vacuum of space, then through the various layers of the atmosphere to the earth, as illustrated in the figure below:



# Propagation

- To determine accurate positions, we need to know the range to the satellite. This is the direct path distance from the satellite to the user equipment
- The signal will “bend” when traveling through the earth’s atmosphere
- This “bending” increases the amount of time the signal takes to travel from the
- satellite to the receiver
- The computed range will contain this propagation time error, or atmospheric error
- Since the computed range contains errors and is not exactly equal to the actual range, we refer to it as a “pseudorange”

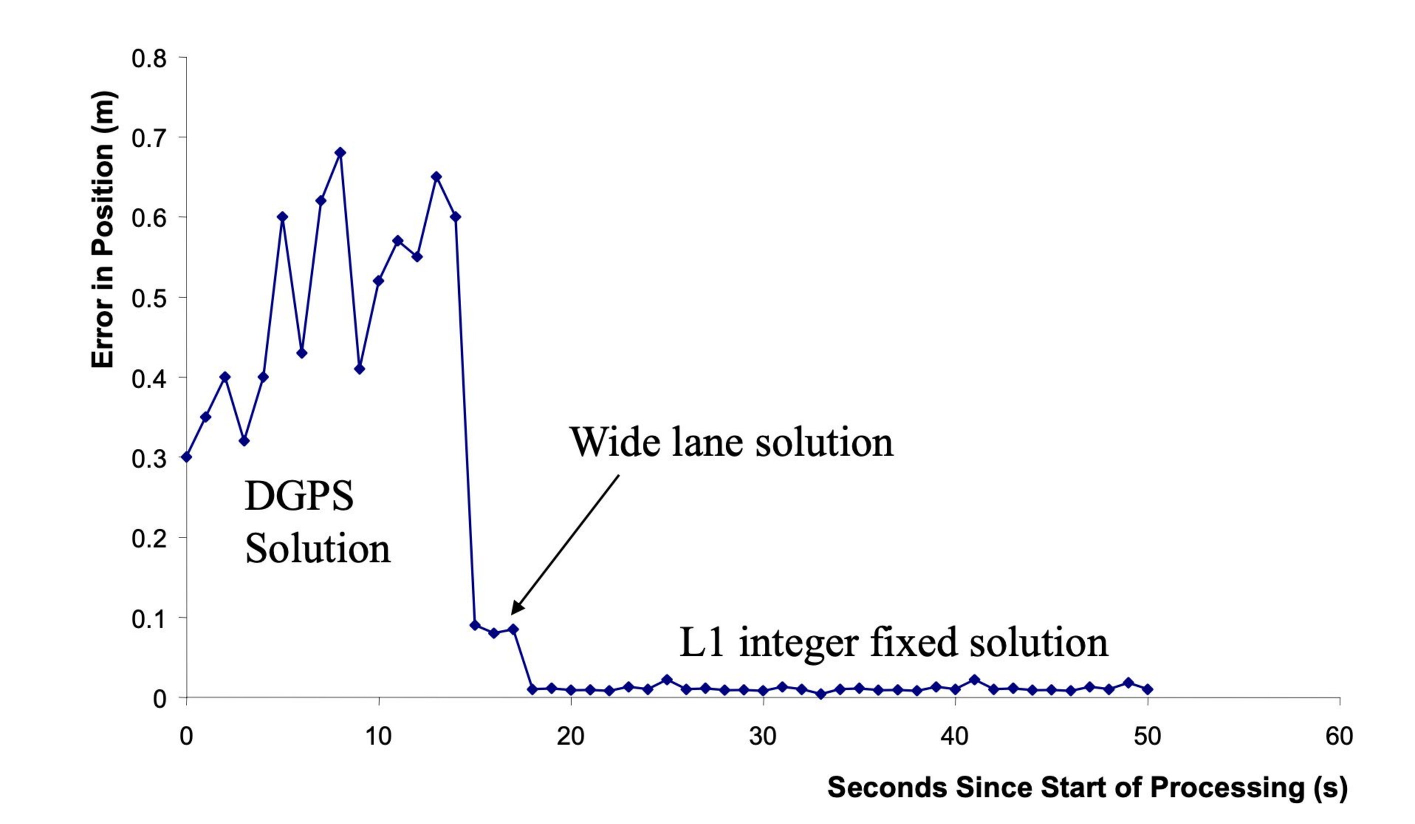
# Propagation

- The ionosphere contributes to most of the atmospheric error. It resides at 70 to 1000 km above the earth's surface.
- Free electrons resides in the ionosphere, influencing electromagnetic wave propagation
- Ionospheric delay are frequency dependent. It can be virtually eliminated by calculating the range using both L1 and L2
- The troposphere, the lowest layer of the Earth's atmosphere, contributes to delays due to local temperature, pressure and relative humidity
- Tropospheric delay cannot be eliminated the way ionospheric delay can be
- It is possible to model the tropospheric delay then predict and compensate for much of the error

# Propagation

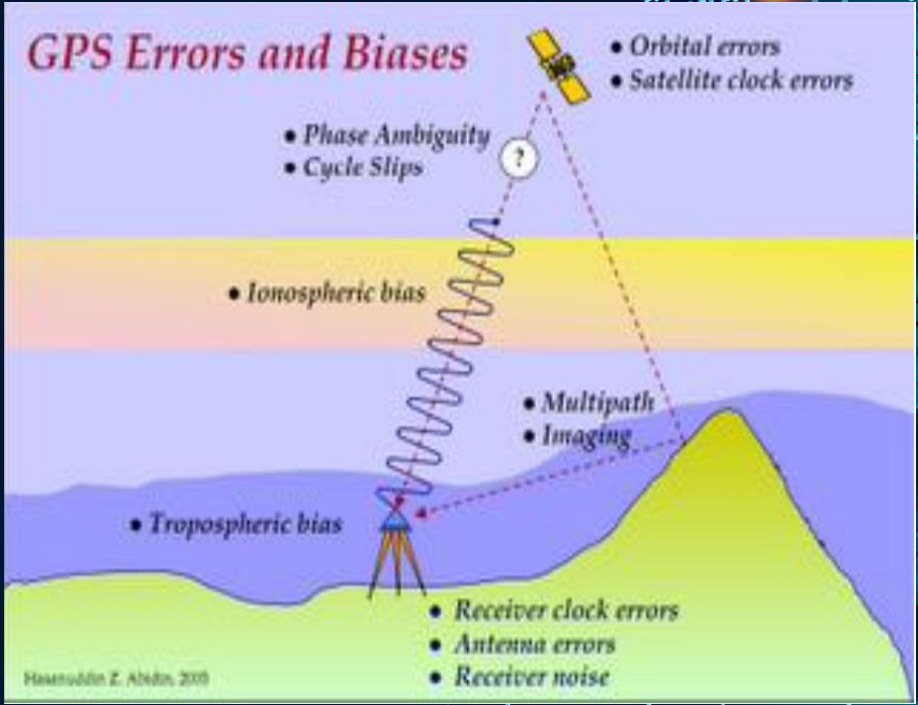
- Signals can be reflected on the way to the receiver. This is called “multipath propagation”
- These reflected signals are delayed from the direct signal, and if strong enough, can interfere with the direct signal
- Techniques have been developed whereby the receiver only considers the earliest-arriving signals and ignore multipath signals, which arrives later
- It cannot be entirely eliminated

# Quality of Different Solutions



# GNSS Error Sources

- Orbital Errors (2m)
- Satellite Clock Errors (2m)
- Ionospheric Errors (4m)
- Tropospheric Errors (0.7m)
- Receiver Errors (0.5m)
- Multipath (1.5m)
- Interference
- Geometry



# Errors 1/2

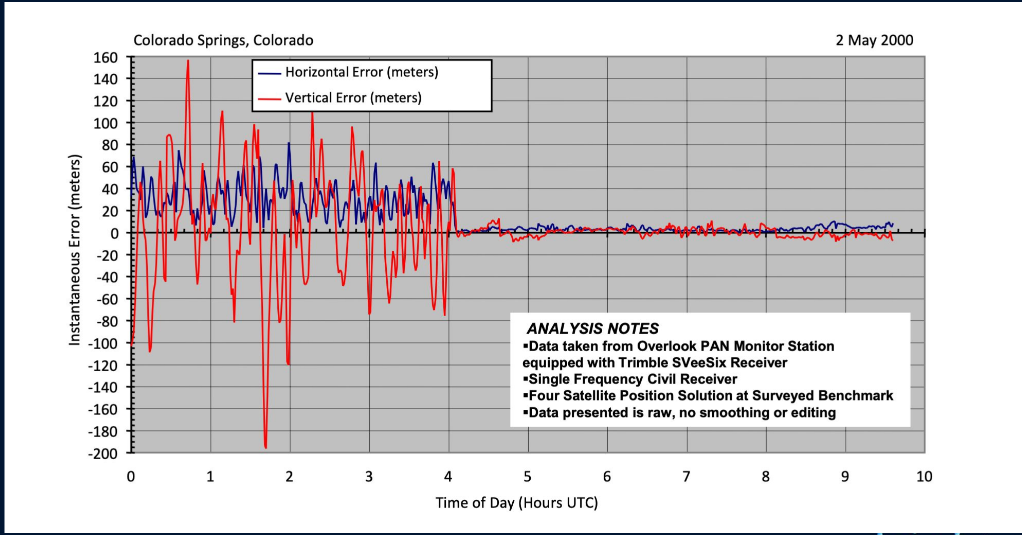
- control system: ephemerides, clocks, codes, measurement errors
- ionosphere: the propagation delay depends on the frequency on on the density of electrons along the path
- troposphere: the propagation delay depends on the pressure, temperature, humidity of the air
- multipath

# Errors 2/2

- receiver noise
- uncompensated relativistic effects
- selective availability (SA): the signal has been intentionally disturbed to limit the accuracy of the GPS to civil user ("ended" May 1st 2000)

# The effect of Selective availability - GPS

- receiver noise
- uncompensated relativistic effects
- selective availability (SA): the signal has been intentionally disturbed to limit the accuracy of the GPS to civil user (“ended” May 1st 2000)



# Relativistic effects

- The satellite clock drift is affected by the relativistic effects. In GPS the satellite clock frequency is adjusted so that the frequency observed by the user at sea level has the nominal value

# Relativistic effects

- The user has to take into account a relativistic periodic effect due to the eccentricity of the satellite orbit
  - – half of the error is due to the periodic change in the speed of the satellite relative to the ECI (Earth Centered Inertial) frame

# Relativistic effects

- The user has to take into account a relativistic periodic effect due to the eccentricity of the satellite orbit

  – the other half is caused by the satellite's periodic change in its gravitational potential

  - At the perigee, the satellite velocity is higher and the gravitational potential is lower, and the satellite clock runs slower
  - At the apogee, the satellite velocity is lower and the gravitational potential is higher, so the satellite clock runs faster

# Relativistic effects

- In the GPS literature, it is stated that this relativistic effect can reach a maximum of 70 ns (21 meters in range)

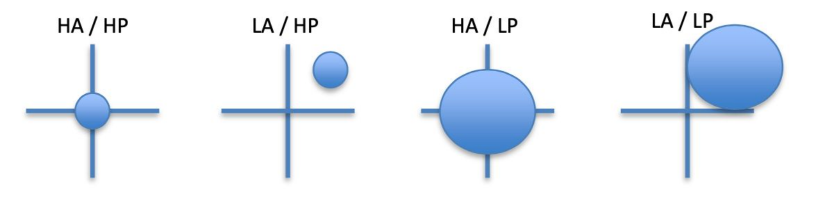
# Required Navigation Performance (RNP)

- **Availability** is the percentage of time the position, navigation or timing solution that can be computed by the user. Values vary greatly according to the specific application and services used but typically range from 95 to 99.9%. We can speak of two types of availability:
  - › System availability: is what GNSS Interface Control Documents (ICDs) refer to.
  - › Overall availability: takes into account the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

- Accuracy is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion –usually 95%- of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre- level: 1-10 metres.

# Required Navigation Performance (RNP)

- ❑ **High Accuracy vs High Precision .....**



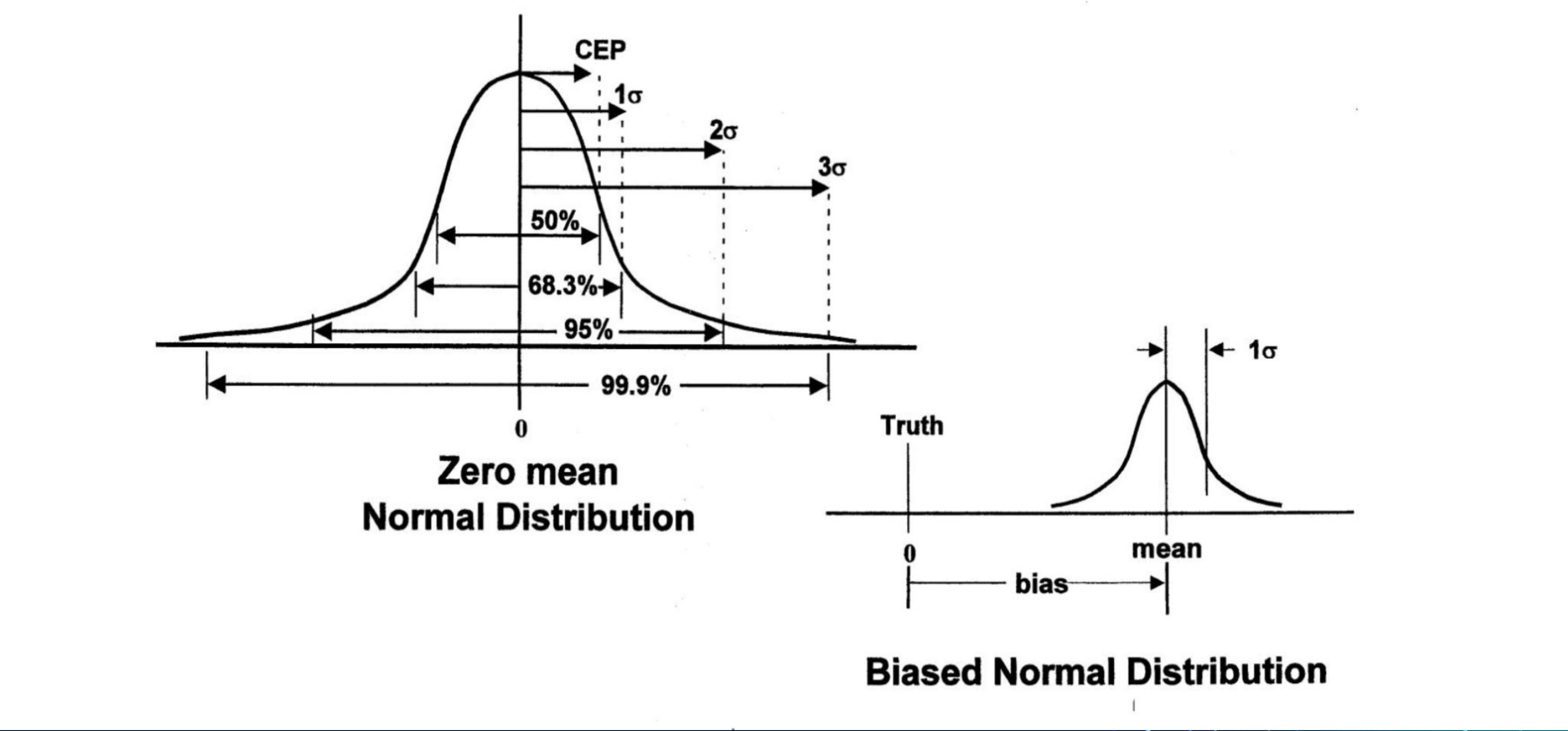

- ❑ Continuity the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1*10-4 over the course of the procedure where the system is in use.

- ❑ Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the “integrity concept” is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

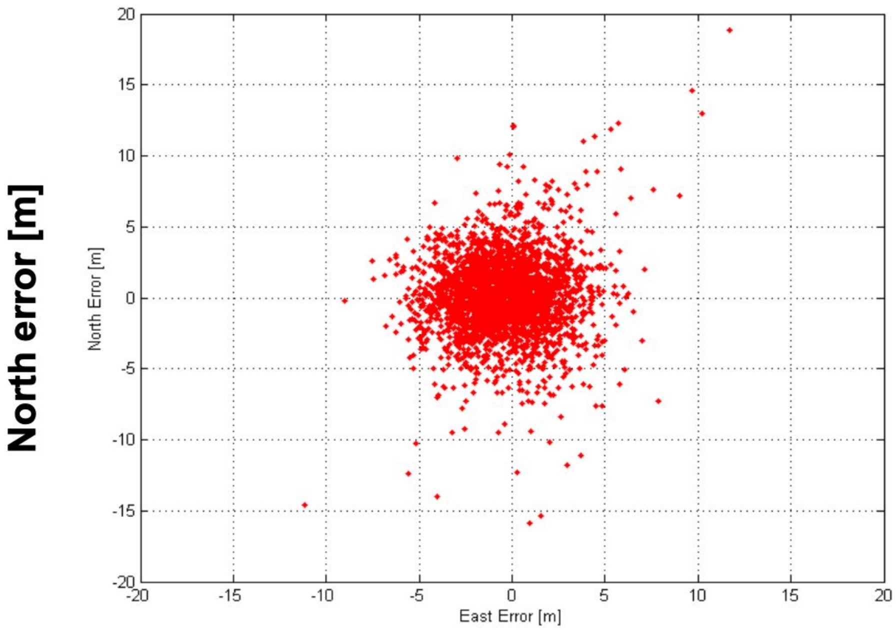
# Definitions: Accuracy and precision

- The position determination is always an estimate based on measurements
- The presence of disturbances, propagation errors, etc. can be modeled as random factors affecting the estimated position that is thus modeled as a random variable
- Performance of a positioning procedure can be evaluated in a stocastic way, using statistical parameters:
  - Mean
  - Variance (or standard deviation)

# Example: Gaussian distribution



# Example of positions dispersion

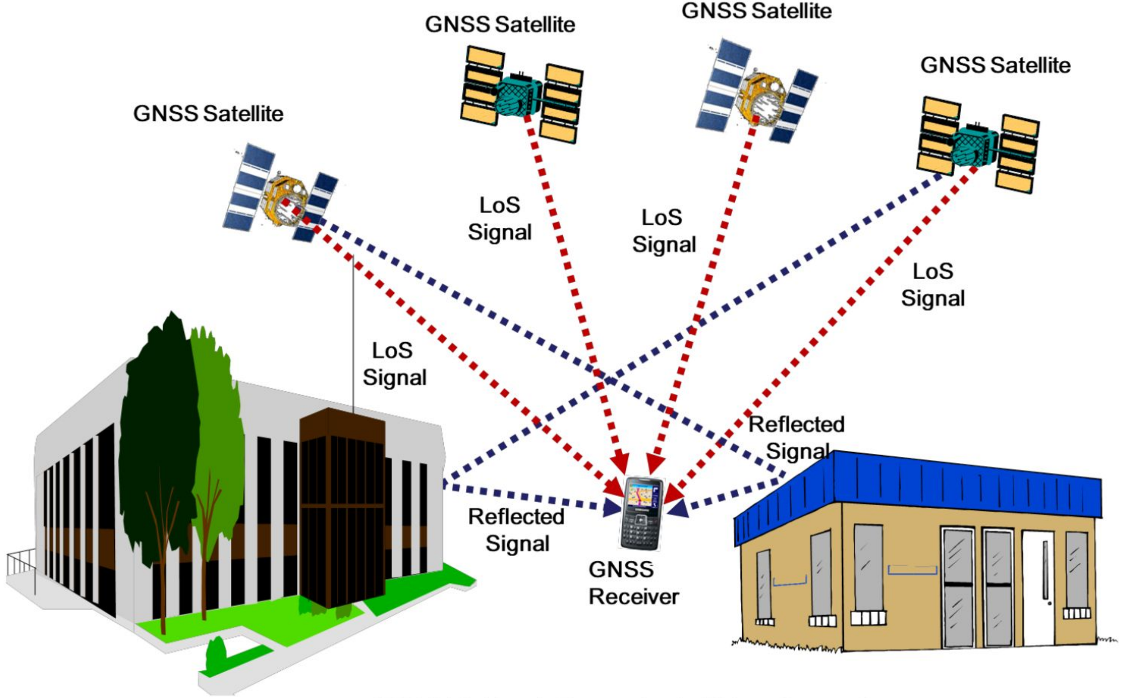



East error [m]
Dispersion in ENU coordinates

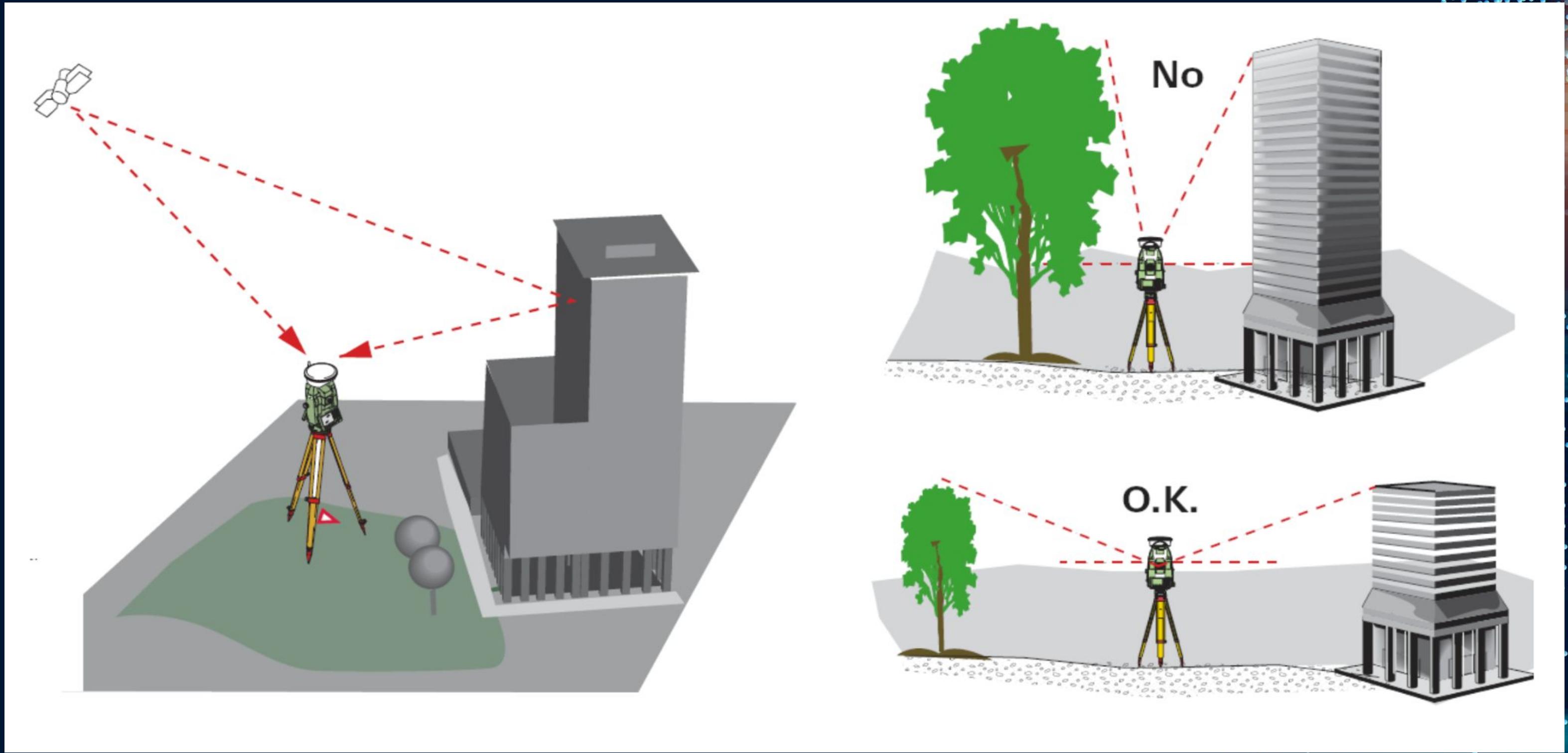
# Multipath

- GNSS relies on line of sight between satellite and receiver
- In Urban environments and indoors (obviously) this direct line of
- sight is disturbed
- This can cause a receiver to either lose lock on a satellite and thus reduce the number of available signals
- Or the signals can be reflected (or attenuated i.e. travel through an object) and still be received and used by the receiver
- This phenomena is known as “Multipath”
- Multipath effects “code” and “carrier” measurements

# Multipath in an Urban Environment



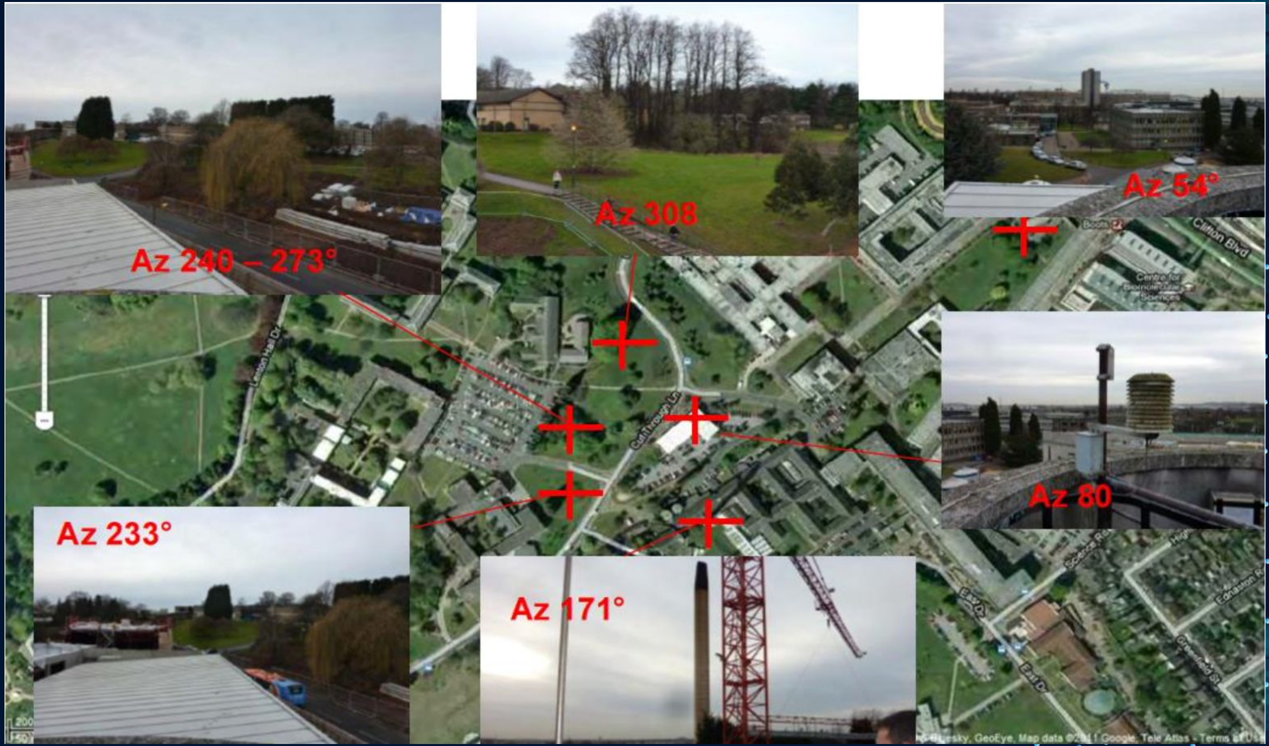

GNSS Multipath Reception in Urban Scenarios

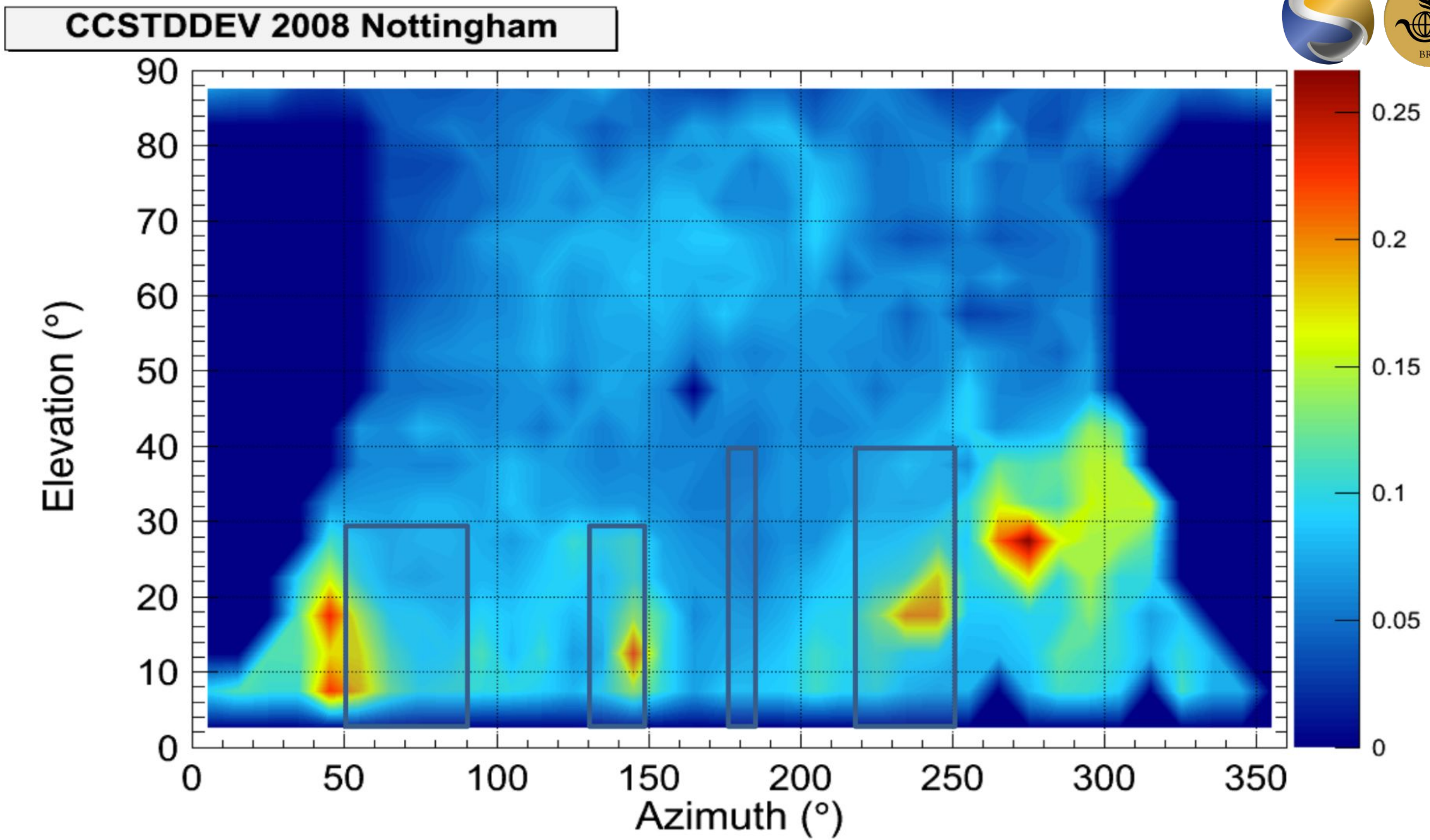



From Surveying with SmartStation An introduction to RTK by Leica Geosystems

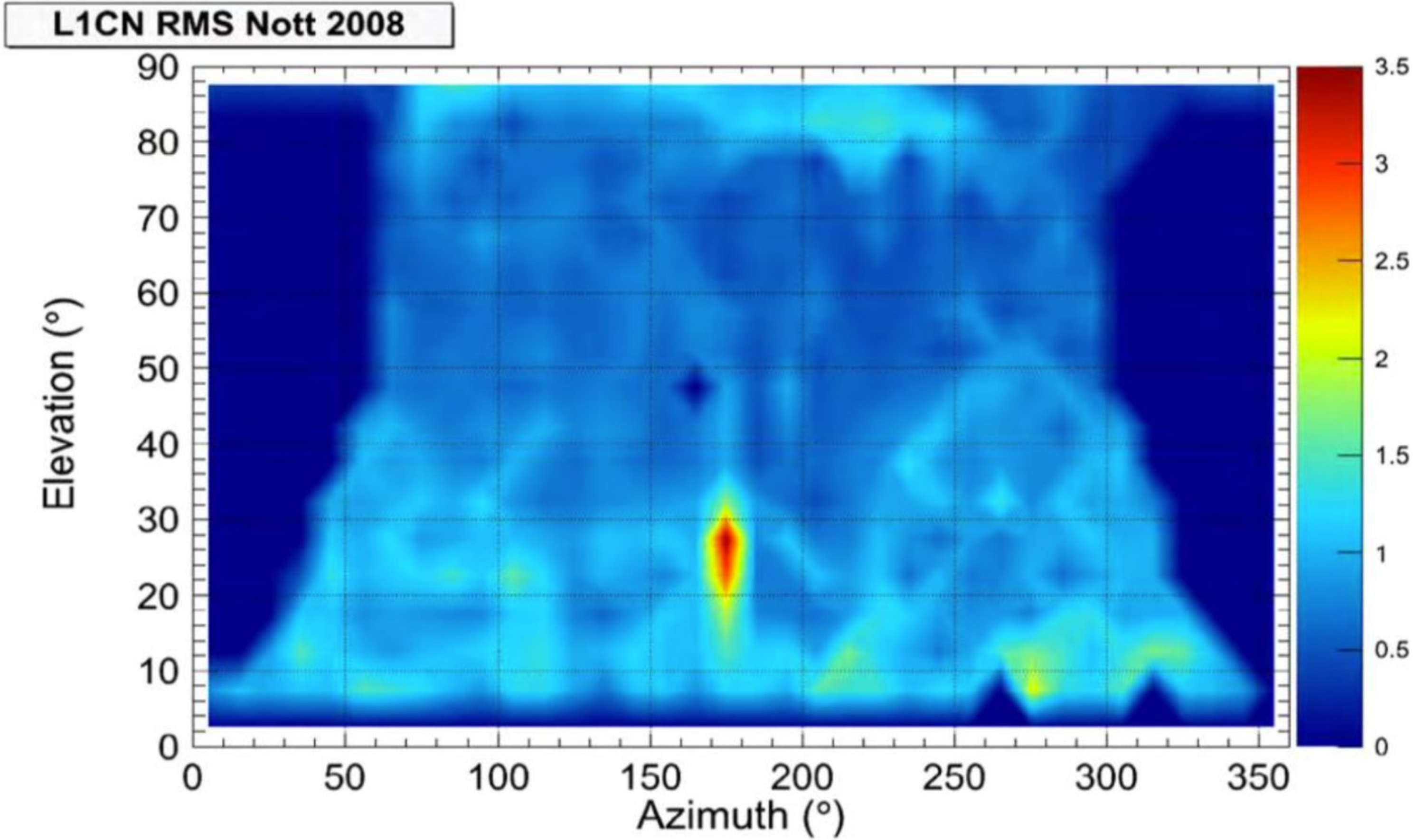
# Station Analysis

- Nottingham – IESSG Building

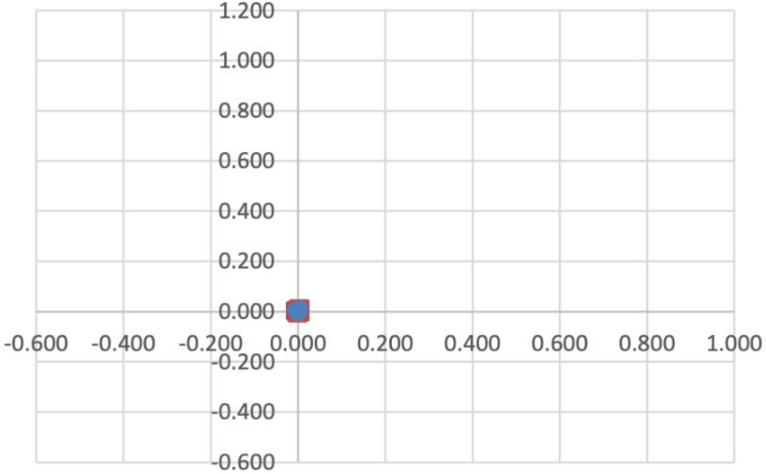



CCSTDDEV 2008 Nottingham
Elevation (°)
Azimuth (°)
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300
350
0
0.05
0.1
0.15
0.2
0.25

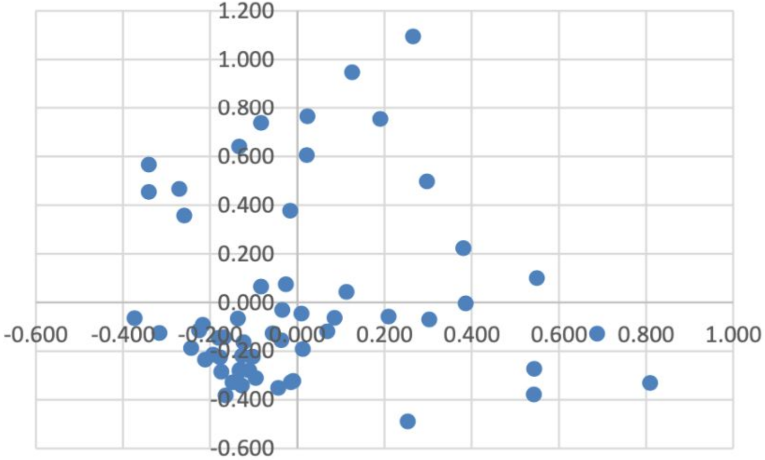
# Station Analysis



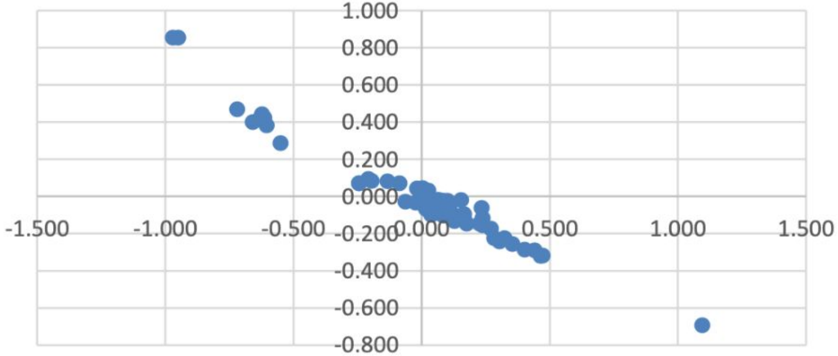
## Open Sky




## Under a Tree




## Next to Wall



# The geometric factor 1/4

- The pseudorange errors can be modeled as random variables
- The elements of the error vector  can be considered as random variables
  - gaussian with zero mean
  - identically distributed
  - independent
  - with variance s2UERE

# The navigation solution

$$\begin{cases} \Delta\rho_1 = a_{x1}\Delta x_u + a_{y1}\Delta y_u + a_{z1}\Delta z_u - c\Delta t_u \\ \Delta\rho_2 = a_{x2}\Delta x_u + a_{y2}\Delta y_u + a_{z2}\Delta z_u - c\Delta t_u \\ \Delta\rho_3 = a_{x3}\Delta x_u + a_{y3}\Delta y_u + a_{z3}\Delta z_u - c\Delta t_u \\ \Delta\rho_4 = a_{x4}\Delta x_u + a_{y4}\Delta y_u + a_{z4}\Delta z_u - c\Delta t_u \end{cases}$$

$$\mathbf{\Delta\rho} = \begin{bmatrix} \Delta\rho_1 \\ \Delta\rho_2 \\ \Delta\rho_3 \\ \Delta\rho_4 \end{bmatrix} \qquad \mathbf{H} = \begin{bmatrix} a_{x1} & a_{y1} & a_{z1} & 1 \\ a_{x2} & a_{y2} & a_{z2} & 1 \\ a_{x3} & a_{y3} & a_{z3} & 1 \\ a_{x4} & a_{y4} & a_{z4} & 1 \end{bmatrix} \qquad \mathbf{\Delta x} = \begin{bmatrix} \Delta x_u \\ \Delta y_u \\ \Delta z_u \\ -c\Delta t_u \end{bmatrix}$$

$$\mathbf{\Delta\rho} = \mathbf{H}\mathbf{\Delta x}$$

# The geometric factor 2/4

$$\mathrm{cov}(d\mathbf{x}) = E\left\{\left(\mathbf{H}^T\mathbf{H}\right)^{-1}\mathbf{H}^T dr\, dr^T \mathbf{H}\left(\mathbf{H}^T\mathbf{H}\right)^{-1}\right\}$$

$$\mathrm{cov}(d\mathbf{x}) = \left(\mathbf{H}^T\mathbf{H}\right)^{-1}\mathbf{H}^T \mathrm{cov}(dr)\mathbf{H}\left(\mathbf{H}^T\mathbf{H}\right)^{-1}$$

$$\mathrm{cov}(dr) = \mathbf{I}_{n\,\acute{}\,n}\, s^{2}_{UERE}$$

$$\mathrm{cov}(\boldsymbol{\delta}\mathbf{x}) = \left(\mathbf{H}^T\mathbf{H}\right)^{-1}\sigma^{2}_{UERE}$$

# The geometric factor 3/4

- Let's define

$$\mathrm{cov}(\boldsymbol{\delta}\mathbf{x}) = \mathbf{G}\sigma_{UERE}^2$$

- where

$$\mathbf{G} = \left(\mathbf{H}^T\mathbf{H}\right)^{-1} = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix}$$

# The geometric factor 4/4

- It is then possible to observe the relation of the error for each dimension

$$\sigma_x^2 = g_{11}\sigma_{UERE}^2$$

$$\sigma_y^2 = g_{22}\sigma_{UERE}^2$$

$$\sigma_z^2 = g_{33}\sigma_{UERE}^2$$

$$\sigma_{c\Delta t}^2 = g_{44}\sigma_{UERE}^2$$

# Geometric Dilution Of Precision

- The standard deviation of the positioning error can be obtained as:

$$\sqrt{tr\{\mathrm{cov}(\boldsymbol{\delta}\mathbf{x})\}} = \sqrt{\sigma_{x_u}^2 + \sigma_{y_u}^2 + \sigma_{z_u}^2 + \sigma_{c\Delta t}^2} = \\ = \mathrm{GDOP} \cdot \sigma_{UERE}$$

- where the GDOP factor is defined as

$$\mathrm{GDOP} = \sqrt{tr\{\mathbf{G}\}}$$

- and represent the Geometrical Dilution of Precision

# Dilution of precision

- Partial factors can be defined:
  - Position Dilution of Precision

$$PDOP = \sqrt{g_{11} + g_{22} + g_{33}}$$

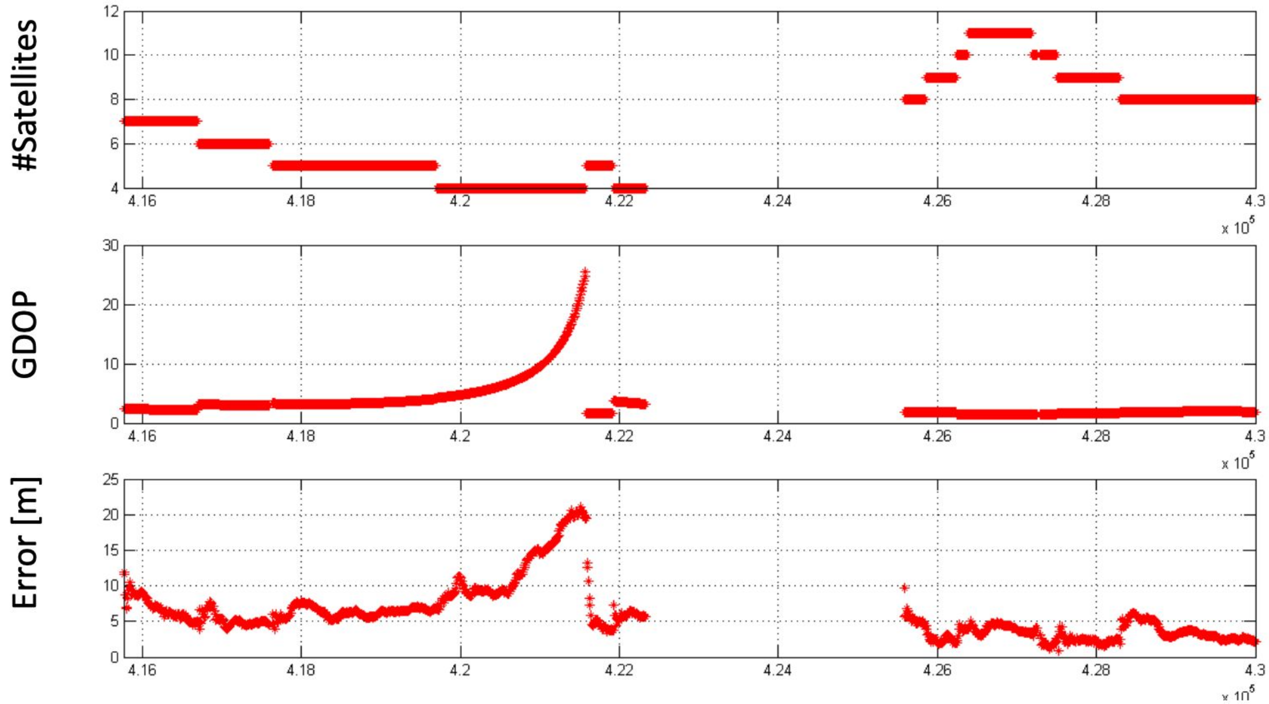
  - Time Dilution of Precision

$$TDOP = \sqrt{g_{44}}$$

  - Horizontal Dilution of Precision

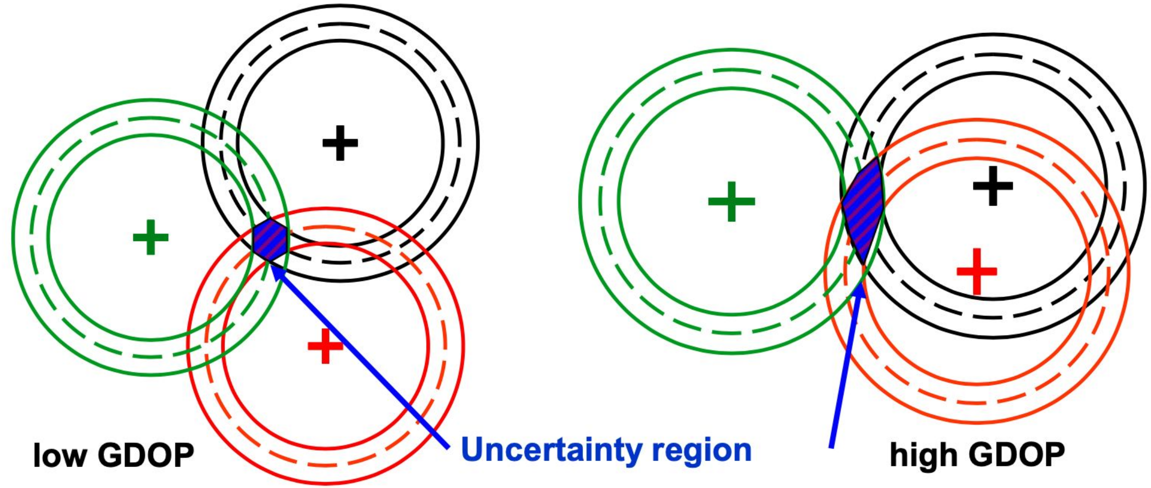
$$HDOP = \sqrt{g_{11} + g_{22}}$$

# Real GDOP behaviour

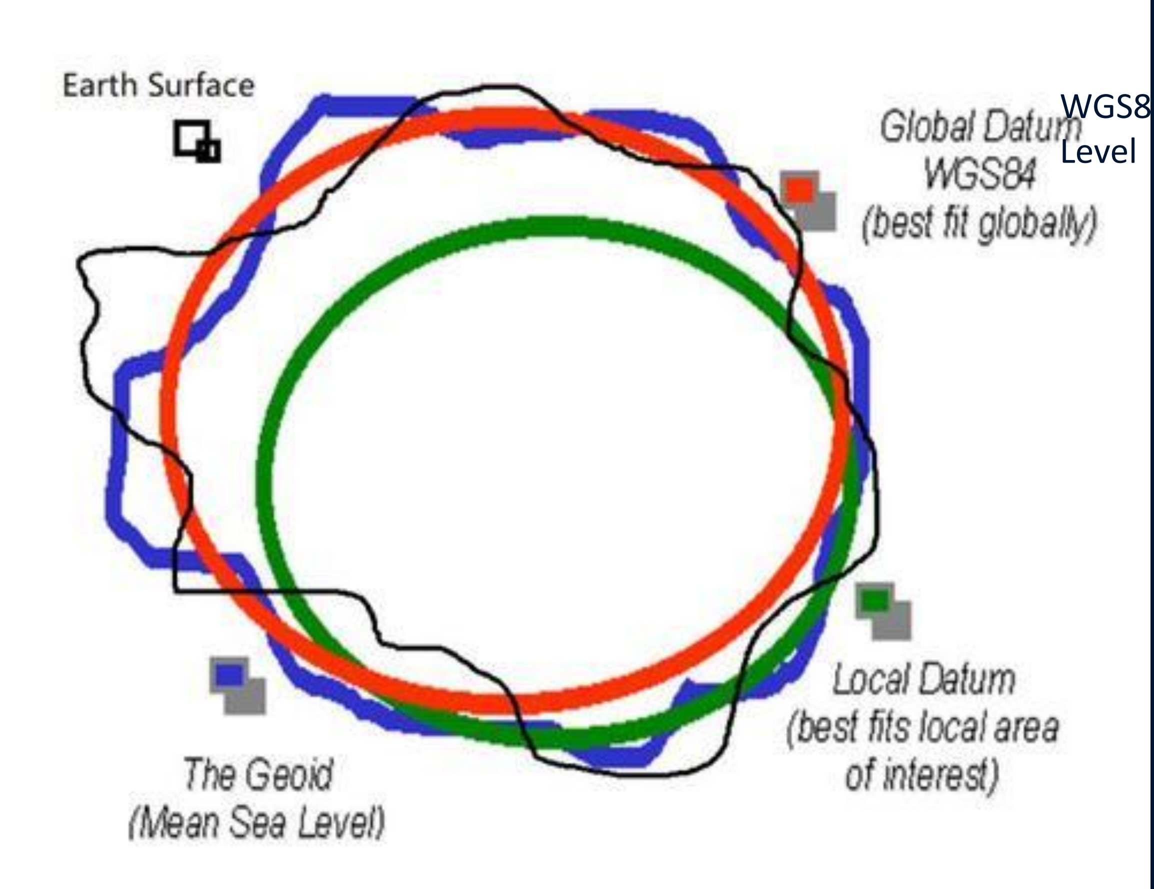


# The geometrical problem

- The impact of the pseudorange error on the final estimated position depends on the displacement of the satellites (reference points)



# Earth Surface Models

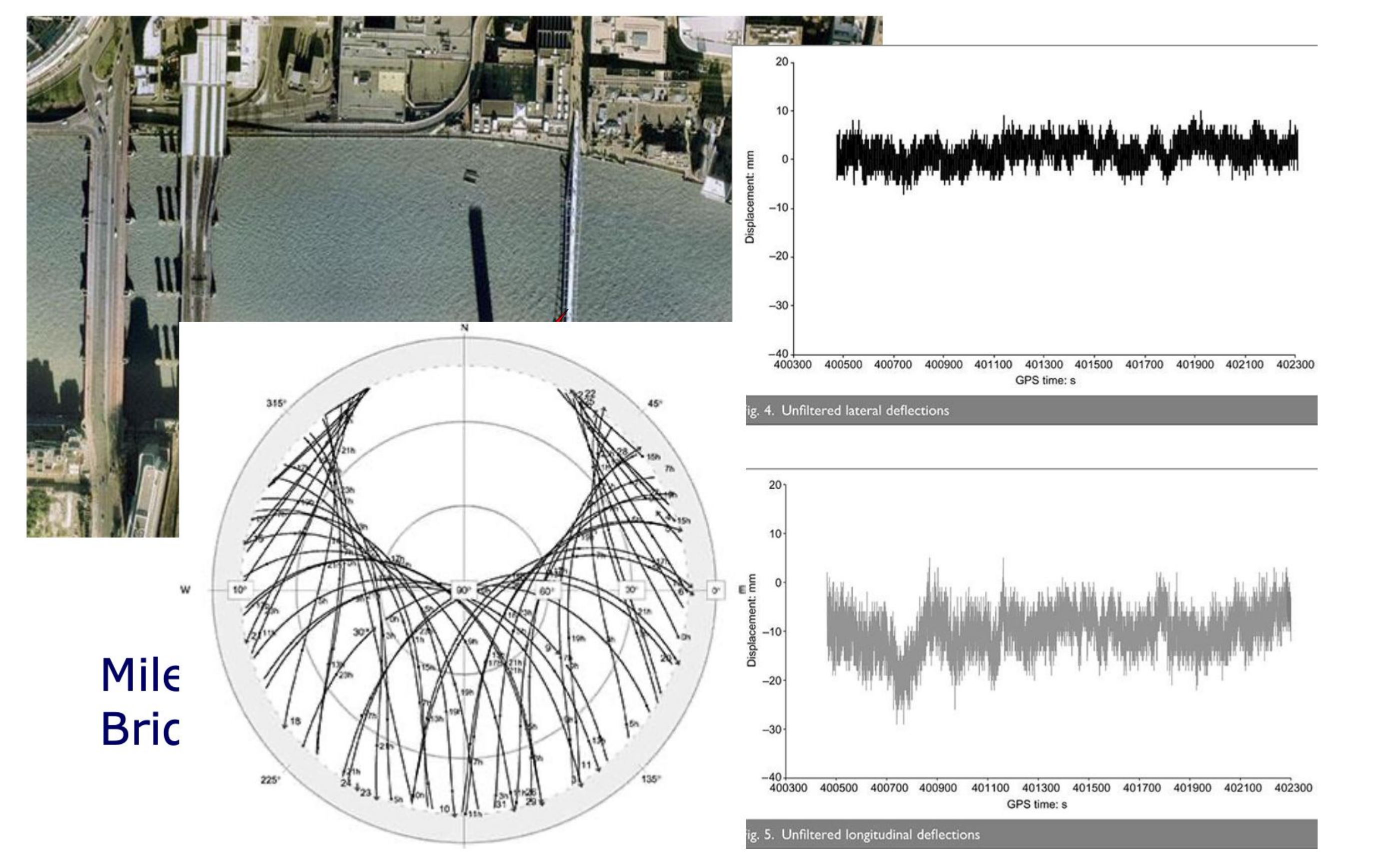



WGS8
Level

# Error ellipse Component

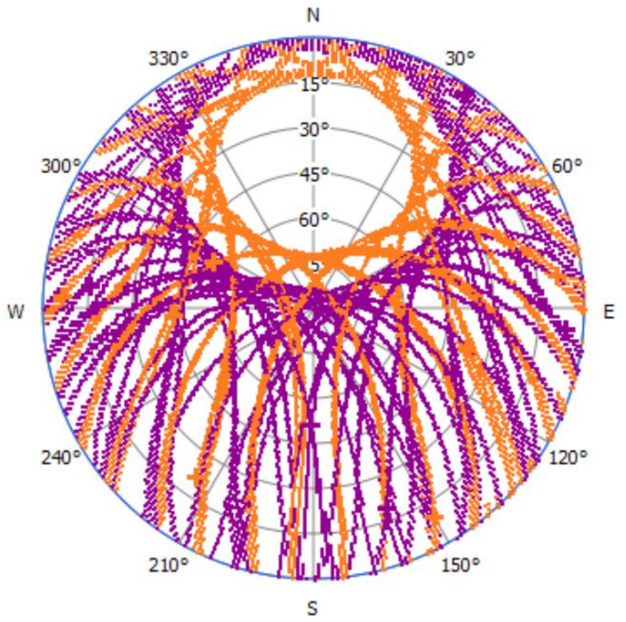
| Survey Point ID | Semi-major axis (m) | Semi-minor axis (m) | Azimuth |
|---|---|---|---|
| ARUC | 0.062 | 0.064 | 2.825649¡ã |
| ISBA | 0.000 | 0.000 | 2.693565¡ã |
| TEHN | 0.047 | 0.046 | 3.107127¡ã |
| DuhR32 | 0.033 | 0.027 | 0.226076¡ã |
| RanR32 | 0.032 | 0.026 | 0.285196¡ã |
| SulR32 | 0.032 | 0.026 | 0.441689¡ã |

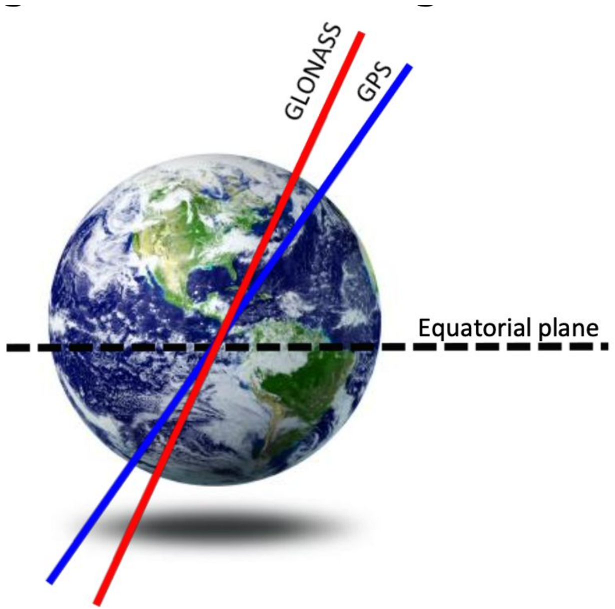
# Example of Geometry Problem



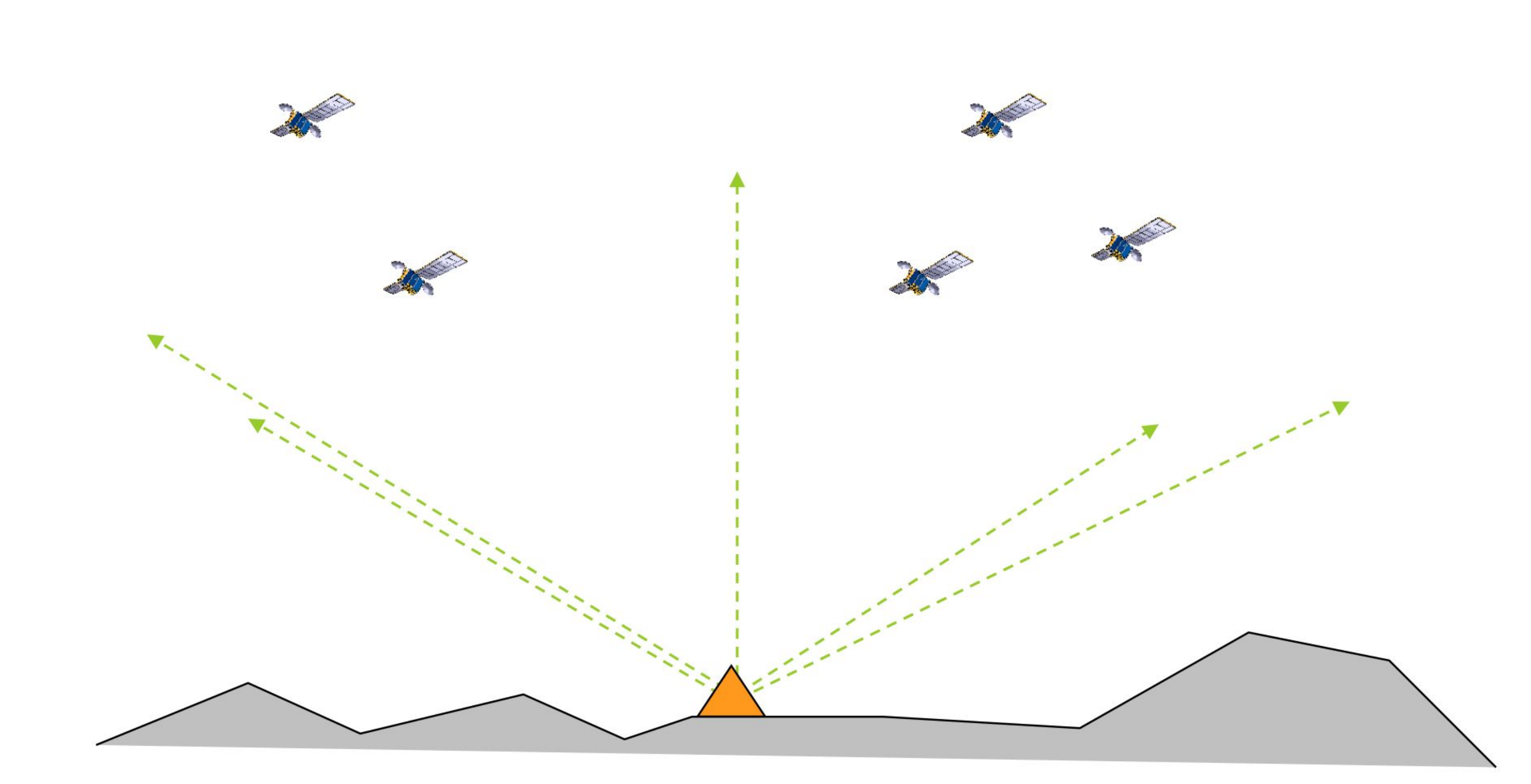
# GLONASS satellite coverage

GLONASS improves satellite coverage over GPS at higher latitudes due to the different inclination.

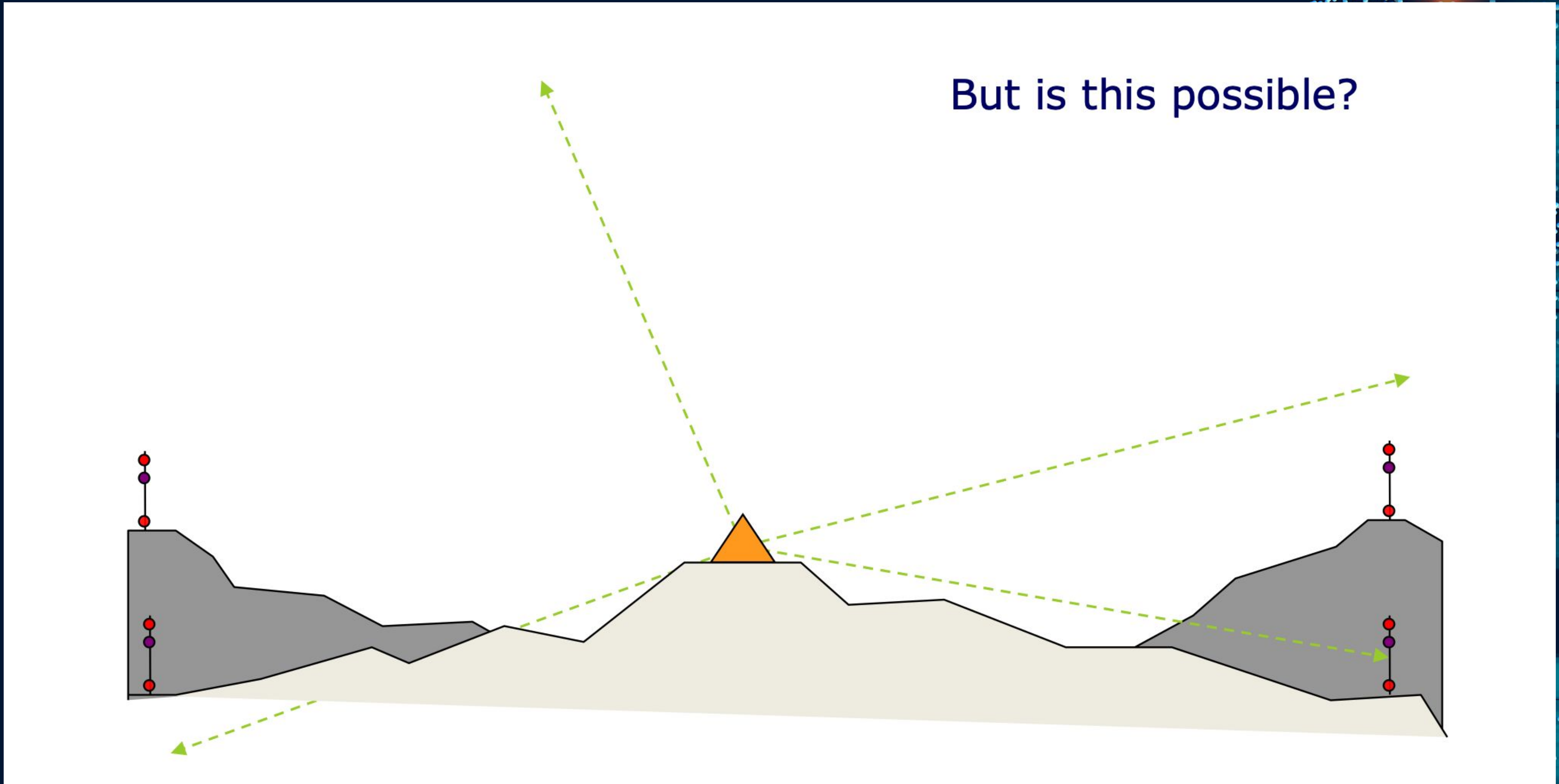


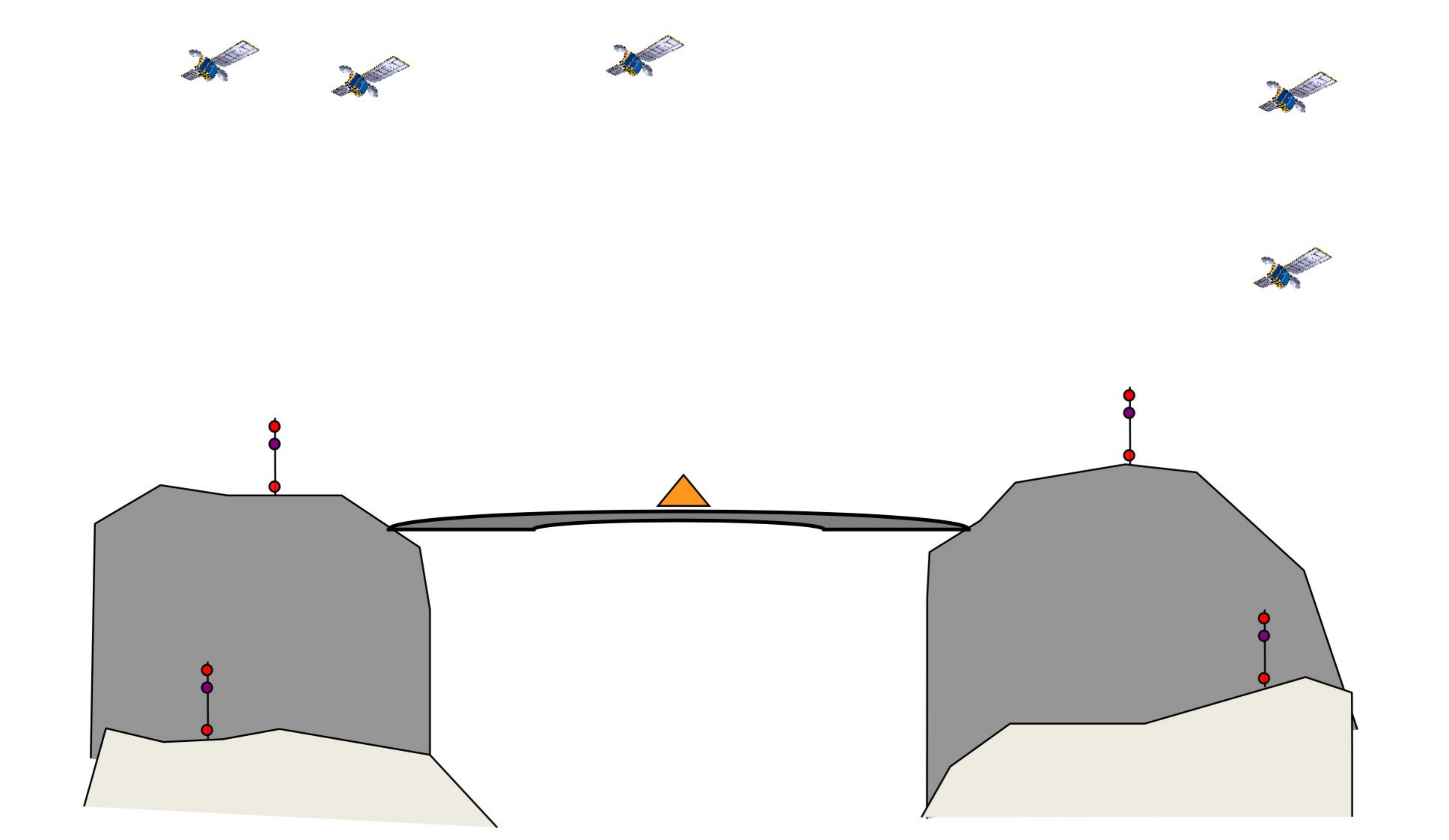
# Optimal Geometry for GNSS



# Optimal Geometry for Locata

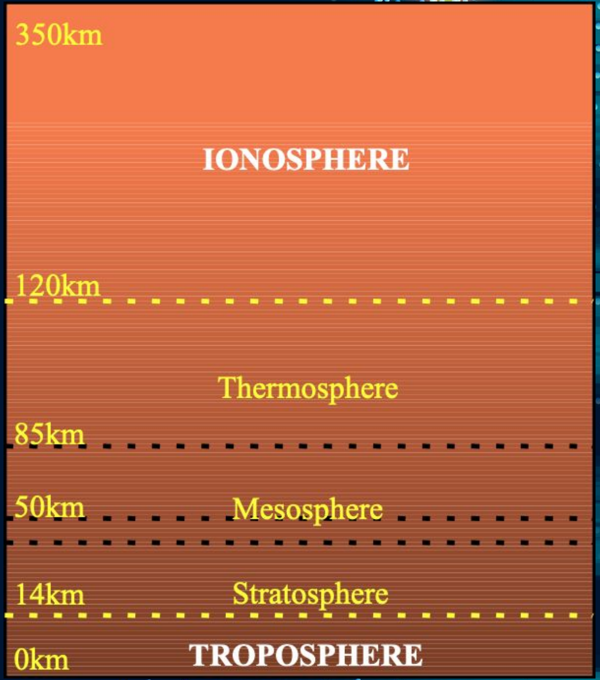


# Joined Geometry

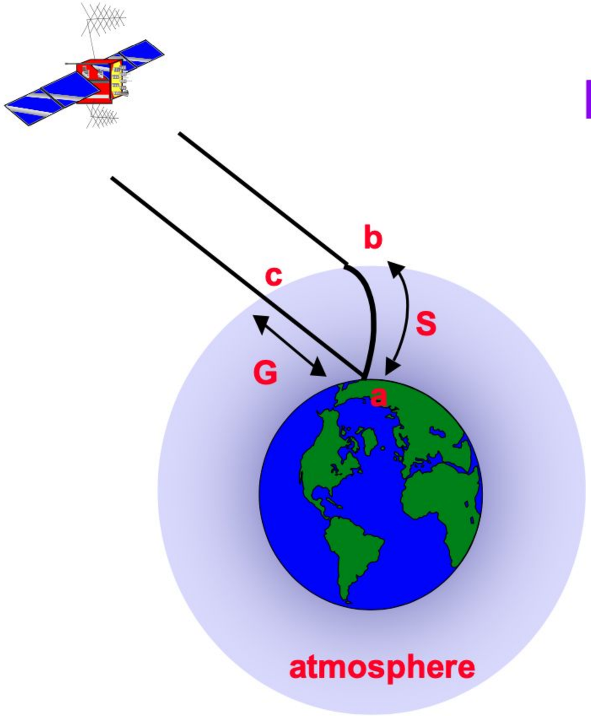


# GNSS range measurement

- Ionosphere
  - – Dispersive at GNSS frequencies
  - – Remove delay with dual-frequency observations
- Troposphere
  - – Non-dispersive at GNSS frequencies
  - – Refractivity depends on temperature, pressure and water vapour pressure



# Atmospheric Delay




$$L - G = \int_a^b (n-1)\,ds + (S - G)$$

Delay — Bending

| Elevation Angle | Bending Effect |
|---|---|
| 2 | 0.417 |
| 5 | 0.075 |
| 10 | 0.019 |
| 20 | 0.005 |
| 45 | 0.001 |
| 90 | 0.000 |

# Atmospheric Delay

- The atmosphere is not a vacuum
- It has density (refractive index (n)  #1)
- n varies from approximately 1.003 at earth's surface to 1.0000 in space
- Density is variable (n varies)
- n in the troposphere is primarily a function of pressure, temperature and water vapour pressure (humidity)
- n in the ionosphere is a function of free electron density and frequency

# Tropospheric Delay

- Large variation in height error at sites when a standard meteorological model (MAGNET) is used
- Height error almost totally reduced to zero when tropospheric delay is stochastically estimated within GPS processing software
- Large degree of correlation evident between relative delay and height error when using standard meteorological model
- GPS stochastic estimation technique accounts for high degree of spatial and temporal variability in atmospheric water vapour
- Delay estimates give useful information about the atmosphere (particularly water vapour)

# Tropospheric Delay

$$N = 77.6\frac{P}{T} + 3.73 \times 10^{5}\frac{e}{T^{2}}$$

*HYDROSTATIC DELAY*

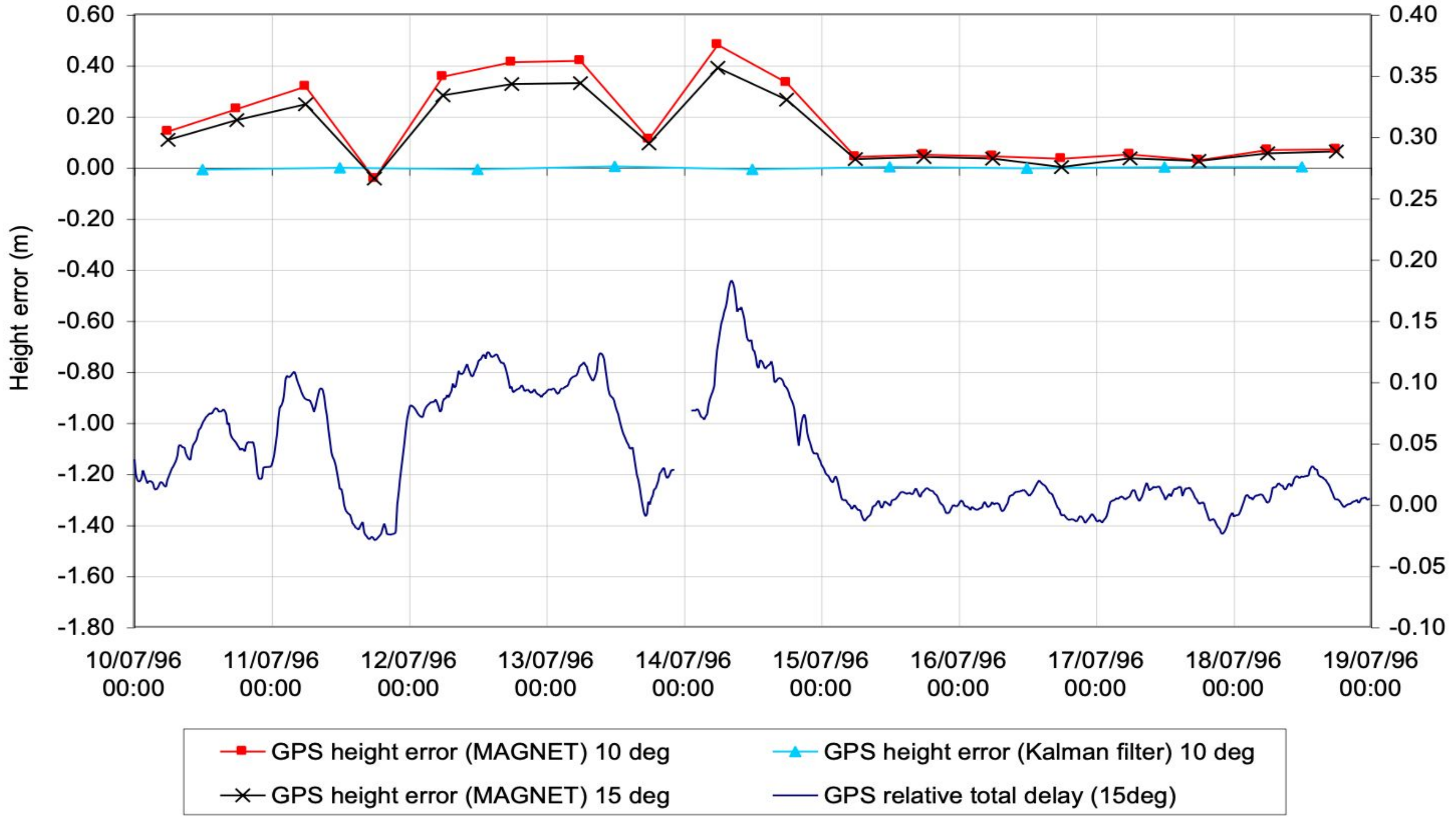
- 90% of total tropospheric delay
- removed using surface barometric pressure measurements

*WET DELAY*

- 10% of total tropospheric delay
- variable in time and space
- surface met. data inadequate
- solve for as extra unknown

- It is possible to estimate tropospheric delay as extra unknown (in the LS solution), using constellation geometry ie varying elevation angles and mapping function to zenith
- Deterministic approach
  - scaling term to tropospheric model
  - absolute term for entire tropospheric delay

- Limitation - one parameter solved for per session
- Alternative: time varying technique
  - Stochastic modelling
  - Kalman Filter


0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
Height error (m)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
Relative total delay (m
10/07/96 00:00
11/07/96 00:00
12/07/96 00:00
13/07/96 00:00
14/07/96 00:00
15/07/96 00:00
16/07/96 00:00
17/07/96 00:00
18/07/96 00:00
19/07/96 00:00
GPS height error (MAGNET) 10 deg
GPS height error (Kalman filter) 10 deg
GPS height error (MAGNET) 15 deg
GPS relative total delay (15deg)

- Large variation in height error at sites when a standard meteorological model (MAGNET) is used
- Height error almost totally reduced to zero when tropospheric delay is stochastically estimated within GPS processing software
- Large degree of correlation evident between relative delay and height error when using standard meteorological model
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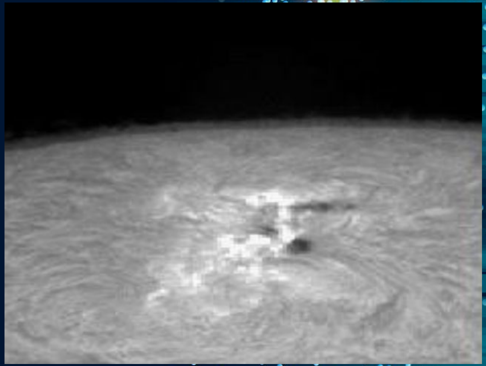
# Ionospheric delay

- ❑ UV and X-ray radiation from the Sun causes ionisation - releases electrons
- ❑ Ionospheric delay therefore largely governed by the activity of the Sun
- ❑ Number of well-known periodicities
  - › 11 year sunspot cycle,
  - › seasonal cycle, diurnal cycle

- ❑ Magnetic storms - sizeable irregular pattern
- ❑ Vertical ionospheric error during Solar maximum (for GNSS frequencies)
  - 10m (day)
  - 1-2m (night)



**An X-flare photographed on Sept. 9th 2008 by Birgit Kremer of Marbella, Spain.**

# Ionosphere

- Ionosphere (50-1000 km) is a region of ionized gases (free electrons and ions)
- 
- Ionization is caused by the sun’s radiation
- 
- The speed of propagation of a radio signal depends upon the number of
- 
- free electrons in its path
- 
- Total electron content (TEC) is defined as the number of electrons in a tube of 1m2 cross section from receiver to satellite

# Ionospheric model

- Ionosphere induces a pseudorange delay that gives an error

$$I_\rho = \frac{40.3 \cdot TEC}{f^2}$$

- The delay in phase measurement have same magnitude but opposite sign
- It can be estimated and compensated for, using double frequency receivers

# Ionosphere free measurements 1/2

- Assuming to be able to measure the pseudorange at two frequencies

$$\rho_1 = \rho^* + \frac{40.3 \cdot TEC}{f_1^2}$$

$$\rho_2 = \rho^* + \frac{40.3 \cdot TEC}{f_2^2}$$

# Ionosphere free measurements 2/2

- being p* the ionosphere-free pseudorange
- The set of equations can be solved for p* and TEC obtaining

$$\rho^* = \frac{f_1^2}{f_1^2 - f_2^2}\rho_1 - \frac{f_2^2}{f_1^2 - f_2^2}\rho_2$$

# Ionosphere model

- Single frequency receivers use models whose parameters are broadcast by the satellites

# The Klobuchar model

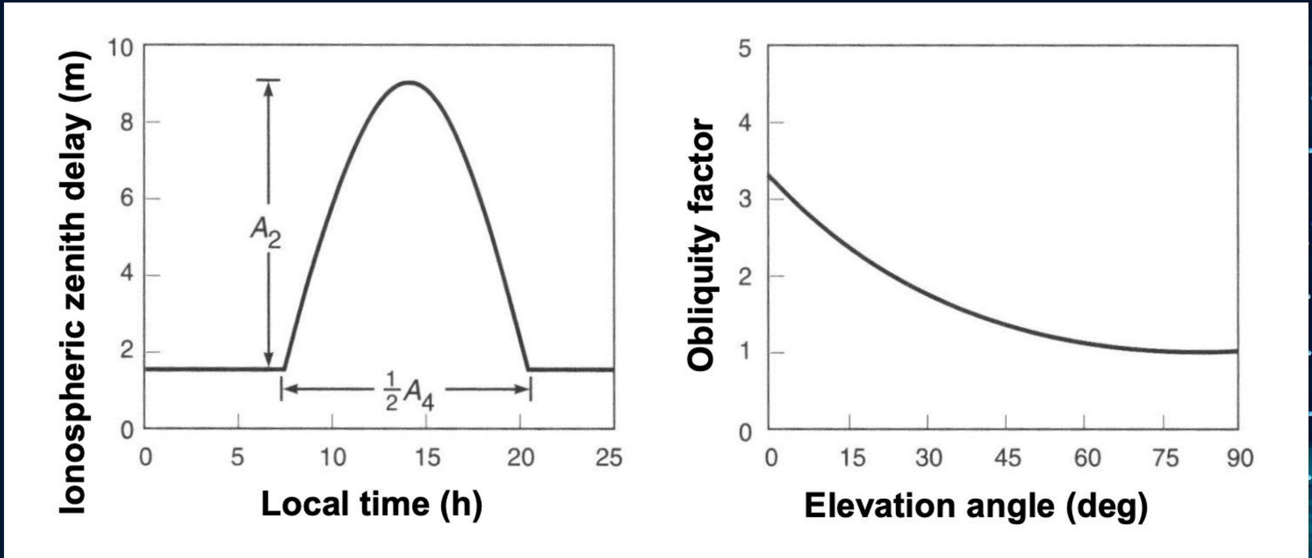
- The Klobuchar model is an empirical model using a reduced number of parameters to be described

$$\frac{\hat{I}_{z,L1}}{c} = \begin{cases} A_1 + A_2 \cos\left(\frac{2\pi(t - A_3)}{A_4}\right), & |t - A_3| < A_4 / 4 \\ A_1 & otherwise \end{cases}$$

- Values A1 and A3 are fixed and A2 and A4 are specified in the navigation message broadcast by each satellite

# Obliquity factor

- The propagation path length of a signal through the ionosphere increases with the zenith angle
- The increased path length is accounted for in terms of a multiplier of the zenith delay



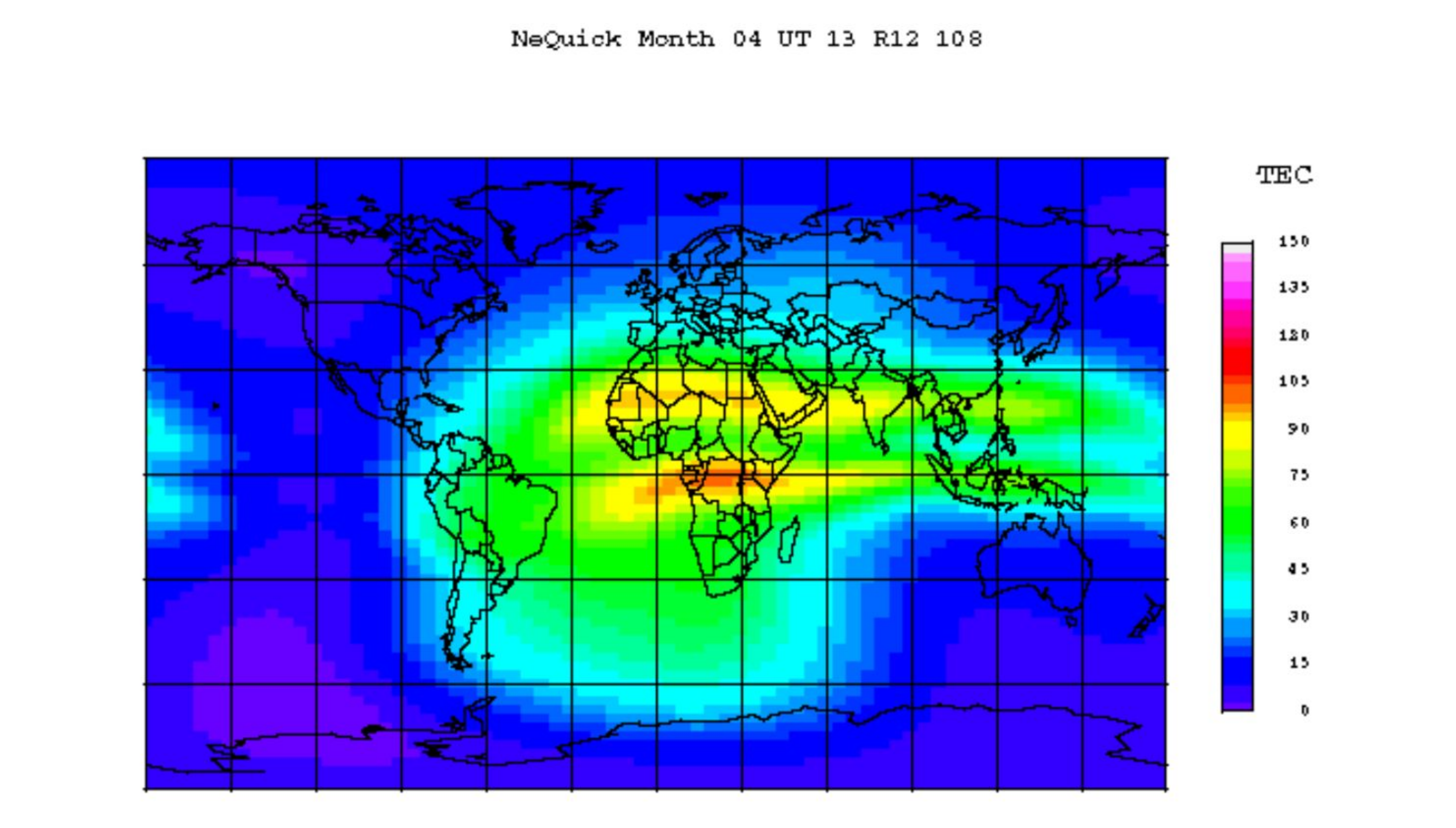
# The NeQuick model 1/2

- The NeQuick model is a ionospheric electron density model
- It is a quick-run model for trans-ionospheric applications that allows to calculate both vertical or slant electron density profile and TEC for any specified path
- It is provided as a grid of points

# NeQuick model input parameters

- ITU-R coefficients and /or monthly mean F 10.7
- Measured values
- Regional maps of coefficients based on grid values constructed from data obtained at given locations

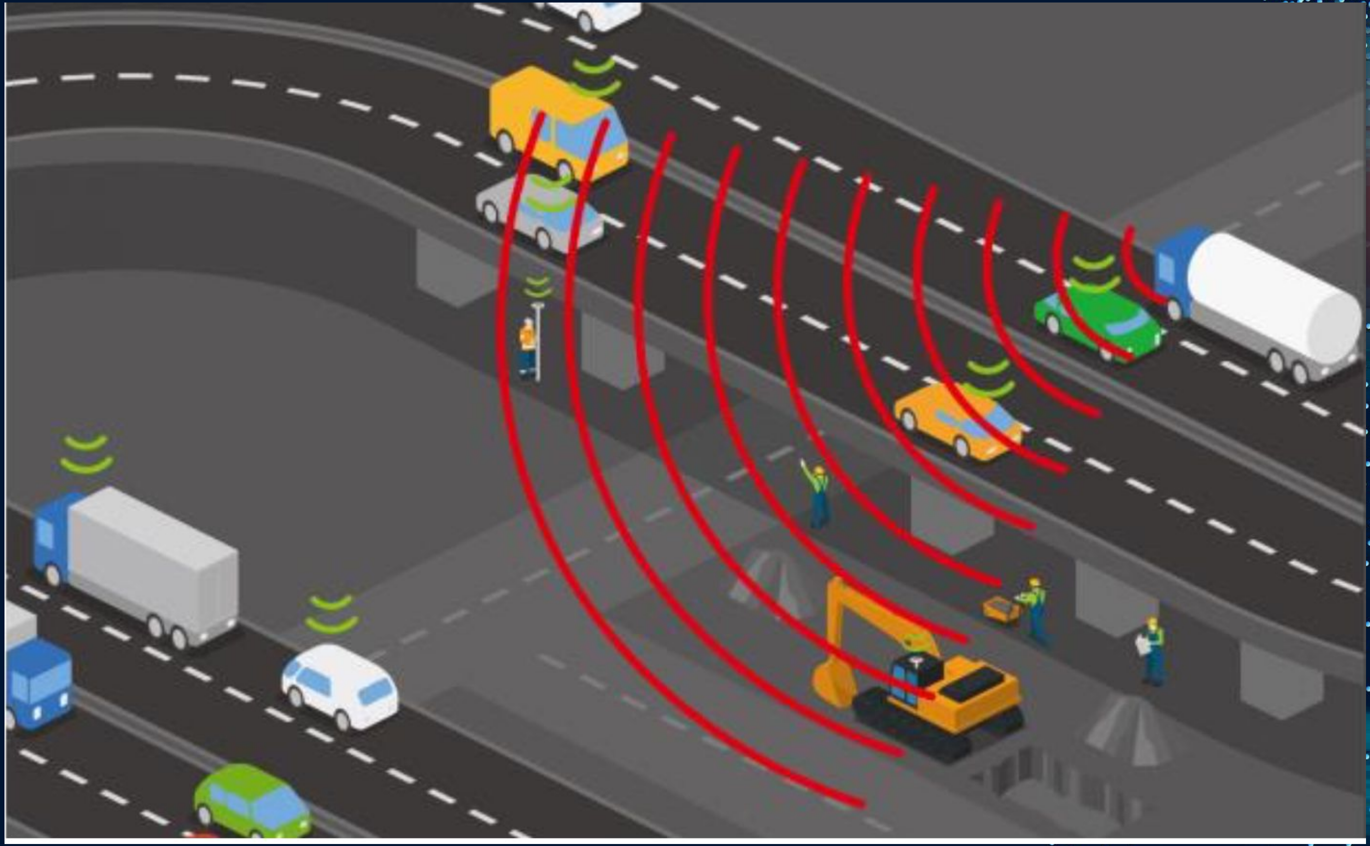
# TEC maps


NeQuick Month 04 UT 13 R12 108
TEC
150
135
120
105
90
75
60
45
30
15
0

# Interference

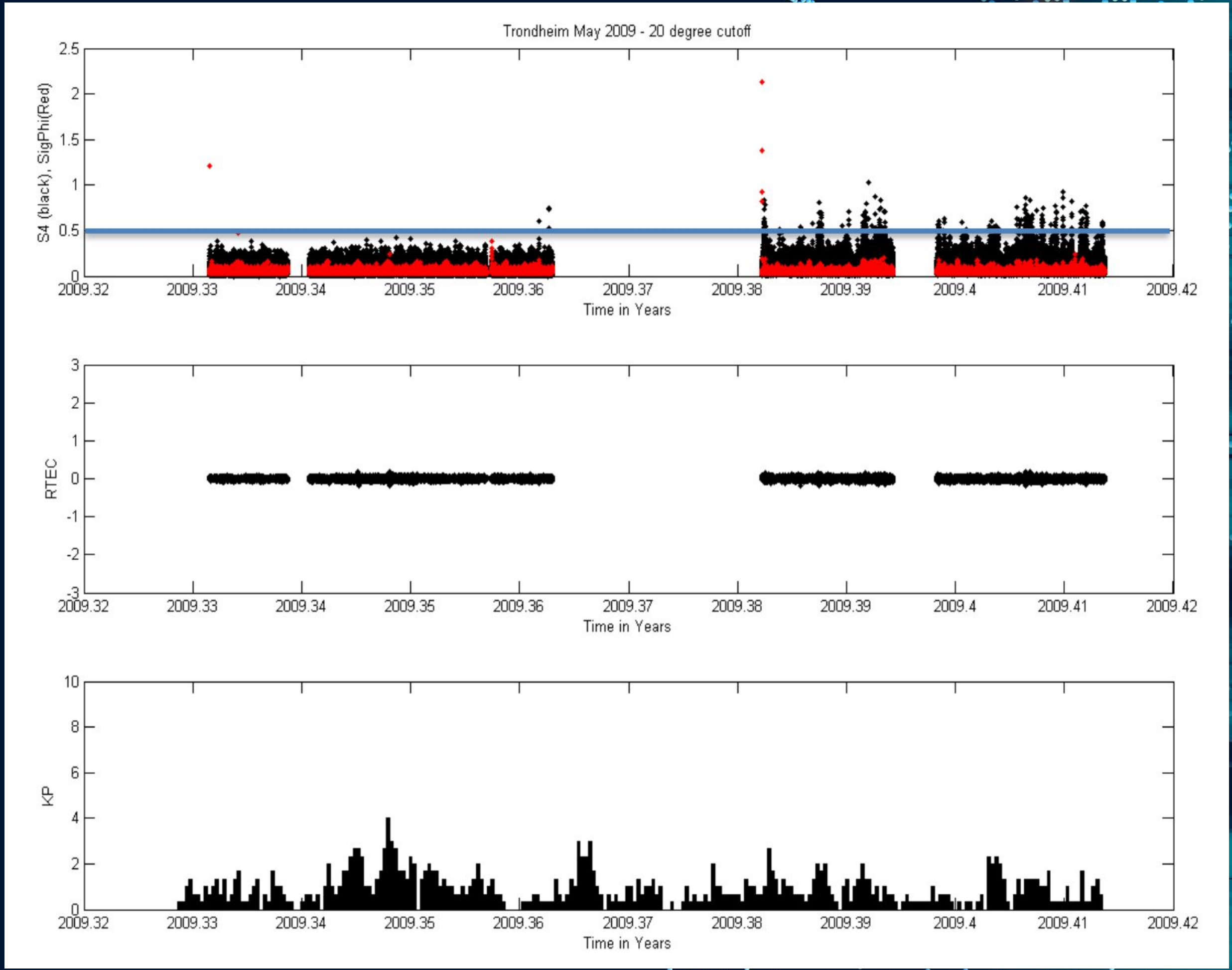
- ❑ As GNSS signals travel a long distance through the atmosphere they are relative weak when they arrive at the ground
- ❑ Generating a similar (or identical) GNSS signal is not difficult (although often illegal)
- ❑ Other Radio signals can also cause problems for GNSS receivers to track signals
- ❑ Interference can be
  - › Intentional
  - › Unintentional

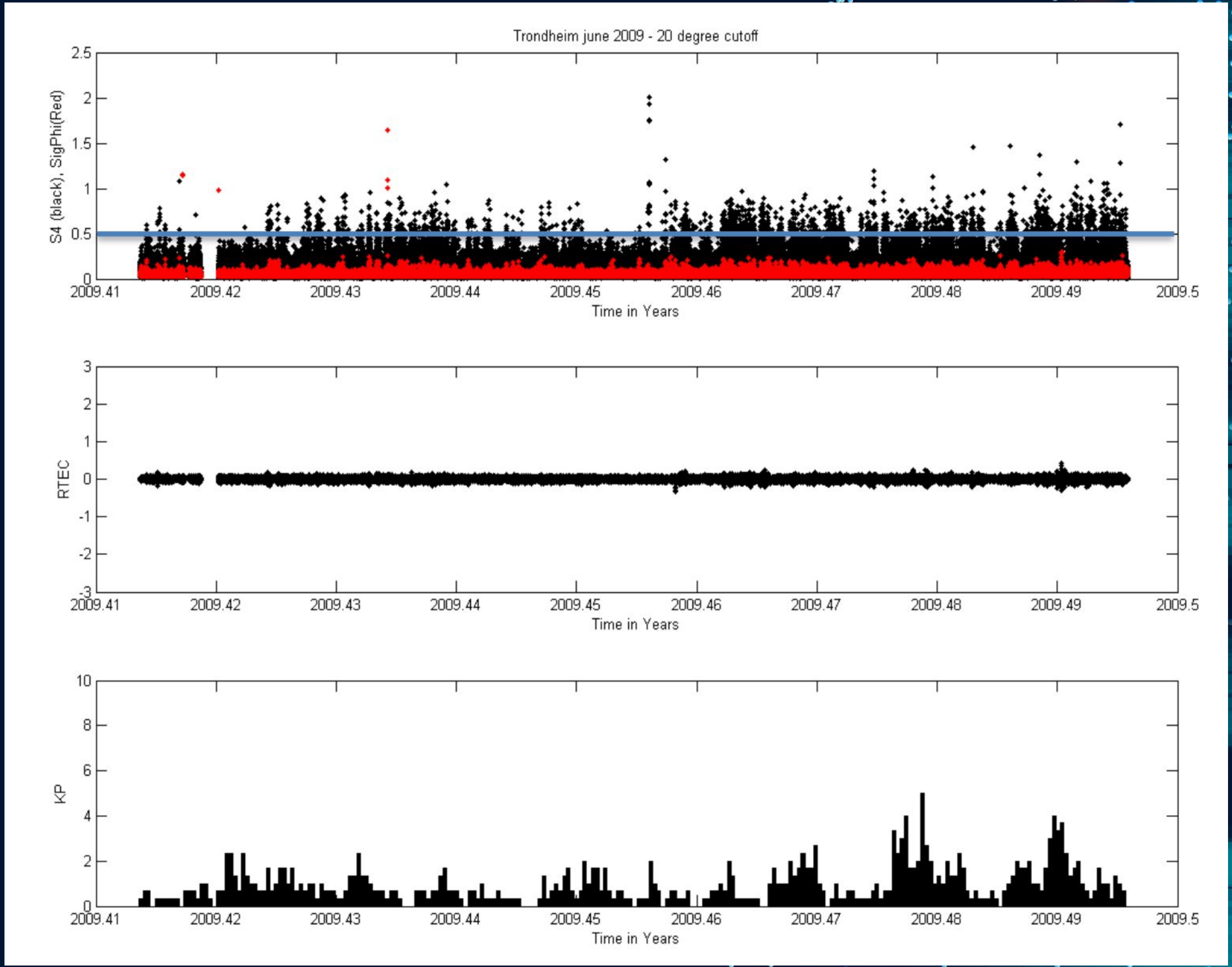
# Intentional Interference



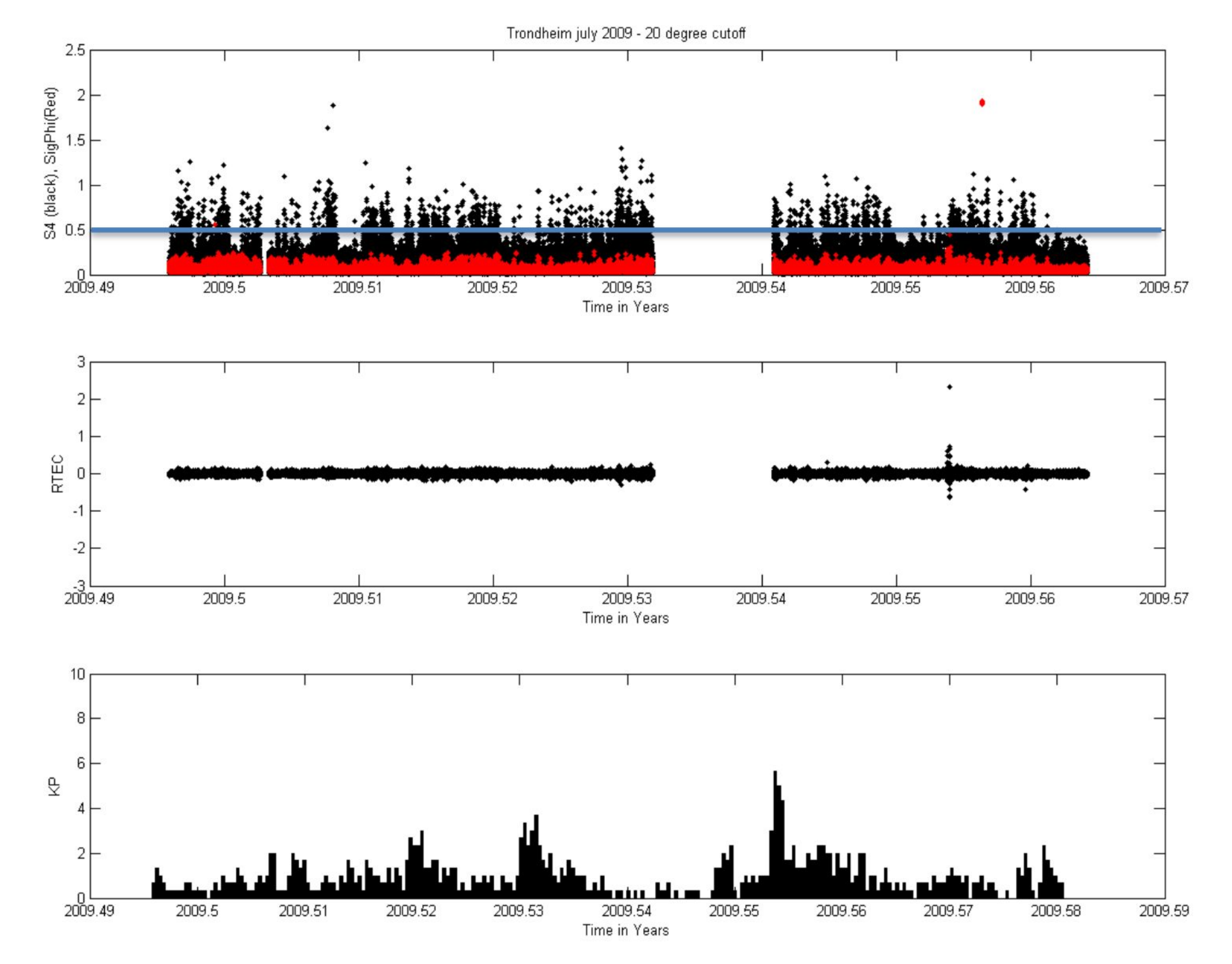
# Station Analysis - Trondheim


# Unintentional Interference

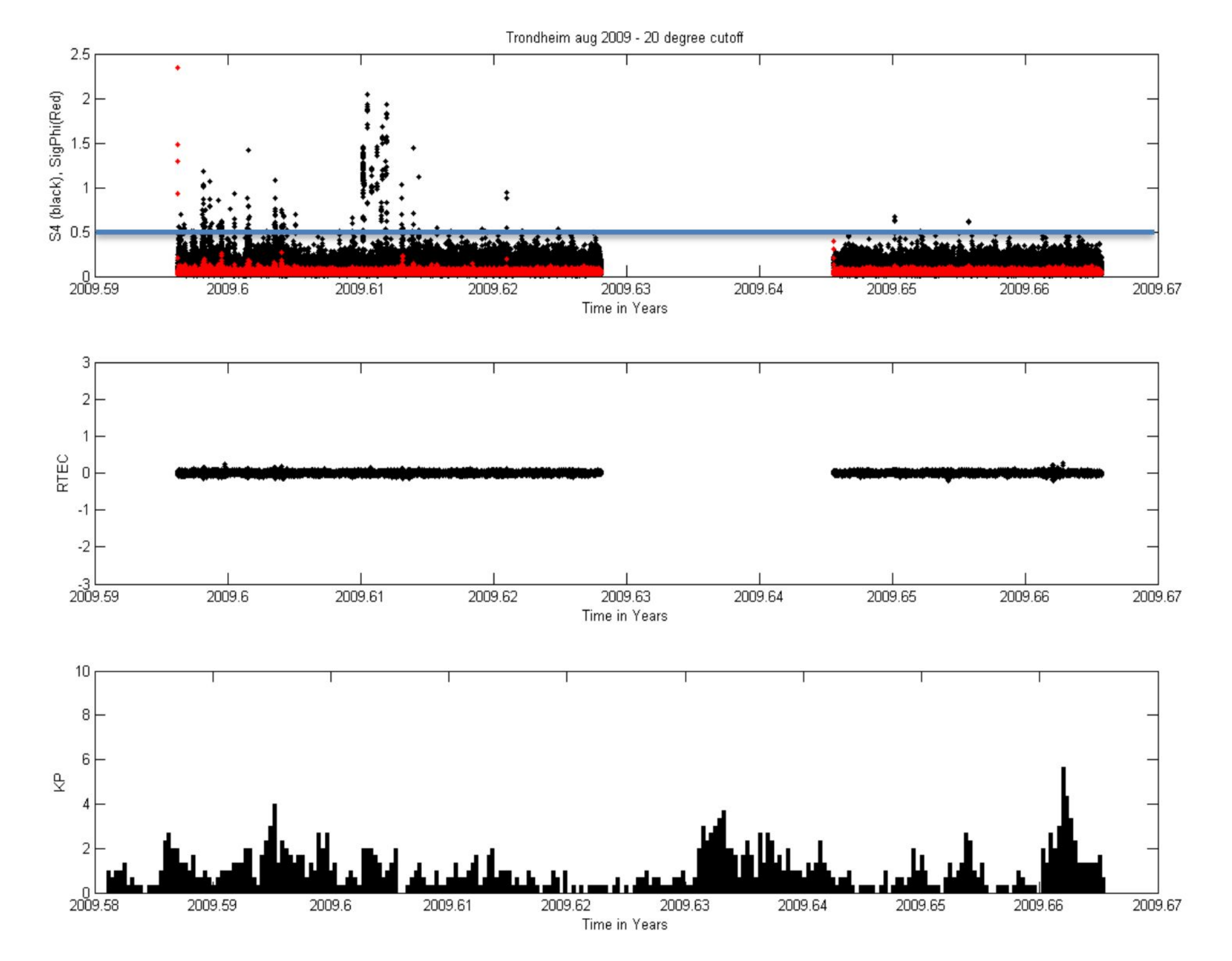


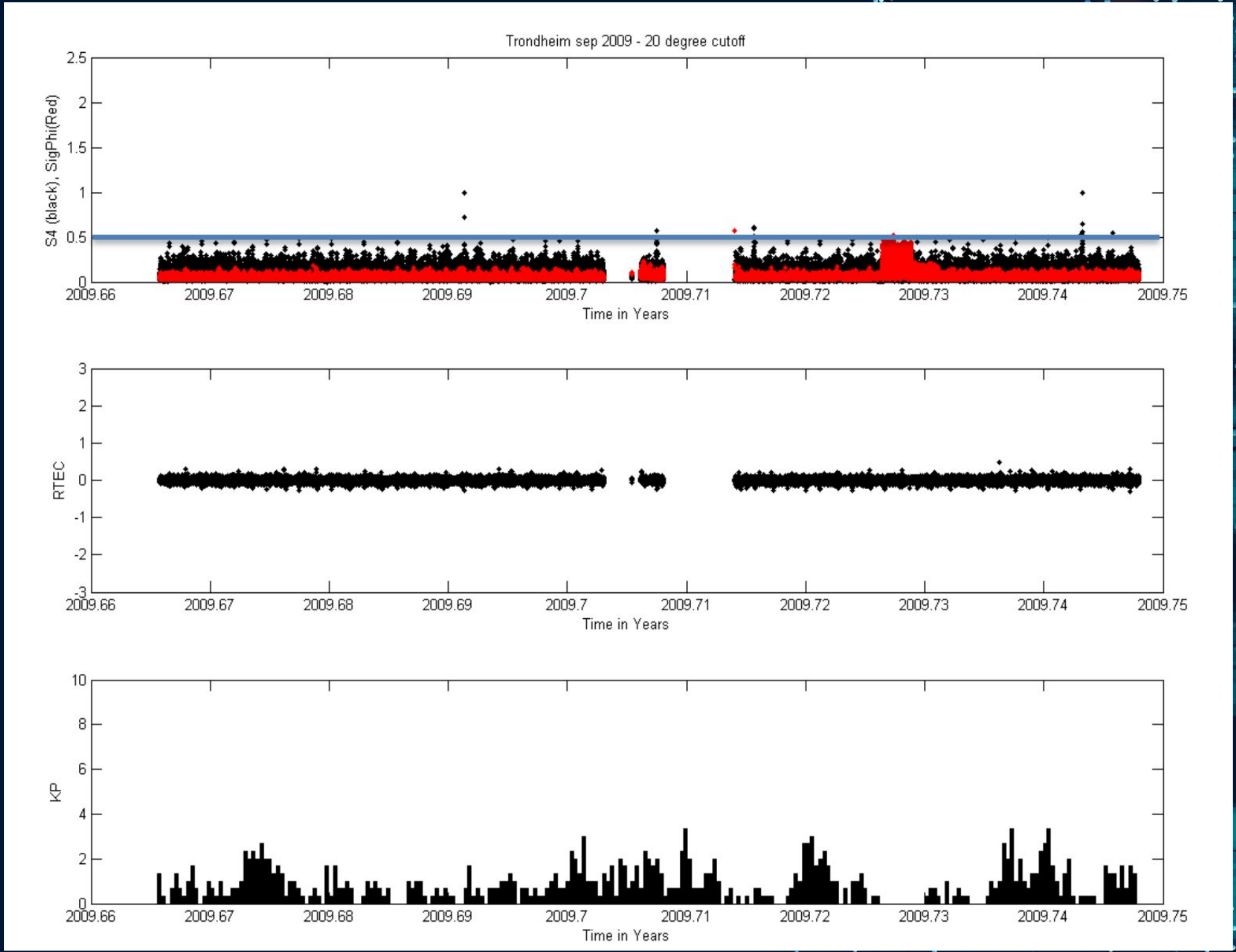


Trondheim june 2009 - 20 degree cutoff
S4 (black), SigPhi(Red)
Time in Years
RTEC
Time in Years
KP
Time in Years



Trondheim july 2009 - 20 degree cutoff
S4 (black), SigPhi(Red)
Time in Years
RTEC
Time in Years
KP
Time in Years

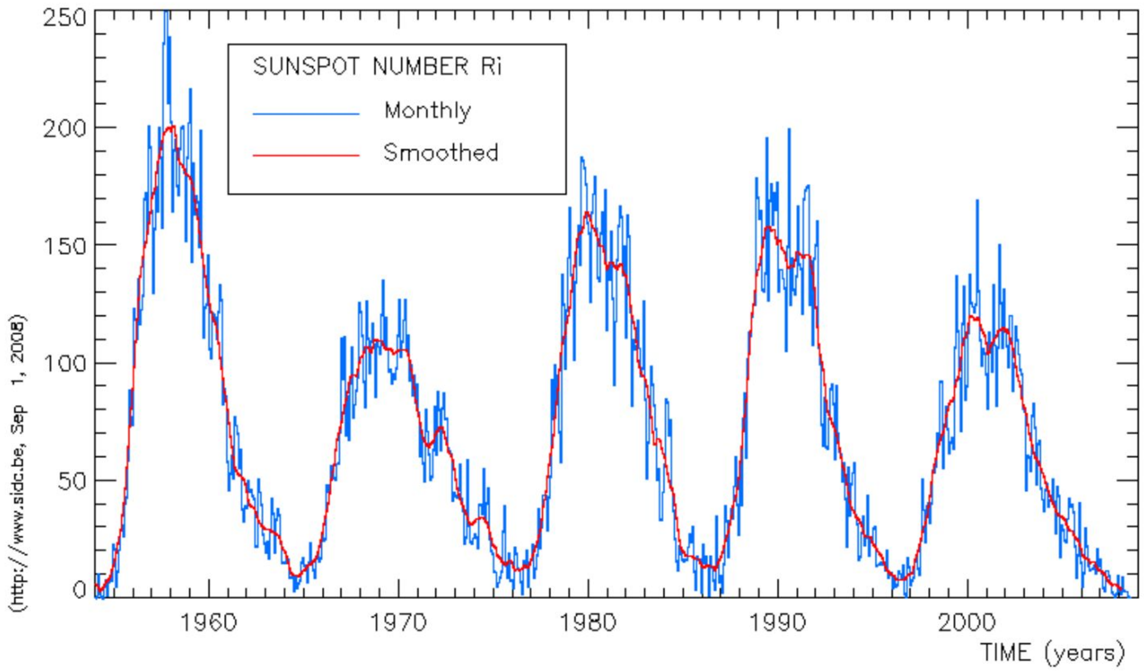

Trondheim aug 2009 - 20 degree cutoff
S4 (black), SigPhi(Red)
Time in Years
RTEC
Time in Years
KP
Time in Years


Trondheim sep 2009 - 20 degree cutoff
S4 (black), SigPhi(Red)
RTEC
KP
Time in Years
2009.66
2009.67
2009.68
2009.69
2009.7
2009.71
2009.72
2009.73
2009.74
2009.75

# The Solar Maximum Problem

- ❑ Ionospheric disturbances in years of high sunspot activity
- ❑ Solar maximum between 2000 and 2002, and again 2011-2013, next is 2024 - 2026
- ❑ More significant effects in equatorial and auroral regions
- ❑ North-South gradients can affect mid-latitude regions
- ❑ GNSS applications suffer with such disturbances
- ❑ Therefore, can use GNSS to study such disturbances

# Sunspot Cycle



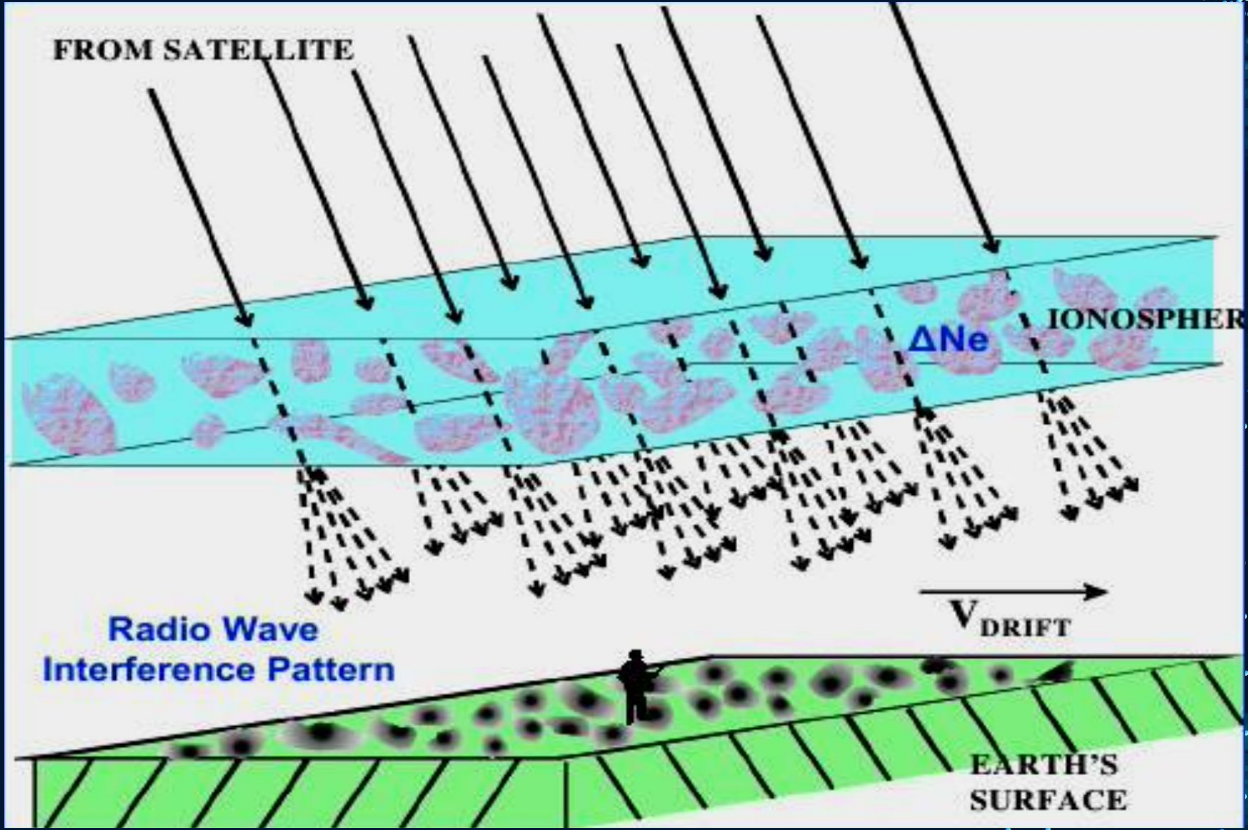

Sunspot Index Data Centre, Royal Observatory of Belgium

# Ionospheric Scintillation

- ❑ Effect of ionosphere dependent on TEC
- ❑ Regular behaviour of TEC allows modeling with 2 frequencies
- ❑ However
  - › Ionosphere greatly influenced by solar activity
  - › Disturbances can take place during high sunspot activity (peak of cycle)
  - › Charged particles from solar flares cause changes in magnetic field
  - › Small scale electron density irregularities + rapid TEC changes occur

- ❑ Result is fluctuation in phase and amplitude of GPS signals
- ❑ Scintillation
- ❑ More severe at Equatorial and Auroral regions

# Radio Waves Scintillation – the problem



# Ionospheric Scintillations Phenomena

- Short-time fluctuations in received signal phase and amplitude.
- Originated from scattering because of electron concentration irregularity zones in the ionosphere (mainly at F region heights).
- Scintillation activity depends on solar and geomagnetic activity, season, local time, location.
- Scintillation Indices:
  - – for intensity scintillation: $$S_4 = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$
  - – for phase scintillation: $\sigma_\phi$

# The Problem

- ❑ Ionospheric Scintillation produced by irregularities
- ❑ Parameters are S4 (amplitude) and σφ (phase)
- ❑ Effects GNSS in 2 ways
  - › Refraction
    - » Variations in group delay and phase advance caused by large scale variations in electron density.
  - › Diffraction
    - » Scattering of the GNSS signal: Can cause signal power fades of up to 30 dB-Hz and fast phase variations that can cause the receiver to lose lock

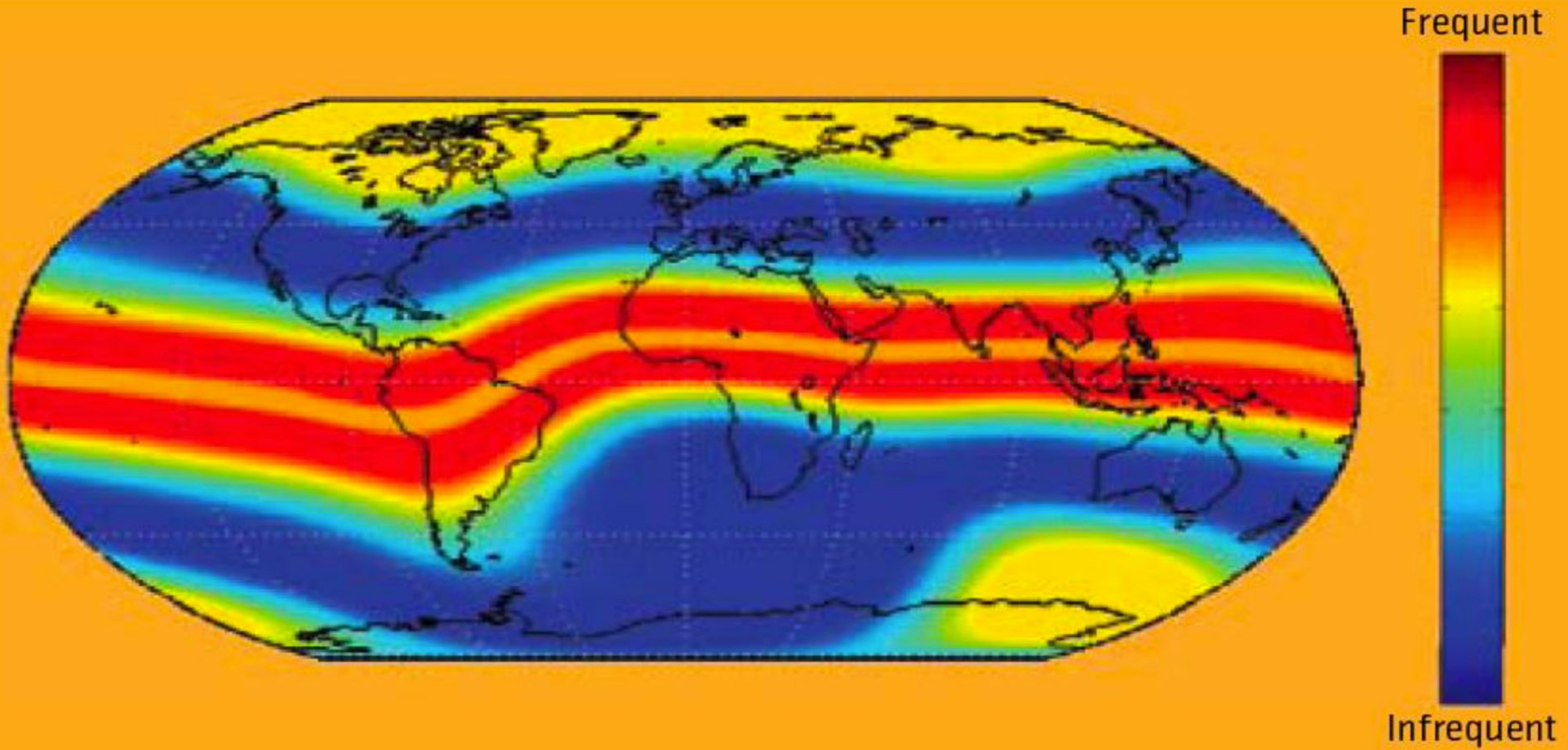
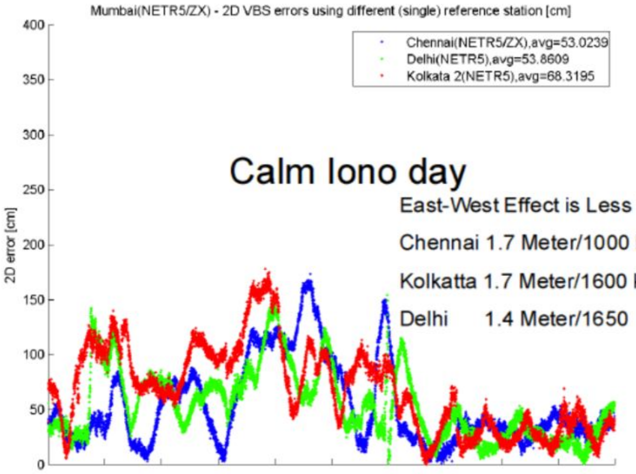



**FIGURE 1** Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.




Calm Iono day

East-West Effect is Less than North-South Effect

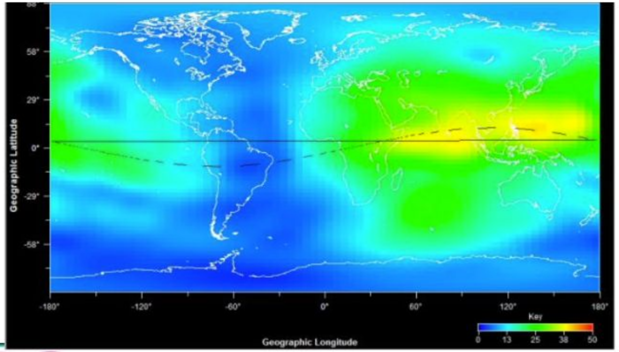
Chennai 1.7 Meter/1000 km = 17 cm/ 100 km Max

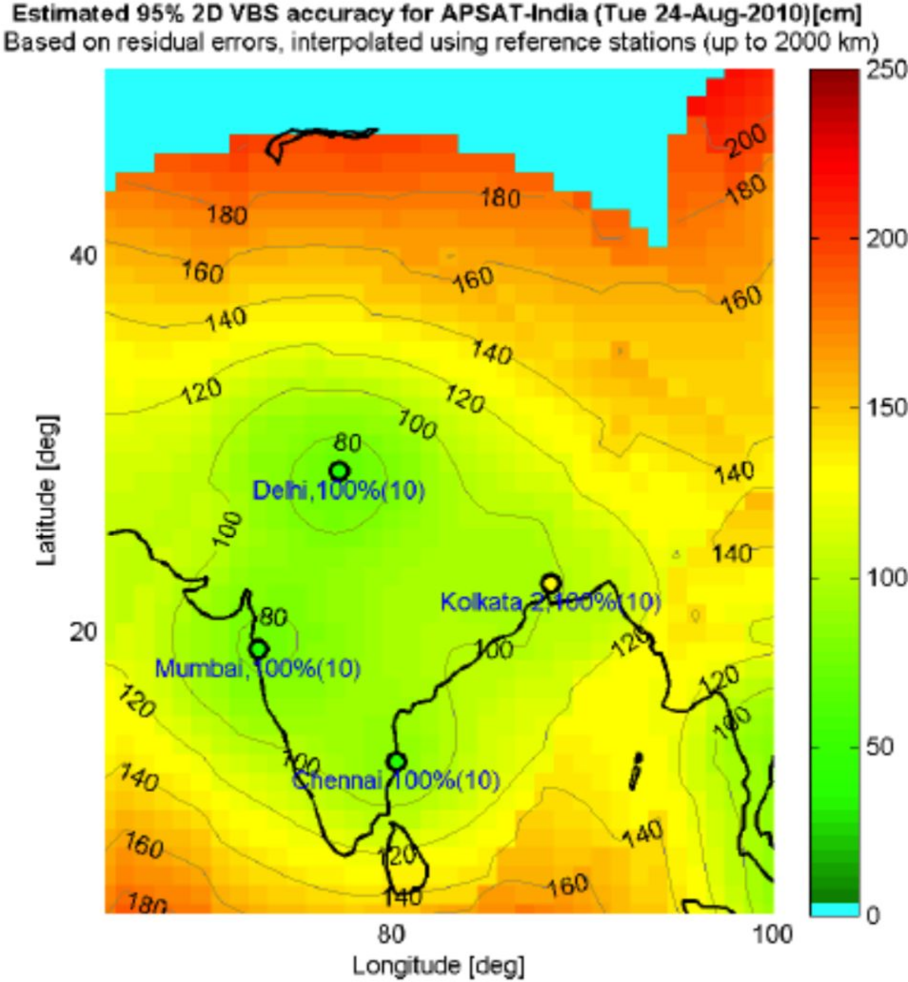
Kolkatta 1.7 Meter/1600 km = 10 cm/100 km Max

Delhi 1.4 Meter/1650 = 8 cm/100 km Max

5 7 9 11 13 15 17 19 21 23 1 3 5 India Time

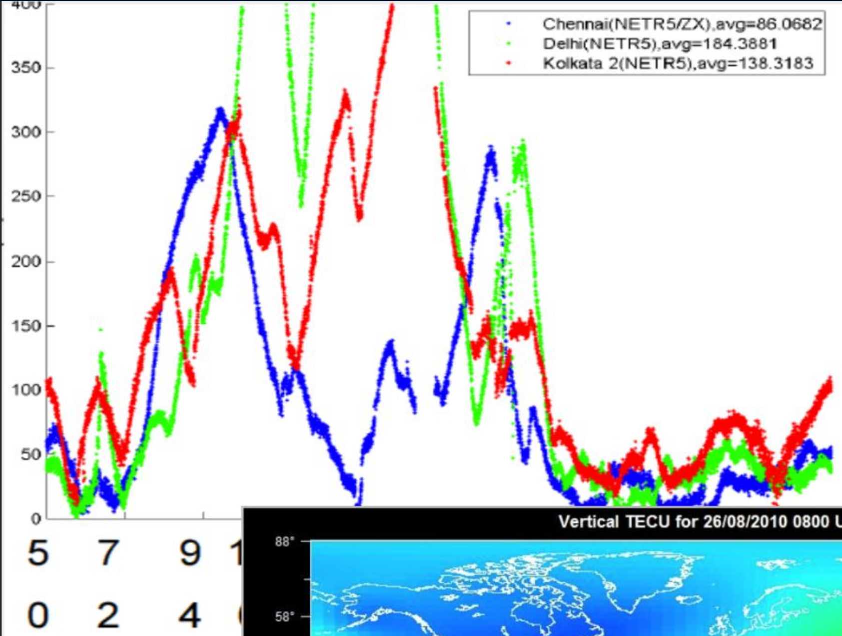
0 2 4 6 8 10 12 14 16 18 20 22 24 UTC

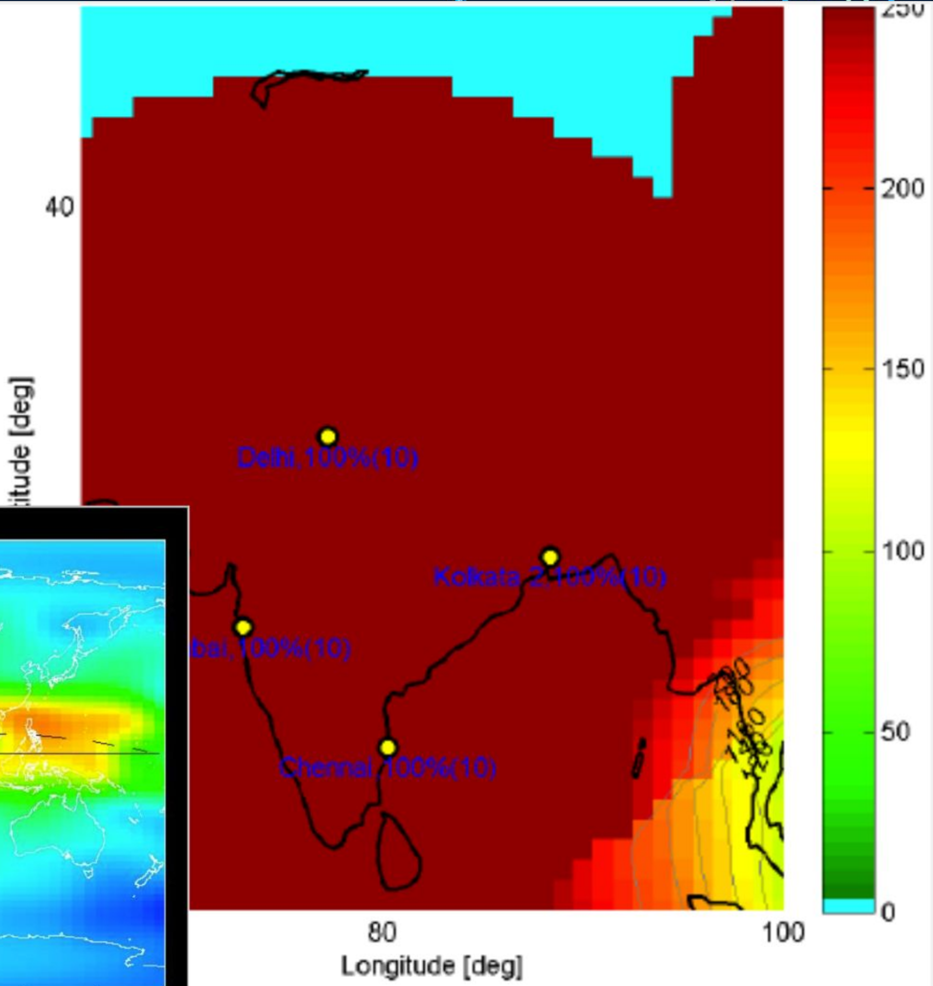


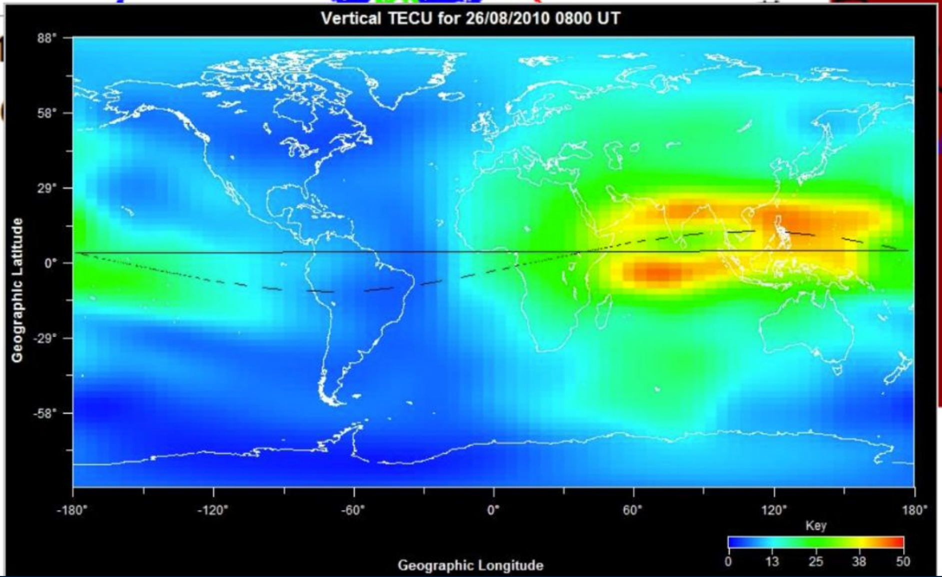




EPSRC

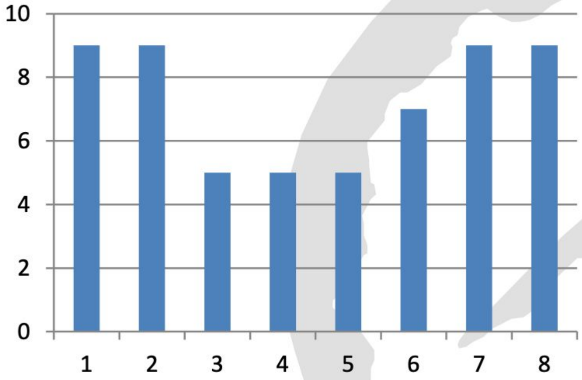
Pioneering research and skills

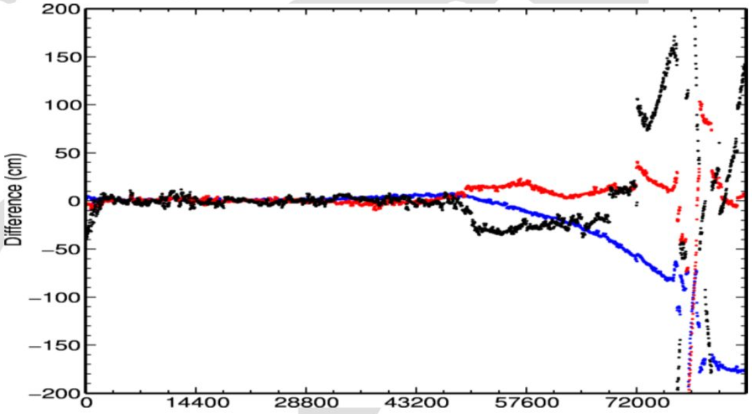

Chennai(NETR5/ZX),avg=86.0682
Delhi(NETR5),avg=184.3881
Kolkata 2(NETR5),avg=138.3183
400
350
300
250
200
150
100
50
0
5 7 9
0 2 4


40
Latitude [deg]
Delhi,100%(10)
Kolkata 2,100%(10)
Chennai,100%(10)
80
100
Longitude [deg]
250
200
150
100
50
0

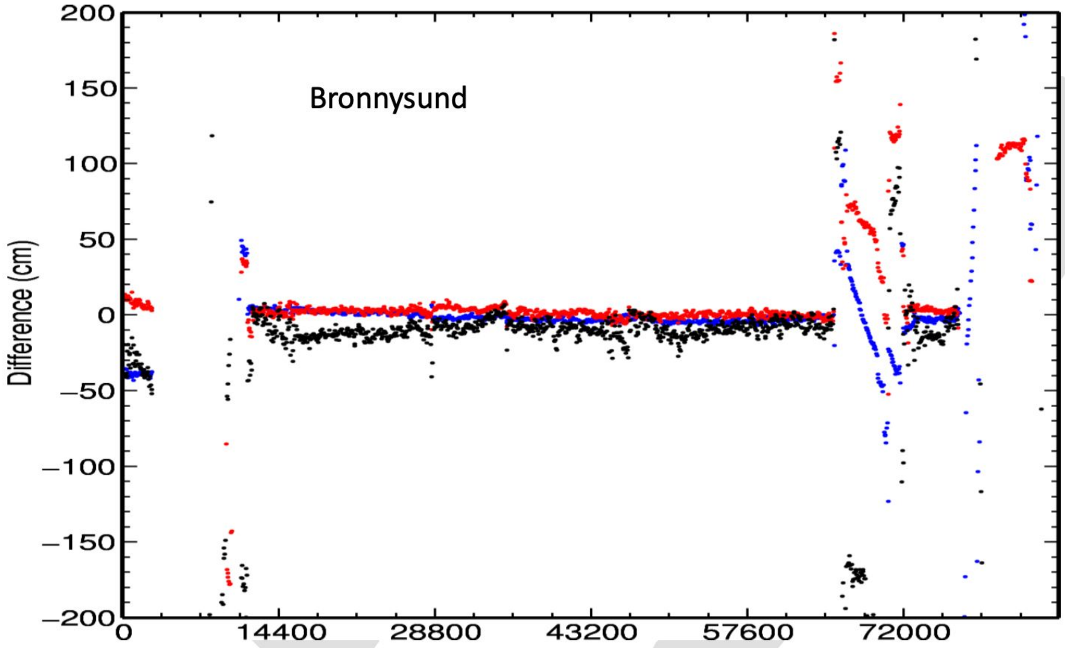

Vertical TECU for 26/08/2010 0800 UT
Geographic Latitude
88°
58°
29°
0°
-29°
-58°
-180°
-120°
-60°
0°
60°
120°
180°
Geographic Longitude
Key
0
13
25
38
50

# PPP Analysis



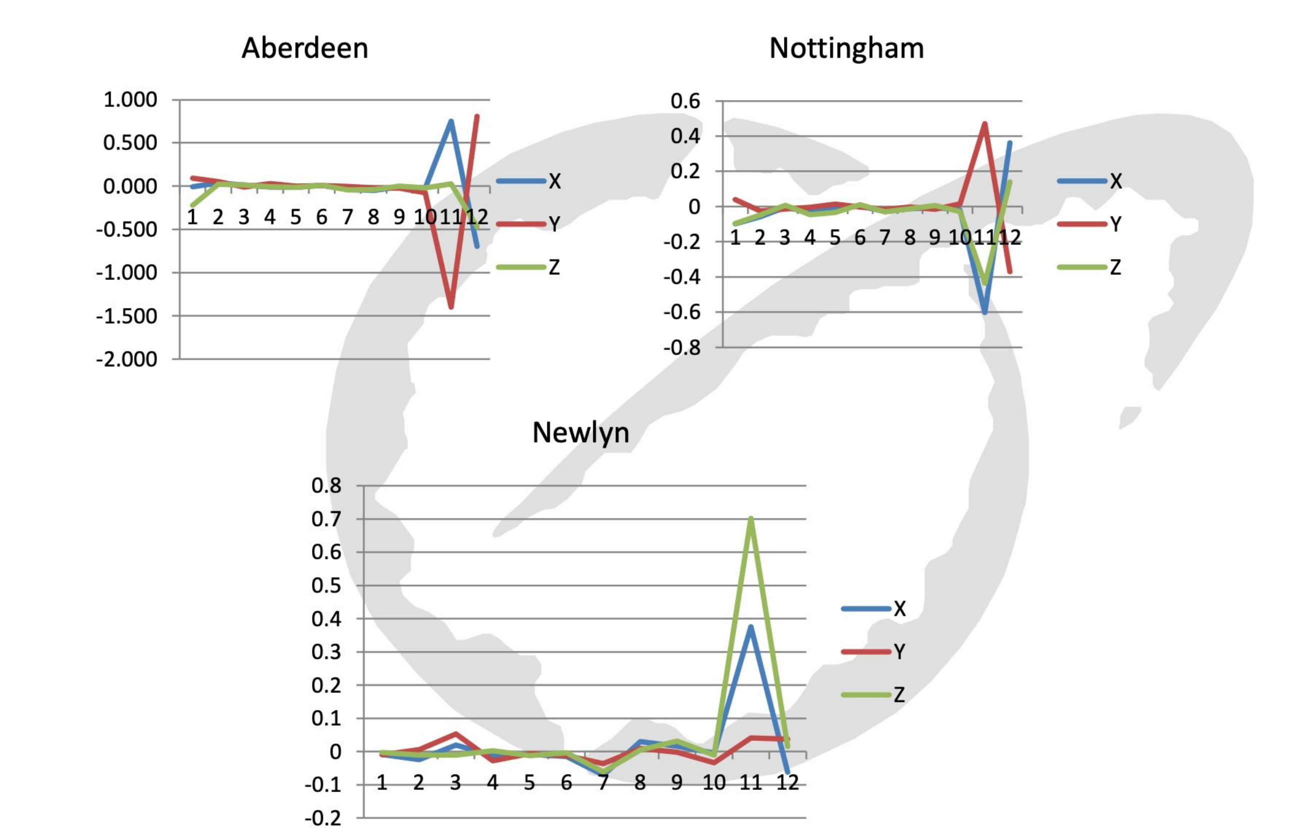



# PPP Analysis




Hammerfest – Ambiguity never solved for 30th Oct

# DD Analysis



Aberdeen
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
1 2 3 4 5 6 7 8 9 10 11 12
X
Y
Z
Nottingham
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1 2 3 4 5 6 7 8 9 10 11 12
X
Y
Z
Newlyn
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1 2 3 4 5 6 7 8 9 10 11 12
X
Y
Z

**Date:** Mon 01 October 2012 **Station:** Brønnøysund

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

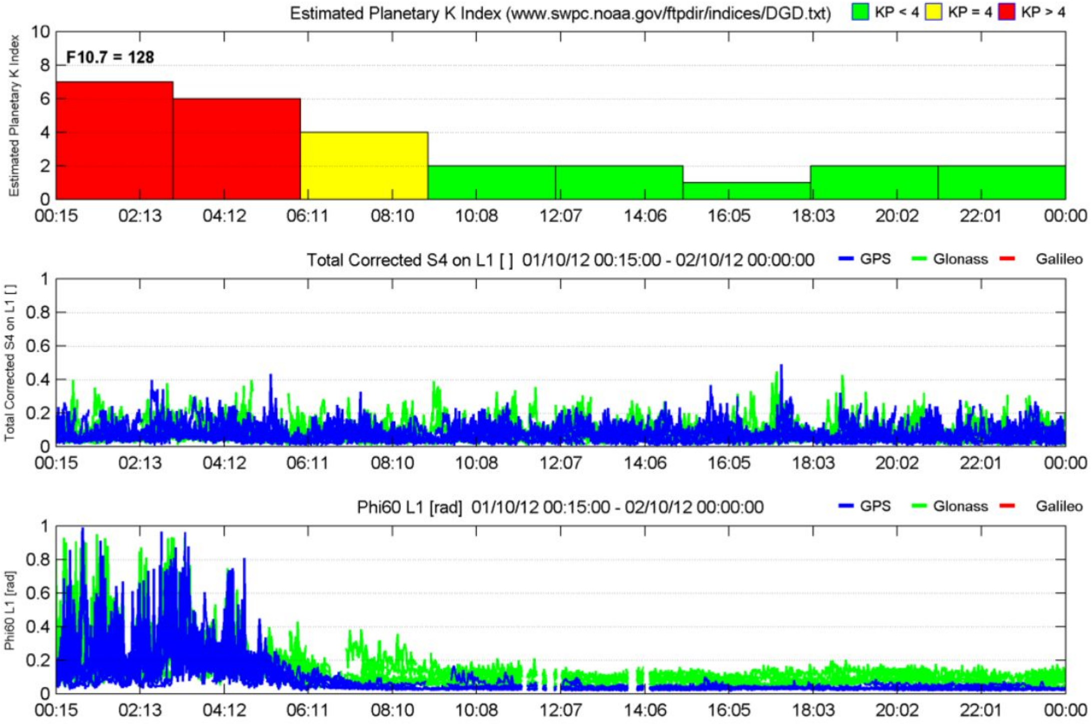

Date: Monday 01 October 2012
Station: Brønnøysund
Station Owner: University of Nottingham

Elevation Mask: 20°
Omit period after new lock: 4 min

Top Plot: Kp Index

Middle Plot: Total Corrected S4 on L1 [ ]

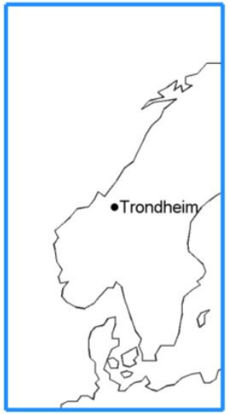
Bottom Plot: Phi60 L1 [rad]

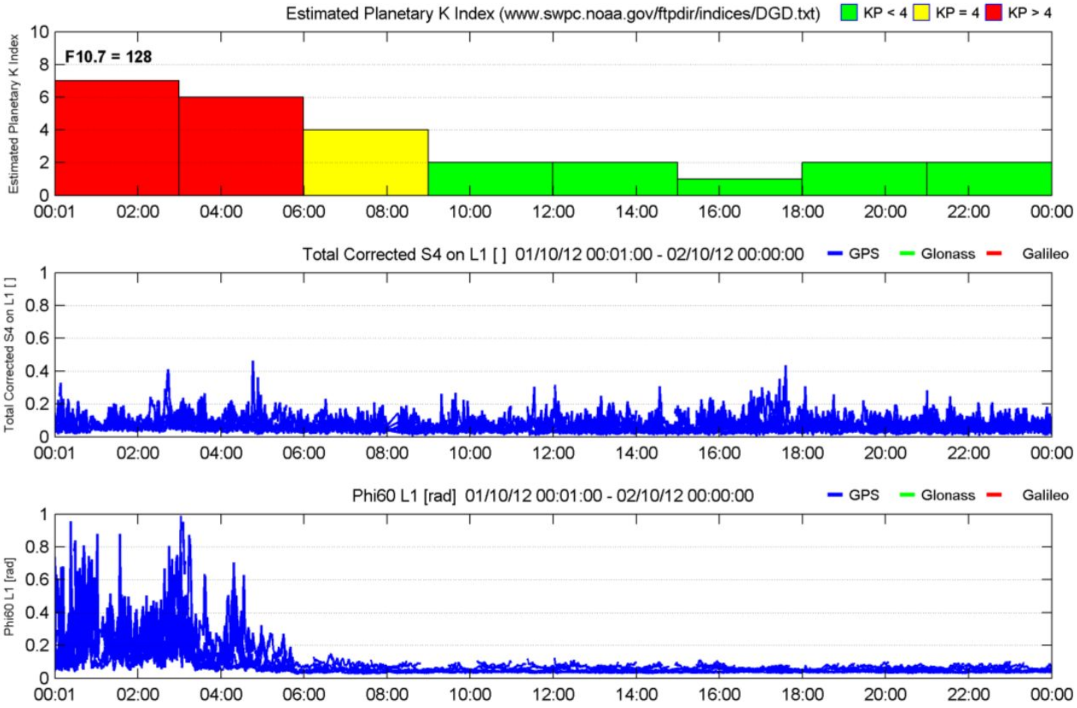



(C) Created by Nottingham University 2012, P. Kieft

**Date:** Mon 01 October 2012 **Station:** Trondheim

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA




Date: Monday 01 October 2012
Station: Trondheim
Station Owner: University of Nottingham

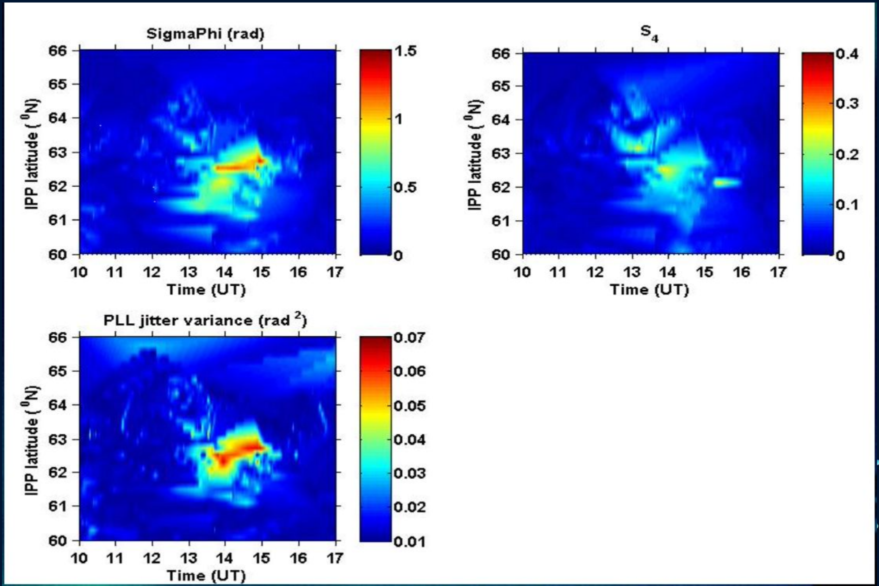
Elevation Mask: 20°
Omit period after new lock: 4 min

Top Plot: Kp Index

Middle Plot: Total Corrected S4 on L1 [ ]

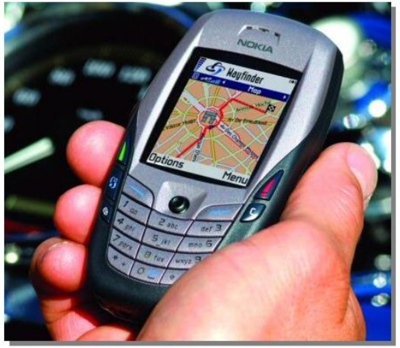
Bottom Plot: Phi60 L1 [rad]

# Receiver PLL jitter variance Maps High latitude station




- Increase in jitter variance with increase in scintillation levels
- Data from Iqaluit station kindly provided by Dr Paul Prikryl

# Isn’t Accurate Enough



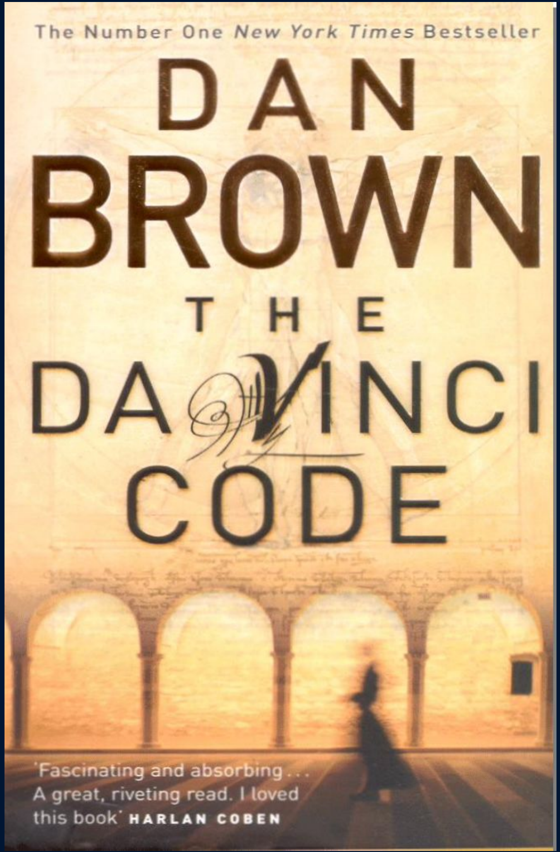

10 m

1 m

1 cm

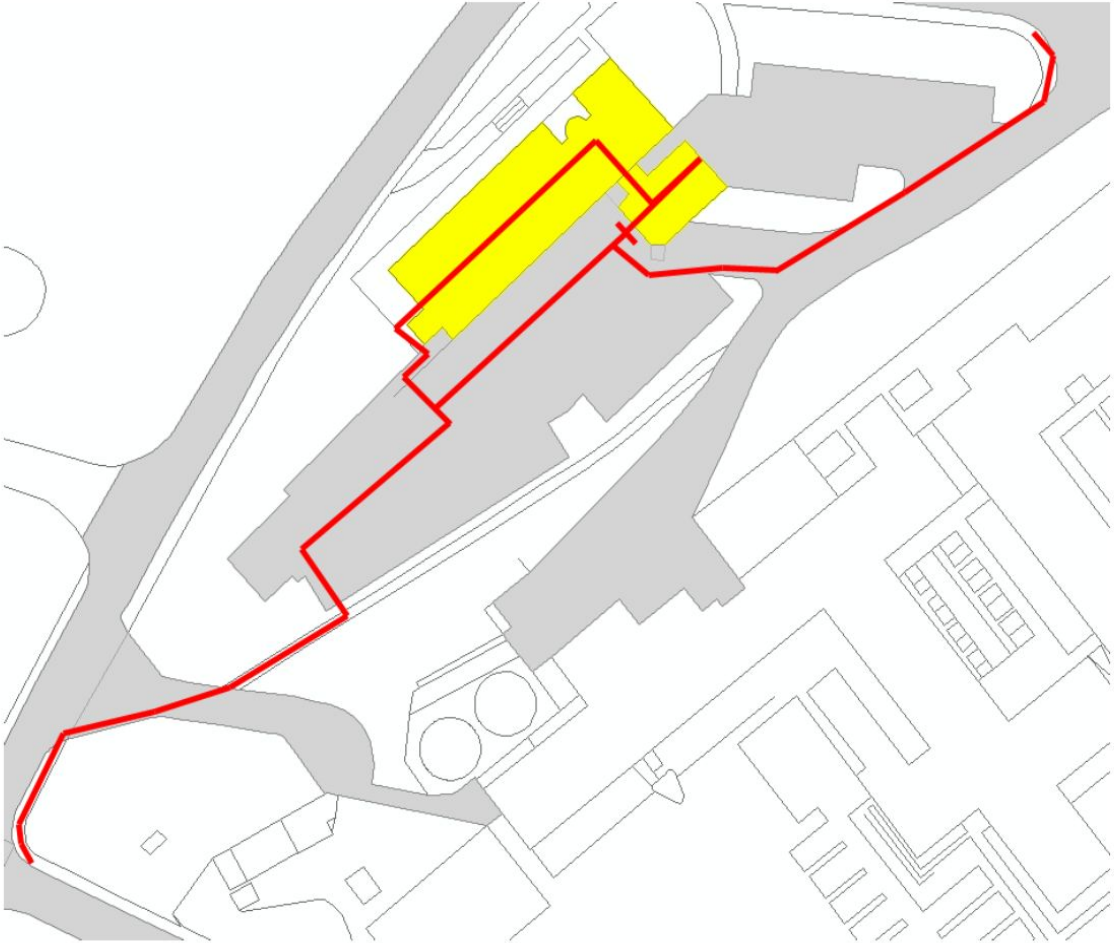
1 mm

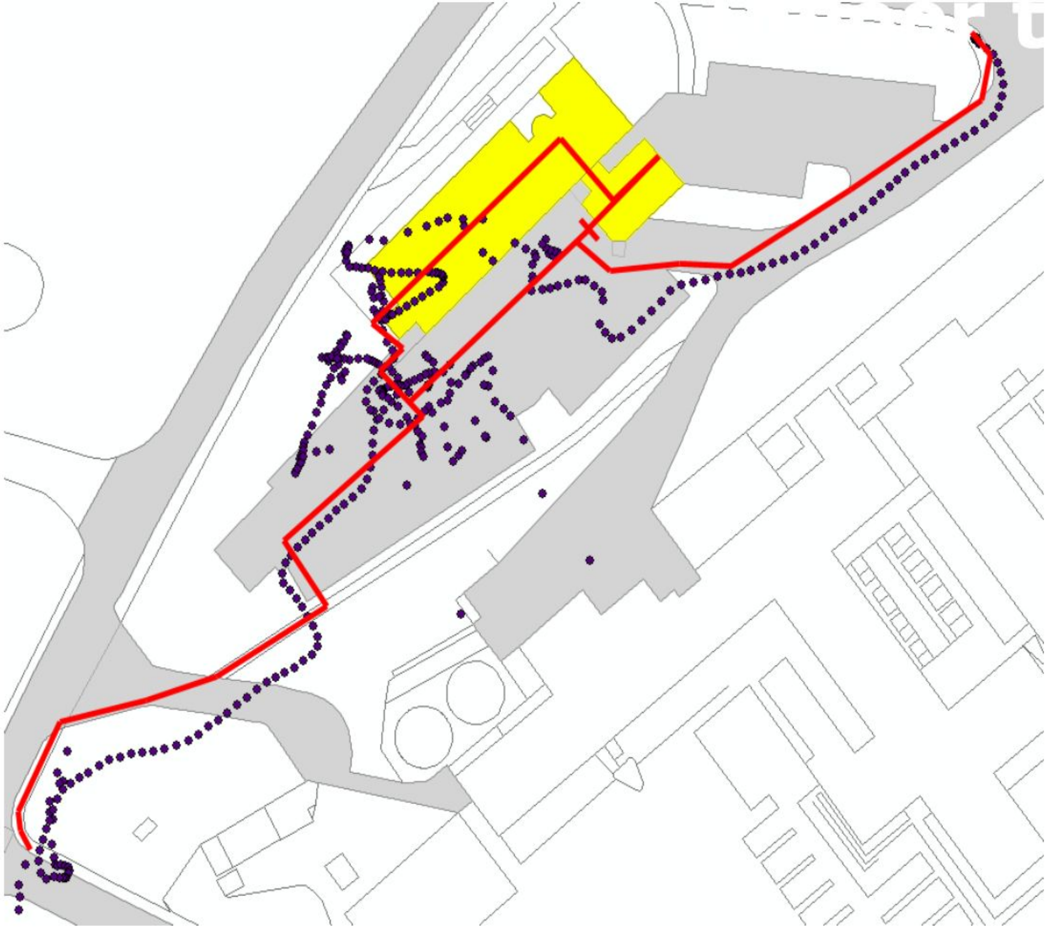
# Doesn't Work Indoors!





*"Captain Fache plants a battery-sized GPS dot in Langdon's pocket to track his location, wherever he is, accurate to 2 feet"*

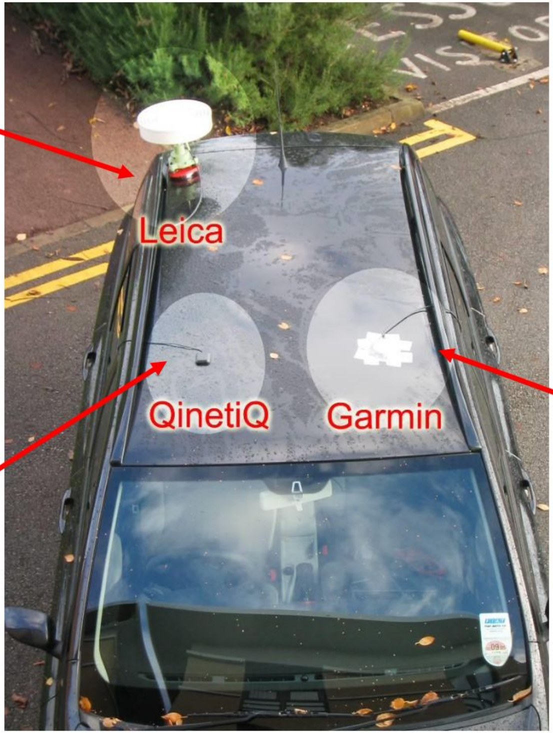




# Doesn’t Work in Urban Areas

- Leica GPS530
- Dual frequency
- Reference station at IESSG (<3km)

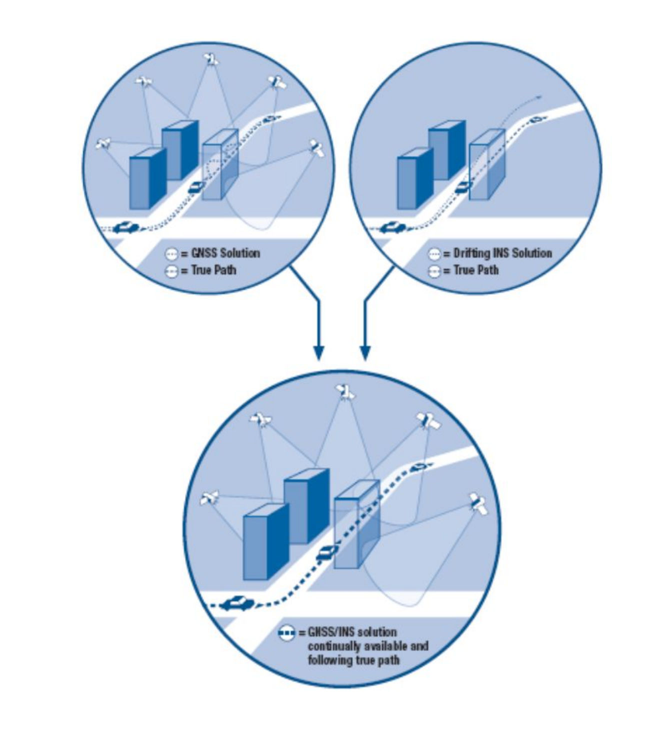
- QinetiQ Q20




- Garmin 76
- EGNOS disabled

# QinetiQ Leica Garmin

- Combination of GNSS and INS will give continuous position, time and velocity information, even in difficult environments where there is limited GPS satellites in view



- INS uses rotation and acceleration information from an Inertial Measurement Unit (IMU) to compute position over time
- An INS can also solve for full attitude (roll, pitch and heading) measurements
- In absence of external reference such as a GNSS solution, INS solution will drift
- over time
- When combined, GNSS and INS will provide accurate and reliable navigation solution
- Tightly coupled systems allow the INS to use GNSS data to contain its drift, while the INS solution feeds back into the GNSS solution to improve signal reacquisition and convergence time

- For applications where real-time solution is not necessary, raw GNSS data can be collected and stored for post mission processing
- Post-processing does not require a real-time transmission of differential corrections, simplifying hardware configuration
- Users can load data from multiple base stations, or download freely available base station data
- Users can also download PPP data (precise ephemeris and clock data) to process without a base station
- Post-processing can be done on static or kinematic data

# Thank you for Your Participation

Halmat Atta Ali

https://www.esurveyiq.com/

BRGTC