

Lecture 9

Introduction to GNSS Positioning Techniques

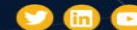
Professors: Dr. J. Sanz Subirana, Dr. J.M. Juan Zornoza
and Dr. Adrià Rovira García

Galileo Masterclass Brazil (GMB) 2022

From Fundamentals to Signal and Data Processing



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pela União Europeia

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August 2022

Contents

1. Introduction

1. GNSS positioning and errors on the signal
2. Standalone Positioning
3. Differential positioning concept and differential corrections

2. Code Based Differential positioning (DGNSS)

1. DGNSS using smoothed codes
2. Augmentation systems (GBAS and SBAS)

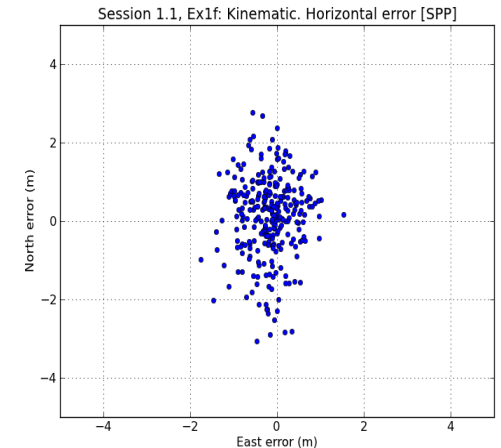
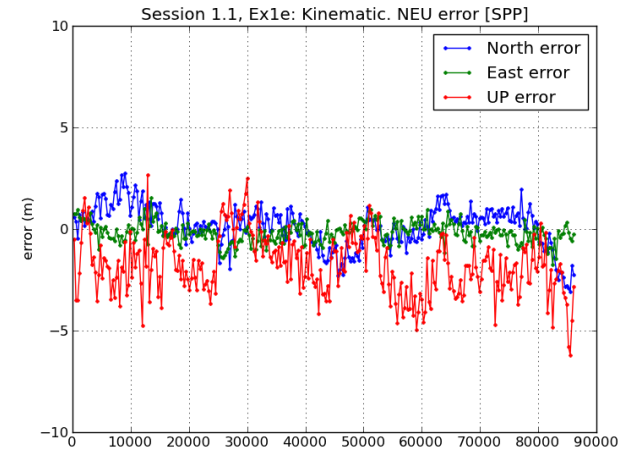
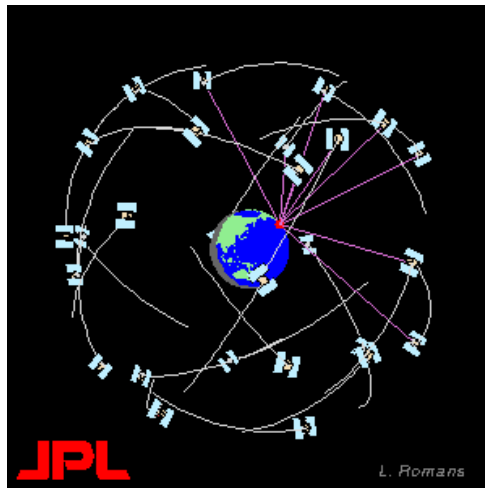
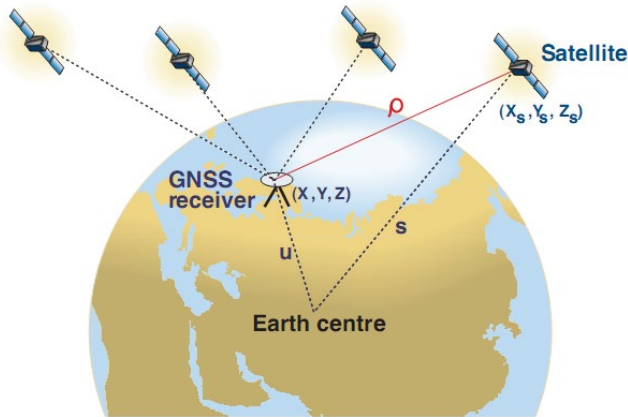
3. Carrier Based Differential positioning

1. Real Time Kinematics (RTK) and Network-RTK concepts
2. Precise Point Positioning (PPP) concept

4. Commercial Services

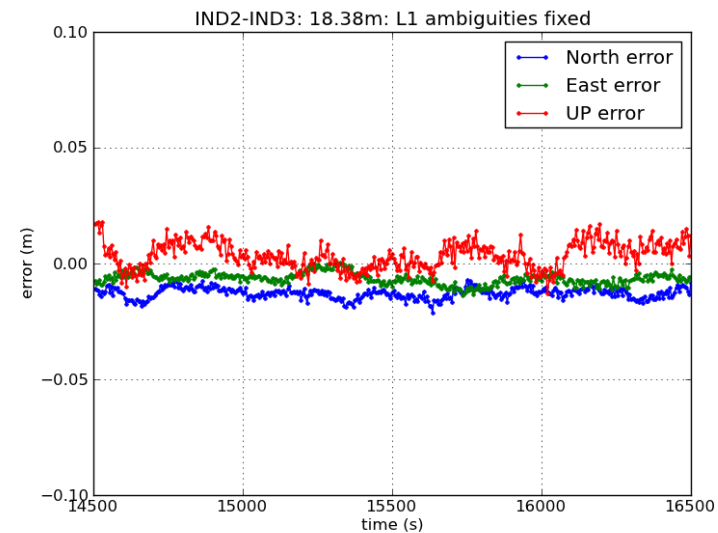
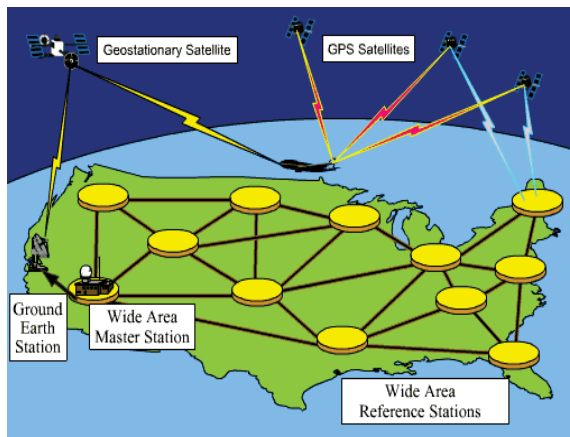
GNSS Positioning

Standalone Positioning: GNSS receiver autonomous positioning using broadcast orbits and clocks.



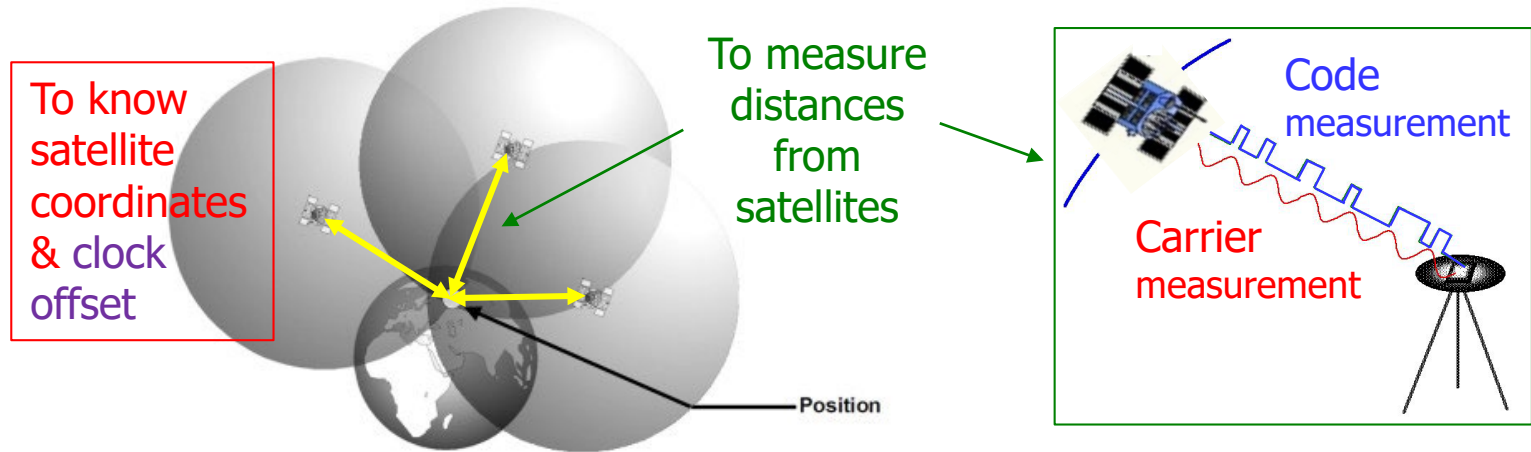
GNSS Positioning

Differential Positioning: GNSS augmented with data (differential corrections or measurements) from a single reference station or a reference station network.



Errors are similar for users separated tens, even hundred of kilometres, and these errors are removed/mitigated in differential mode, improving positioning.

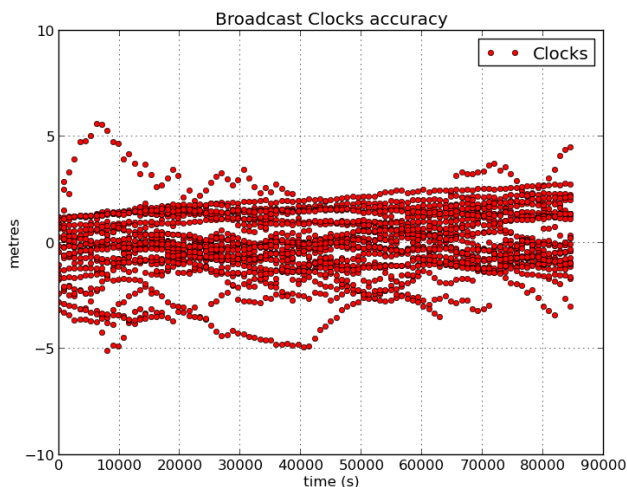
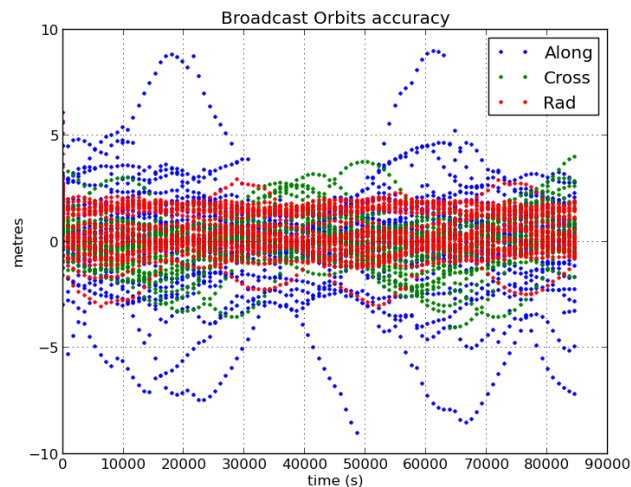
Reviewing the GNSS positioning concept



This picture is from <https://gpsfleettrackingexpert.wordpress.com>

- GNSS uses technique of **“triangulation”** to find user location
- To **“triangulate”** a GNSS receiver needs:
 - **To know the satellite coordinates** and clock synchronism errors:
 - ➔ Satellites broadcast orbits parameters and clock offsets.
 - **To measure distances from satellites**:
 - ➔ This is done measuring the **traveling time** of radio signals: (“Pseudo-ranges”: **Code** and **Carrier** measurements)
 - ➔ Measurements must be corrected by several error sources: Atmospheric propagation, relativity, clock offsets, instrumental delays...

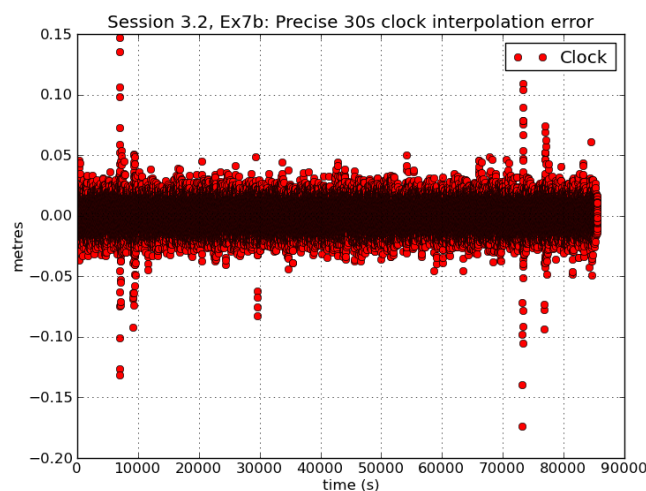
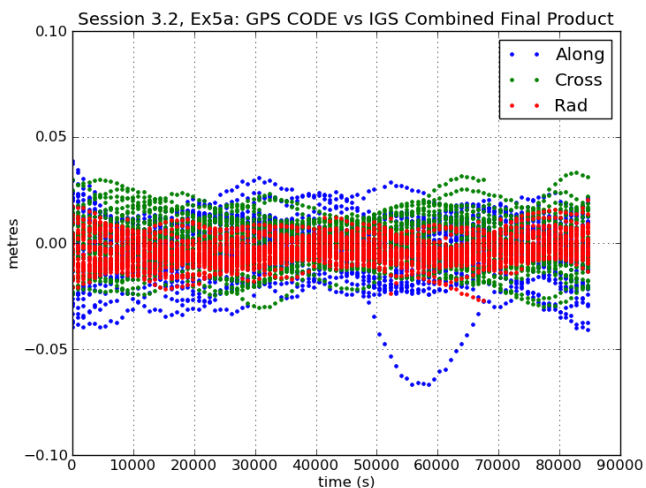
Satellite Orbit and clock accuracies



Broadcast:

Few metres of accuracy for broadcast orbits and clocks

Transmitted in the satellite navigation message.

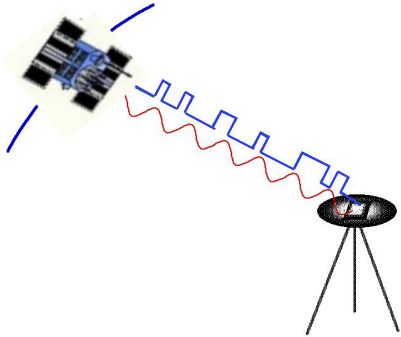


Precise:

Few centimetres of accuracy for precise orbits and clocks

Precise clocks for GPS satellites can be found on the International GNSS Service (IGS) server <http://igsceb.jpl.nasa.gov>

Ranging signals measurement noise



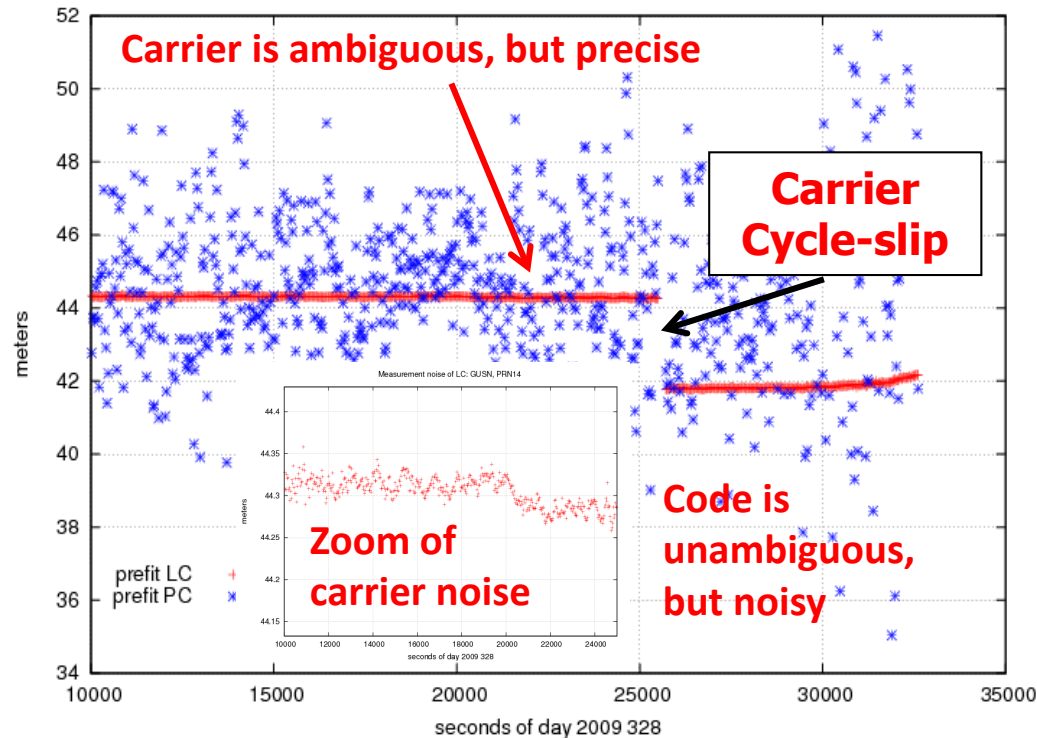
Two different types of measurements:

- **Code** measurements are noisy but unambiguous (metre level measurement noise).
- **Carrier** measurements are precise but ambiguous, meaning that they have some millimetres of noise, but also have “unknown carrier biases” that could reach thousands of km.

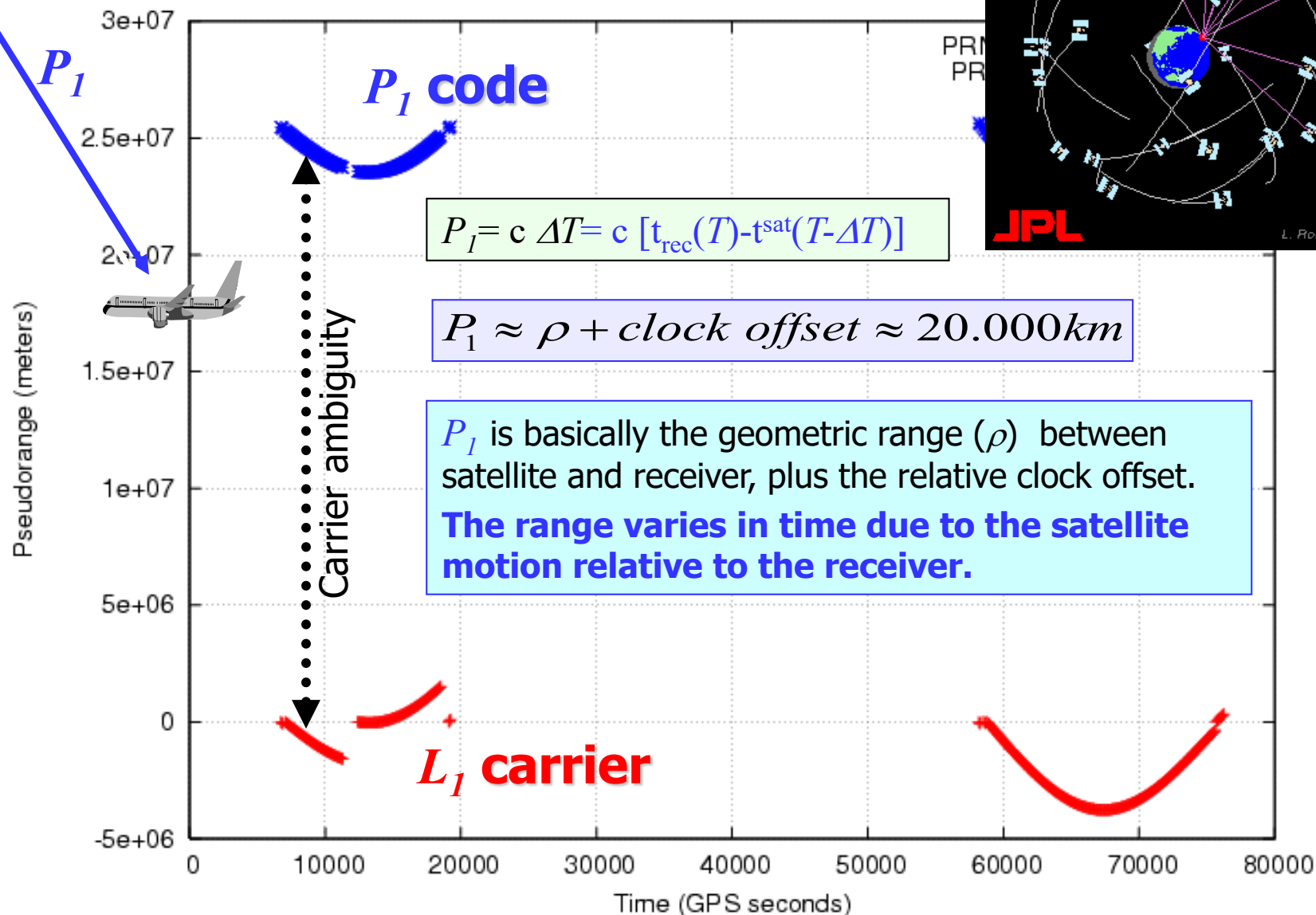
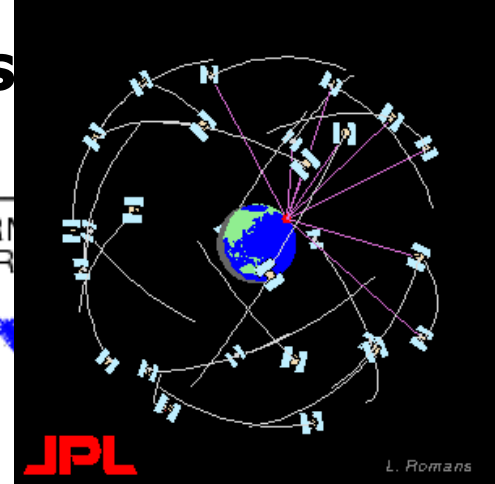
Carrier biases are estimated in the navigation filter along with the other parameters (coordinates, clock offsets, etc.).

Note: Figure shows the noise of code and carrier prefit-residuals, which are the input data for navigation equations.

Comparison of measurement noise of LC and PC: GUSN, PRN14

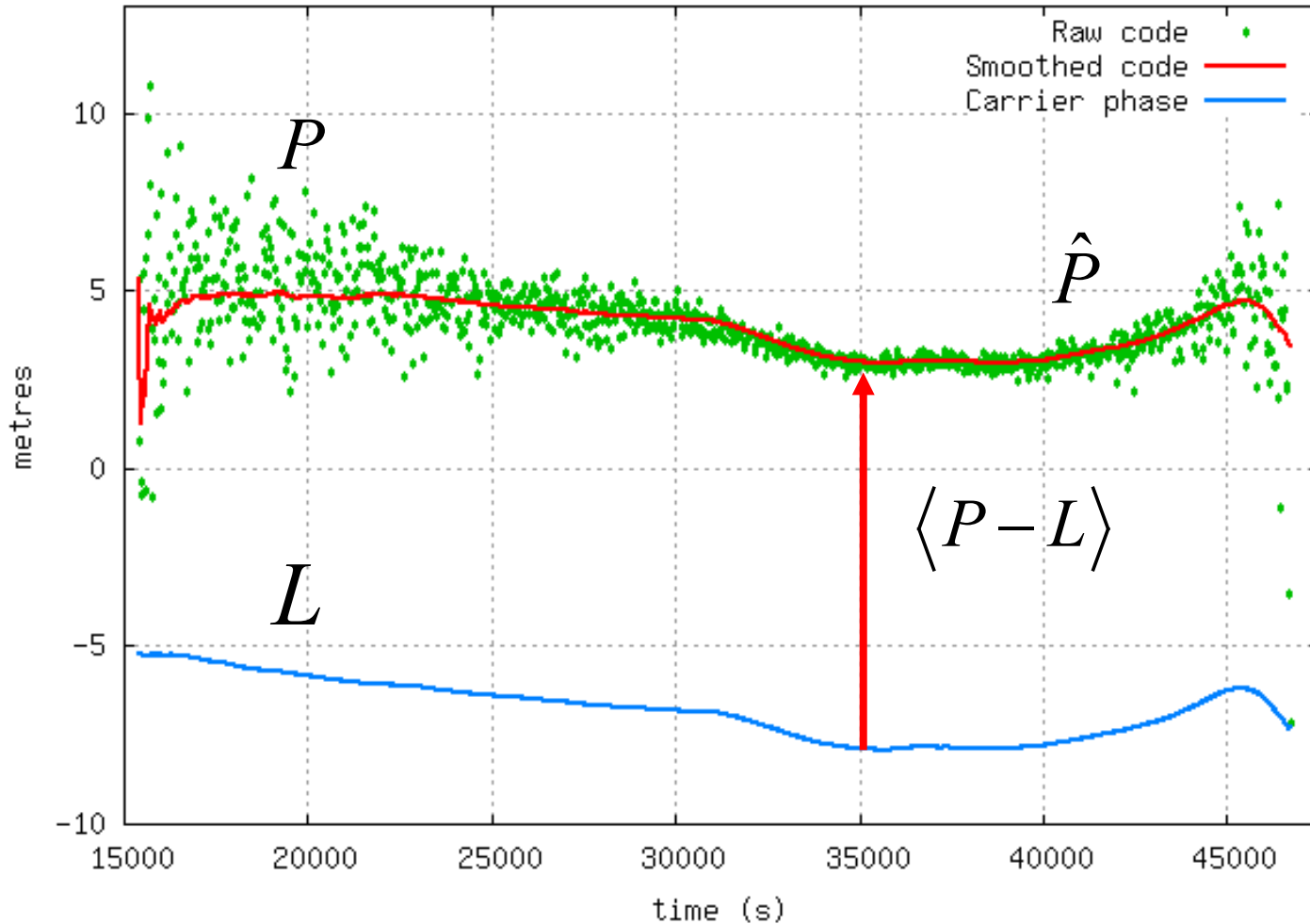


Carrier and Code pseudorange meas



L_1 Carrier is Ambiguous measurement. P_1 Code is Not ambiguous

Carrier-Smoothed code: Hatch Filter



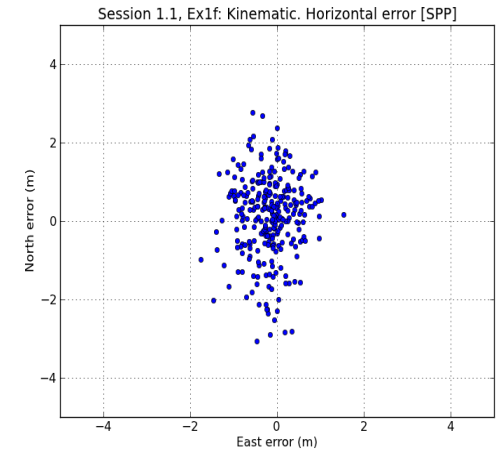
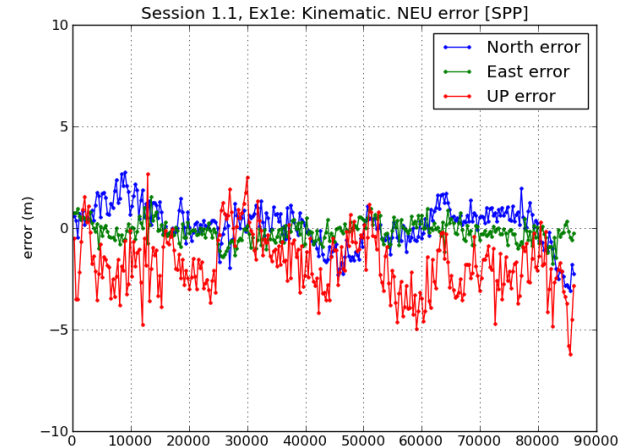
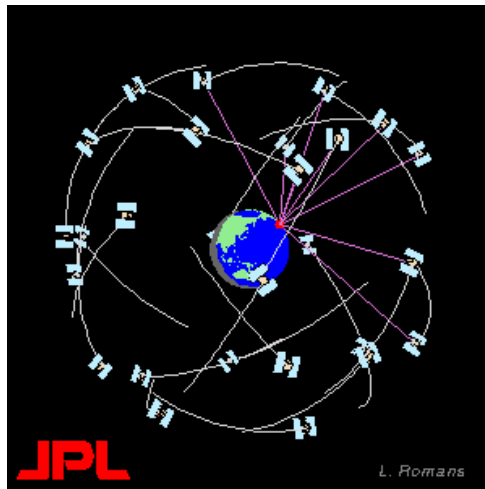
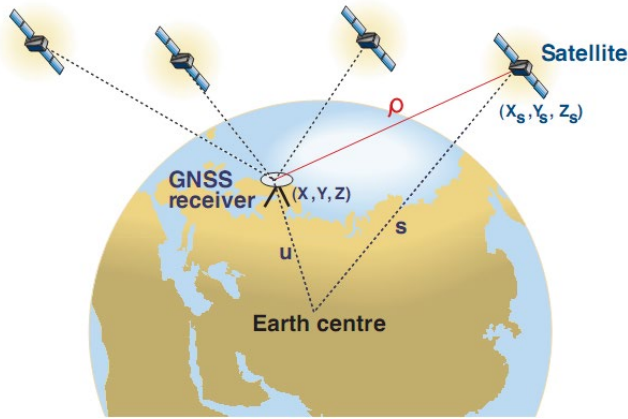
$$\hat{P}(k) = \frac{1}{n} P(k) + \frac{n-1}{n} \left(\hat{P}(k-1) + L(k) - L(k-1) \right) = L(k) + \langle P - L \rangle_{(k)}$$

Contents

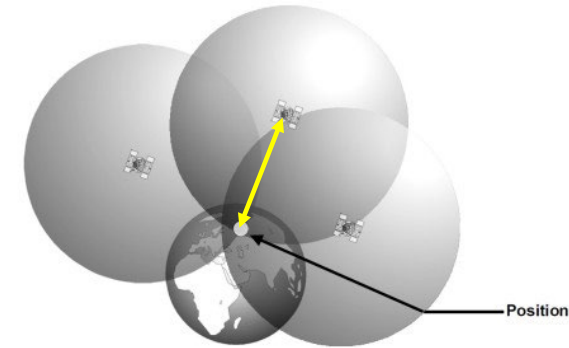
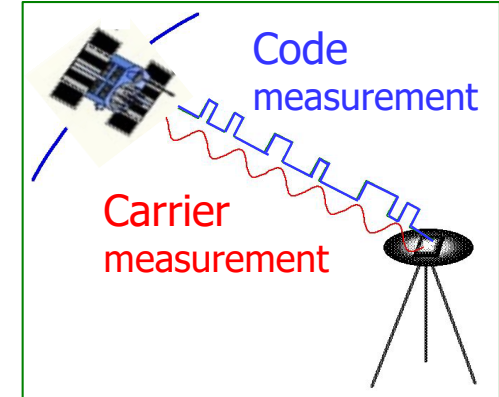
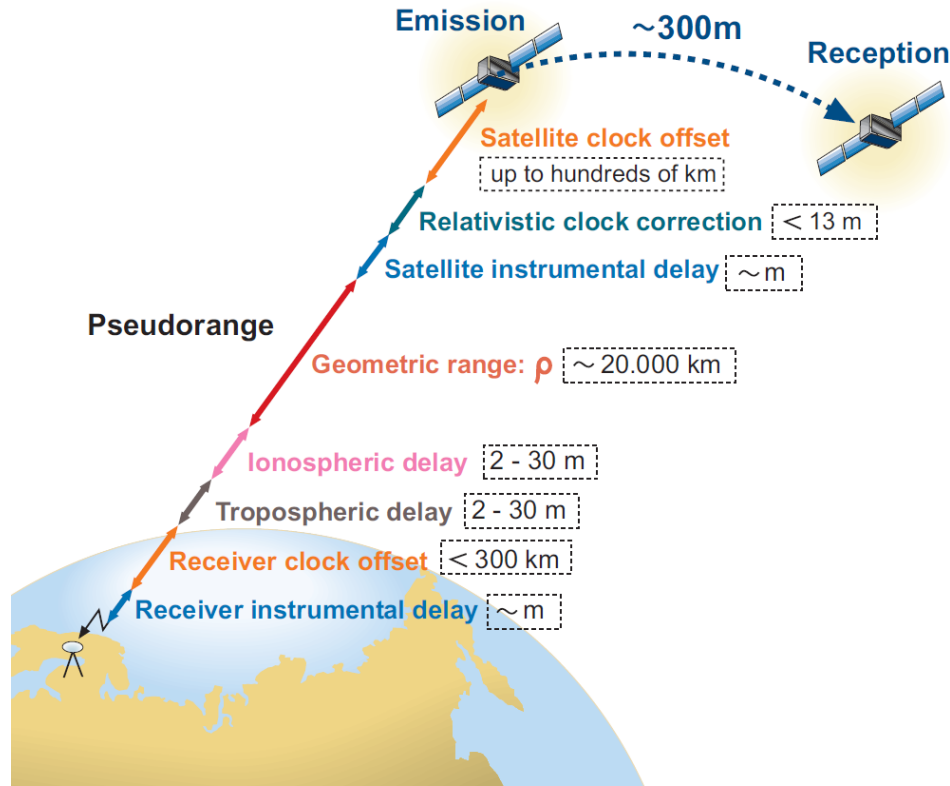
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 1. GNSS positioning and errors on the signal
 2. **Standalone Positioning**
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GNSS Positioning

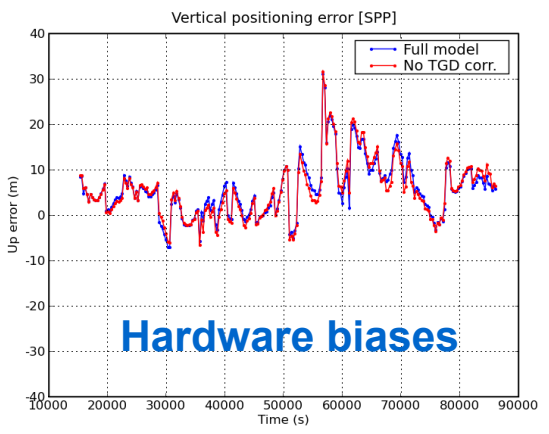
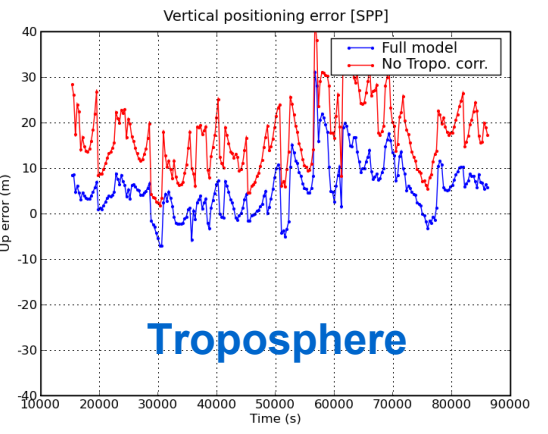
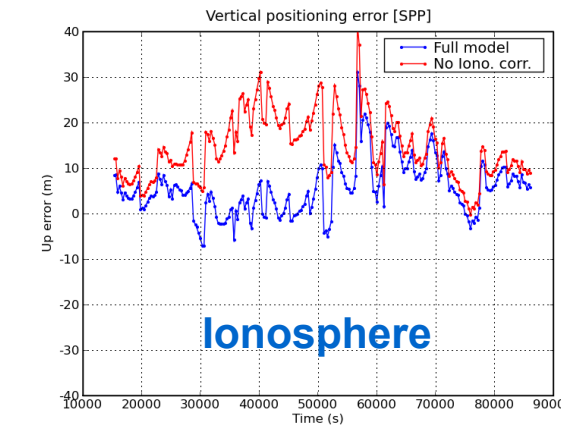
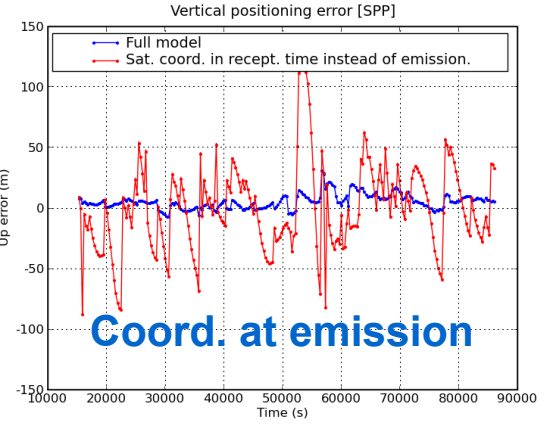
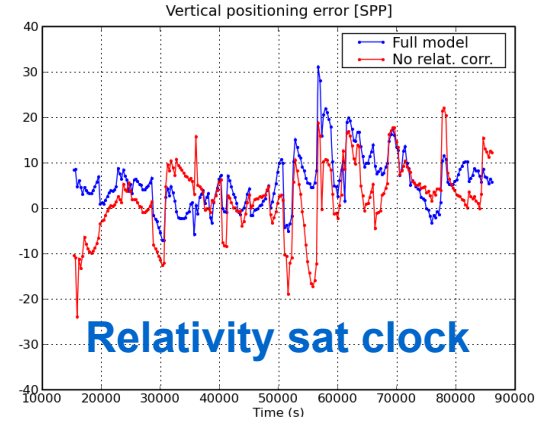
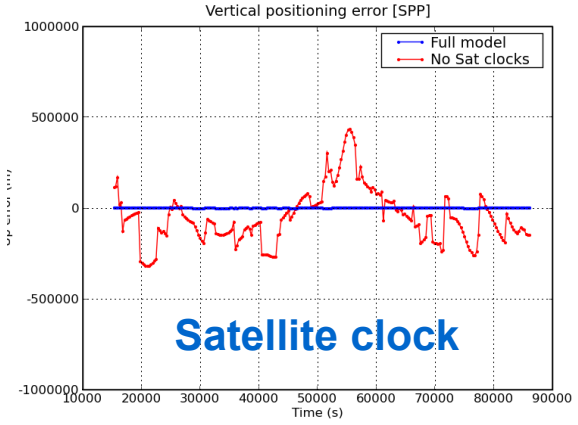
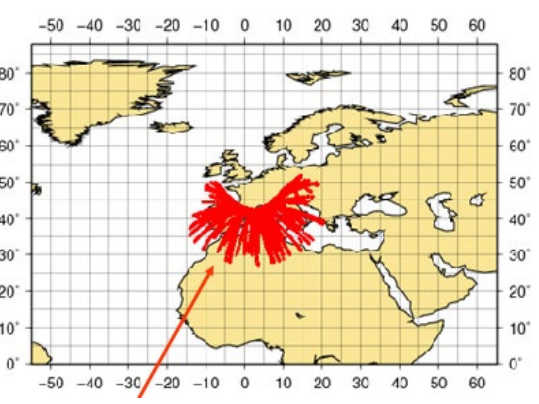
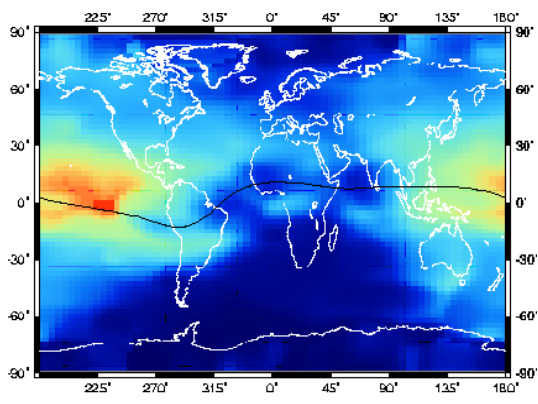
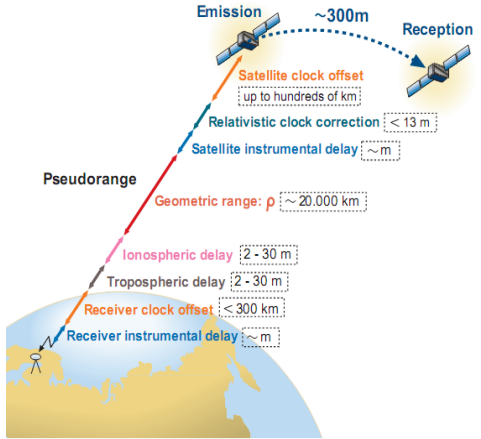
Standalone Positioning: GNSS receiver autonomous positioning using broadcast orbits and clocks.



Errors on the signal



- **To measure distances from satellites:**
 - ➔ This is done measuring the **traveling time** of radio signals: ("Pseudo-ranges": **Code** or **Carrier smoothed code** is used).
 - ➔ Measurements must be corrected by several error sources: Atmospheric propagation, relativity, clock offsets, instrumental delays..



Examples of model terms and their impact of user positioning

Contents

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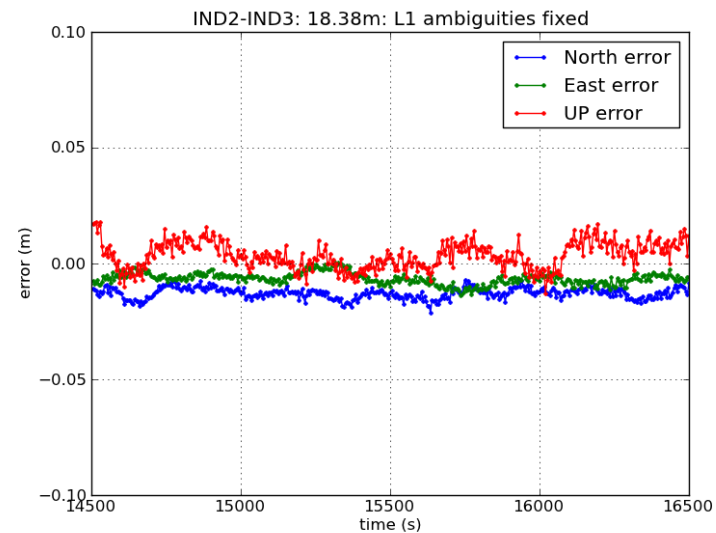
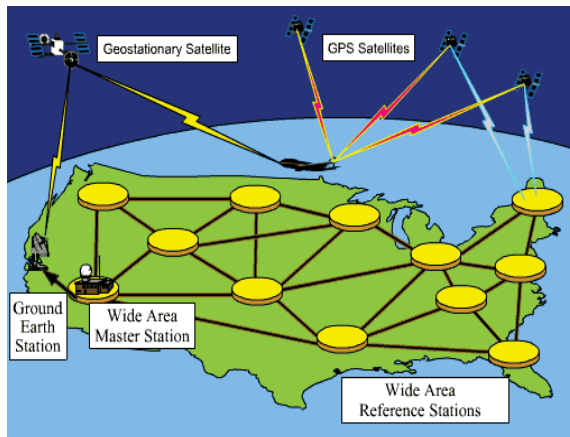
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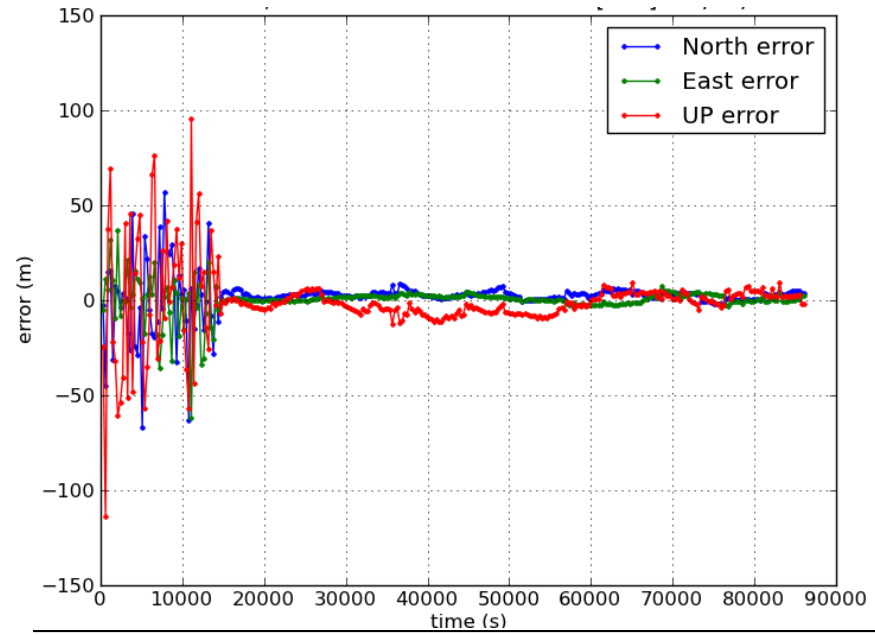
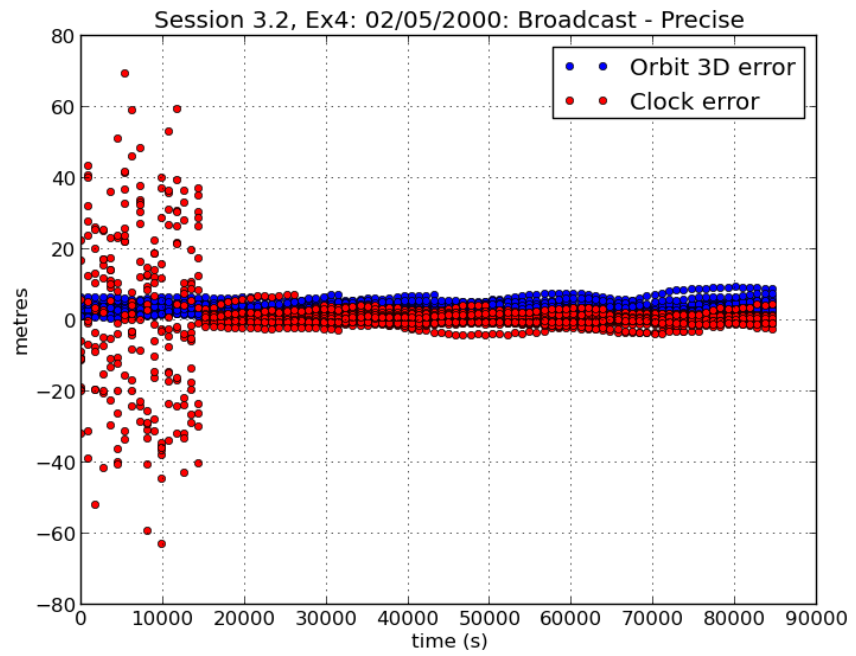
Differential Positioning: GNSS augmented with data (differential corrections or measurements) from a single reference station or a reference station network.



Errors are similar for users separated tens, even hundred of kilometres, and these errors are removed/mitigated in differential mode, improving positioning.

Errors on the signal

- Space Segment Errors:
 - Clock errors Common
 - Ephemeris errors Strong spatial correlation
- Propagation Errors
 - Ionospheric delay Weak spatial correlation
 - Tropospheric delay Weak spatial correlation
- Local Errors
 - Multipath No spatial correlation
 - Receiver noise No spatial correlation



Selective Availability (S/A)

was an intentional degradation of public GPS signals implemented for US national security reasons.

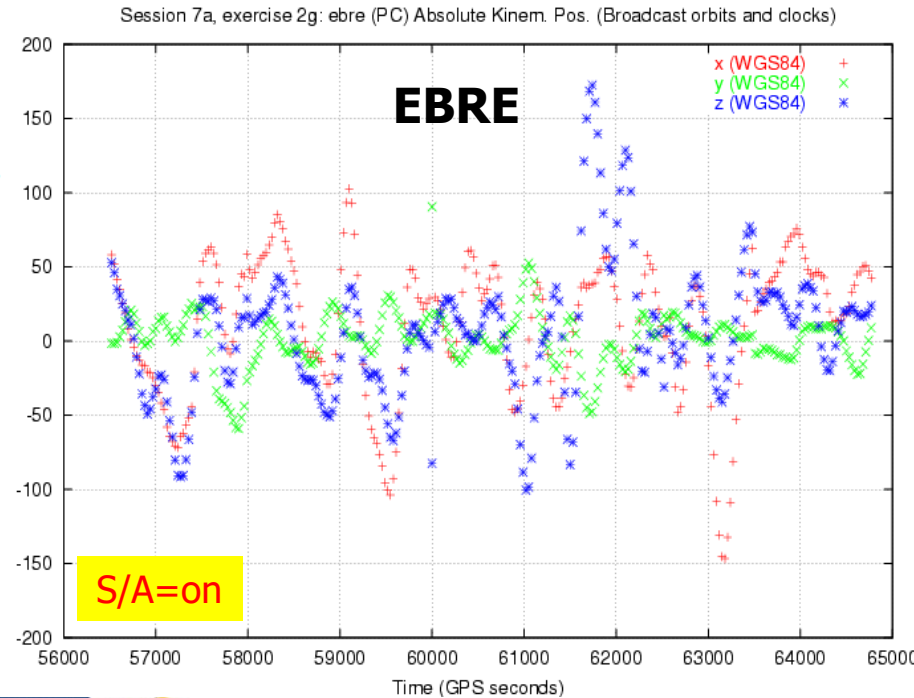
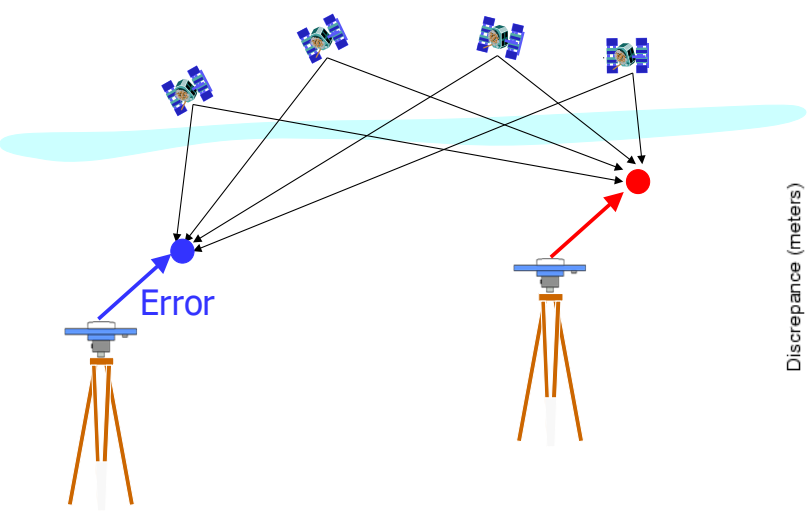
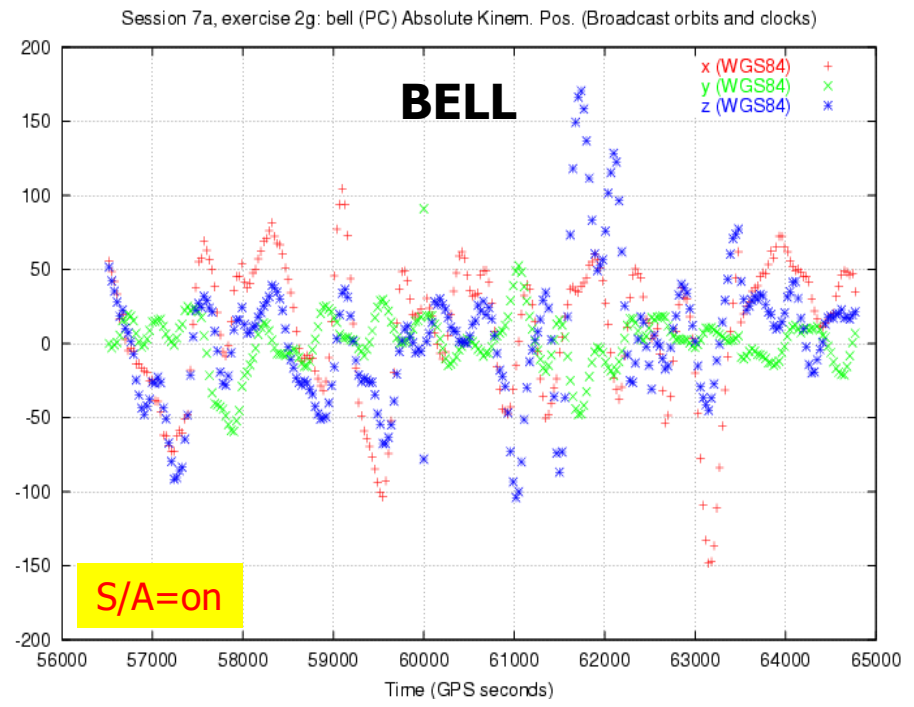
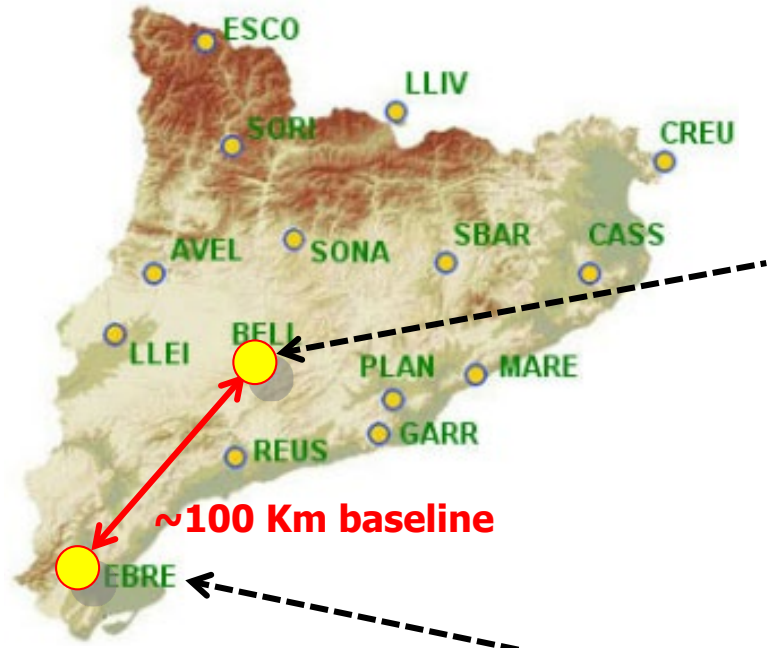
S/A was turned off at May 2nd 2000 (Day-Of-Year 123).

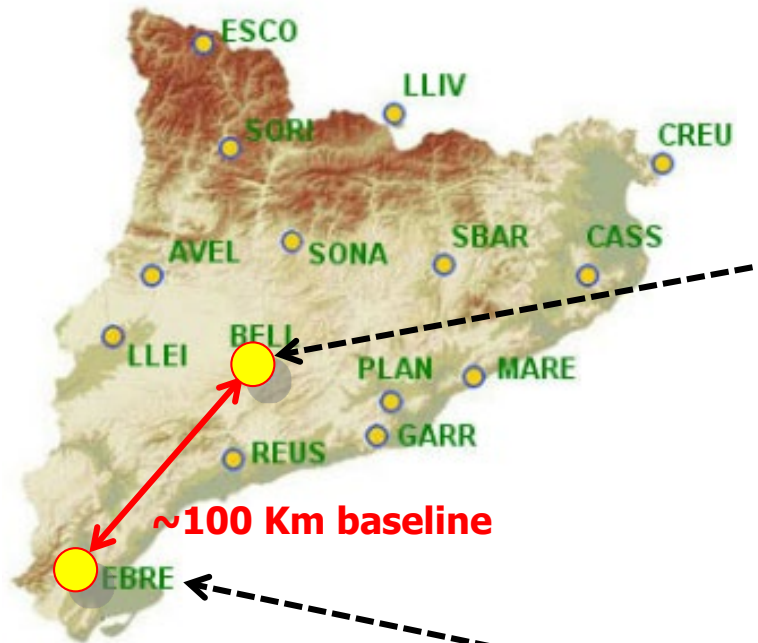
It was permanently removed in 2008, and not included in the next generations of GPS satellites.

In the 1990s, the S/A motivated the development of DGPS.

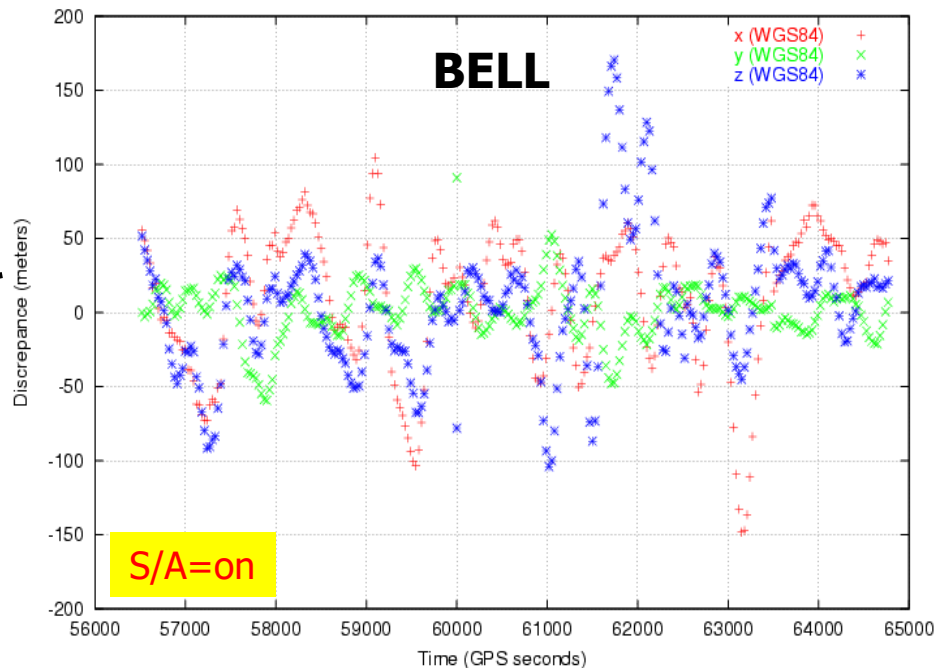
-These systems typically computed PseudoRange Corrections (PRC) and Range-Rate Corrections (RRC) every 5-10 seconds.

- With S/A=off the life of the corrections was increased to more than one minute.

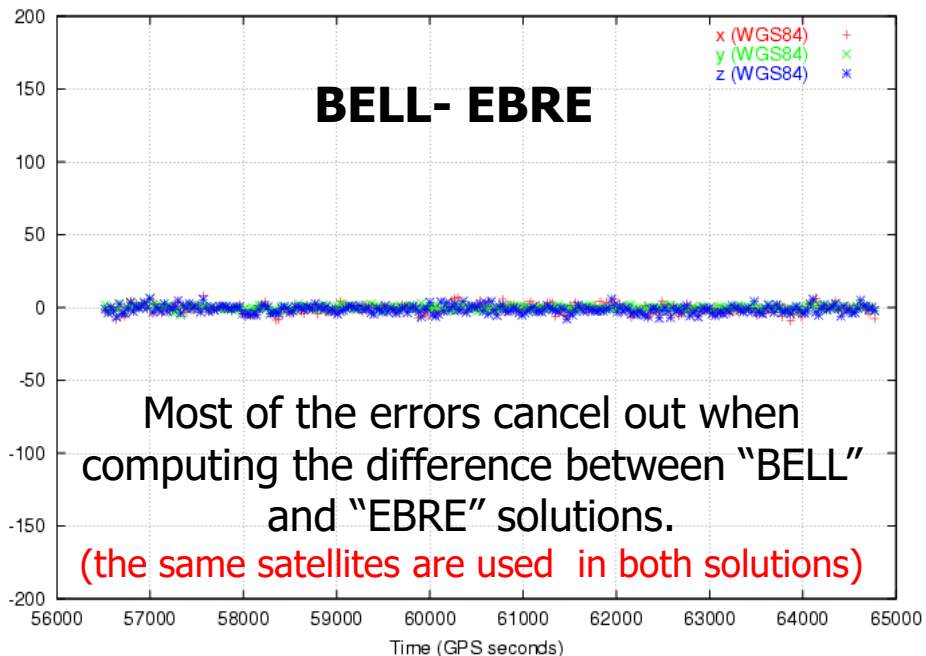




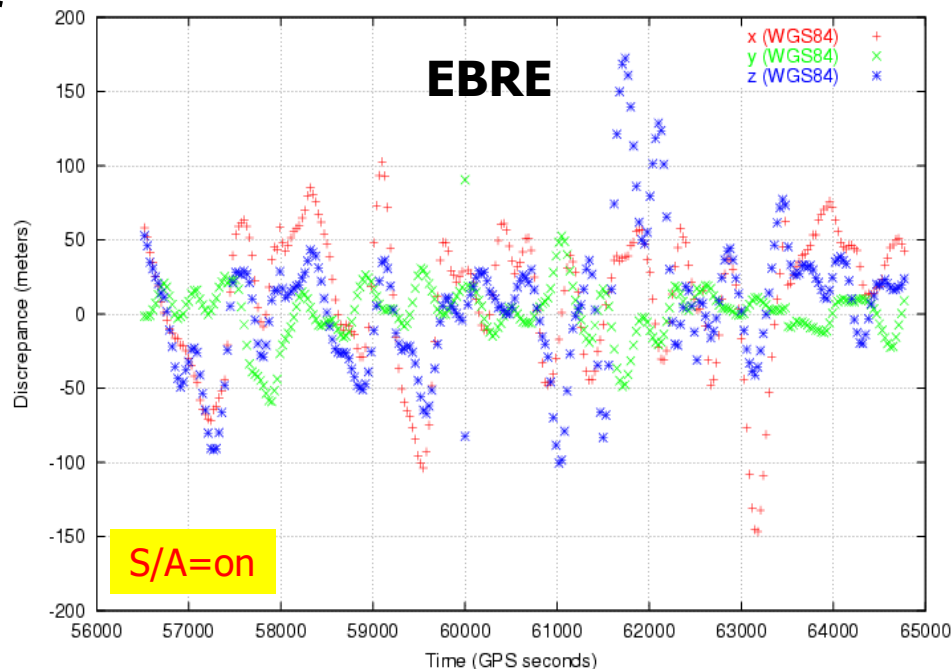
Session 7a, exercise 2g: bell (PC) Absolute Kinem. Pos. (Broadcast orbits and clocks)

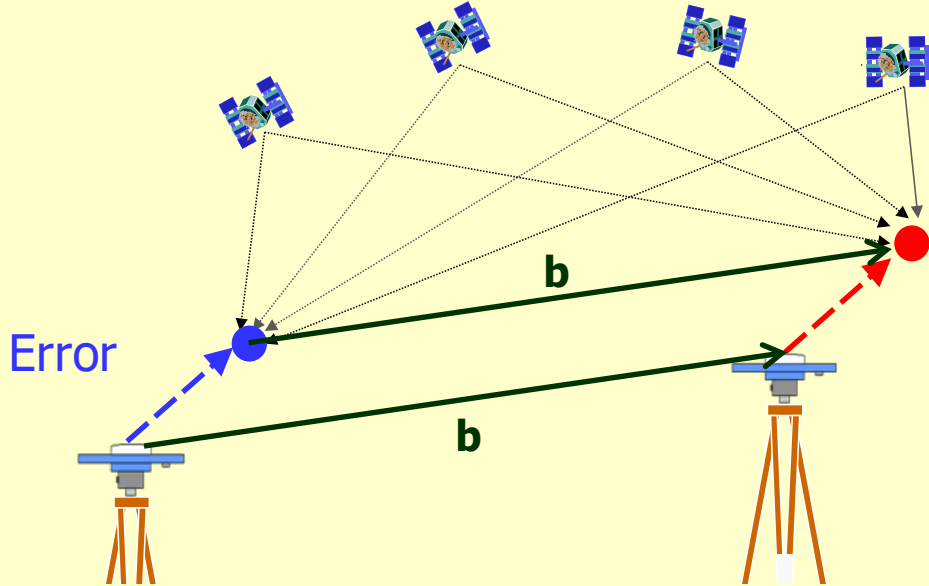


Session 7a, exercise 2f: bell relative to ebre: D(PC) Kinem. Pos. (Broadcast orbits)

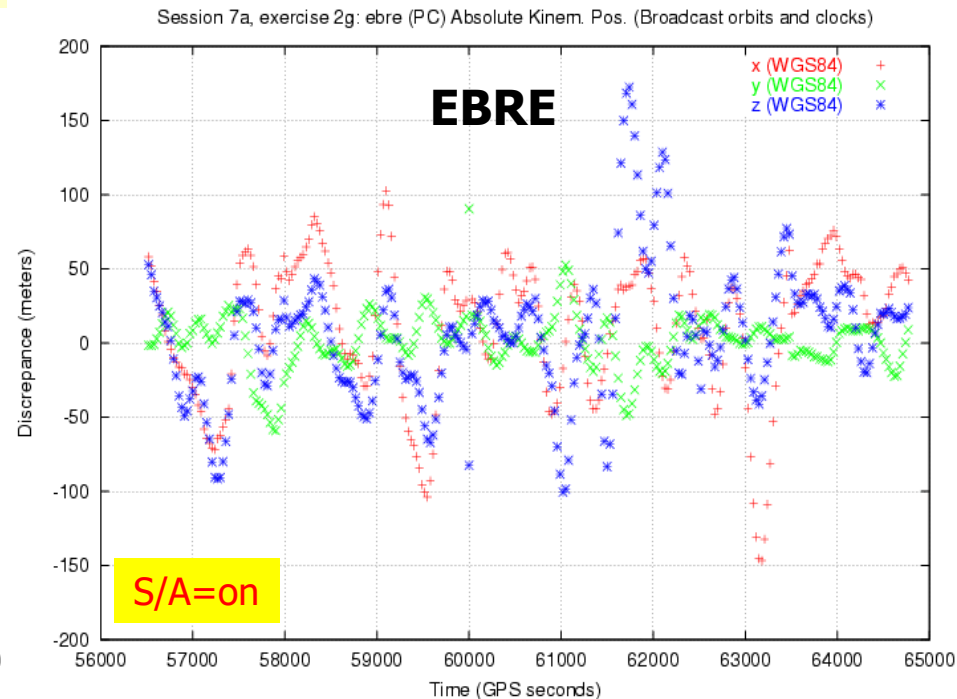
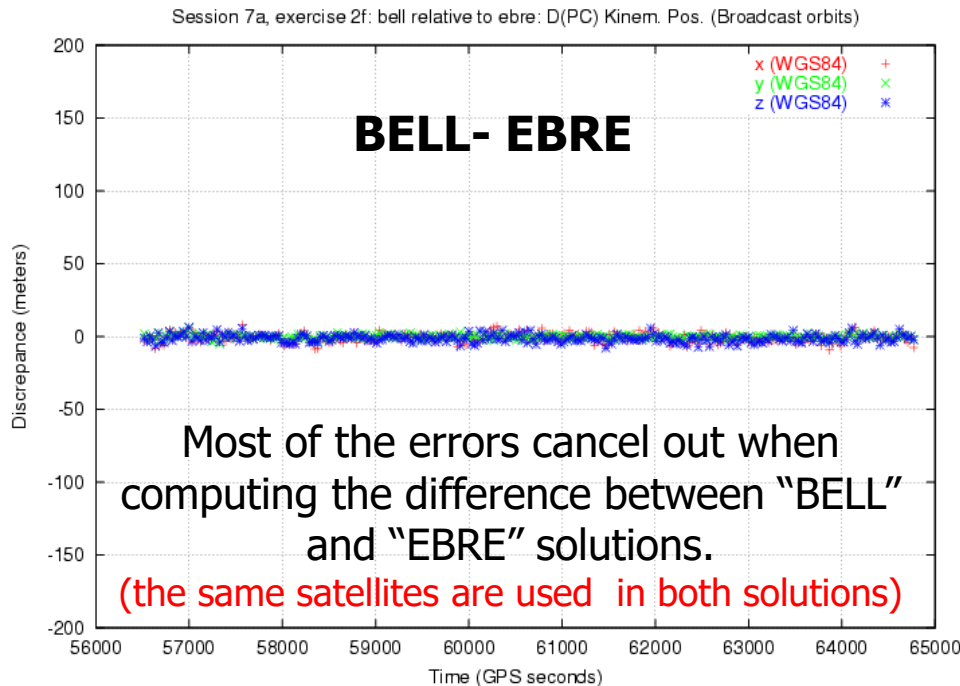
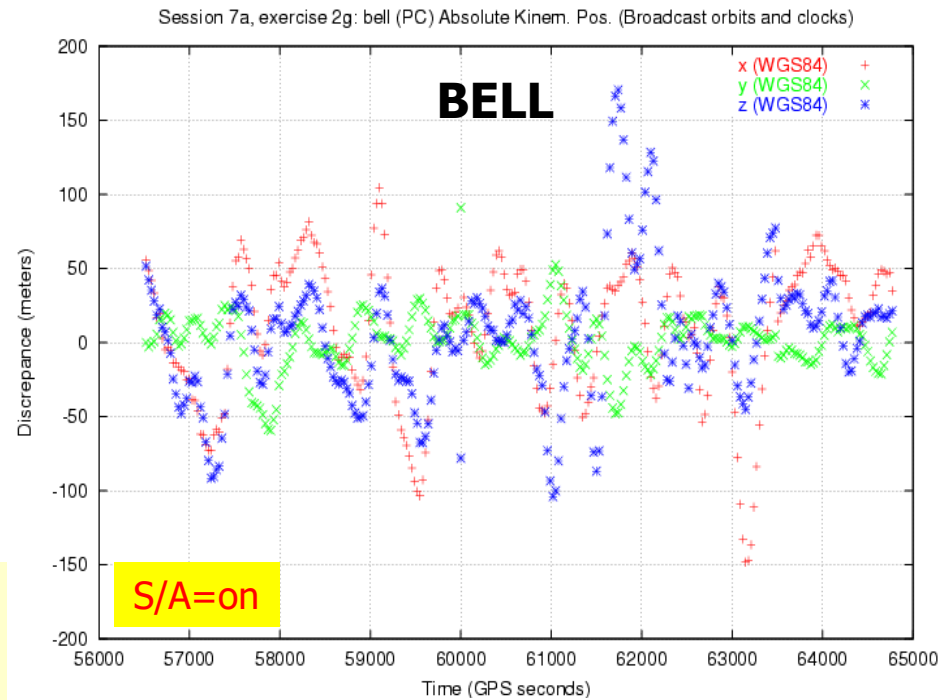


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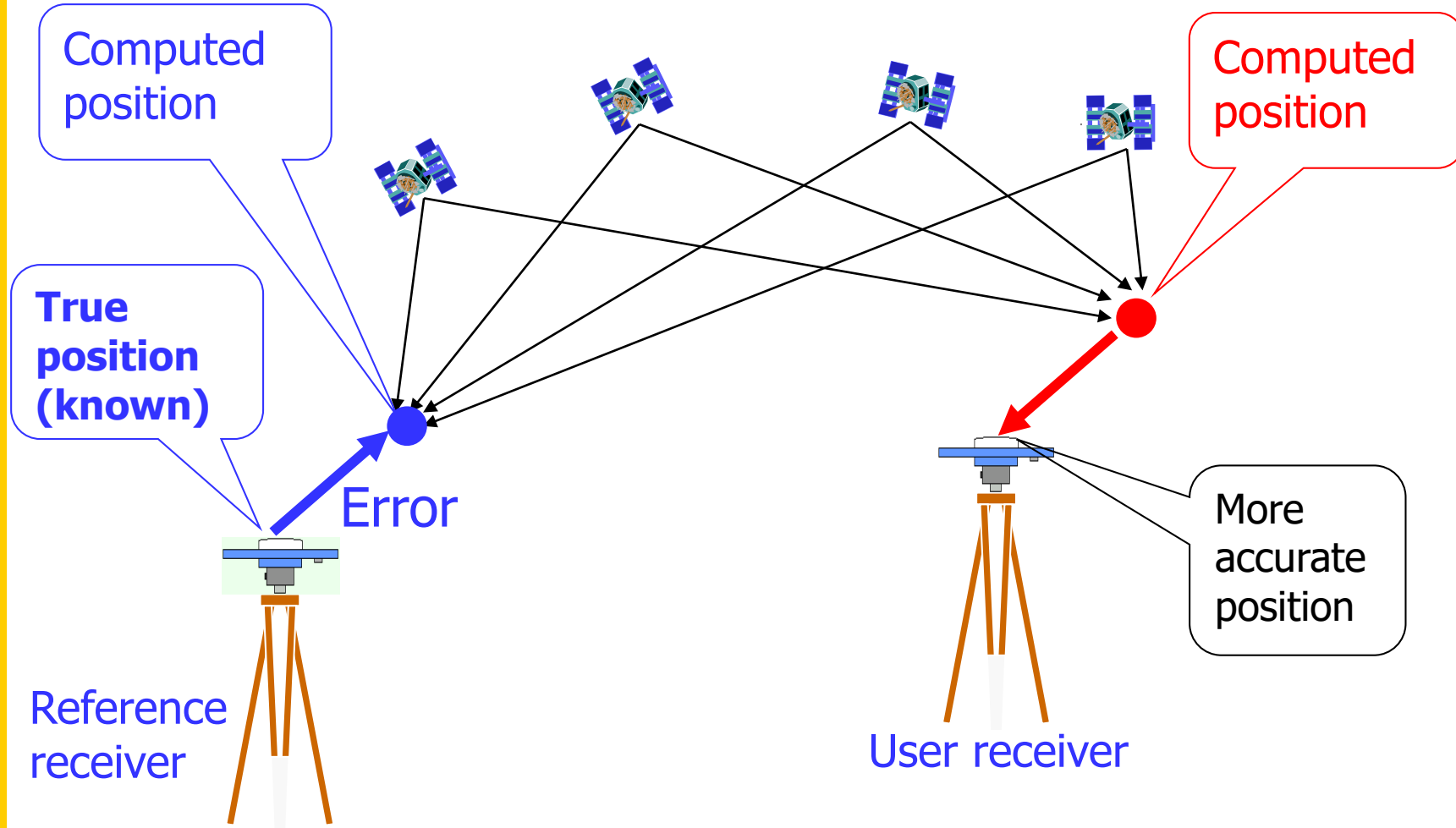




The determination of the vector between the receivers APCs (i.e. the baseline " b ") is more accurate than the single receiver solution, because common errors cancel



Differential GNSS (DGNSS): absolute position



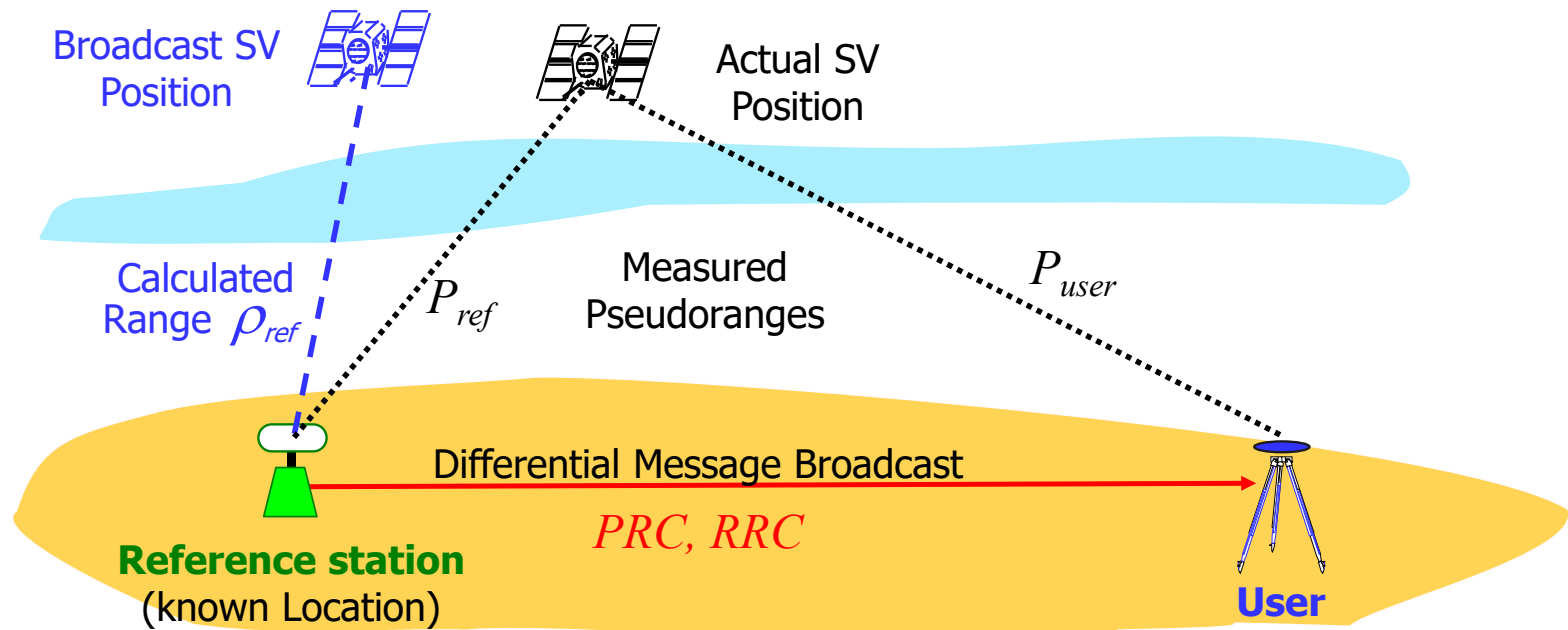
If the coordinates of the reference receiver are known, thence the reference receiver can estimate its positioning error, which can be transmitted to the user. Then, the user can apply these corrections to improve the positioning

Note: Actually the corrections are computed in range domain (i.e. for each satellite) instead of in the position domain.

In the previous example, the differential error has been cancelled in the "position" domain (*i.e. solution domain approach*).

But it requires to use the same satellites in both stations.

Thence, is much better to solve the problem in the "**range domain**" than in the "position" domain. That is, to provide corrections for each satellite in view (*i.e. range domain approach*):



The reference station, with known coordinates, computes range corrections for each satellite in view. These corrections are broadcasted to the user. The user applies these corrections to compute its "**absolute position**".

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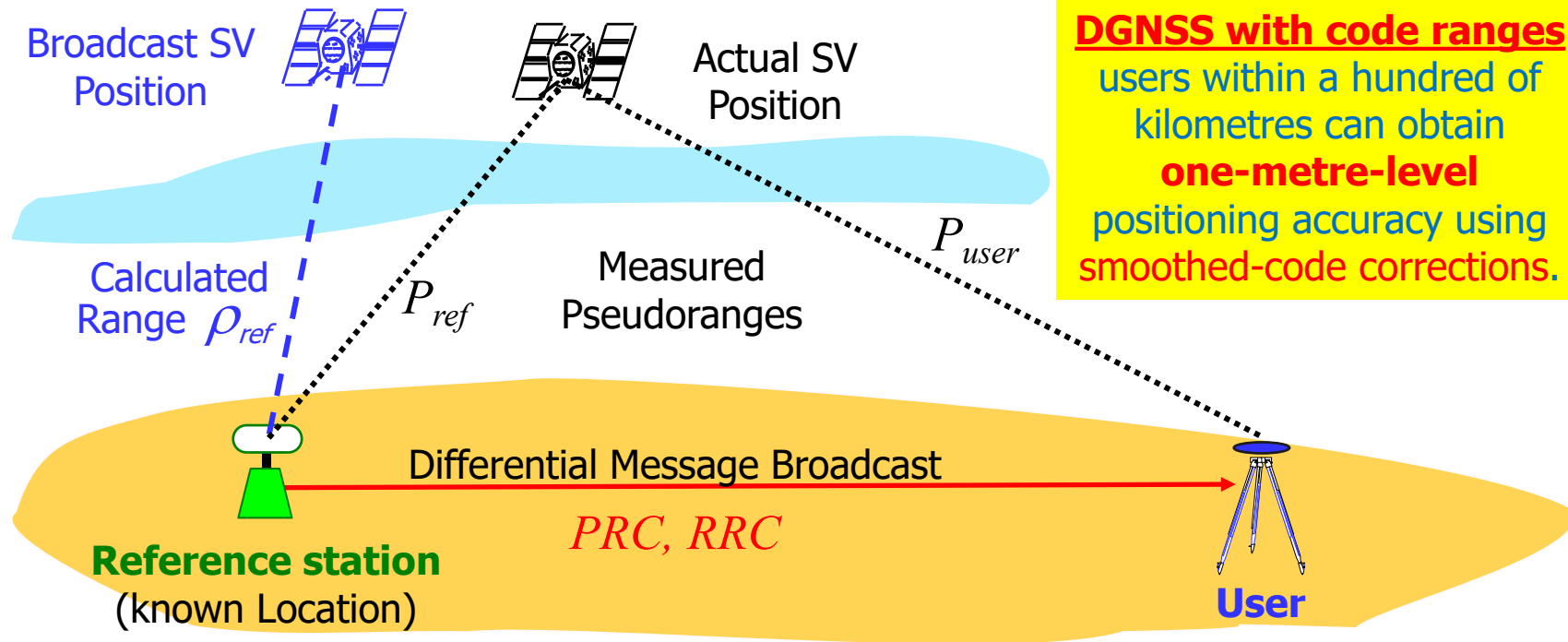
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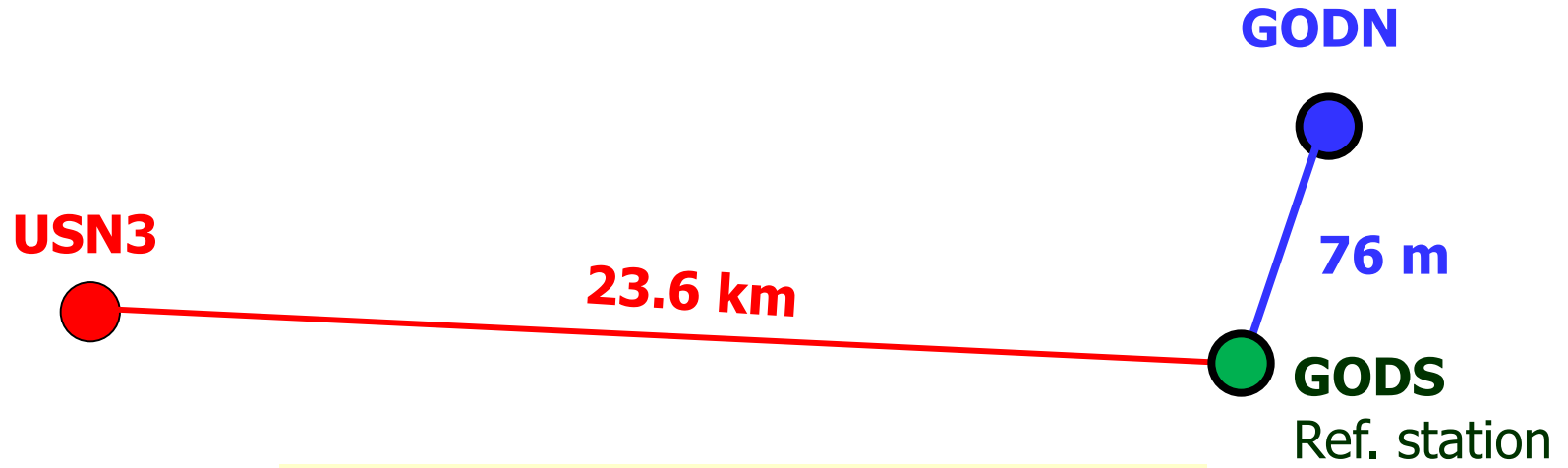
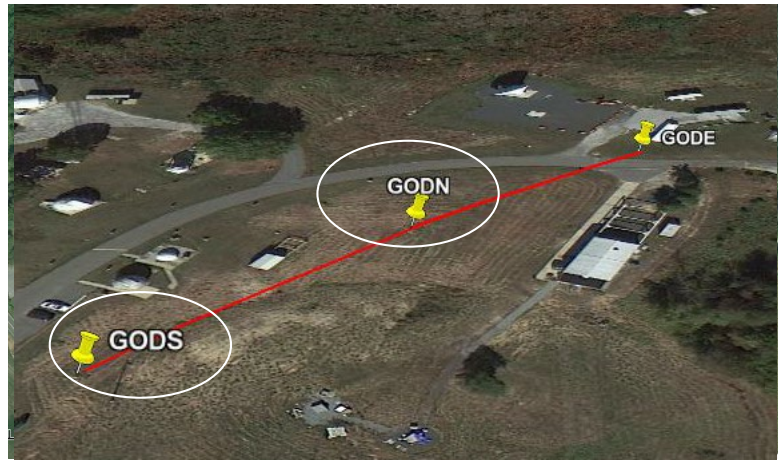
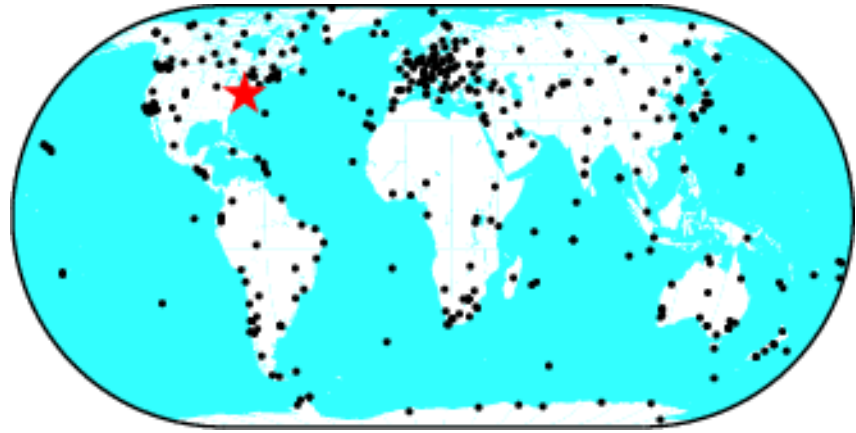
4. Commercial Services

Code Based Differential positioning (DGNSS)



DGNSS with code ranges users within a hundred of kilometres can obtain **one-metre-level** positioning accuracy using **smoothed-code corrections**.

- The **reference station** with known coordinates, computes pseudorange and range-rate corrections: $PRC = \rho_{ref} - P_{ref}$, $RRC = \Delta PRC / \Delta t$.
- The **user** receiver applies the PRC and RRC to correct its own measurements, $P_{user} + (PRC + RRC(t-t_0))$, removing SIS errors and improving the positioning accuracy.

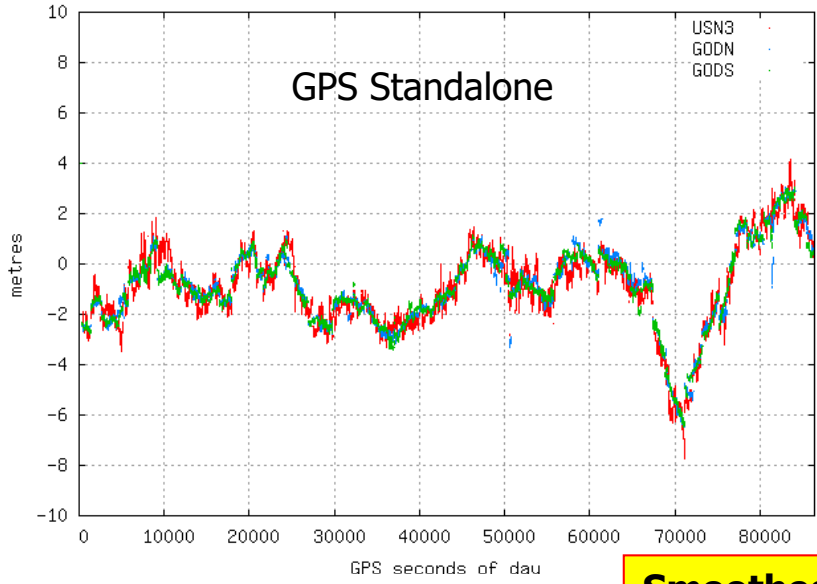


```
ftp://cddis.gsfc.nasa.gov/highrate/2013/
1130752.3120 -4831349.1180 3994098.9450 gods
1130760.8760 -4831298.6880 3994155.1860 godn
1112162.1400 -4842853.6280 3985496.0840 usn3
```

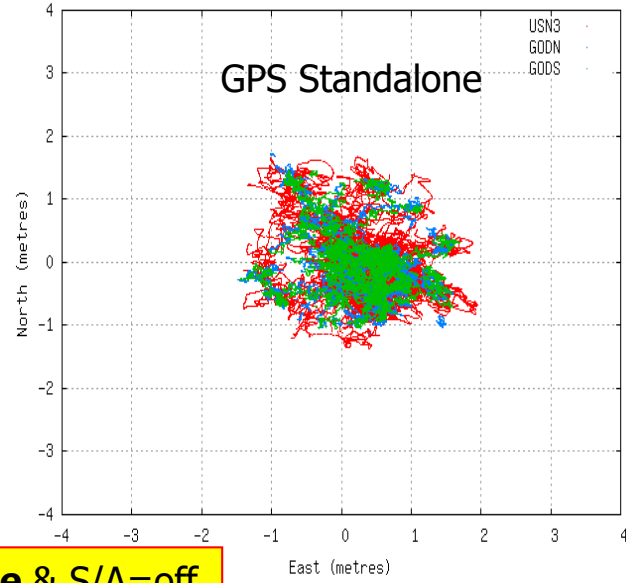


Differential Positioning Performance

Vertical Error (GPS Standalone): 2013 02 21

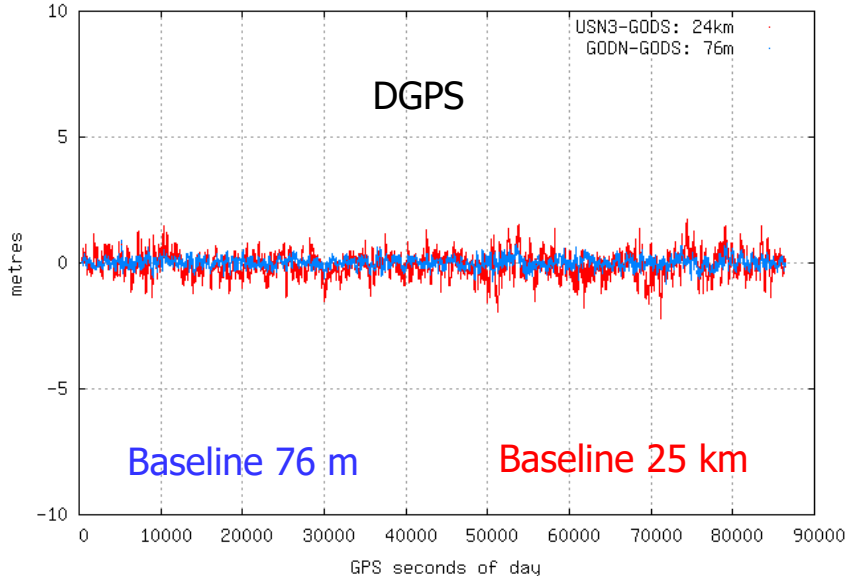


Horizontal Error (GPS Standalone): 2013 02 21

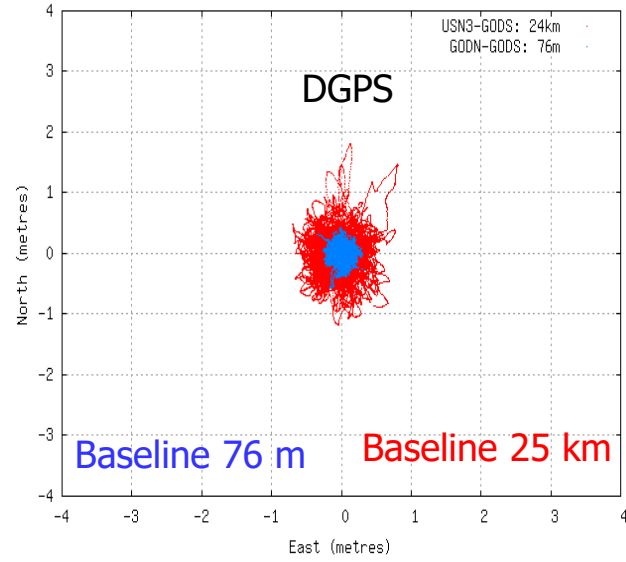


Smoothed code & S/A=off

Vertical Error: 2013 02 21

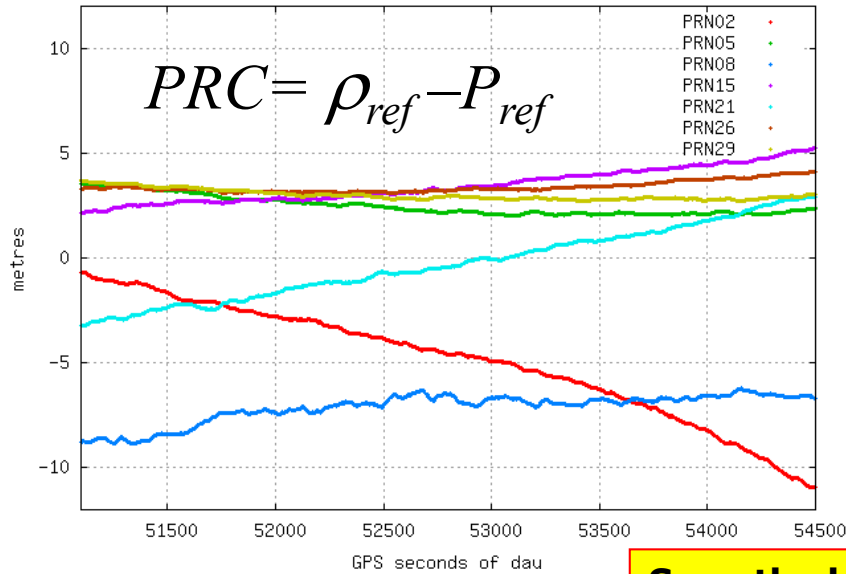


Horizontal Error: 2013 02 21

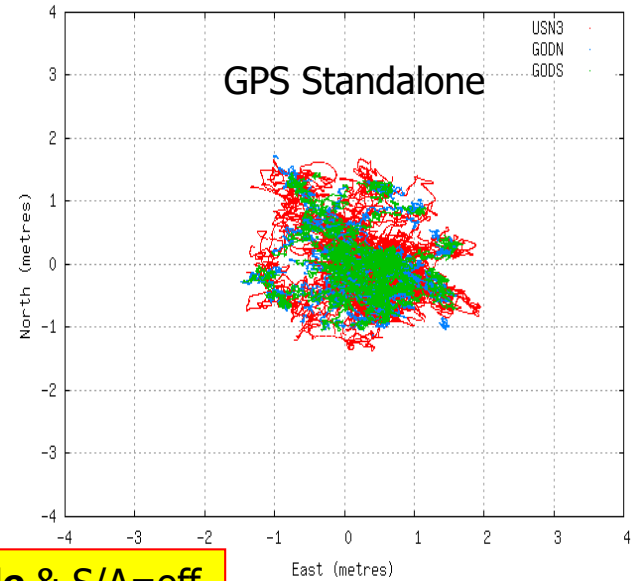


Differential Corrections

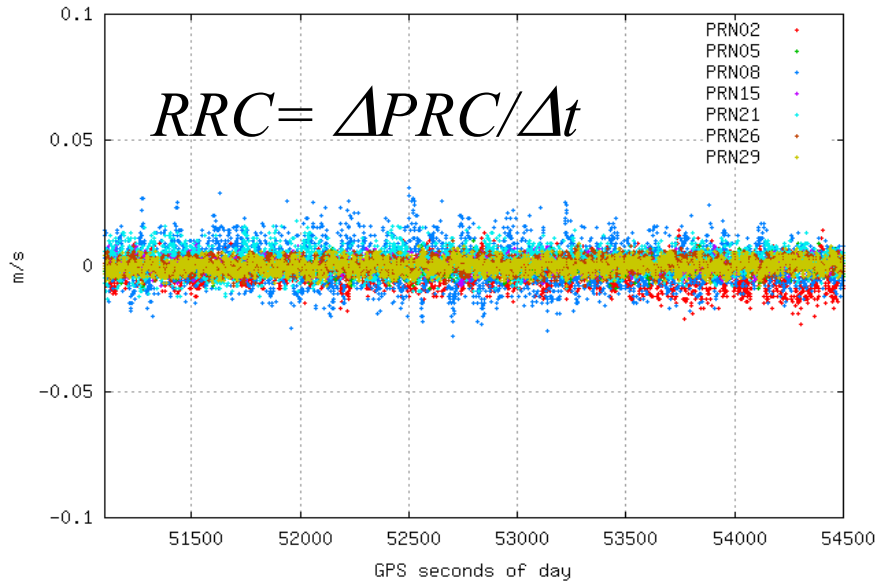
PRC (from GDS) : 2013 02 21



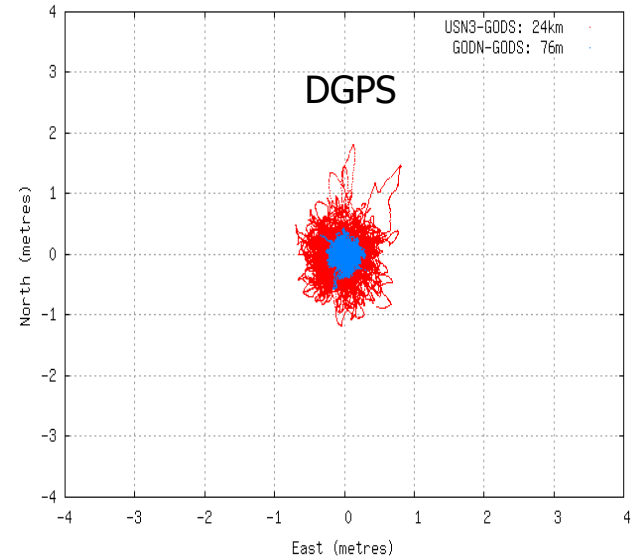
Horizontal Error (GPS Standalone): 2013 02 21



RRC (from GDS) : 2013 02 21

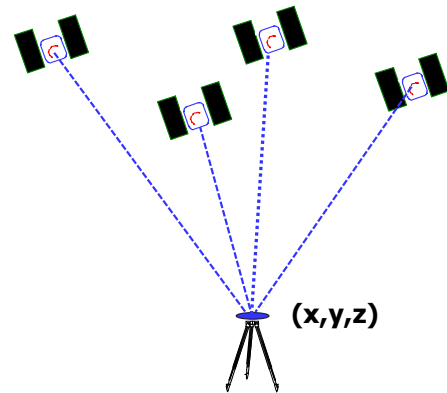


Horizontal Error: 2013 02 21



Standalone (code) positioning

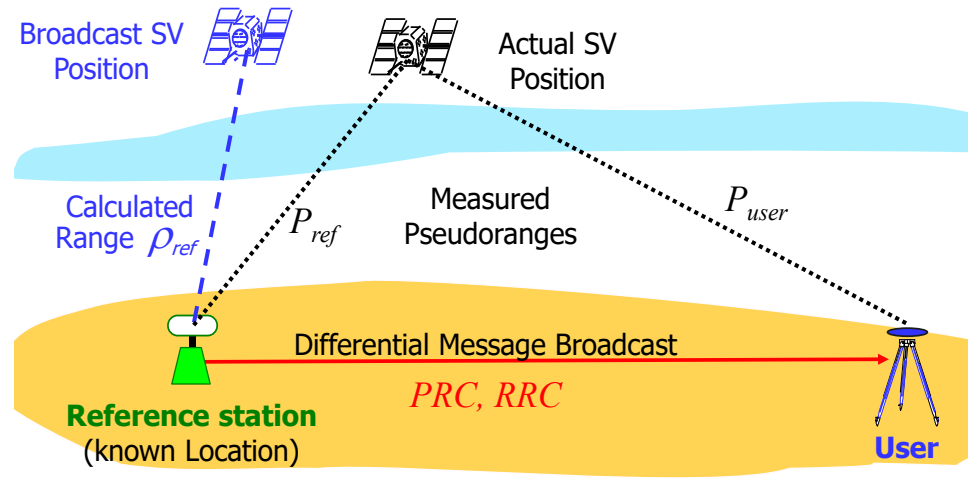
Standard Point Positioning (SPP)



**Few metres.
World wide.
Single epoch.**

Code based Differential positioning (DGNSS)

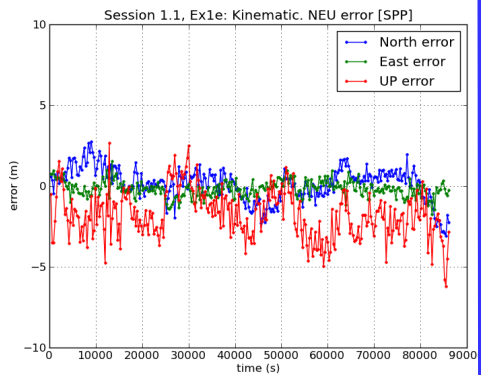
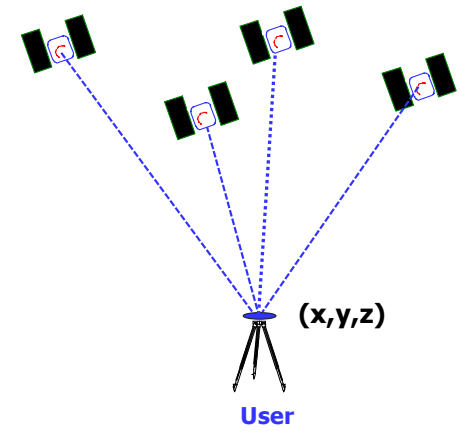
← Improved Accuracy →



Picture from <http://signus-sas.blogspot.com.es>

Standalone (code) positioning

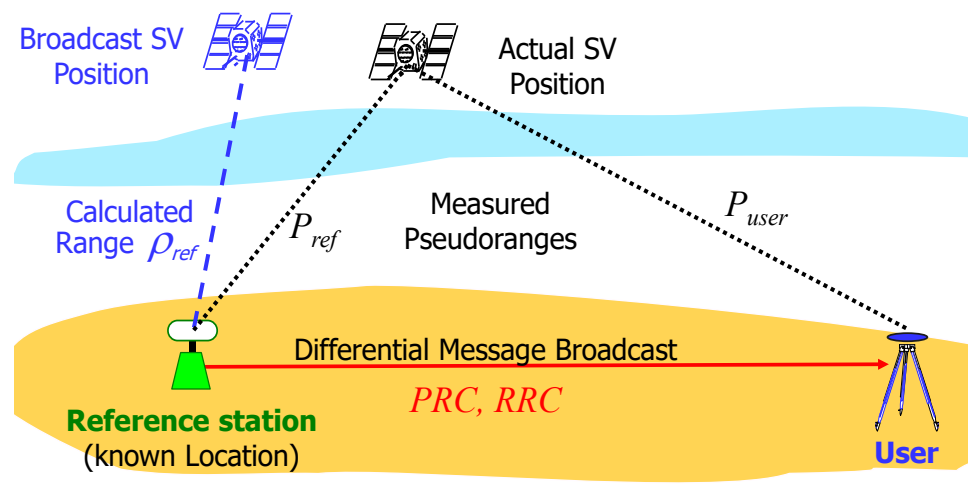
Standard Point Positioning (SPP)



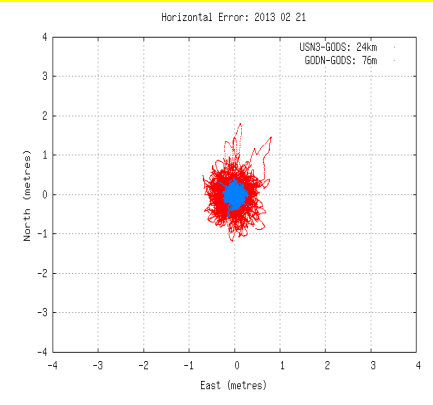
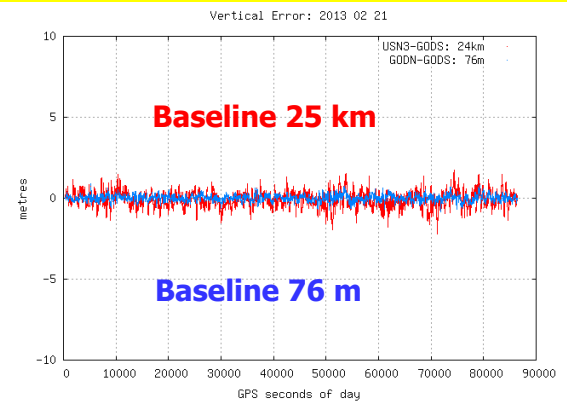
**Few metres.
 World wide.
 Single epoch.**

Code based Differential positioning (DGNSS)

← Improved Accuracy →



Errors are similar for users separated tens, even hundred of km, and are removed/mitigated in differential mode, improving positioning.

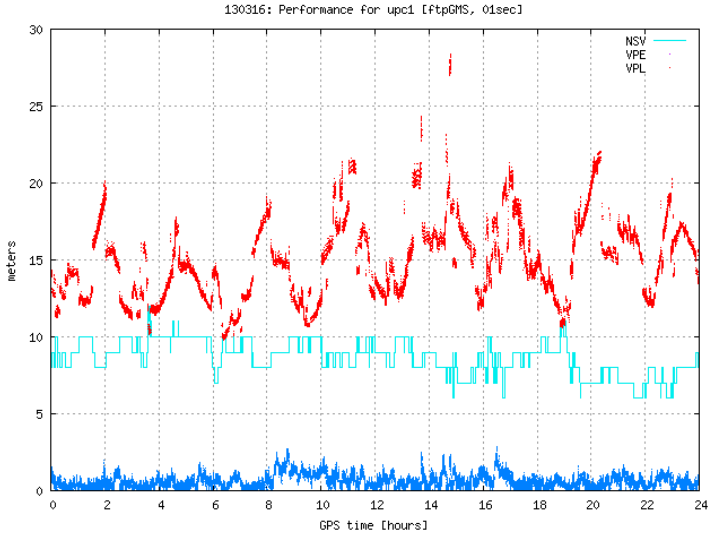


**Metre level
 Regional Area (~100 km)
 Single epoch**

Other DGNSS using smoothed code but for Safety of Life applications:

Among the accuracy, the main target is to provide integrity!!!

- To provide timely alarms in case of GNSS signal failure.
- To provide information to users to compute the level of trust (such as confidence bounds) that can be applied to the GNSS signals.



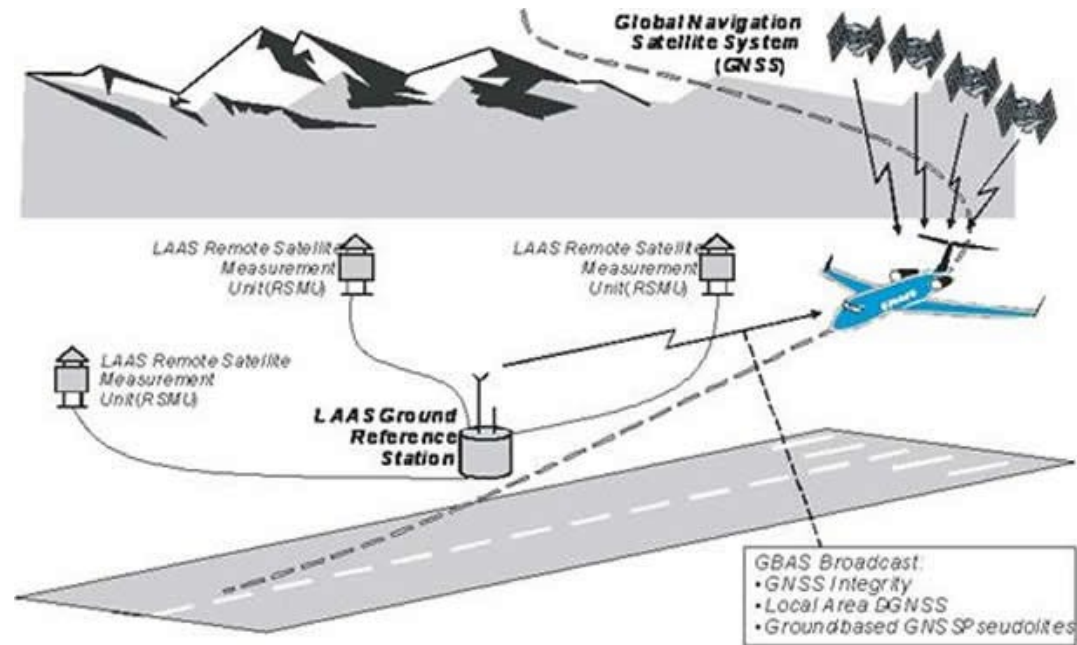
Local Area DGNSS (LADGNSS): GBAS

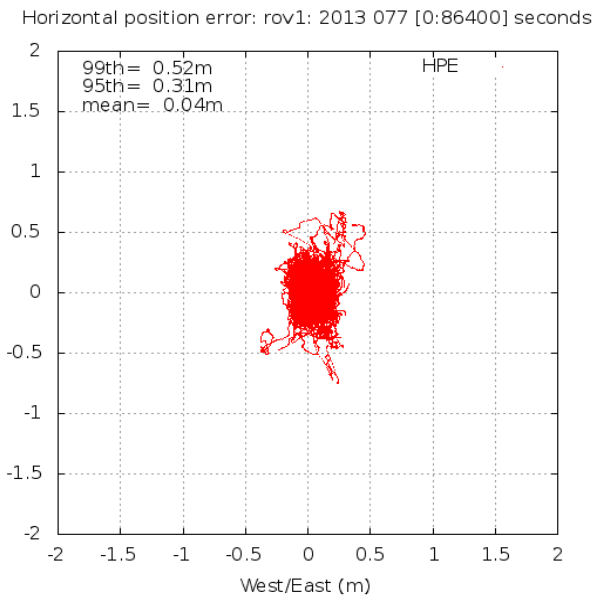
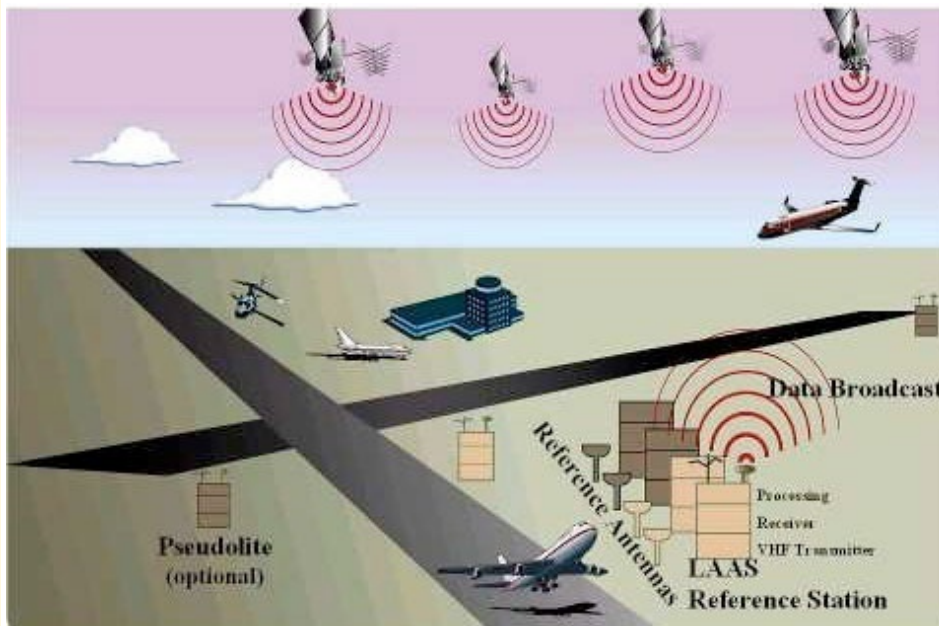
LADGNSS includes a Master station and several monitor stations. The **master station** collects the range measurements of the monitor stations and process the data to generate the range corrections, which are broadcasted to users.

- In Local Area Augmentation System (**LAAS**) or the Ground Based Augmentation System (**GBAS**), a ground facility computes differential corrections and integrity data from measurements collected by several redundant receivers.

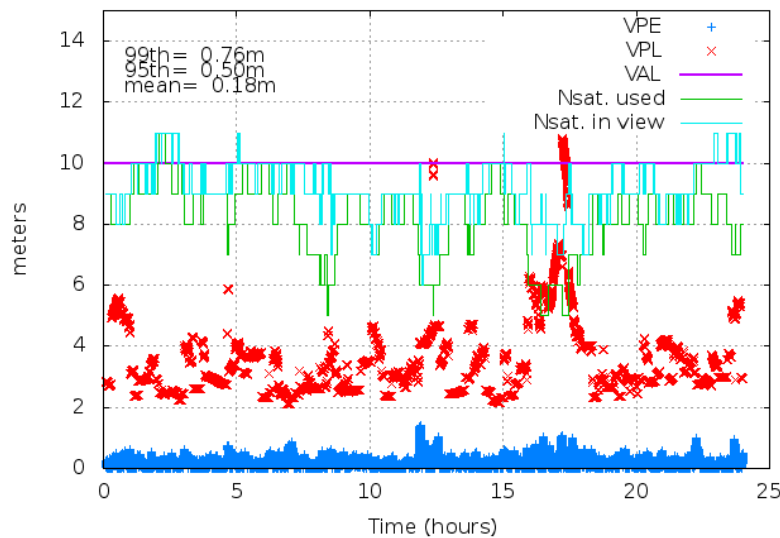
This system is designed to support aircraft operations during approach and landing. The differential corrections are transmitted on a VHF channel, up to about 40km.

Metre level accuracies with integrity fulfilling the stringent requirements of Civil Aviation are met.

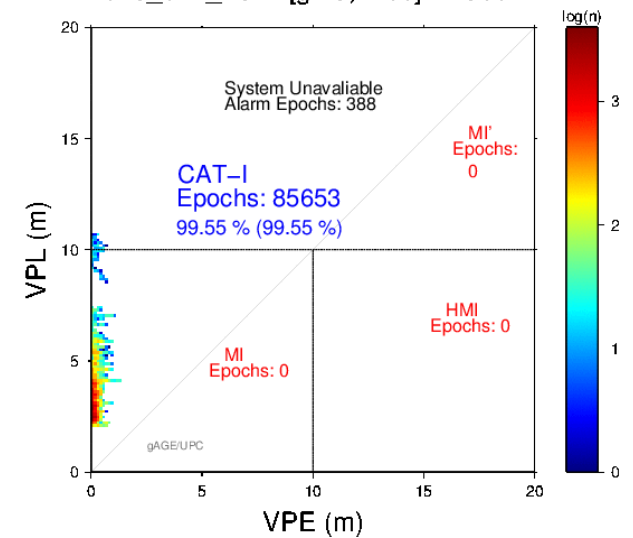




Vertical position error: rov1 : 2013 077 [0:86400] seconds



2013_077_rov1 [gRS, 1.0s] N=86041



Wide Area DGNSS (WADGNSS)

To cover a wide-area is more suitable to broadcast corrections for each error source separately: Satellite clocks, ephemeris and ionosphere.

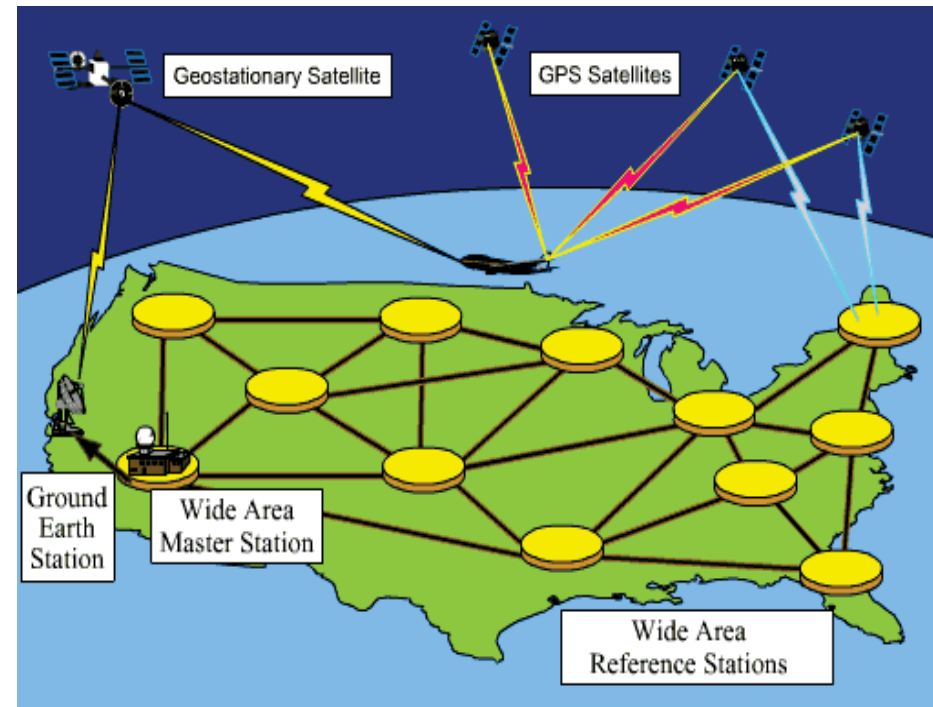
These corrections are computed by a **Central Processing Facility (CPF)** from the range measurements of the monitor stations network with baselines of several hundreds up to thousand of kilometres.

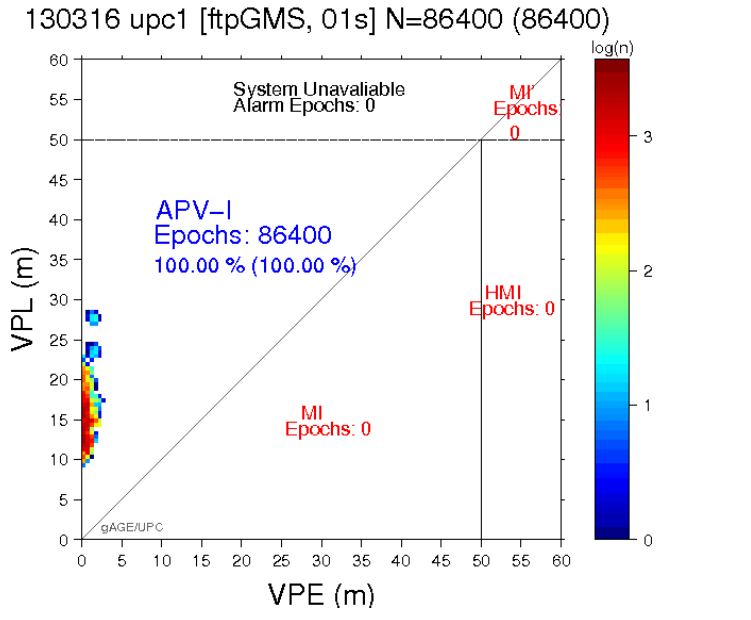
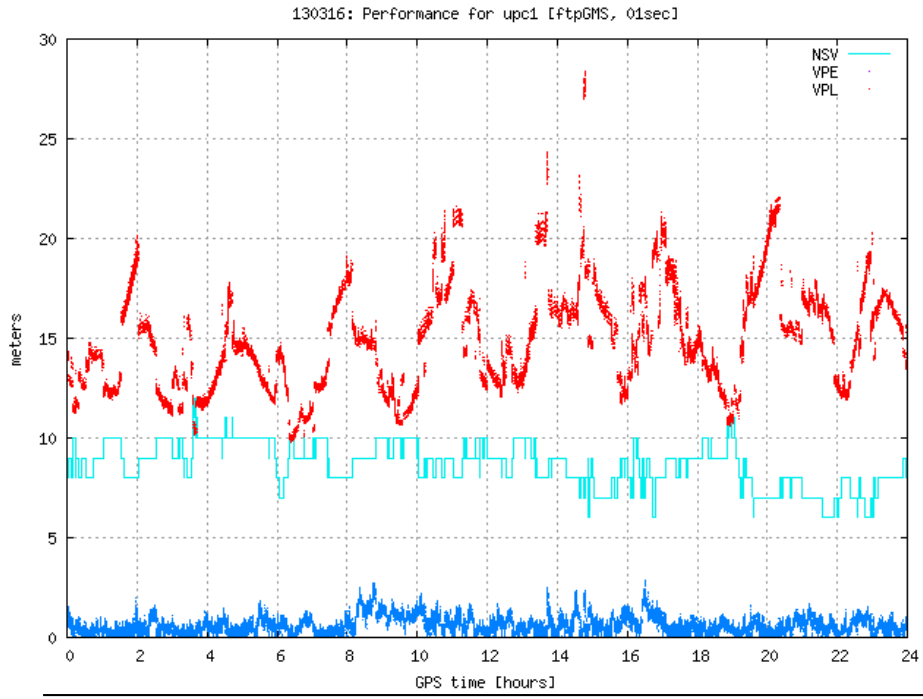
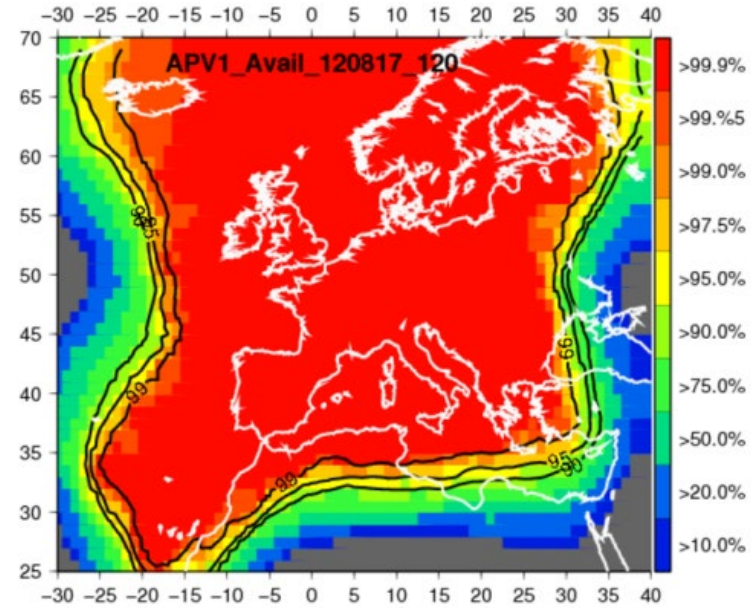
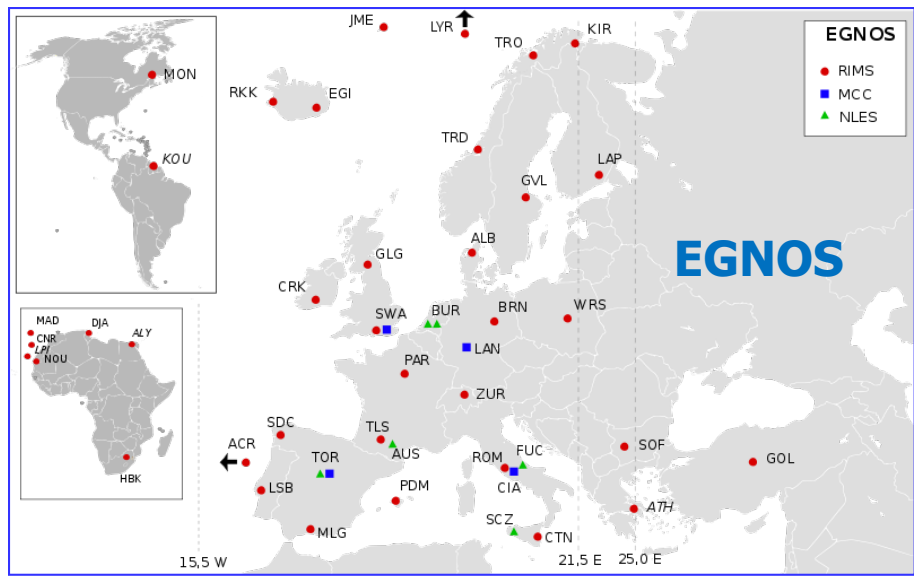
- Examples using L1 carrier smoothed code are the Satellite Based Augmentation Systems (SBAS), e.g. **WAAS**, **EGNOS**, **MSASS**, **GAGAN** ... for Civil Aviation, where differential corrections and integrity data fulfilling the **Civil aviation** requirements are broadcast over continental areas by a GEO satellite.

Metre level accuracies with integrity are met.

Evolution to a dual frequency

(L1,L5) signals in the Aeronautical Radio Navigation Service protected band.





Contents

1. Introduction

1. GNSS positioning and errors on the signal
2. Standalone Positioning
3. Differential positioning concept and differential corrections

2. Code Based Differential positioning (DGNSS)

1. DGNSS using smoothed codes
2. Augmentation systems (GBAS and SBAS)

3. Carrier Based Differential positioning

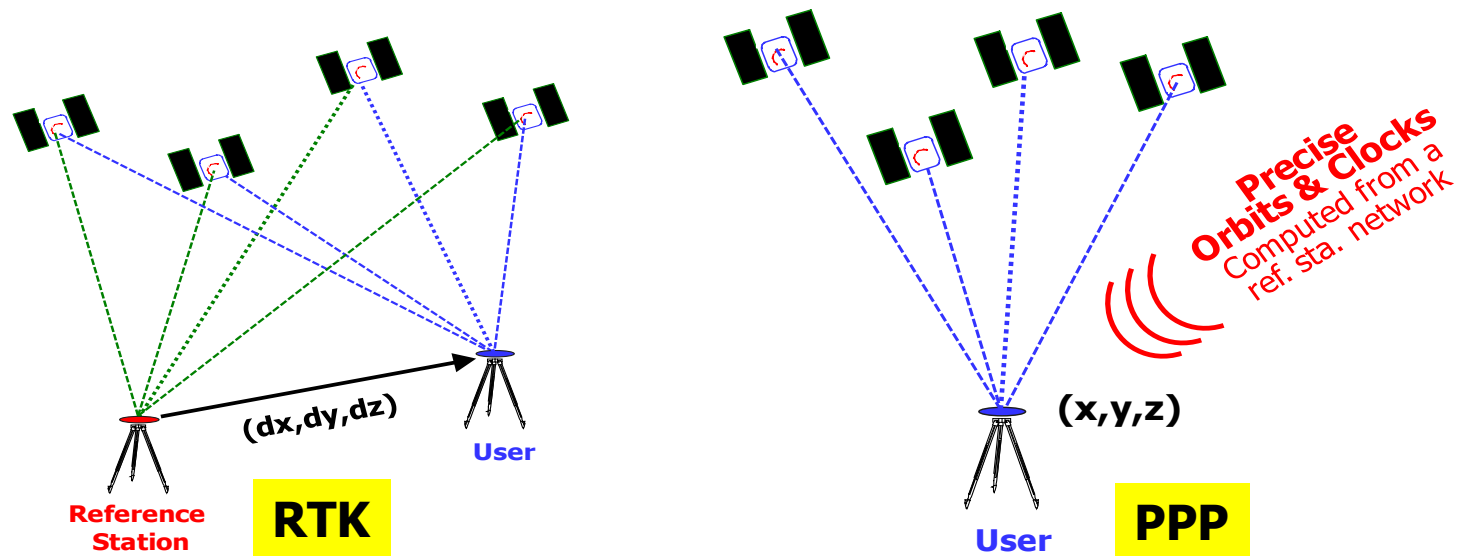
1. Real Time Kinematics (RTK) and Network-RTK concepts
2. Precise Point Positioning (PPP) concept

4. Commercial Services

High Accuracy Positioning

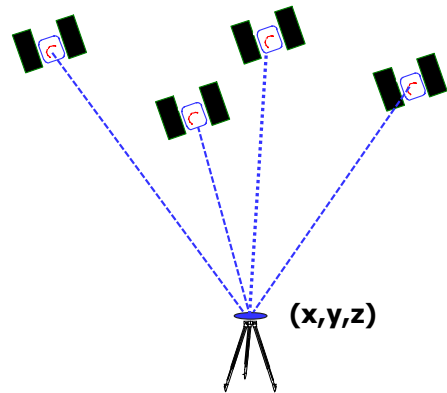
Carrier based Differential Positioning techniques:

- Relative GNSS positioning (e.g. RTK, Network-RTK)
 - ➔ At least two operating receivers are needed. It makes use of the spatial correlation of the errors between stations to remove/mitigate their effects in differential mode, improving accuracy.
- Precise absolute (point) positioning (e.g. PPP, PPP-AR, Fast-PPP)
 - ➔ It uses observation data of a single receiver and additionally state information on individual GNSS errors (orbits, clocks...) derived from a GNSS network.



Code based positioning

Standard Point Positioning (SPP)

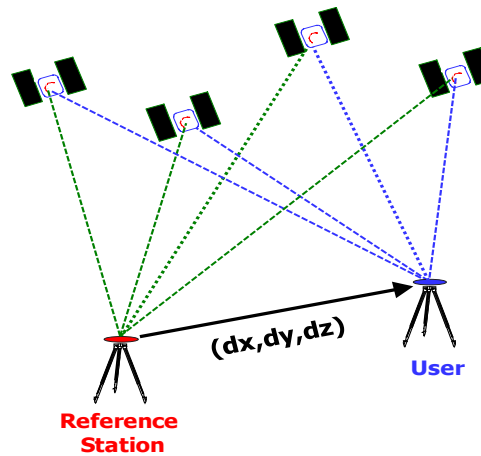


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

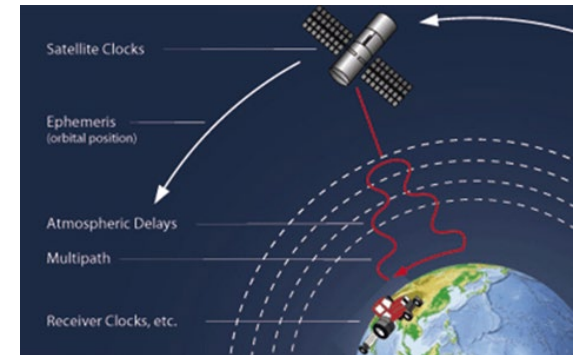
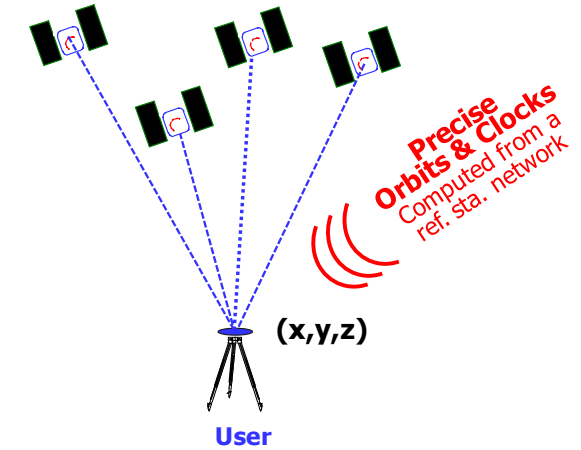
← **High Accuracy** →

Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

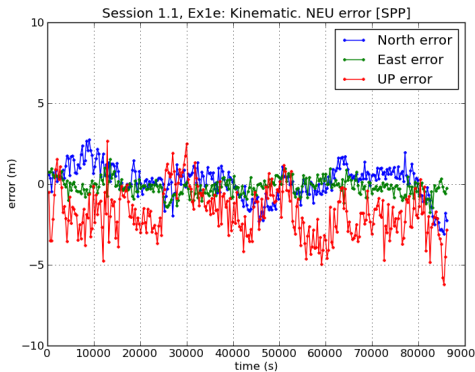
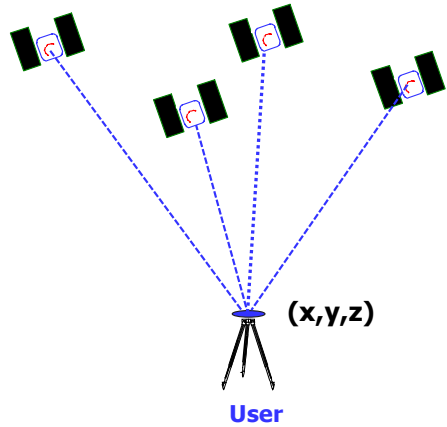
Precise Point Positioning (PPP)



**cm – dm level.
World wide.
Best part of one hour.**

Code based positioning

Standard Point Positioning (SPP)

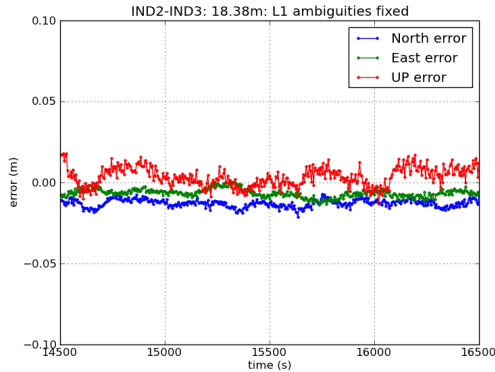
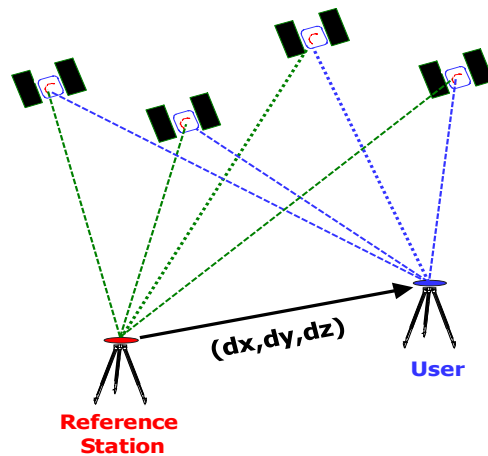


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

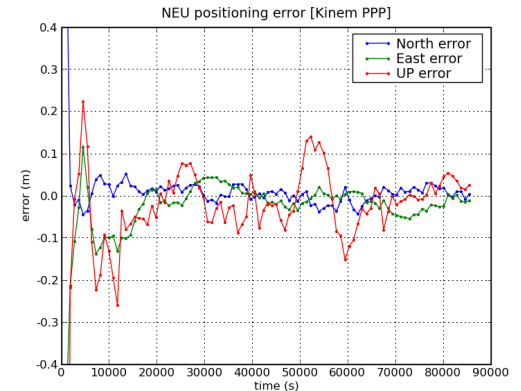
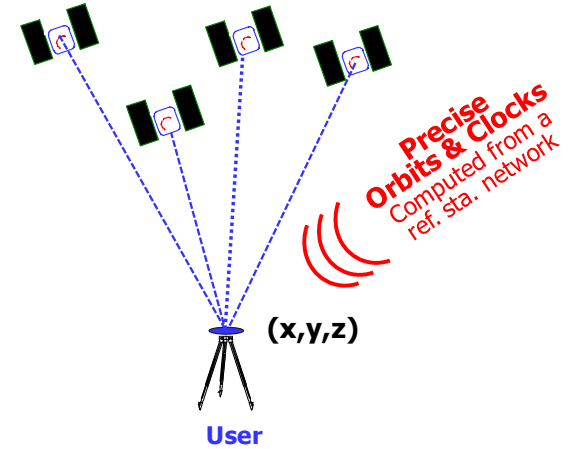
← **High Accuracy** →

Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

Precise Point Positioning (PPP)



**cm – dm level.
World wide.
Best part of one hour.**

Contents

1. Introduction

1. GNSS positioning and errors on the signal
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3. Differential positioning concept and differential corrections

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1. DGNSS using smoothed codes
2. Augmentation systems (GBAS and SBAS)

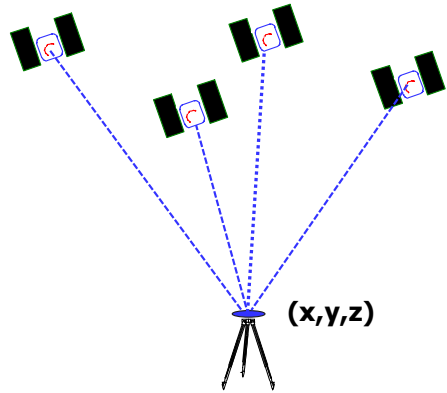
3. Carrier Based Differential positioning

1. Real Time Kinematics (RTK) and Network-RTK concepts
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4. Commercial Services

Code based positioning

Standard Point Positioning (SPP)

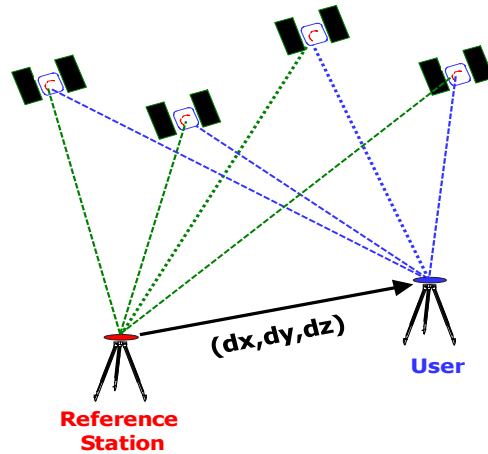


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

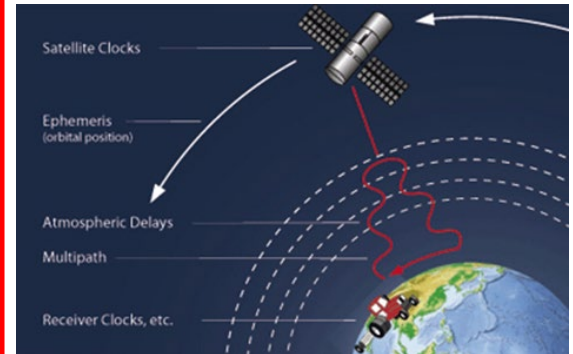
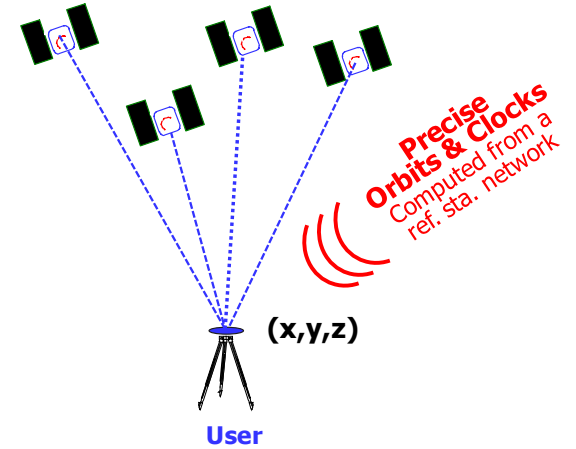
← High Accuracy →

Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

Precise Point Positioning (PPP)



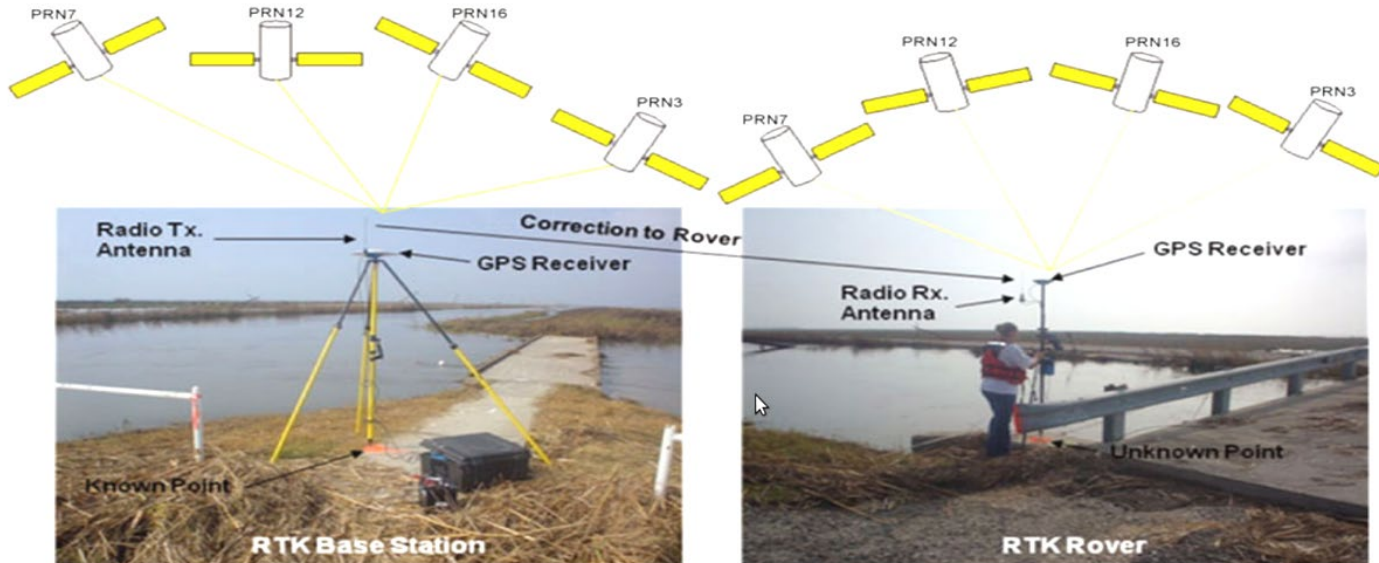
**cm – dm level.
World wide.
Best part of one hour.**

Carrier based Differential positioning: RTK

gAGE

research group of Astronomy and Geomatics
BarcelonaTECH, Spain

Centimetre level accuracy positioning in real-time based on GPS (or GNSS) was developed in mid 1990s and nowadays is referred as RTK

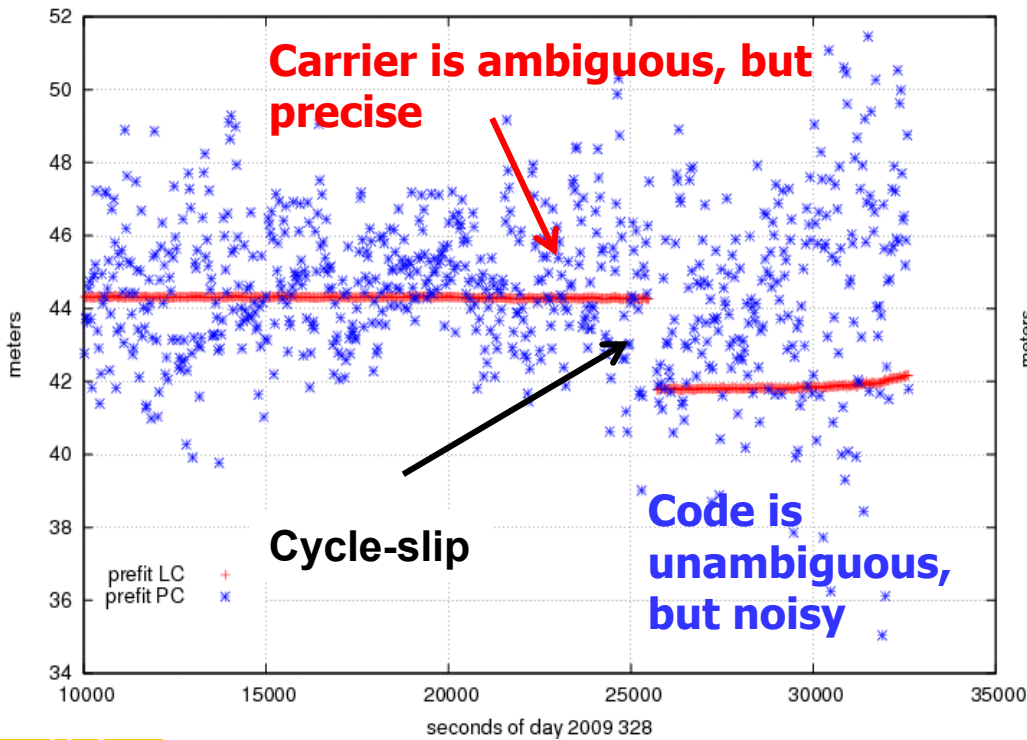


(Picture from <http://water.usgs.gov/osw/gps/index.html>)

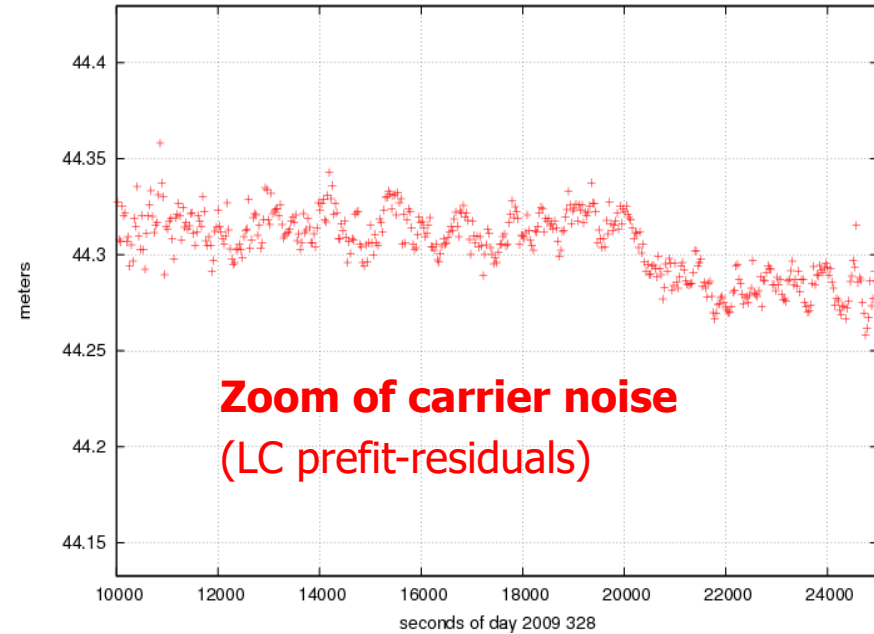
It involves a reference receiver transmitting its raw measurements to a rover receiver via some sort of communication link (e.g. VHF or UHF radio, cellular phone). The data processing at the rover receiver includes ambiguity resolution of the differential carrier data and coordinate estimation of the rover position.

Users within some ten of kilometres can obtain centimetre level positioning. The baseline is **limited by the differential ionospheric error** that can reach up to 10cm, or more, in 10km, depending of the ionospheric activity.

Comparison of measurement noise of LC and PC: GUSN, PRN14



Measurement noise of LC: GUSN, PRN14

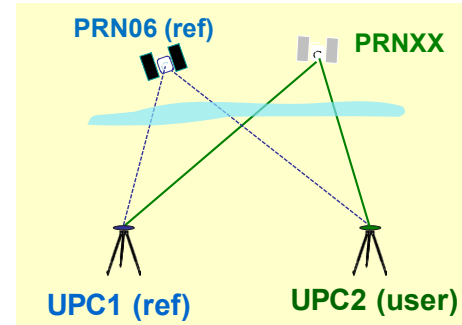


- **Code** measurements are unambiguous but noisy (metre level noise).
- **Carrier** measurements are precise (few millimetres of noise) but ambiguous (the unknown biases can reach thousands of km).
- **Carrier phase biases are estimated in the navigation filter** along with the other parameters (coordinates, clock offsets, etc.). If these biases were fixed, measurements accurate to the level of few millimetres would be available for positioning. However, some time is needed to decorrelate such biases from the other parameters in the filter, and the estimated values are not fully unbiased.

Double Differences (DD) and RTK: AMBIG. FIX

RTK uses DD measurements to:

- Remove differential errors (cm level short baselines)
- **Benefit of the integer nature of DD ambiguities**

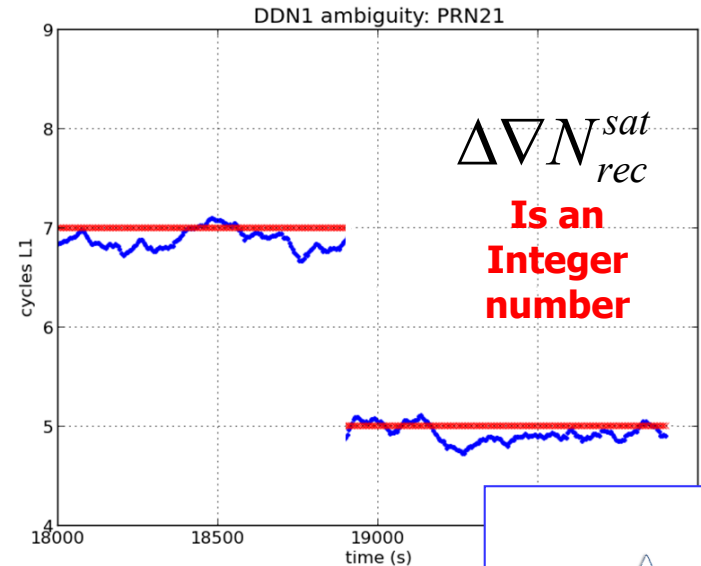


Carrier ambiguities contains (real-valued) hardware biases

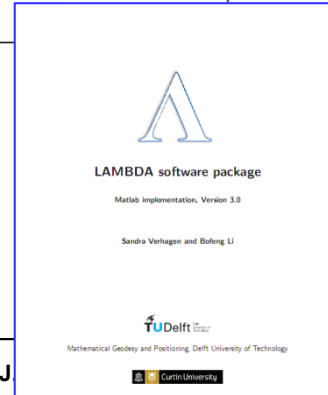
$$B_{rec}^{sat} = \lambda N_{rec}^{sat} + b_{rec} + b^{sat}$$

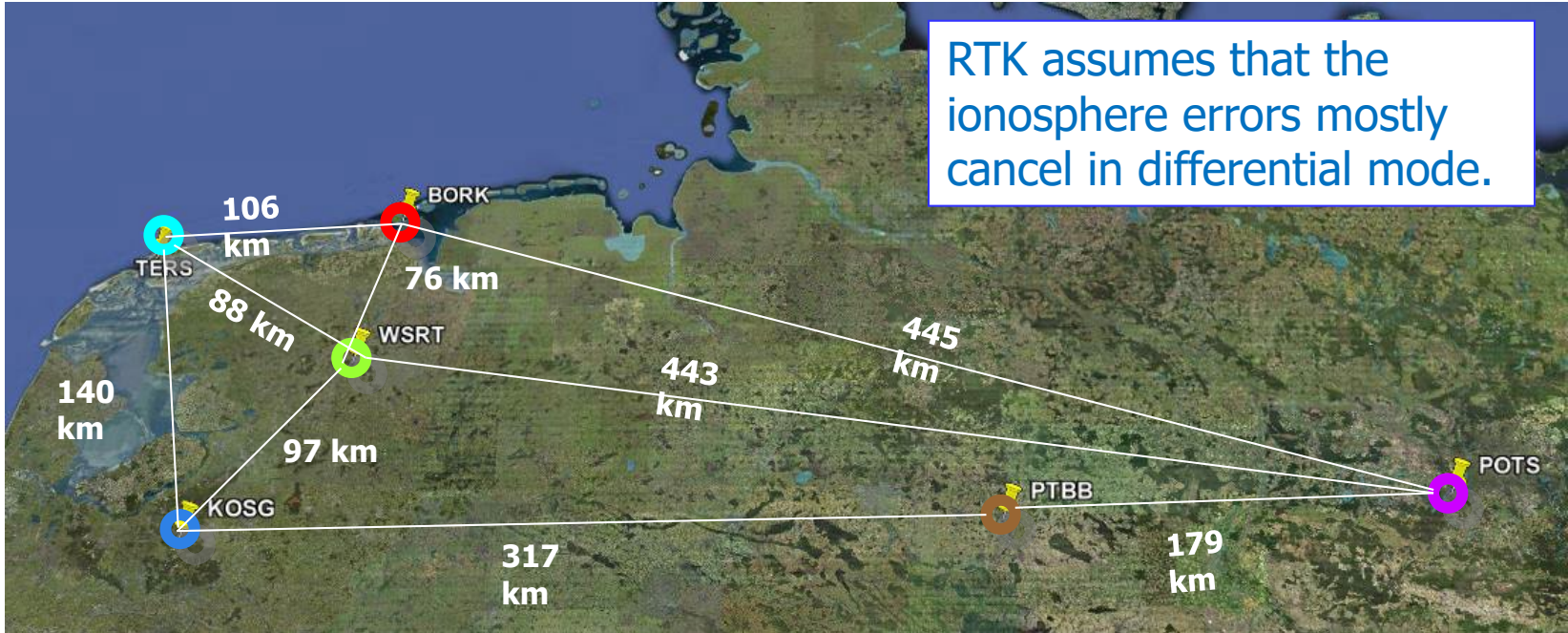
But, they cancel in Double Differences (DD) between pairs of satellites and receivers.

Thence the double differenced carrier ambiguities are integer numbers of wavelengths:



$$\Delta\Delta B_{rec}^{sat} = B_{rec}^{sat} - B_{rec,R}^{sat} - (B_{rec}^{sat,R} - B_{rec,R}^{sat,R}) = \lambda \Delta\Delta N_{rec}^{sat}$$

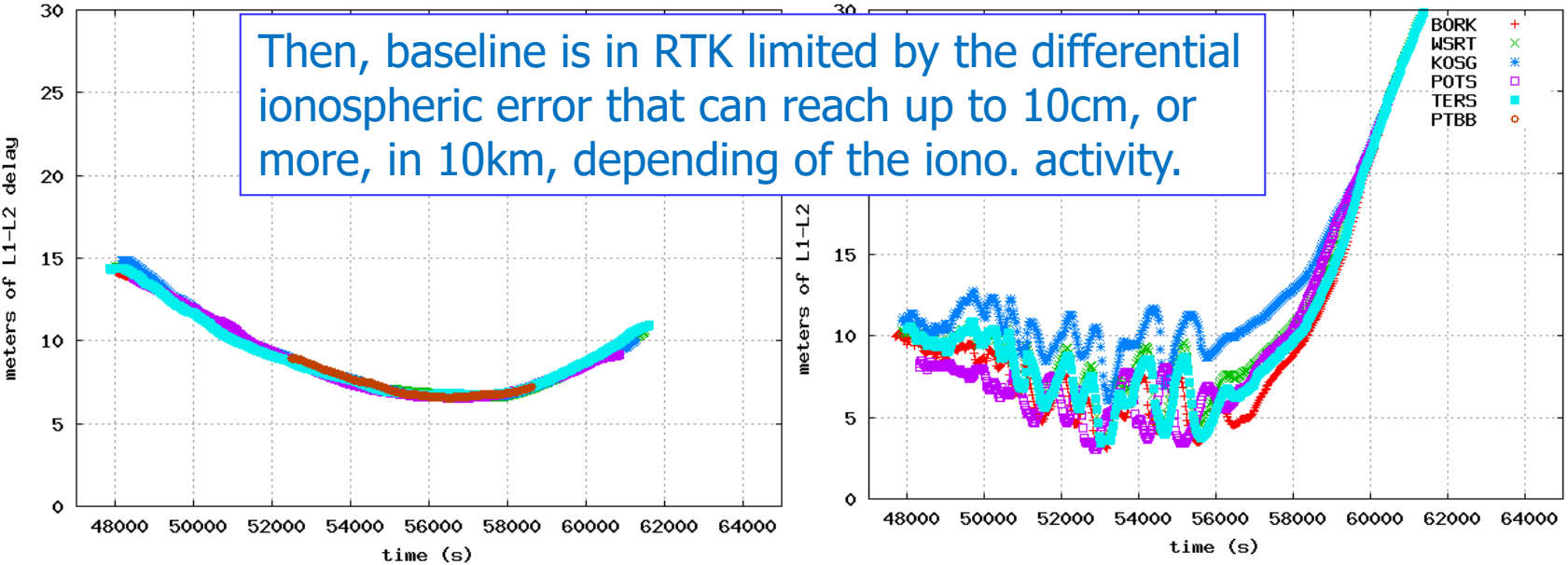


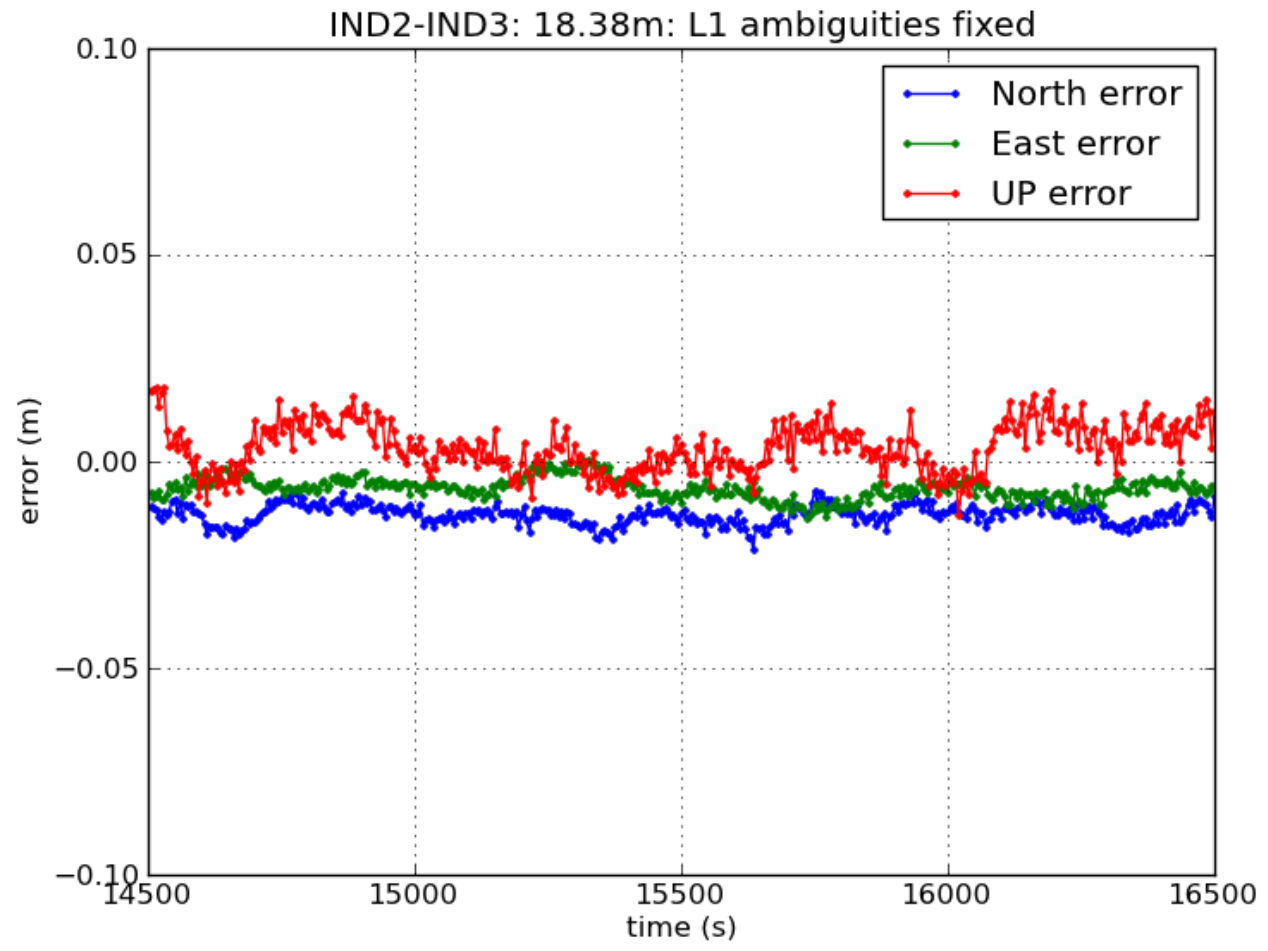


RTK assumes that the ionosphere errors mostly cancel in differential mode.

2001 DoY 327: STEC PRN29

2001 DoY 328: STEC PRN29







The key feature of RTK is the ability to **fix the carrier ambiguities On-The-Flight (OTF)**, i.e. while on the move. Major receivers manufacturers offer RTK solution packages consisting on a pair or receivers, a radio link, and software. The performance of RTK is measured by (i) **initialization time**, and (ii) **reliability (or, correctness) of the ambiguity fixing**. There is an obvious trade-off between getting the answer quickly and getting it right.

For typical baselines up to 10 km, **integer ambiguity resolution in few tens of seconds is common, achieving centimetre error level of accuracy.**

The main drawback of the single base RTK is that the maximum distance between rover and reference stations cannot exceed 10 to 20 km in order to be able to rapidly and reliably resolve the carrier ambiguities.

- ➔ Many reference stations are needed to provide service to a larger region or a whole country (e.g. 30 stations to cover 10.000 km²) (e.g. Corsica -8.000 km²- or Cyprus islands -9.000 km²-).
- This limitation comes from the distance-dependent biases such as differential atmospheric refraction (Ionosphere, Troposphere), mainly, and orbit error, as well.

These errors, however can be accurately modelled from the measurements collected by a continuously operating reference stations network, surrounding the rover receivers.

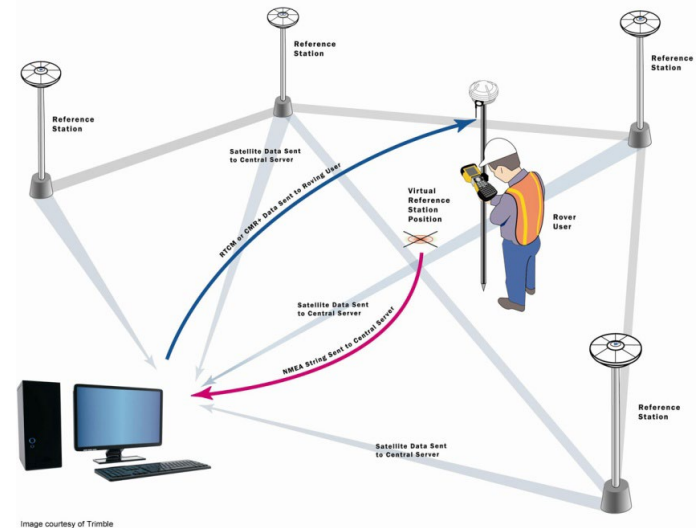


Image courtesy of Trimble

The basic scenario for VRS surveying is as follows:

- The **user sends its approximate position** to the Real-Time Network (RTN) system using a cell phone (or other communication method).
- The **RTN system emulates a virtual reference station**, in close proximity to the user based on the position sent.
 - ➔ The RTN system computes and sends “virtually shifted measurements” as if a real base station were broadcasting from the location of the virtual reference station.

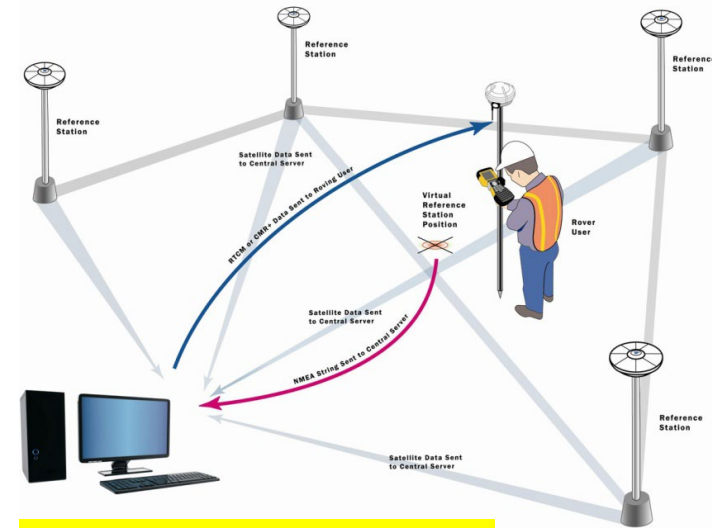


Image courtesy of Trimble

After initialization, the survey proceeds in exactly the same manner as an RTK survey. **No receiver upgrade is needed (regarding to RTK).**

Limitations of Network-RTK include:

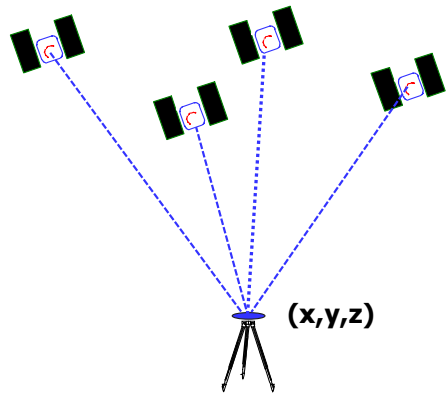
- Limitation in the **distance** between reference stations (over 50-100km), **which depends on the geographic location of the network and the level of ionospheric activity.**
- There is **a high cost of setting up and maintaining** the RTN:
 - ➔ Note: With typical baselines between reference stations of 50-100 km, about 5 to 10 reference stations are still needed per 10.000 km² (e.g. Corsica -8.000 km²- or Cyprus islands -9.000 km²-).
- Use of the RTN is limited by **data link coverage and system latencies or down times.**
- **Availability is dependent on network extent** and accuracy can be affected by the network density.
- In the case of VRS, it requires a two way communication link. Then, the number of potential VRS users is limited.

Contents

1. Introduction
 1. GNSS positioning and errors on the signal
 2. Standalone Positioning
 3. Differential positioning concept and differential corrections
2. Code Based Differential positioning (DGNSS)
 1. DGNSS using smoothed codes
 2. Augmentation systems (GBAS and SBAS)
3. Carrier Based Differential positioning
 1. Real Time Kinematics (RTK) and Network-RTK concepts
 2. **Precise Point Positioning (PPP) concept**
4. Commercial Services

Code based positioning

Standard Point Positioning (SPP)

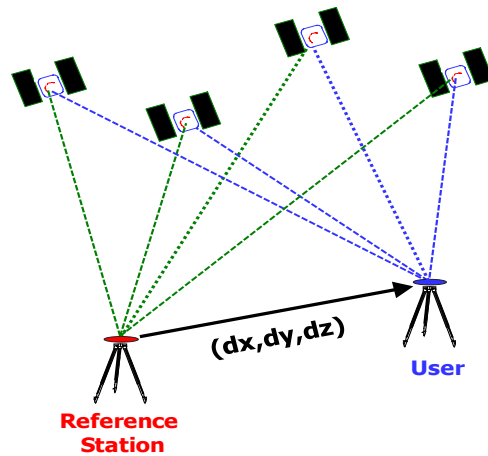


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

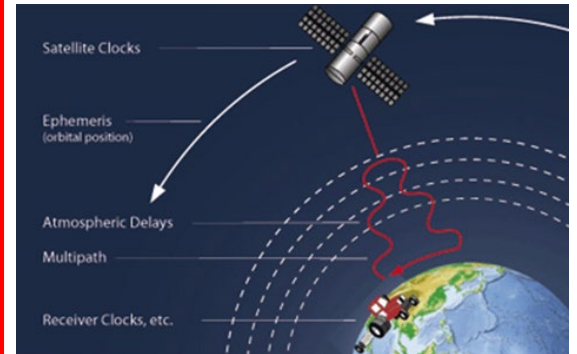
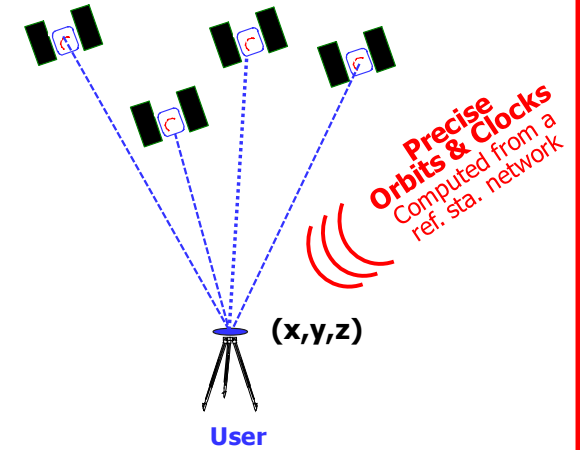


Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

Precise Point Positioning (PPP)

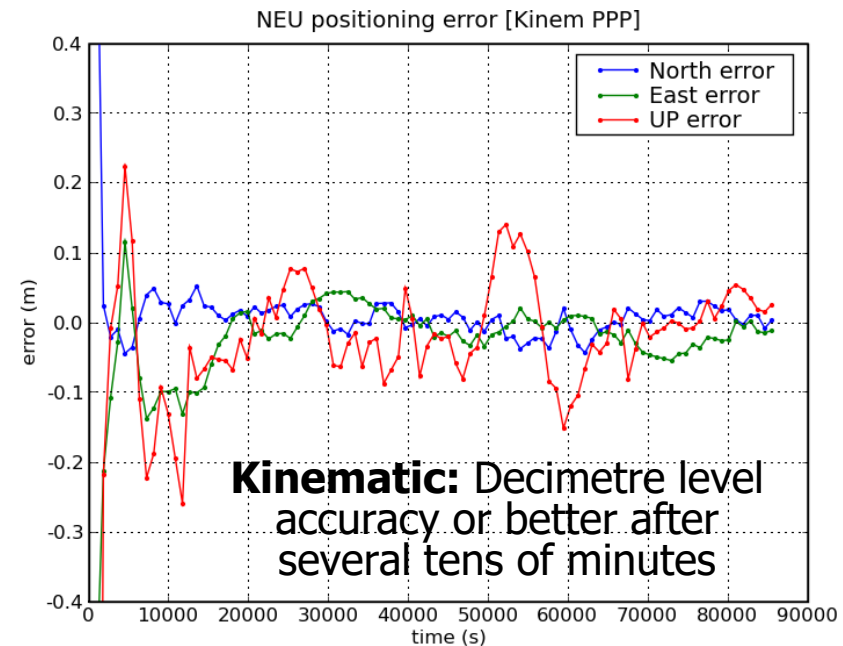
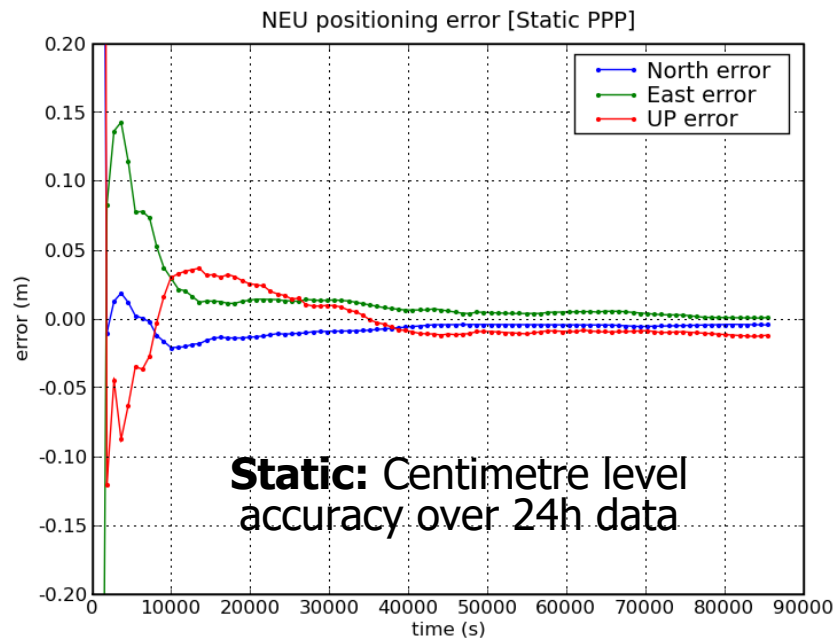


**cm – dm level.
World wide.
Best part of one hour.**

Precise (Absolute) Point Positioning: PPP

Zumberge et al. (1997), proposed the Precise Point Positioning (PPP) method for absolute positioning of a single receiver.

Using **precise orbits and clocks** (post-processed or Real-time, e.g. from IGS) and with **an accurate measurements modelling**, provides centimetre (static) or decimetre (kinematic) level of accuracy for any worldwide user with a **dual-frequency receiver (iono-free combination)**.



The main disadvantage of PPP is that the solutions take longer to converge than the RTK or NRTK differential solutions.

Ionospheric delay

The ionosphere extends from about 60 km over the Earth surface until more than 2000 km, with a sharp electron density maximum at around 350 km. The ionospheric refraction depends, among other things, of the location, local time and solar cycle (11 years).

- First order (~99.9%) ionospheric delay δ_{ion} depends on the inverse of squared frequency:

$$\delta_{ion} = \frac{40.3}{f^2} I$$

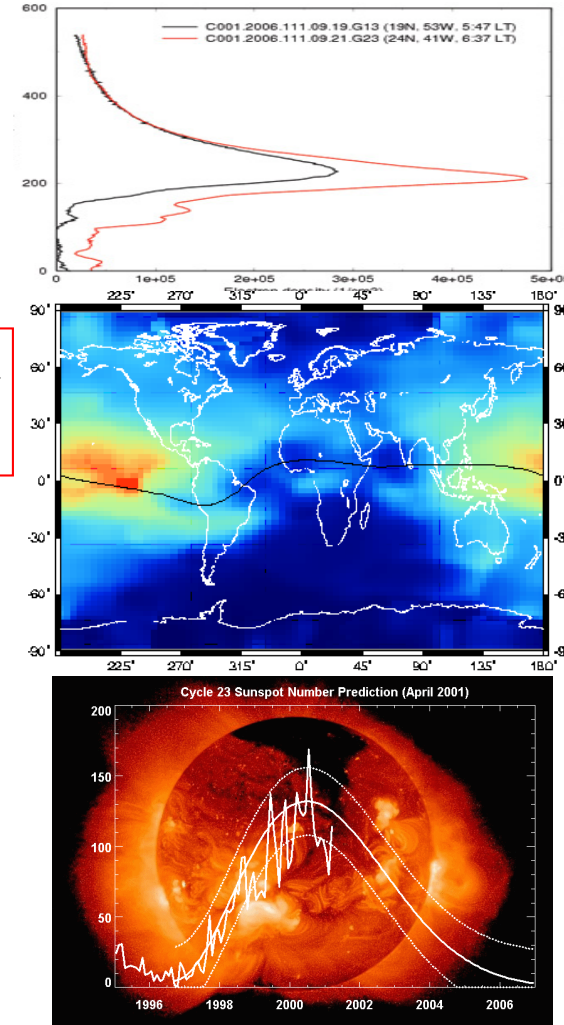
where I is the number of electrons per area unit along ray path (STEC: Slant Total Electron Content).

$$I = \int N_e ds$$

- Two-frequency receivers can remove this error source (up to 99.9%) using ionosphere-free combination of pseudoranges (PC) or carriers (LC).
(→ ionosphere-free combination)

$$LC = \frac{f_1^2 L1 - f_2^2 L2}{f_1^2 - f_2^2}$$

- Single-frequency users can remove about a 50% of the ionospheric delay using the Klobuchar model, whose parameters are broadcast in the GPS navigation message.



GDC GNSS DATA CENTER

User: Password: login

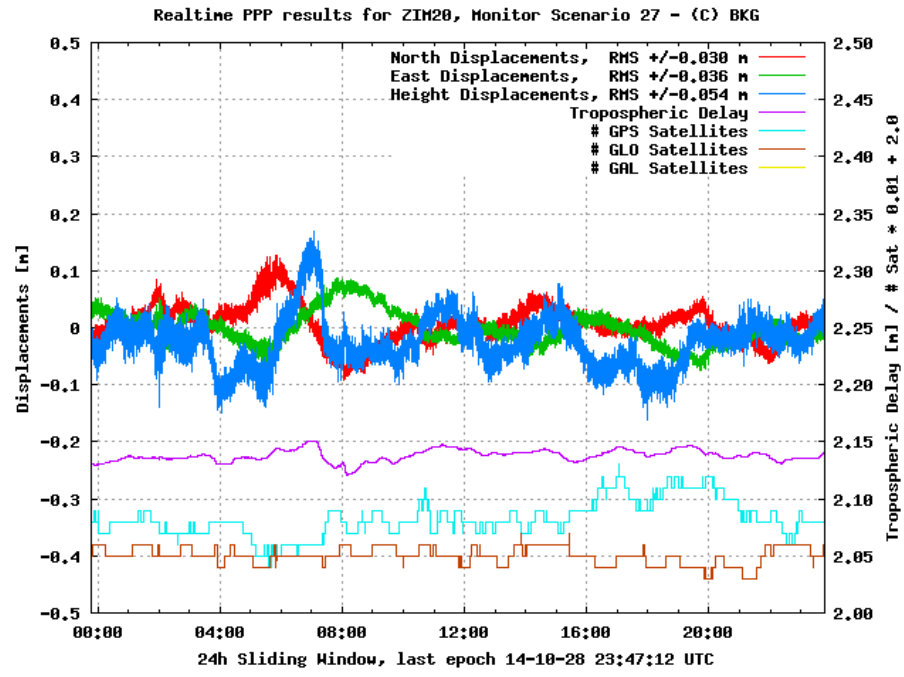
Home About Us Data & Products NTRIP Links

Project Filter: ALL

NTRIP > EUREF & IGS products > Orbits

Real-time Satellite Orbit and Clock Corrections to Broadcast Ephemeris from IGS and EUREF Resources

EUREF's Real-time Analysis project and the IGS Real-time Pilot Project provide access to precise GNSS satellite orbits and clocks via NTRIP for test and evaluation.



Precise orbits and clocks can be derived from corrections to Broadcast Ephemeris.

RTCM's 'State Space Representation' (SSR) Working Group has developed appropriate v3 messages to disseminate such Corrections in real-time.

Pros

- PPP provides absolute worldwide positioning for a single receiver, from a reduced reference stations network (some tens for the whole planet).
- The “state-space” modelling used in PPP, where the different error components (orbits, clocks...) are treated separately, is more close to the physical error sources.
- It also allows to reduce the message bandwidth for transmission. Different time update rates can be used for different state parameters.

Cons:

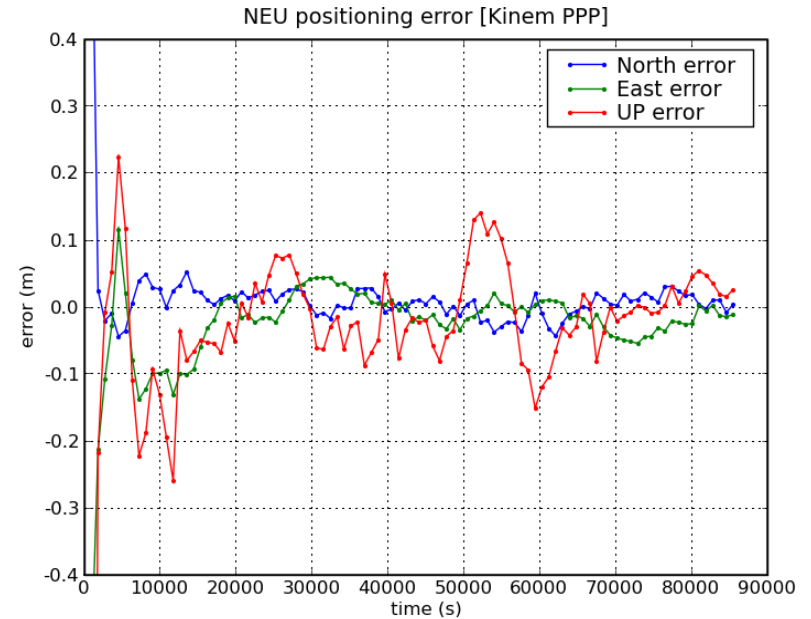
- The main disadvantage of PPP is the **large converge time**. Decimetre level navigation can require from tens of minutes to more than one hour, depending on the satellite geometry.
- Also it is limited in accuracy, because in the conventional PPP, carrier **ambiguities are estimated as real numbers (floated)**, i.e. are not fixed as integer values as in RTK.

Comment: The ionosphere-free ambiguity parameter estimated in the conventional PPP is a combination of integer ambiguities and the satellite and receiver carrier hardware biases. **Then the integer property is lost.**

Note: These biases are canceled in RTK when forming Double-Differences of measurements between pairs of satellites and receivers.

PPP and floating ambiguities

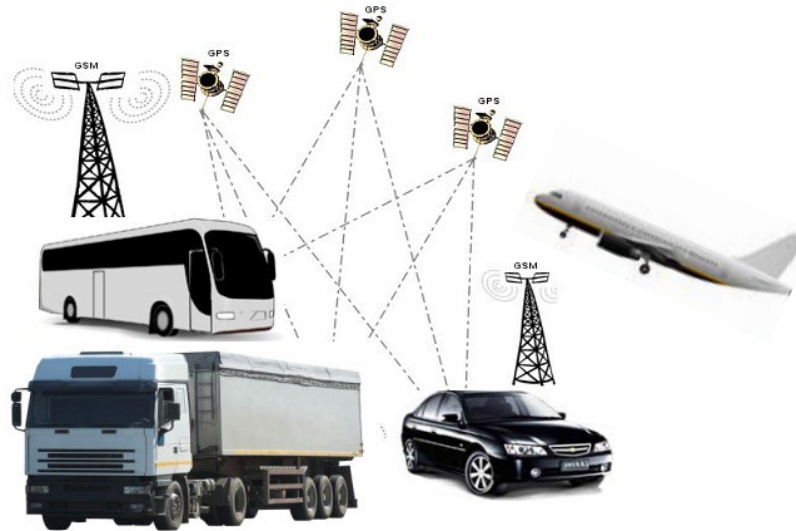
- The main disadvantage of PPP is the **large converge time**. Decimetre level navigation can require from tens of minutes to more than one hour, depending on the satellite geometry.



For an observation span relatively long, e.g. one hour, the floated ambiguities (in PPP) would typically be very close to integers, and the change in the position solution from the float to the fixed solution should not be large.

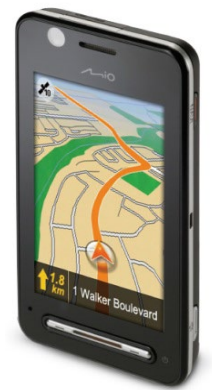
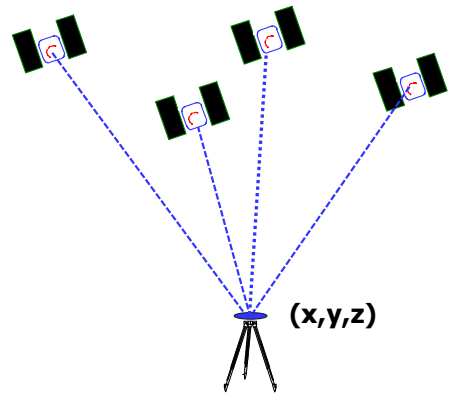
As the observation span becomes smaller, ambiguity fixing (e.g. RTK) play a more important role. But very short observation spans implies the risk of wrong ambiguity fixing, which can degrade the position solution significantly.

Brief Conceptual Summary: DGNSS, RTK, PPP



Standalone (code) positioning

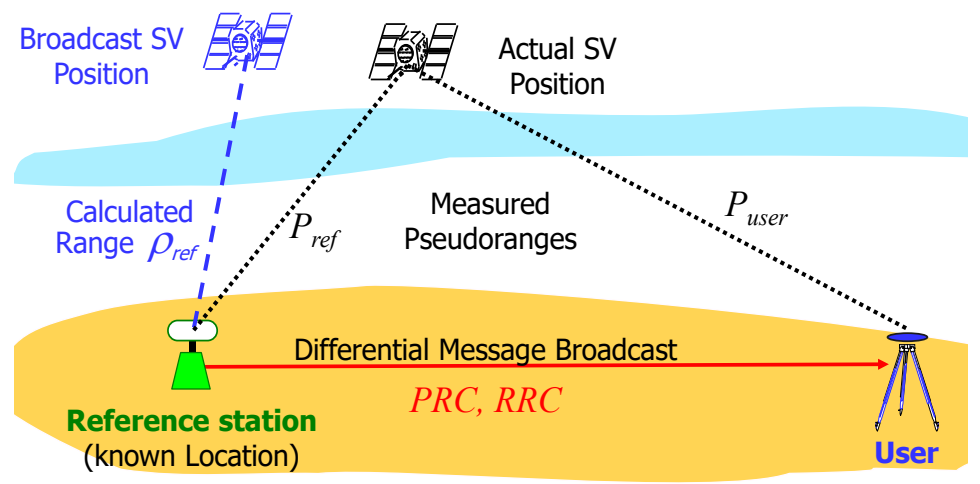
Standard Point Positioning (SPP)



**Few metres.
World wide.
Single epoch.**

Code based Differential positioning (DGNSS)

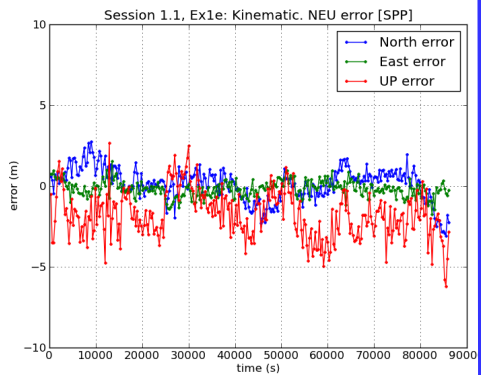
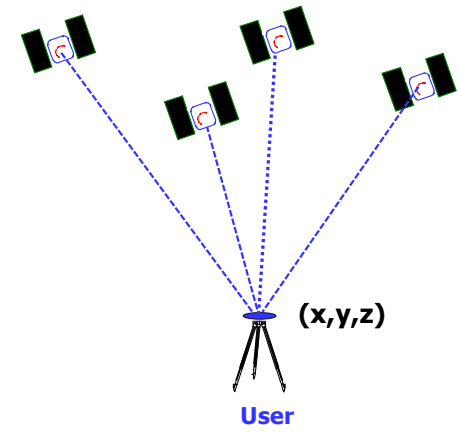
← **Improved Accuracy** →



Picture from <http://signus-sas.blogspot.com.es>

Standalone (code) positioning

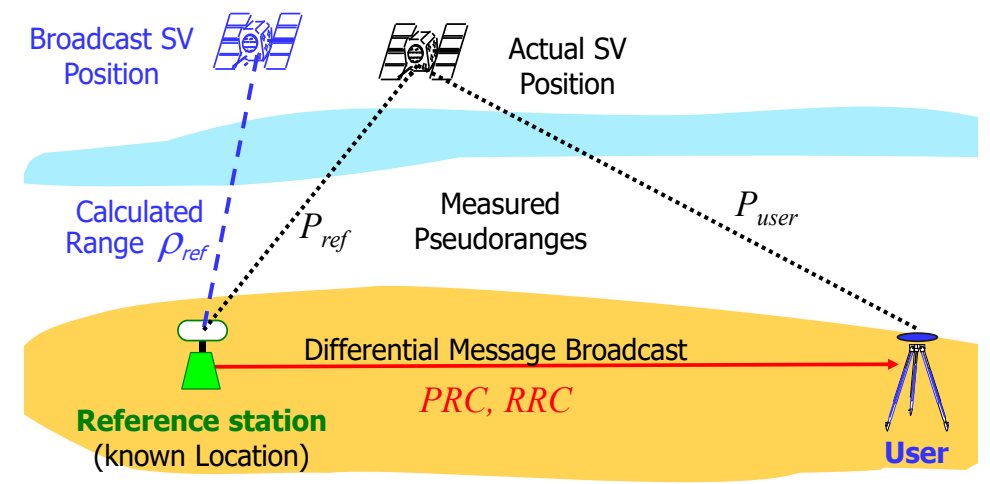
Standard Point Positioning (SPP)



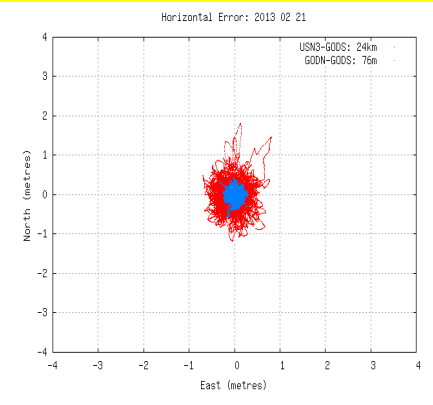
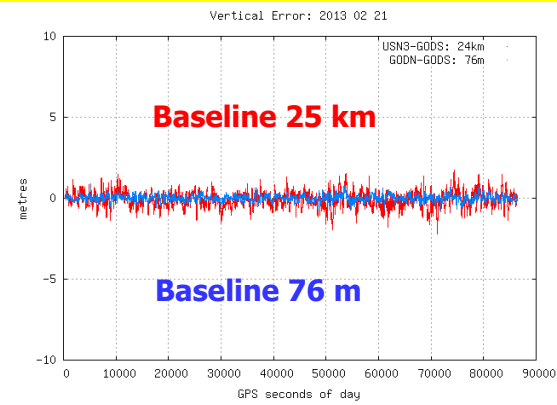
**Few metres.
World wide.
Single epoch.**

Code based Differential positioning (DGNSS)

← **Improved Accuracy** →



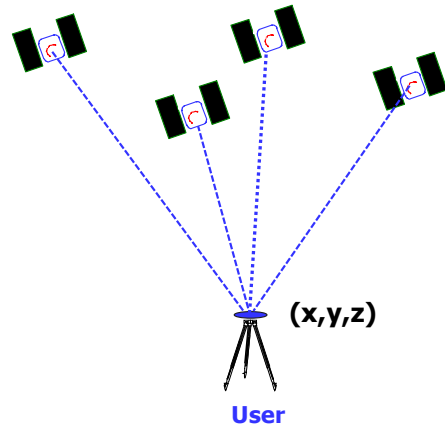
Errors are similar for users separated tens, even hundred of km, and are removed/mitigated in differential mode, improving positioning.



**Metre level
Regional Area (~100 km)
Single epoch**

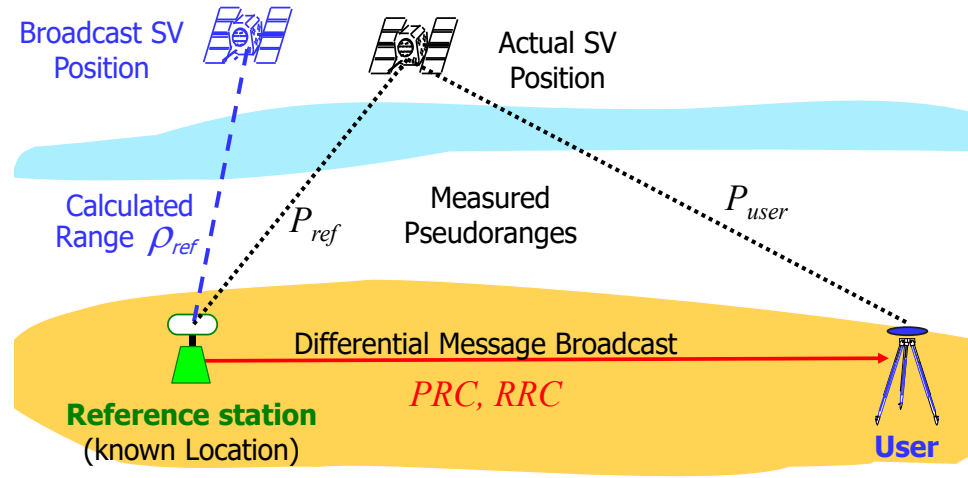
Standalone (code) positioning

Standard Point Positioning (SPP)



Code based Differential positioning (DGNSS)

← Improved Accuracy →



Errors are similar for users separated tens, even hundred of km, and are removed/mitigated in differential mode, improving positioning.

Uses single receiver (undifferenced) 1-freq. measur.+ computed differential corrections (from a reference station with know coordinates)

- Signal errors are removed from these differential corrections (degradation of accuracy with baseline).
- **Carrier smoothed code**

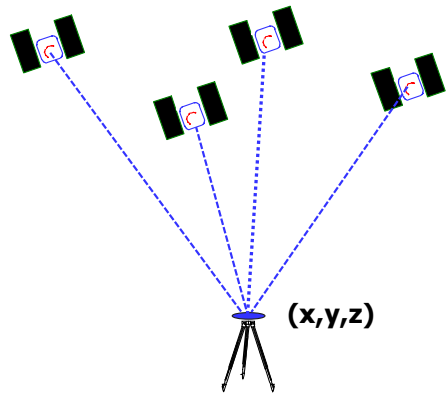
- Uses single receiver (undifferenced) 1 freq. measur.+ broad. orbits /clocks
- **Metre level measurements modelling**
- **Code measurements (or carrier smoothed code).**
- *No ambiguity resolution is needed.*

**Few metres.
World wide.
Single epoch.**

**Metre level
Regional Area (~100 km)
Single epoch**

Code based positioning

Standard Point Positioning (SPP)

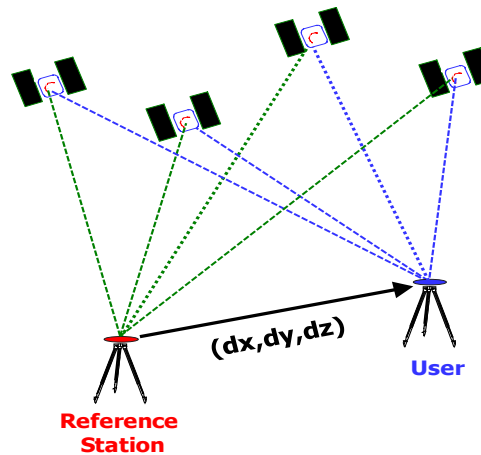


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

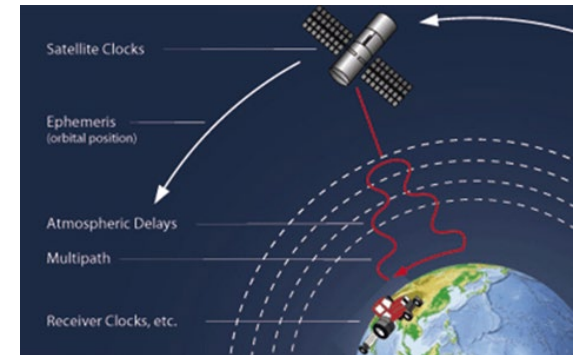
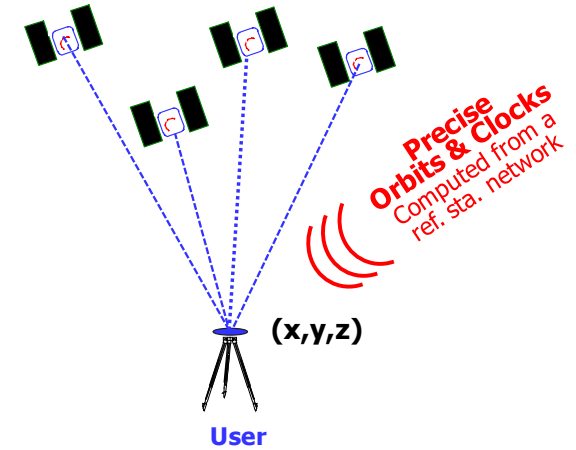
← **High Accuracy** →

Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

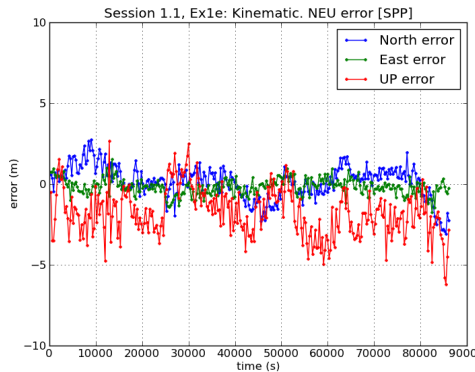
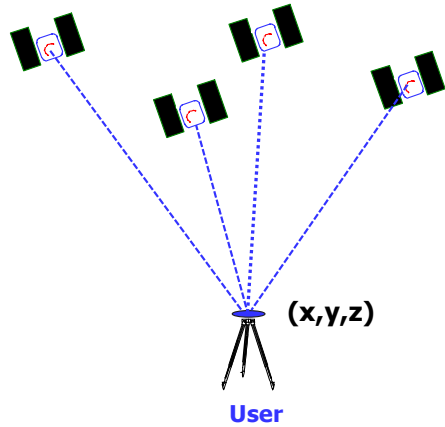
Precise Point Positioning (PPP)



**cm – dm level.
World wide.
Best part of one hour.**

Code based positioning

Standard Point Positioning (SPP)

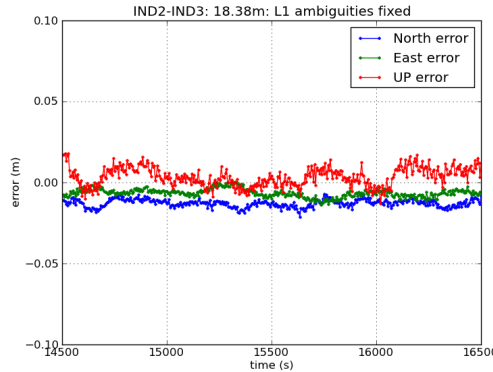
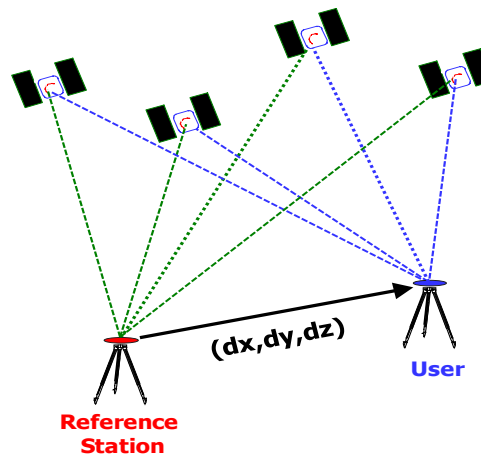


**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

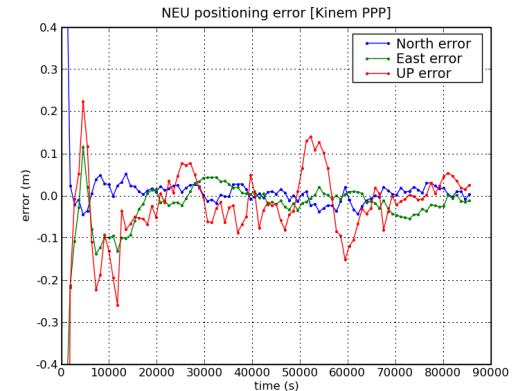
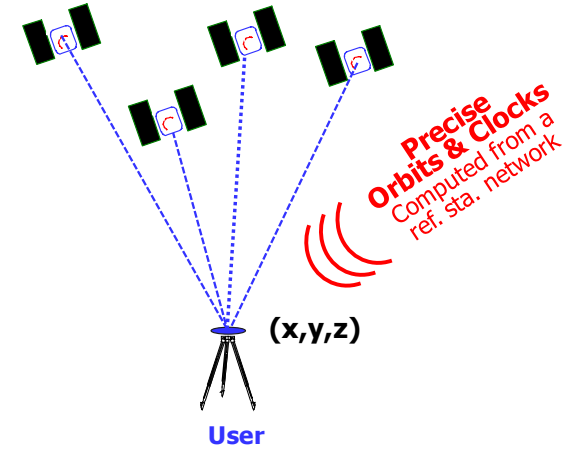


Relative Positioning (RTK)



**Few centimetres.
Local Area (few km).
Few seconds.**

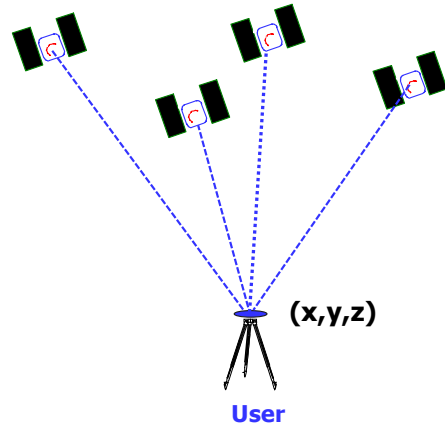
Precise Point Positioning (PPP)



**cm – dm level.
World wide.
Best part of one hour.**

Code based positioning

Standard Point Positioning (SPP)



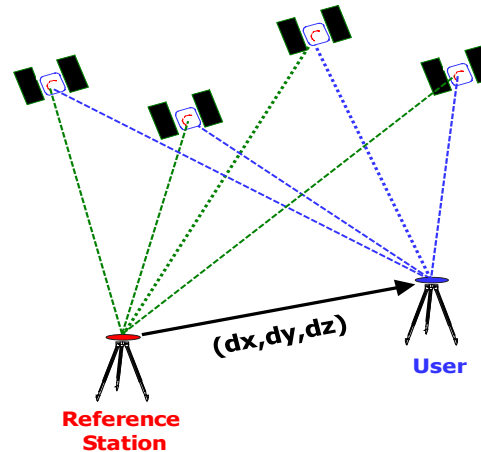
- Uses single receiver (undifferenced)
1 freq. measur. + broad. orbits / clocks
- Metre level measurements modelling
 - Code measurements (*or carrier smoothed code*).
 - *No ambiguity resolution is needed.*

**Few metres.
World wide.
Single epoch.**

Carrier based Differential positioning

← High Accuracy →

Relative Positioning (RTK)

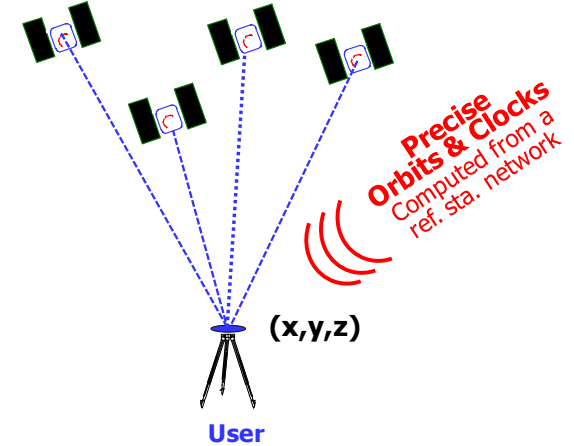


Uses Double differenced (DD) measurements between pairs of satellites and receivers.

- Signal errors are removed from these DD. (baseline limitation due to ionosphere dif. error).
- Carrier ambiguities are "**fixed**" (as integer numbers in DD)

**Few centimetres.
Local Area (few km).
Few seconds.**

Precise Point Positioning (PPP)



Uses single receiver (undifferenced)
2freq measur+ precise orbits/clocks

- Accurate measurement modelling is need (up to the cm level).
 - Carrier ambiguities are "**floated**" (i.e. estimated as real values)
- Note: in PPP the integer property is lost with undifferenced carriers

**cm – dm level.
World wide.
Best part of one hour.**

This table is from the book: Pratap Misra, Per Enge. Global Positioning System. Signals, Measurements, and Performance. Ganga –Jamuna Press, 2004.

Source	Potential Error size	Error mitigation & Residual error
Satellite clock	Clock modelling error: 2 m (RMS)	DGPS: 0.0m
Ephemeris prediction	Line-Of-Sight error: 2 m (RMS)	DGPS: 0.01m (RMS)
Ionospheric Delay	Vertical delay: ~ 2-10 m (depending upon user location, time of day & solar activity) Obliquity factor: 1 at zenith, 1.8 at 30°, 3 at 5°.	Single-freq. using Klobuchar: 1-5m. DGPS: 0.2m (RMS)
Tropospheric Delay	Vertical delay ~ 2.3-2.5 m at sea level. (lower at a higher altitudes) Obliquity factor: 1 at zenith, 2 at 30°, 4 at 15° and 10 at 5°.	Model based on average meteorolog. Conditions: 0.1 -1 m DGPS: 0.2m (RMS) plus altitude effect.
Multipath	In clean environment: Code : 0.5 – 1 m Carrier: 0.5 -1 cm	Uncorrelated between antennas. Mitigation trough antenna design and sitting and carrier smoothing of code.
Receiver noise	Code : 0.25 – 0.50m (RMS) Carrier: 1-2 mm (RMS)	Uncorrelated between receivers

Contents

1. Introduction
 1. GNSS positioning and errors on the signal
 2. Differential positioning concept and differential corrections
2. Error mitigation in differential positioning
3. Code Based Differential positioning (DGNSS)
 1. DGNSS using smoothed codes
 2. Augmentation systems (GBAS and SBAS)
4. Carrier Based Differential positioning
 1. Real Time Kinematics (RTK) and Network-RTK concepts
 2. Precise Point Positioning (PPP) concept
5. Commercial Services

DGNSS Commercial services

Commercial WADGNSS services are already operational and in world-wide use for different applications: **agriculture** (e.g. OmniSTAR or CenterPoint RTX from **Trimble**), **operations at sea** (e.g. Starfix and Skyfix from **Fugro**), among others

<http://www.fugro.com/> <http://www.trimble.com>

- **OmniSTAR** provides four levels of service: <http://www.omnistar.com/>
 - Virtual base Station (VBS) offering sub-metre positioning,
 - World-wide service “XP” delivering better than 20 centimetre accuracy,
 - High performance (HP) service delivering greater than 10 centimetres accuracy
 - OmniSTAR “G2” service combines GPS plus GLONASS-based corrections to provide decimetre level positioning.

OmniSTAR services were initially introduced by Fugro company and in 2011 was acquired by Trimble company.

- Similar levels of services are provided by **Starfix**: <http://www.starfix.com>
 - Starfix.L1 , Starfix.XP, Starfix.HP , Starfix.G2

OmniSTAR VBS

Global Reliable Sub-Metre Accuracy



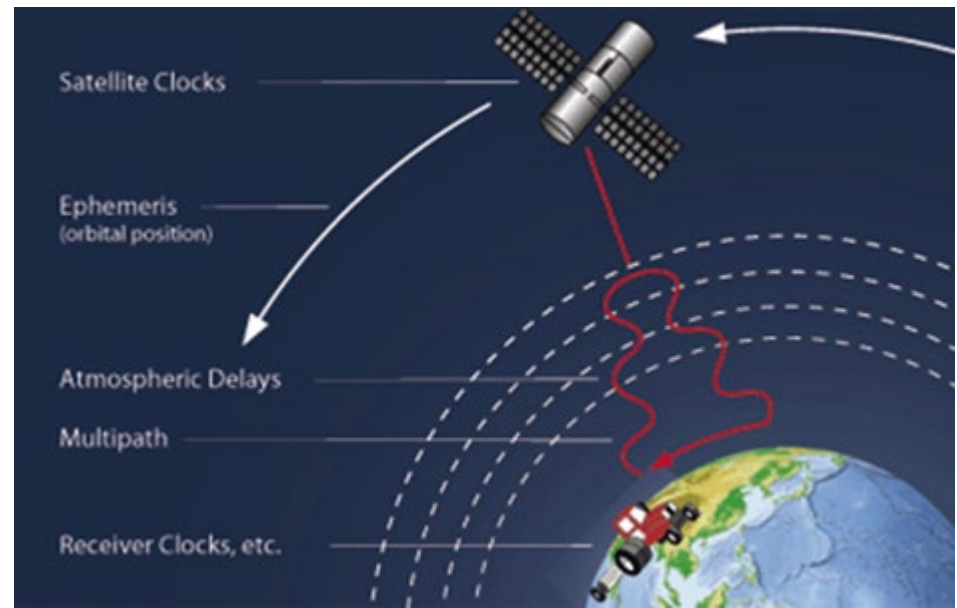
OmniSTAR VBS is the foundational "**sub-metre**" level of service. It is an **L1 only**, code phase pseudo-range solution.

Pseudo-range correction data from OmniSTAR's regional reference sites is broadcast via satellite link to the user receiver.

These data are used, together with atmospheric modeling and knowledge of the receiver's location, to generate an internal RTCM SC104 correction specific to that location. This correction is then applied to the R-T solution.

A typical 24-hour sample of OmniSTAR VBS will show a 2-sigma (95%) of significantly less than 1 metre horizontal position error and the 3-sigma (99%) horizontal error will be close to 1 metre.

OmniSTAR XP: 15 cm Worldwide Service



OmniSTAR XP (15cm) is a **worldwide dual frequency** high accuracy solution. It is a L1/L2 solution requiring a dual frequency receiver.

Orbit and Clock correction data is used together with atmospheric corrections derived from the dual frequency data.

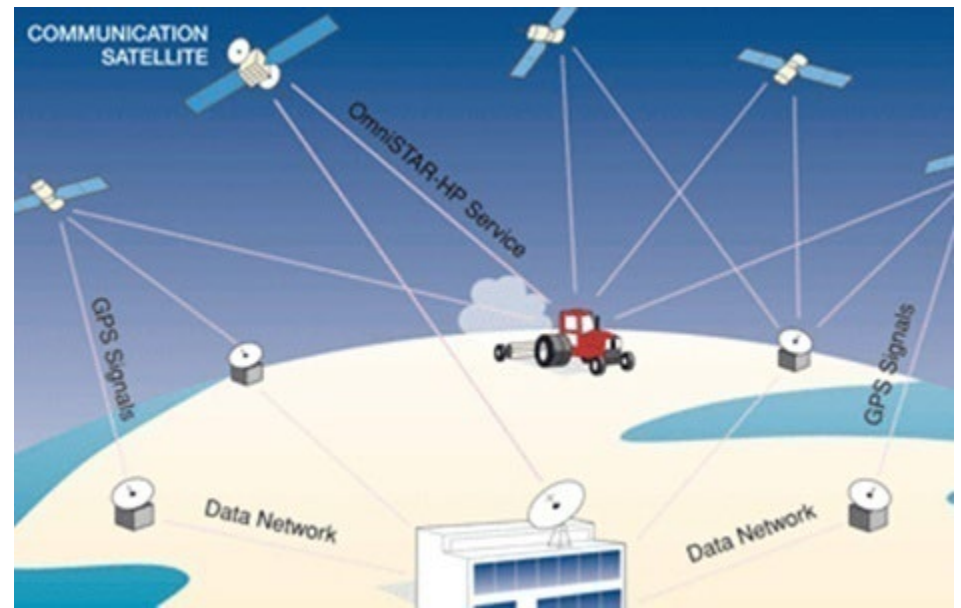
By utilizing carrier phase measurement, very high accuracy can be achieved. OmniSTAR XP service provides short term accuracy of 1-2 inches and long term repeatability of better than 10 centimetres, 95%CEP.

It is especially suited for **Agricultural automatic steering systems**. While it is slightly less accurate than OmniSTAR HP, it is available worldwide and its accuracy is a significant improvement over regional DGNSS such as WAAS.

OmniSTAR HP

10 cm High Performance

<http://www.omnistar.com/SubscriptionServices/OmnistarHP.aspx>



OmniSTAR HP (10cm) service is the **most accurate solution** available in the OmniSTAR portfolio of correction solutions. It is a L1/L2 solution requiring a **dual frequency** receiver.

OmniSTAR HP corrections are modeled on a network of reference sites using carrier phase measurement to maximize accuracy.

The expected 2-sigma (95%) accuracy of OmniSTAR HP is 10cm. It is particularly useful for **Agricultural Machine guidance and many surveying** tasks. It operates in real time and without the need for local Base Stations or telemetry links. OmniSTAR HP is a true advance in the use of GPS for on-the-go precise positioning.

OmniSTAR G2

GPS + GLONASS



OmniSTAR G2 is a **worldwide dual frequency** high-accuracy solution which uses **Orbit and Clock** correction data.

OmniSTAR G2 includes GLONASS satellites and GLONASS correction data in the solution. The addition of GLONASS to the solution significantly **increases the number of satellites available** which is useful when faced with **conditions that limit satellite visibility**, such as terrain, vegetation or buildings.

OmniSTAR G2 service provides short-term accuracy of 1-2 inches and long term repeatability of better than **10 cm**, 95%CEP. It is especially suited for operations in areas where trees or buildings may block the view of the sky and in areas affected by scintillation during times of high sunspot activity.

		Observable	Baseline	Broadcast message	accuracy	Init. time	Examples of Products
LA-DGNSS	DGPS (code)	Smoothed code (L1)	<100km	PRC, RRC	~ metre	Single epoch	OmniSTAR VBS
	RTK	Carrier L1/L2, L1	<10-15km	Carrier measurements	~ cm	~30 s	Several packages ...
	GBAS/LAAS	Smoothed code (L1)	< 40 km	PRC, RRC sigmas	~ metre + Integrity	Single epoch	Honeywell GBAS station
	VRS	Carrier L1/L2, L1	< 50 km	Virtual Carrier measurements	few cm	~30 - 60 s	Omnistar HP, StarFix HP
WA-DGNSS	SBAS	Smoothed code (L1)	Continental	Orbits+ Clocks+ Iono. + sigma	~ metre + Integrity	Single epoch	WAAS, EGNOS, MSAS...
	PPP	Iono-free code and carrier	Worldwide	Orbits + Clocks	~ dm	1/2h-1h.	Omnistar XP, StarFix XP,

References

- [RD-1] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 1: Fundamentals and Algorithms. ESA TM-23/1. ESA Communications, 2013.
- [RD-2] J. Sanz Subirana, J.M. Juan Zornoza, M. Hernández-Pajares, GNSS Data processing. Volume 2: Laboratory Exercises. ESA TM-23/2. ESA Communications, 2013.
- [RD-3] Pratap Misra, Per Enge. Global Positioning System. Signals, Measurements, and Performance. Ganga –Jamuna Press, 2004.
- [RD-4] B. Hofmann-Wellenhof et al. GPS, Theory and Practice. Springer-Verlag. Wien, New York, 1994.

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The **Learning material** is composed by a collection of slides for **Theory & Laboratory** exercises.

A book on GNSS Data Processing is given as complementary material.



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- ▷ Useful GNSS links
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- MasterMast
- gAGE upload file facility

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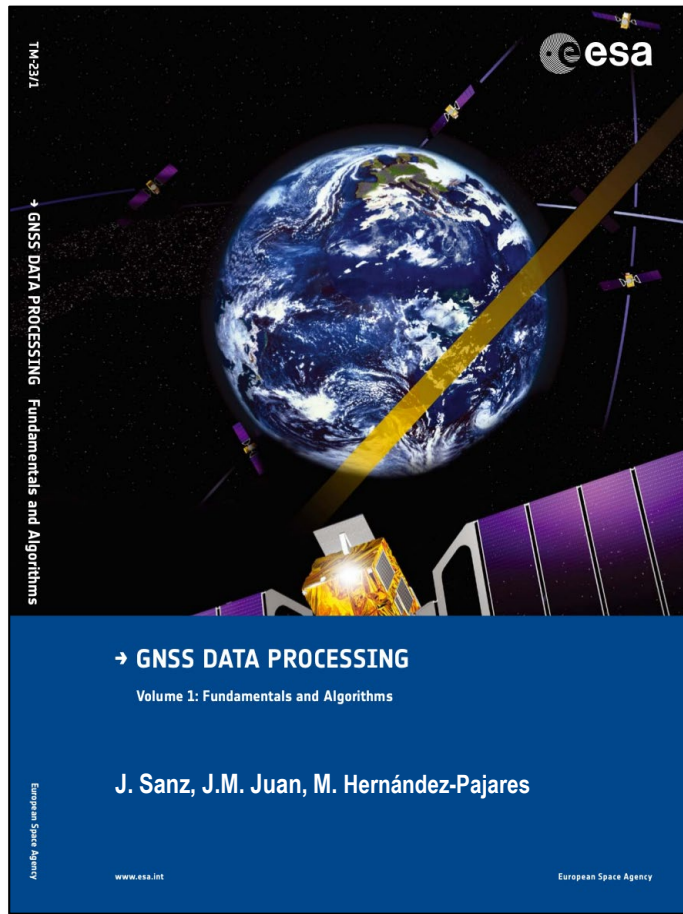
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