POLITECNICO DI TORINO
DET - DIATI

LAB 1
Planning of GNSS Survey

MARCO PIRAS

All preliminary operations:

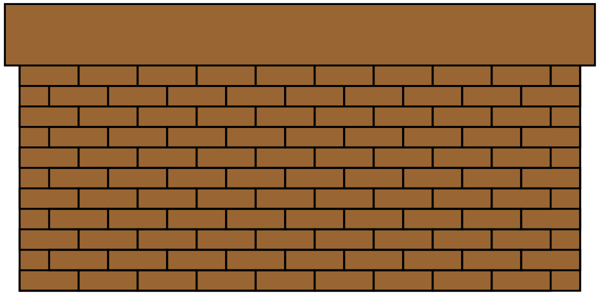
- on-the-field investigation
- materialization of points
- selection of appropriate instruments
- analysis of satellite configuration
- observation window
- measurement sessions
- number and type of baselines (if necessary)

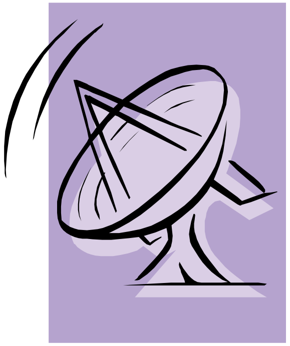
On-the-field investigation

Points suitable for our purpose

→ Purpose of our work

- intervisibility of points
- no obstacles
- no electromagnetic interference
- stable structures



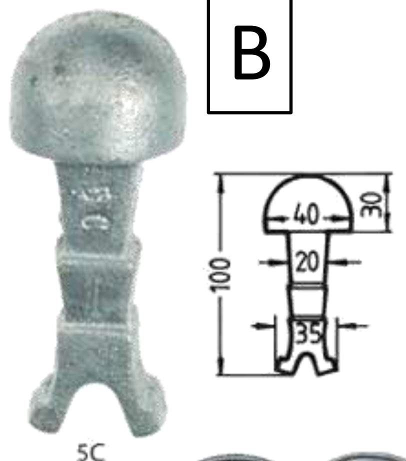


Materialization of points

Selection of the correct support for the materialization

→ applications

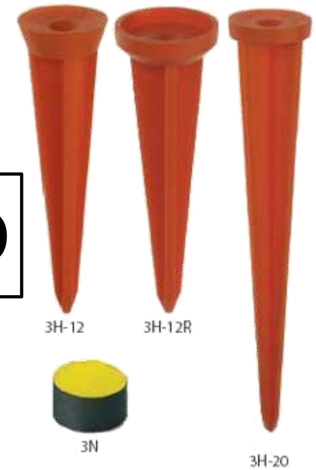
A



B

C

D



E

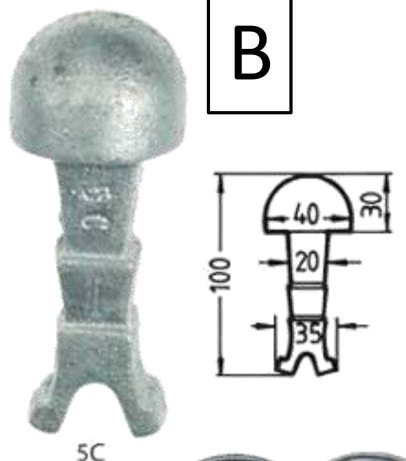
SURVEY:

Which materialization is used for very high precision measurements?

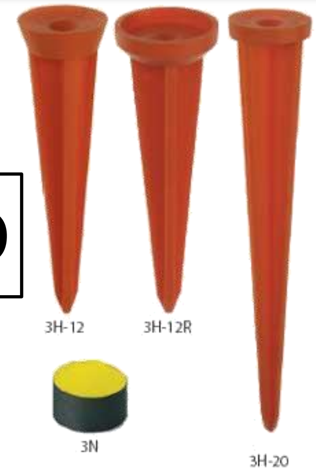
Selection

→ applications

A



B



D

C

E

An example: RDN

Rete dinamica nazionale IGM

(National Dynamic network)

- defines the R.F. ETRF2000 in a ‘dynamic’ way (in sense of continuous acquisition and recalculation)
- the Geoid is WGS84
- 99 CORS in Italy
- starting from:

    1 January 2009

from: http://www.igmi.org/

Materialization of points

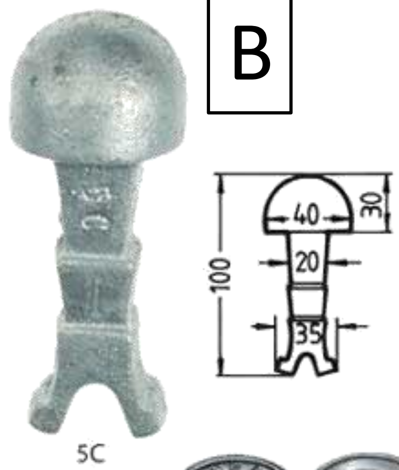
SURVEY:

Which is better to use for leveling operations?

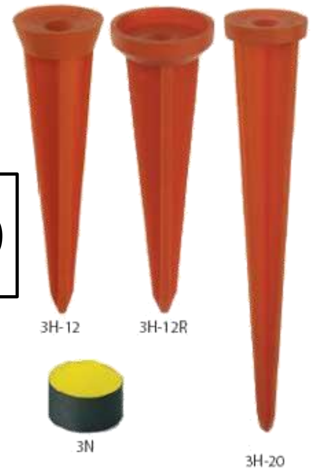
Selectio

→ applications

A



B



D

C

E

Materialization of points

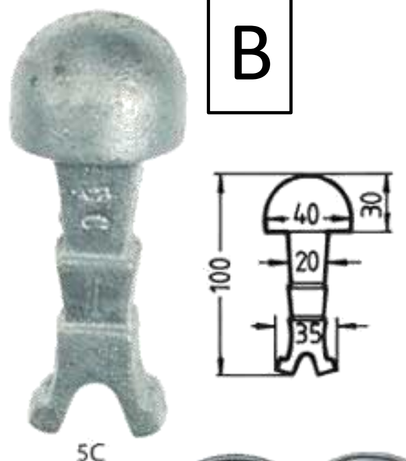
SURVEY:

Which is better to use for temporary networks?

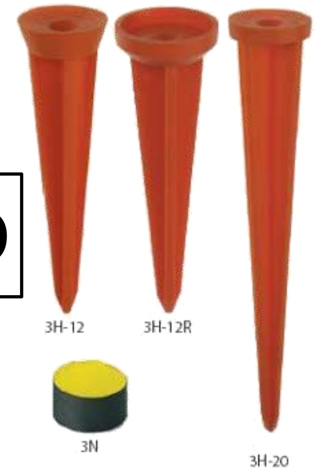
Selectio[n]

→ applications

A



B



D

C

E

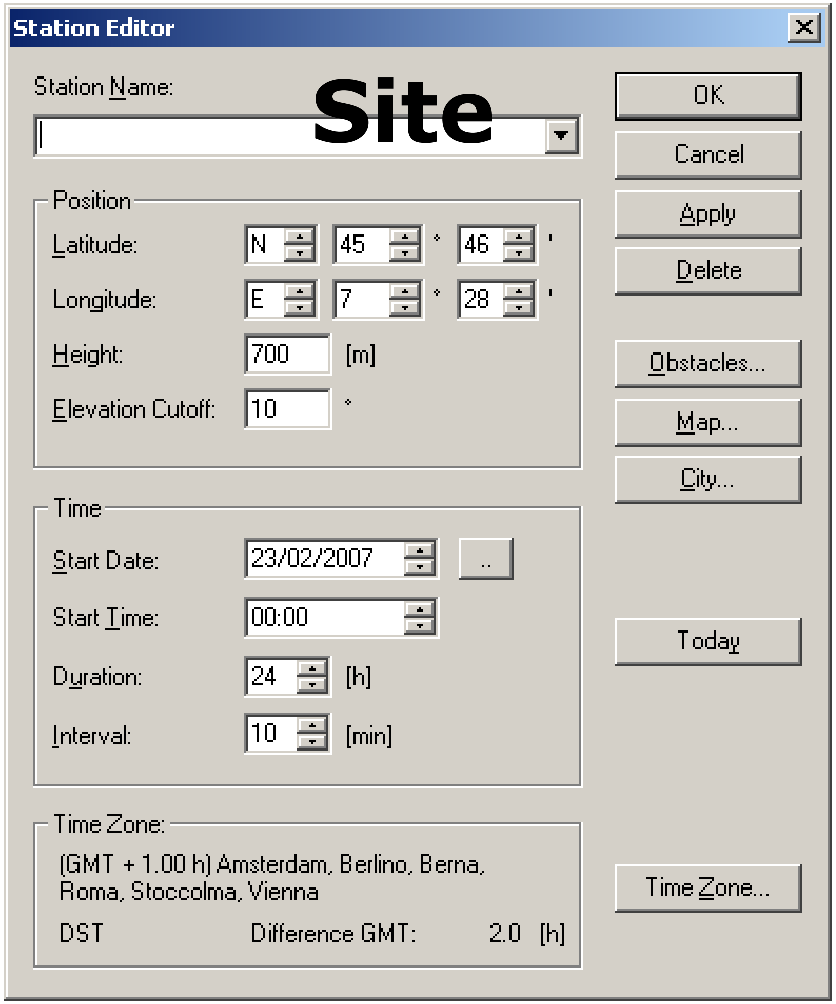
Planning

- no obstacles
- no reflective surfaces
  - multipath
- presence of electromagnetic fields
- number of satellites
- Elevation mask (cut off)
- session length
- sampling time (1”, 30” …)

Planning

Navigation files

- -YUMA
- -SSF
- -ALM
- -Eph
- -Rinex *.yyn



websites to download almanacs

TRIMBLE:

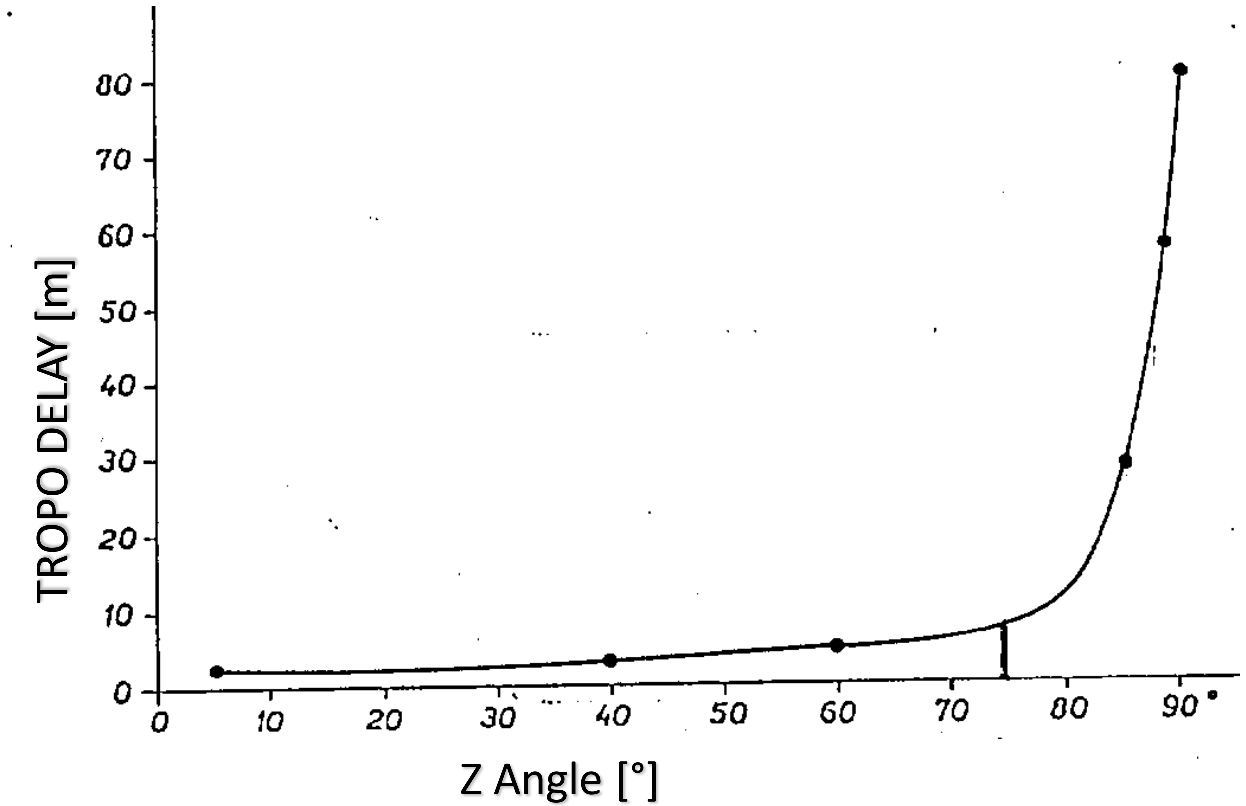
ftp://ftp.trimble.com/pub/eph/almanac.alm

IGS:

ftp://igs.ensg.ign.fr/pub/igs/products/

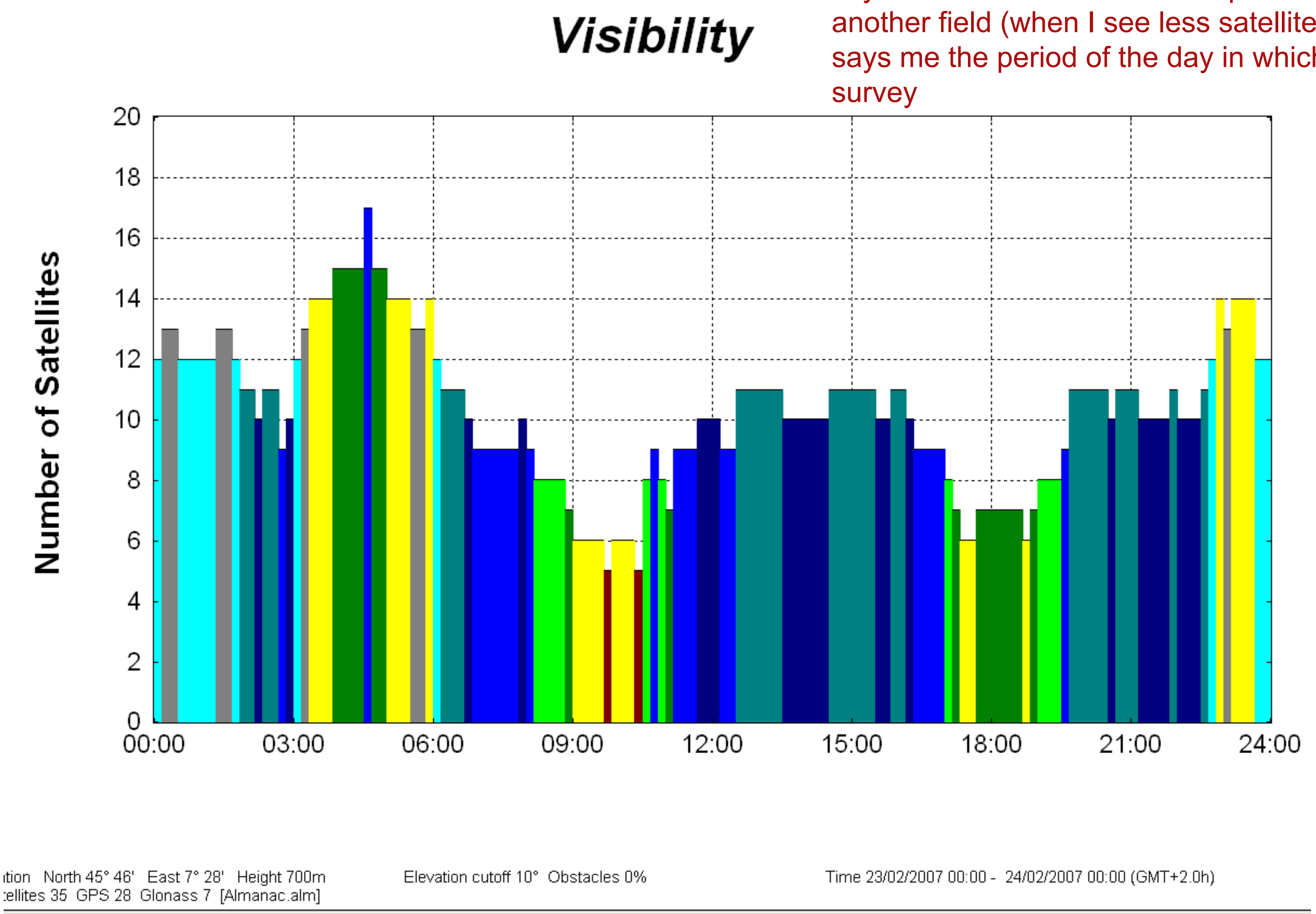
Parameters to consider for having a good survey

ELEVATION MASK (or CUT OFF ANGLE)

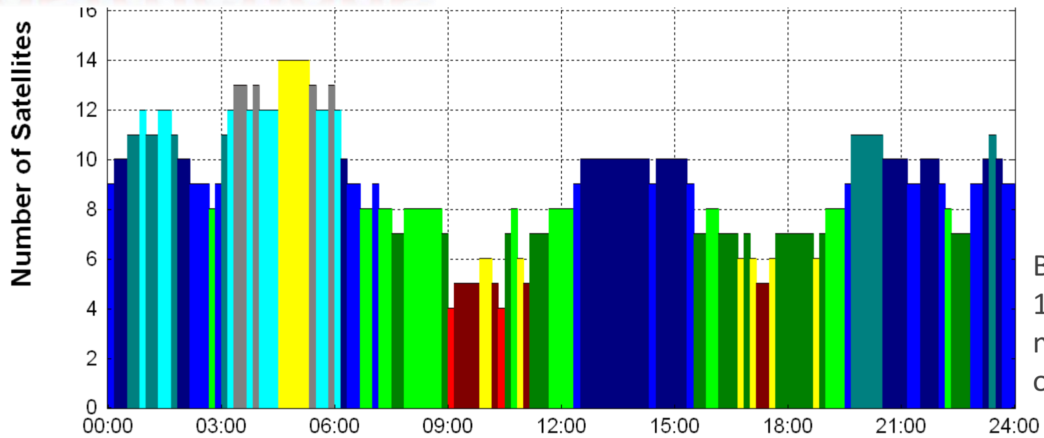


PLANNING GNSS– Visibility plot

this visibility are estimated by navigation files. It says me when to move from a point of survey to another field (when I see less satellites) and it says me the period of the day in which do the survey

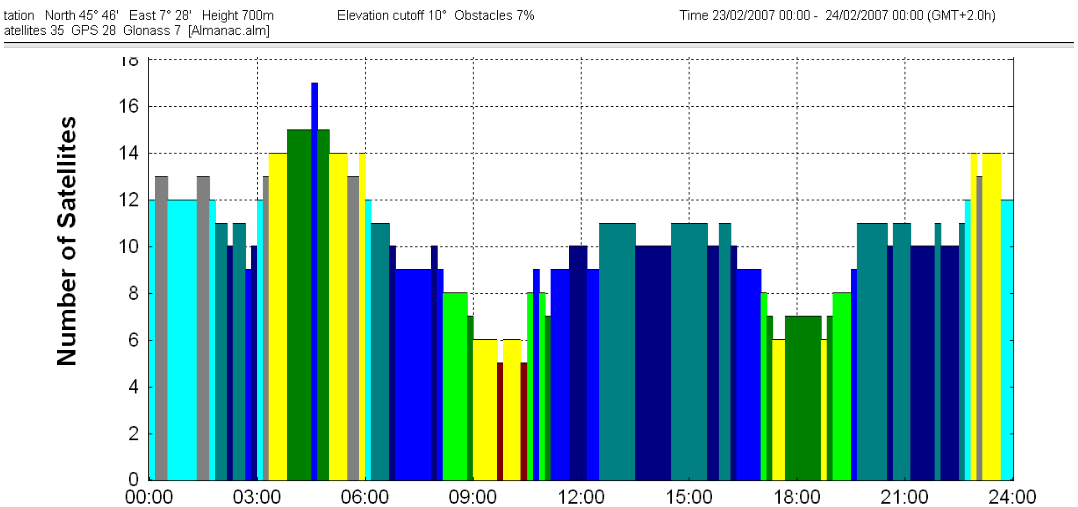


PLANNING GNSS – Visibility with obstructions



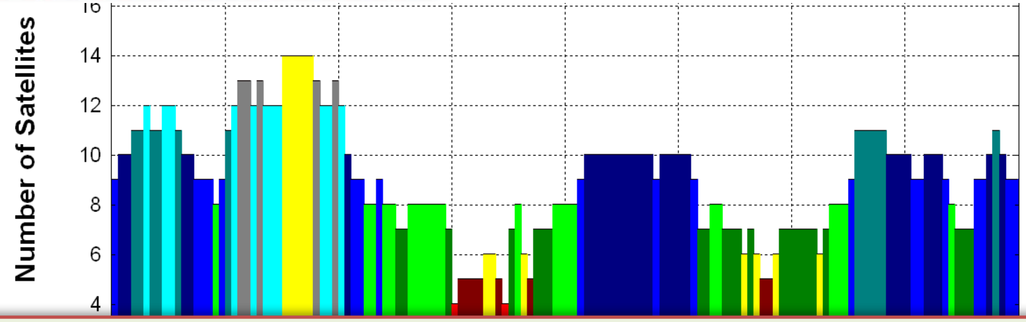
Obstruction

Better having obstacles 100 m high and 100 meters away each other than 6 meters hight and 6 meters away each other



NO obstruction

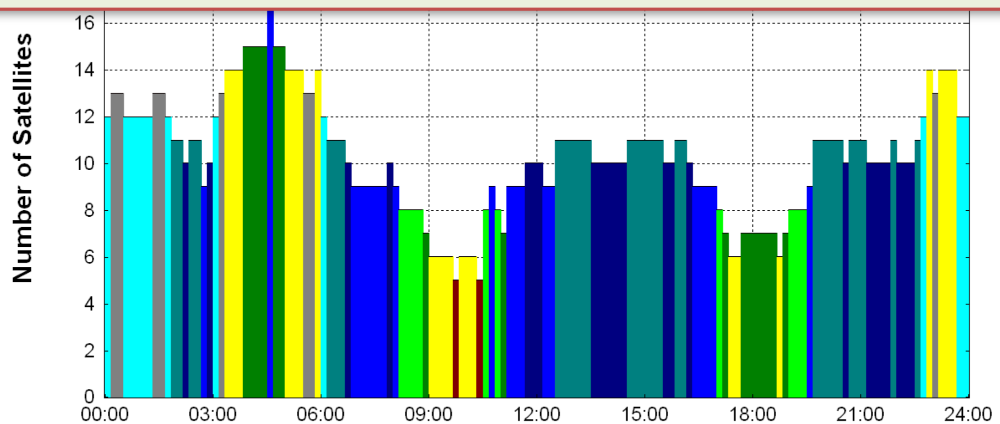
PLANNING GNSS – Visibility with obstructions



Obstruction

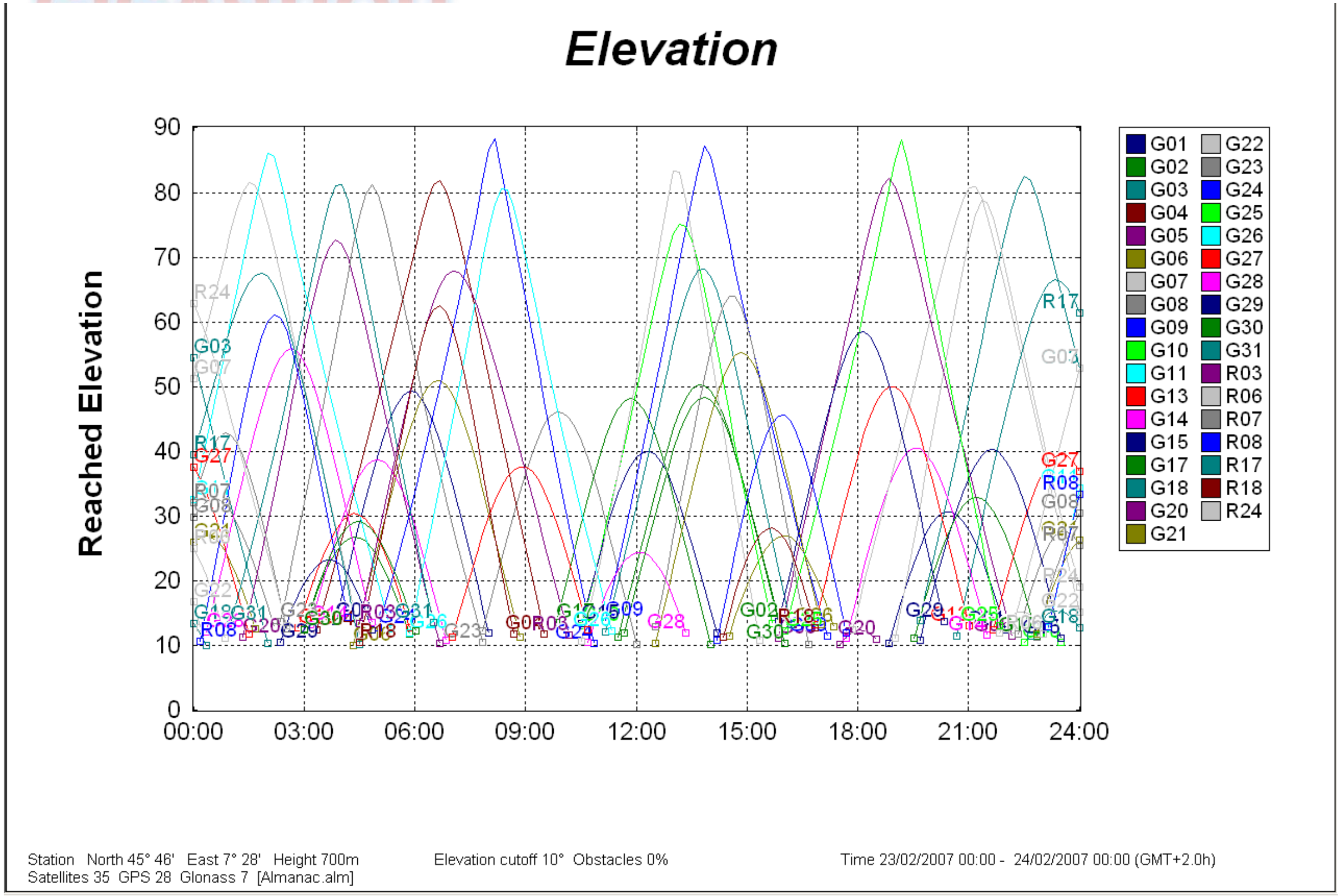
SURVEY:

Is it better to have a 100 m high obstacle 100 m away or a 6 m obstacle 5 m away??

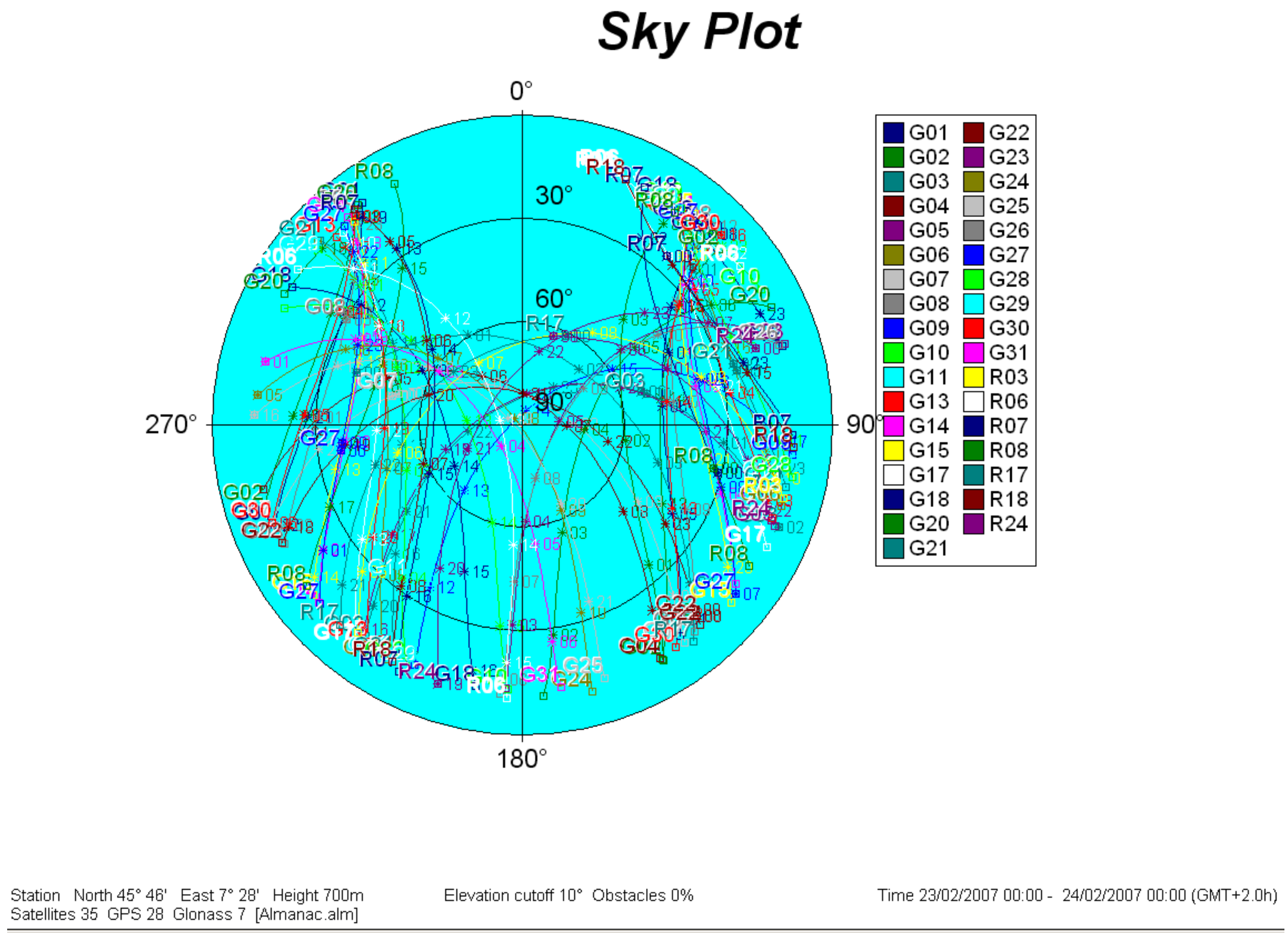


NO obstruction

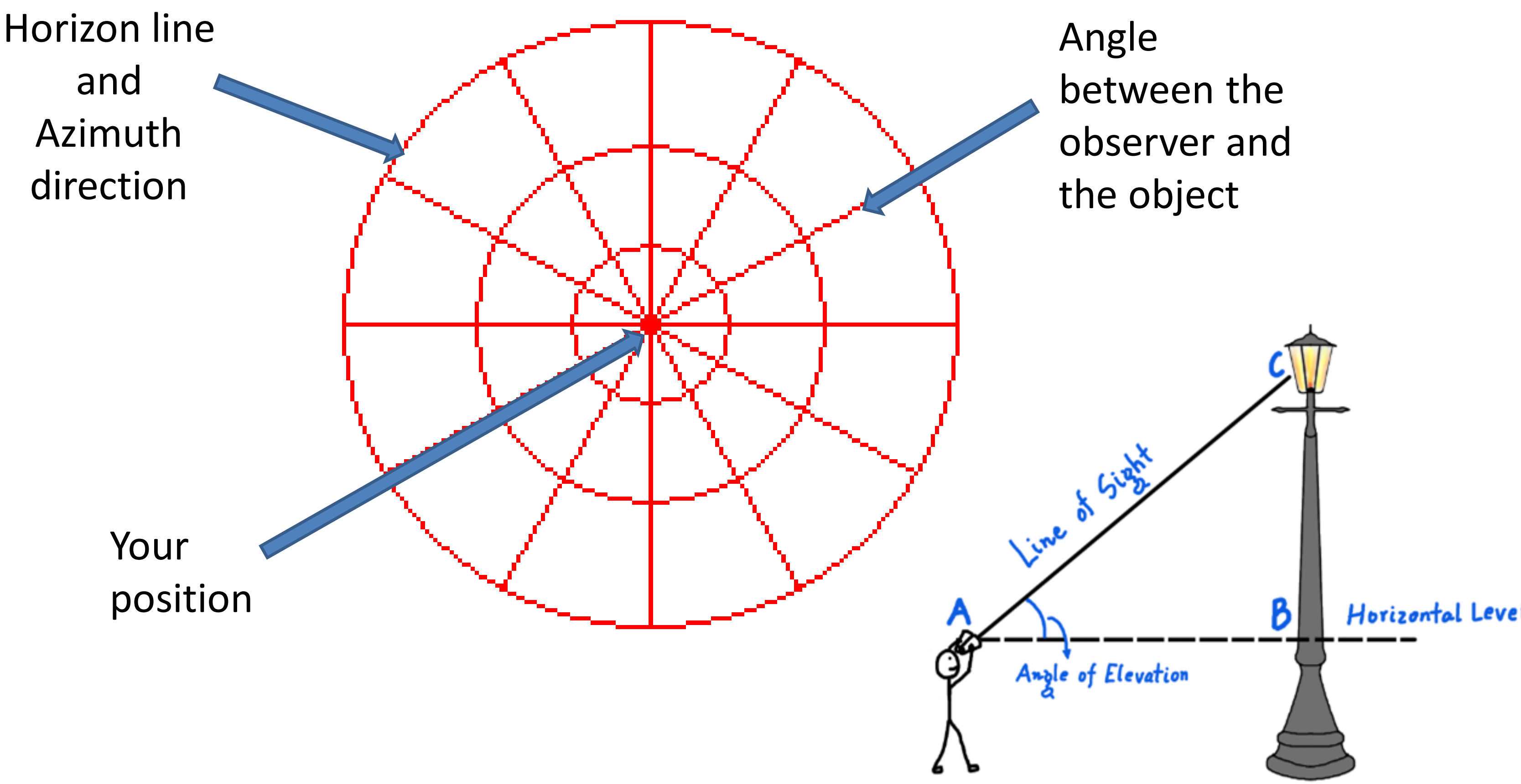
PLANNING GNSS – Satellites elevation



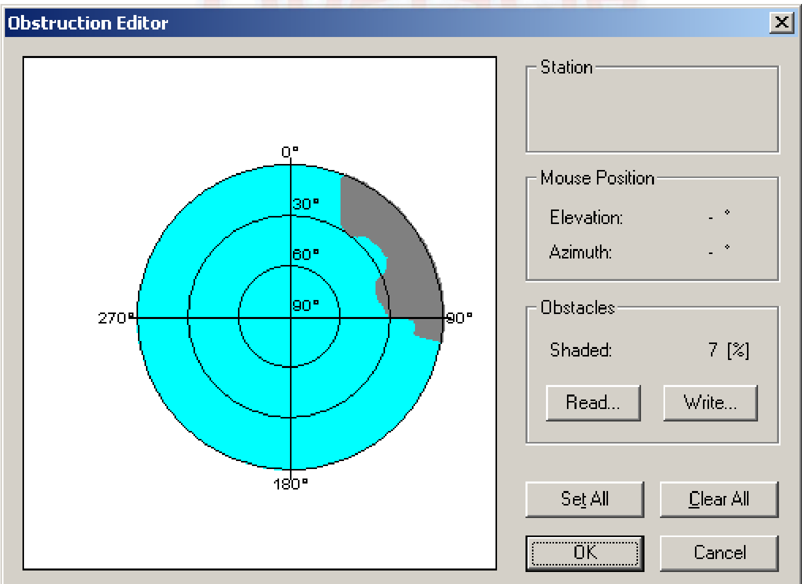
PLANNING GNSS – Skyplot

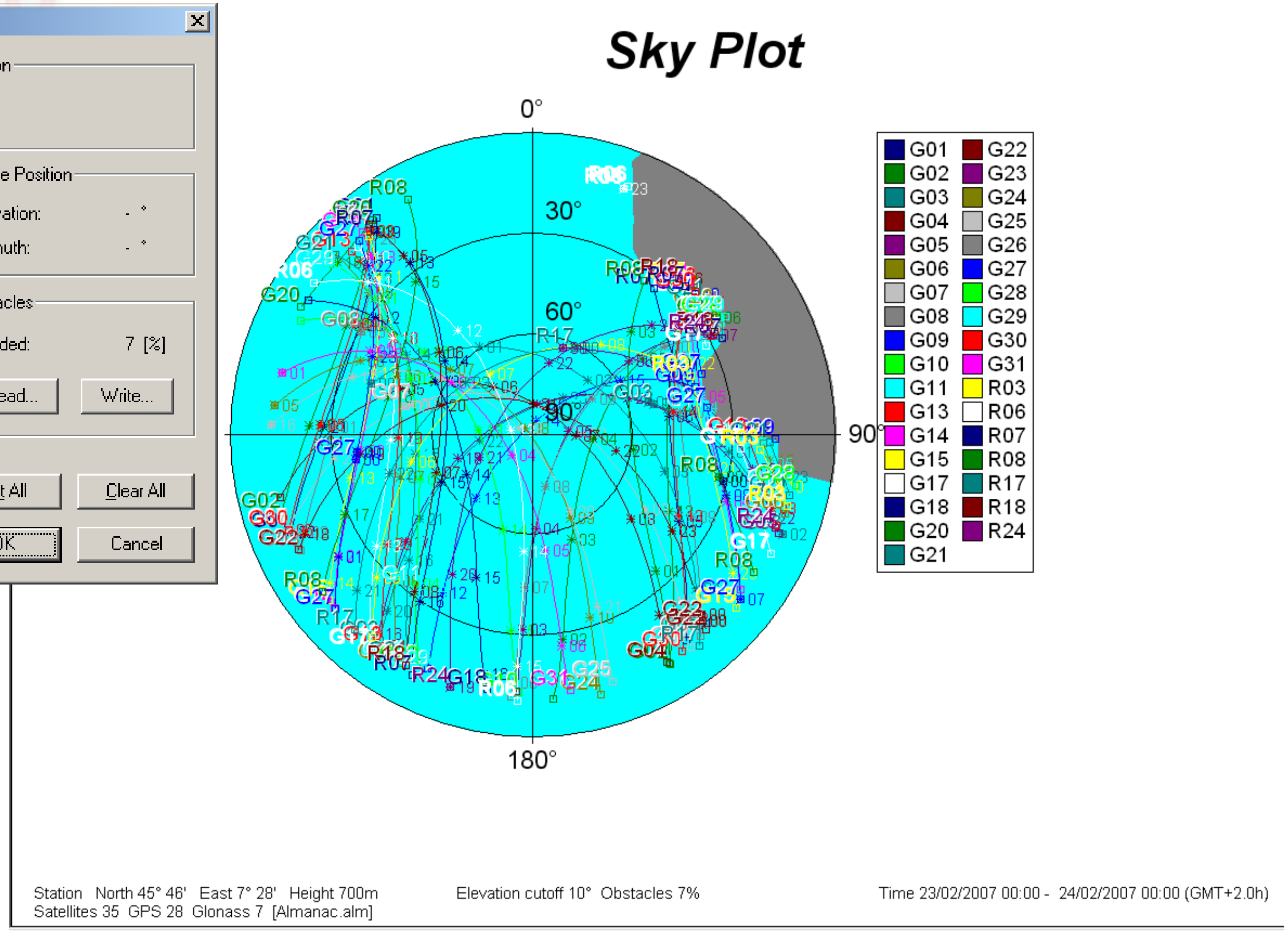


How to read the stereoplot



PLANNING GNSS – Sky plot - Obstacle





DOP - Dilution of precision

$$GDOP = \sqrt{\sigma_T^2 + \sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}$$

$$PDOP = \sqrt{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}$$

$$HDOP = \sqrt{\sigma_X^2 + \sigma_Y^2}$$

$$VDOP = \sqrt{\sigma_Z^2}$$

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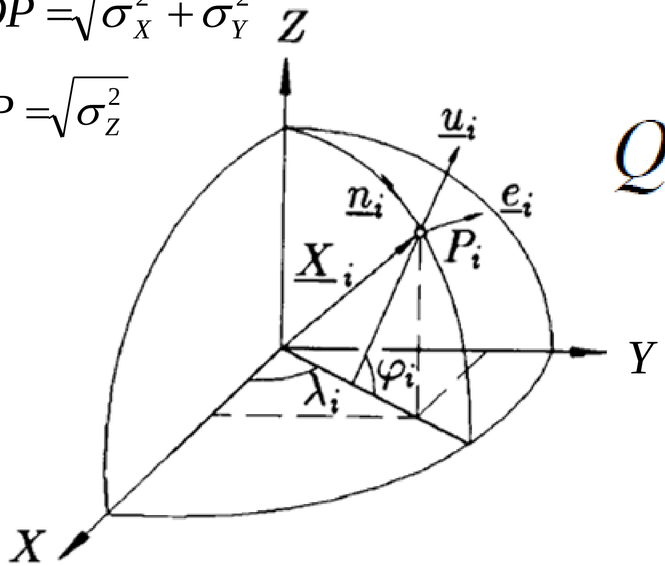


Co-factor matrix of site coordinates in a local system

$$Q_{UU} = \begin{bmatrix} \sigma_e^2 & \sigma_{en}^2 & \sigma_{eu}^2 & \sigma_{et}^2 \\ \sigma_{en}^2 & \sigma_n^2 & \sigma_{nu}^2 & \sigma_{nt}^2 \\ \sigma_{eu}^2 & \sigma_{nu}^2 & \sigma_u^2 & \sigma_{ut}^2 \\ \sigma_{et}^2 & \sigma_{nt}^2 & \sigma_{ut}^2 & \sigma_t^2 \end{bmatrix}$$

DOP - Dilution of precision

$$GDOP = \sqrt{\sigma_T^2 + \sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}$$

$$PDOP = \sqrt{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}$$

$$HDOP = \sqrt{\sigma_X^2 + \sigma_Y^2}$$

$$VDOP = \sqrt{\sigma_Z^2}$$

The DOP can be estimated during the planning phase, as the co-factor matrix can be obtained a priori.

$$Qxx = (D^T D)^{-1}$$

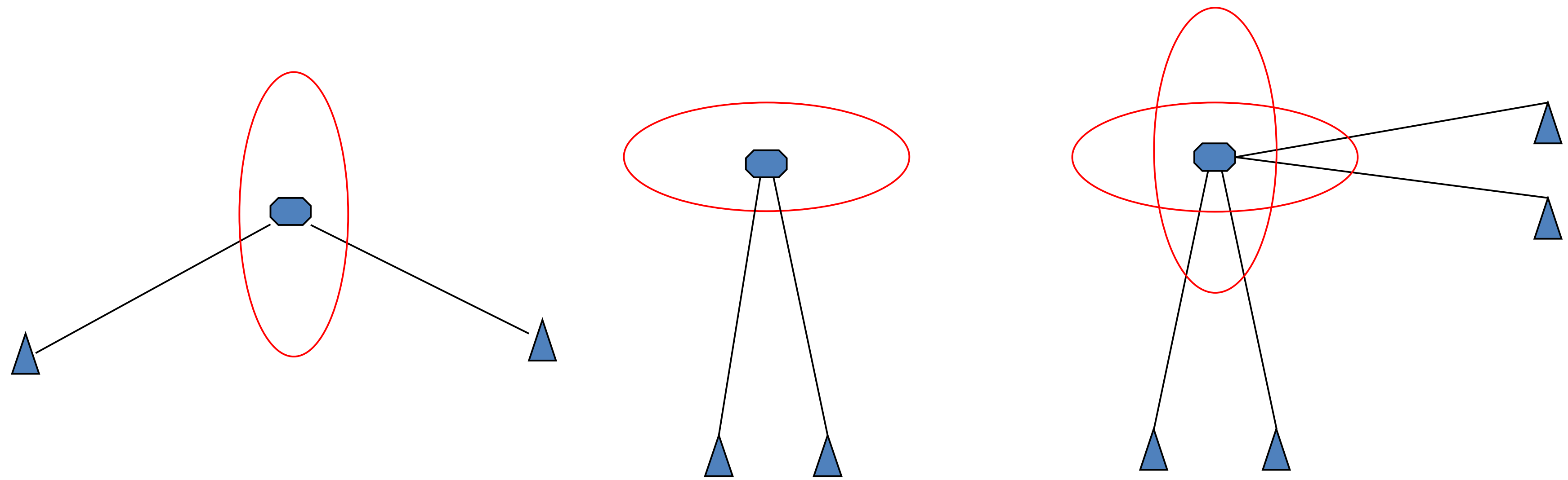
$$Q_{UU} = R Q_{XX} R^T$$

$$D = \begin{bmatrix} \frac{X_i^{(0)} - X^{(1)}}{\rho_i^{1(0)}} & \frac{Y_i^{(0)} - Y^{(1)}}{\rho_i^{1(0)}} & \frac{Z_i^{(0)} - Z^{(1)}}{\rho_i^{1(0)}} & -1 \\ \frac{X_i^{(0)} - X^{(2)}}{\rho_i^{2(0)}} & \frac{Y_i^{(0)} - Y^{(2)}}{\rho_i^{2(0)}} & \frac{Z_i^{(0)} - Z^{(2)}}{\rho_i^{2(0)}} & -1 \\ \frac{X_i^{(0)} - X^{(3)}}{\rho_i^{3(0)}} & \frac{Y_i^{(0)} - Y^{(3)}}{\rho_i^{3(0)}} & \frac{Z_i^{(0)} - Z^{(3)}}{\rho_i^{3(0)}} & -1 \\ \cdots & \cdots & \cdots & \cdots \\ \frac{X_i^{(0)} - X^{(8)}}{\rho_i^{8(0)}} & \frac{Y_i^{(0)} - Y^{(8)}}{\rho_i^{8(0)}} & \frac{Z_i^{(0)} - Z^{(8)}}{\rho_i^{8(0)}} & -1 \end{bmatrix} =$$

DOP - Dilution of precision

Depending on the different locations of the satellites in space, we have a different form of the error ellipse

(This ellipse is interpreted analytically from the covariance matrix, in particular by the N^{-1} matrix).

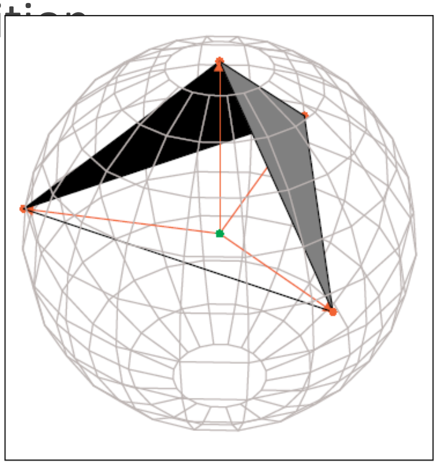


But what is the meaning of DOP?

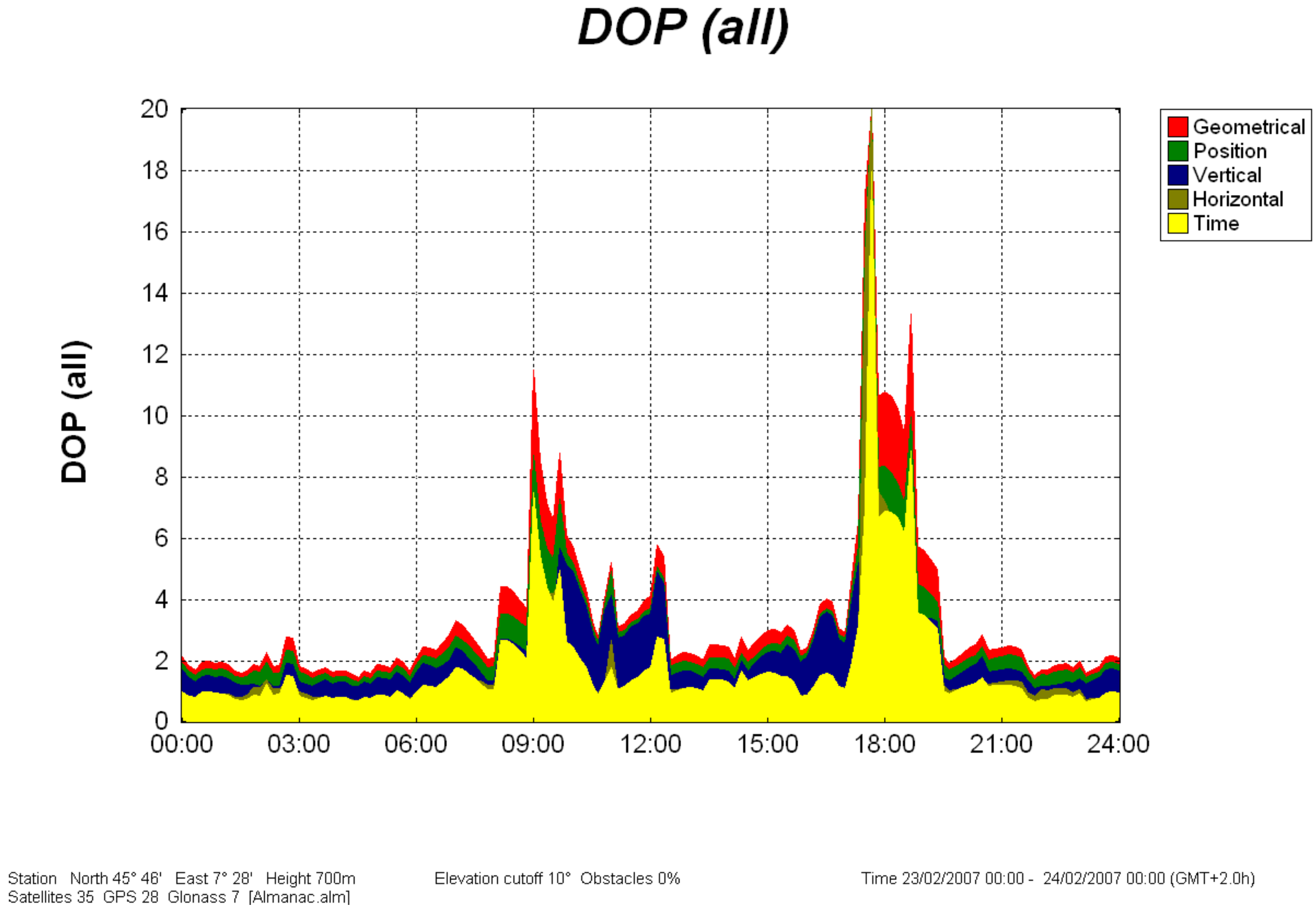
Considering to have 4 satellites and connect them with the station point. We've a tetrahedron.

The volume of this tetrahedron is strongly correlated with the value of GDOP, in particular by **increasing the volume decreases the DOP**.

This means that it is not enough to have a large number of satellites to ensure a good DOP, but also a good satellites disposition.



DOP - Dilution of precision



Parameters to consider in evaluating the "goodness " of the survey

PDOP → assessments on the geometric configuration

N° of satellites → duration of the survey

S/N → quality of the signal

PDOP and the n° of satellites can be known a priori by good planning and knowledge of any obstructions on the site!!!

→ An example: TRIMBLE Planning on line

→ https://www.gnssplanning.com/#/settings

→ http://gnssmissionplanning.com/

See TUTORIAL PLANNING.pdf

Ex.1 – Planning

a) **Realize a planning in four different cities:**
   - List of cities (Student's home town)

b) **Realize the analysis: GPS only, GPS+GLONASS, GNSS (full constellation)**

c) **Using the second tool, include some obstacles and make a new analysis.**
   solo per un sito e non per tutti

GOAL: prepare a report discussing the results

Ex.2 – Calculate elevation and azimuth

Input data

X_{sat} = 15487292,829 m
Y_{sat} = 6543538,932 m
Z_{sat} = 20727274,429 m

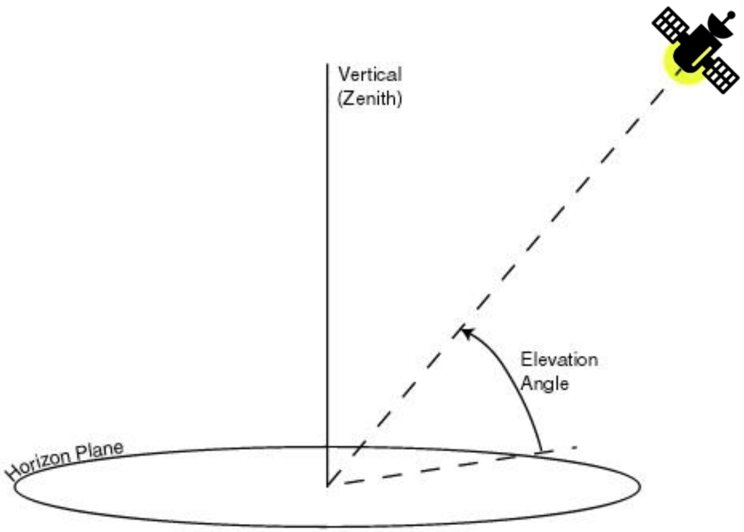
Latitude (station) = 45° 3’ 48.114’’
Longitude (station) = 7°39’ 40.605’’

Goal

To define X_i, Y_i, Z_i station

To estimate AZ, EL of the SATELLITE

Ex.2 – Calculate elevation and azimuth



$$\begin{pmatrix} e \\ n \\ u \end{pmatrix} = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\varphi \end{bmatrix} \begin{pmatrix} X - X_i \\ Y - Y_i \\ Z - Z_i \end{pmatrix}$$

Where
e,n,u = local coordinates
φ,λ = station coordinates (geographic)
X,Y,Z = satellites position (ECEF)
X_i, Y_i, Z_i, = station position (ECEF)

$$azimuth = atn\frac{u}{\sqrt{n^2 + e^2}}$$

$$elev = atn\frac{e}{n}$$

Ex.2 – elevation and azimuth - Appendix

$$\begin{cases} X_i = \dfrac{a \cdot \cos\varphi \cdot \cos\lambda}{W} \\ Y_i = \dfrac{a \cdot \cos\varphi \cdot \sin\lambda}{W} \\ Z_i = \dfrac{a \cdot (1-e^2) \cdot \sin\varphi}{W} \end{cases}$$

trasformare phi e lambda in radianti

lambda : longitudine
phi: latitude

$$where \quad W = \sqrt{1-e^2 \cdot \sin^2\varphi}$$

WGS84

Parameter	Notation	Value
semi-major axis	a	6378137.0 m
flattening	f	1 / 298.257223

$e^2 = 1 - b^2/a^2 = 2f - f^2$

Ex.2 – Calculate elevation and azimuth

a) **Convert latitude and longitude of the station from degrees to radians;**

b) **Calculate e^2 and W;**

c) **Calculate X_i, Y_i, Z_i;**

d) **Calculate local coordinates e, n, u;** position of satellites in some places

e) **Estimate Azimuth and Elevation**

Soluzione nel video

Ex.3 – DOP estimation

$$
Quu = \begin{pmatrix} XDOP^2 & & & \\ & YDOP^2 & & \\ & & VDOP^2 & \\ & & & TDOP^2 \end{pmatrix}
$$

Goal

$$
\begin{cases}
HDOP = \sqrt{XDOP^2 + YDOP^2} \\
PDOP = \sqrt{XDOP^2 + YDOP^2 + VDOP^2} \\
GDOP = \sqrt{XDOP^2 + YDOP^2 + VDOP^2 + TDOP^2}
\end{cases}
$$

Ex.3 – DOP estimation

$$\rho_i^j(t) = \sqrt{(X^j(t) - X_I)^2 + (Y^j(t) - Y_I)^2 + (Z^j(t) - Z_I)^2}$$

$$D1 = \frac{Xsat - Xrec}{\rho} \qquad D2 = \frac{Ysat - Yrec}{\rho} \qquad D3 = \frac{Zsat - Zrec}{\rho} \qquad D4 = -1$$

$$D = \begin{bmatrix} D1s1 & D2s1 & D3s1 & -1 \\ D1s2 & D2s2 & D3s2 & -1 \\ \ldots & \ldots & \ldots & \ldots \\ D1sn & D2sn & D3sn & -1 \end{bmatrix} \qquad Qxx = (D^T D)^{-1}$$

Geographic coordinates of the station
(expressed in radians)

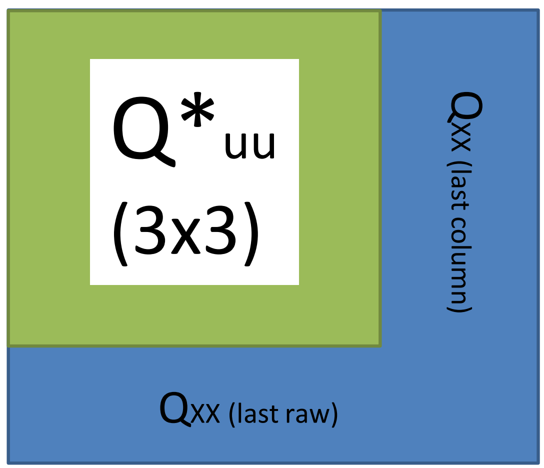
$$R = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\varphi \end{bmatrix}$$

Ex.3 – DOP estimation

$$Q_{XX}^{*} = Qxx(1:3;1:3)$$

$$Q_{UU}^{*} = RQ_{XX}^{*}R^{T}$$

$Quu =$



From the matrix Qxx, a sub-matrix 3x3 is extracted, considering only the first 3 columns and 3 raws.

$$\text{Quu} = \begin{pmatrix} \boxed{\begin{matrix} XDOP^2 & & \\ & YDOP^2 & \\ & & VDOP^2 \end{matrix}} & \\ & TDOP^2 \end{pmatrix}$$

Q_{XX}^{*}

Input data:

Coordinates of the receiver

$$\varphi = 45°3'48'', \ \lambda = 7°39'41'', h=0m$$

Satellite's coordinates (file: pos_sat.txt)

sat	X [m]	Y [m]	Z [m]
1	22504974,806	13900127,123	-2557240,727
2	-3760396,280	-17947593,853	19494169,070
4	9355256,428	-12616043,006	21189549,365
7	23959436,524	5078878,903	-10562274,680
10	10228692,060	-19322124,315	14550804,347
13	23867142,480	-3892848,382	10941892,224
17	21493427,163	-15051899,636	3348924,156
20	14198354,868	13792955,212	17579451,054
23	18493109,722	4172695,812	18776775,463
31	-8106932,299	12484531,565	22195338,169
32	8363810,808	21755378,568	13378858,106

Ex.3 – DOP estimation

a) Calculate the coordinates X_i, Y_i, Z_i of the receiver;

```
wgs84 = wgs84Ellipsoid('meter');
[x,y,z] = geodetic2ecef(wgs84,fi,lam,h) %mapping toolbox
```

trasformare in x,y,z

b) Calculate ρ and the D matrix;

c) Calculate R and Q_{xx} matrix;

d) <u>Calculate Q_{uu} matrix and estimate the GDOP, PDOP and HDOP</u>