INTRODUCTION TO GNSS

Tailor-made qualification exam

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2024-08-15

NOR Lab

UNIVERSITÉ LAVAL

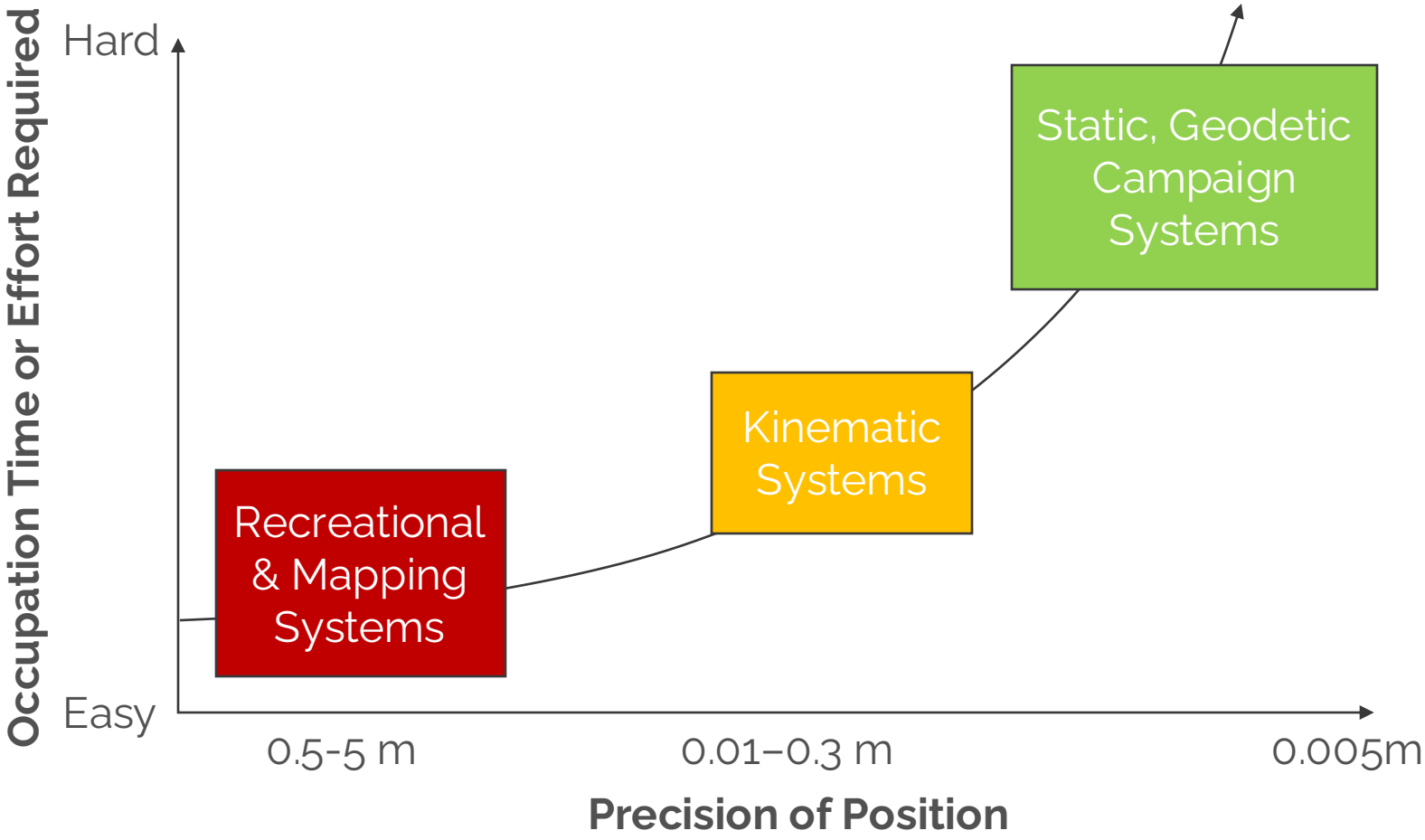
Grades of GNSS systems

- Consumer or **Recreational** Grade
  ~5 meters, No post-processing required

- **Mapping** Grade
  ~30 cm, Post-processing/correction required

- **Survey** Grade
  ~3 mm to 2 cm precision. Considerable post-processing required
  Professional tools, Longer occupations, Static and kinematic devices

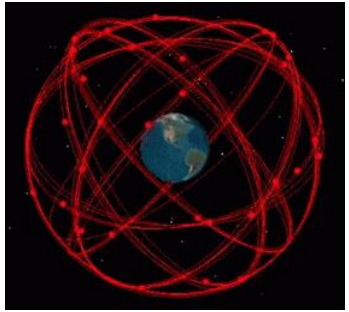
Time and effort



I. Positioning methods & computation

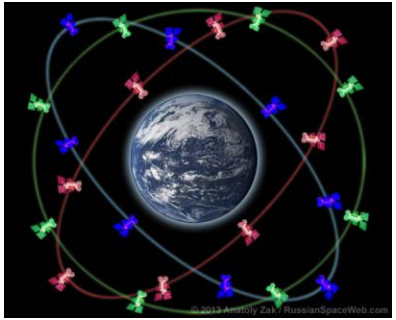
5 GNSS constellations

GPS



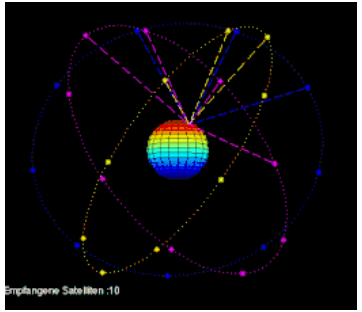
6 orbital planes
24 satellites
55˚ inclination
20 200 km altitude

GLONASS



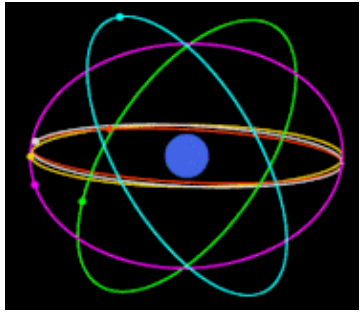
3 orbital planes
21 satellites + 3 spares
64.8˚ inclination
19 100 km altitude

Galiléo



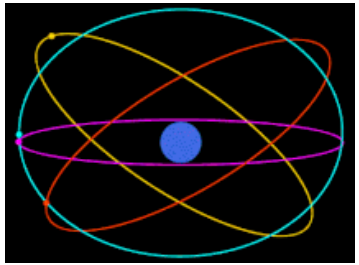
3 orbital planes
27 satellites + 3 spares
56˚ inclination
23 616 km altitude

Beidou



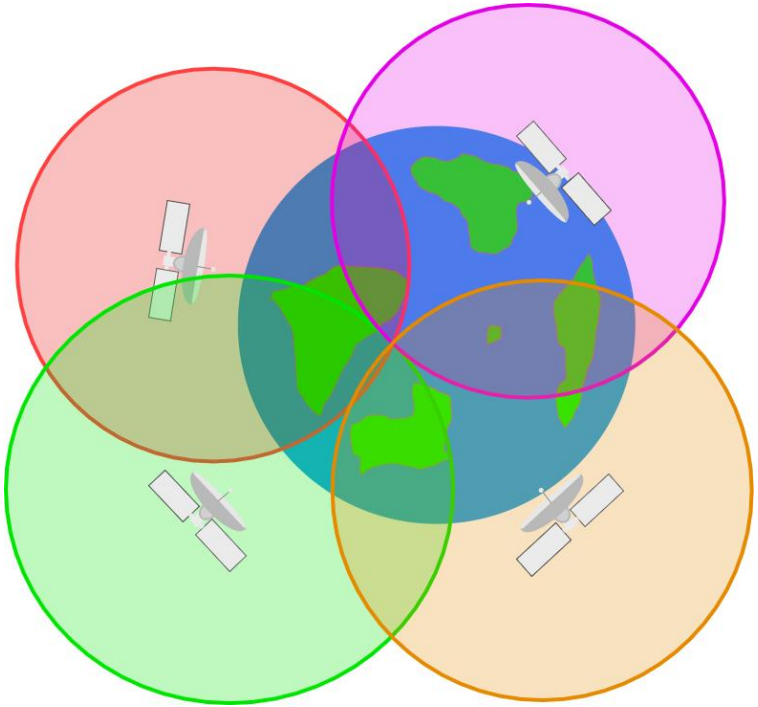
6 orbital planes
35 satellites
55˚ inclination
21 500 - 38 300 km
altitude

QZSS



4 orbital planes
4 satellites
43˚ inclination
32 000 - 40 000 km
altitude

Position computation



- ✓ Receiver's coordinates (Xr, Yr, Zr)
- ✓ Receiver's clock offset (dtr)

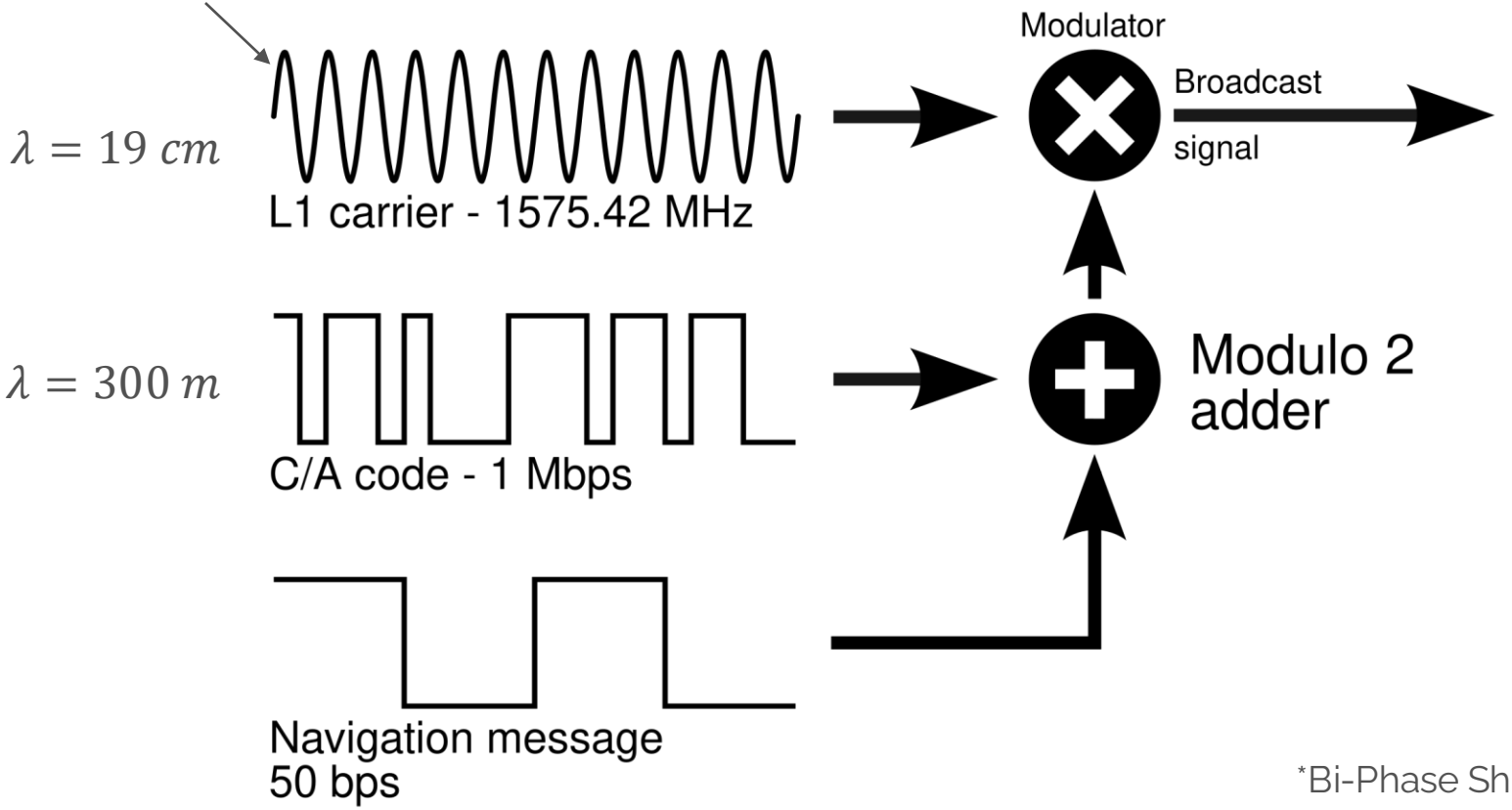
=> 4 unknowns

Antenna position is determined by calculating the distances to at least 4 satellites. This enables the solving for four variables: *x*, *y*, *z* and time using **trilateration**.

Satellite broadcast signal

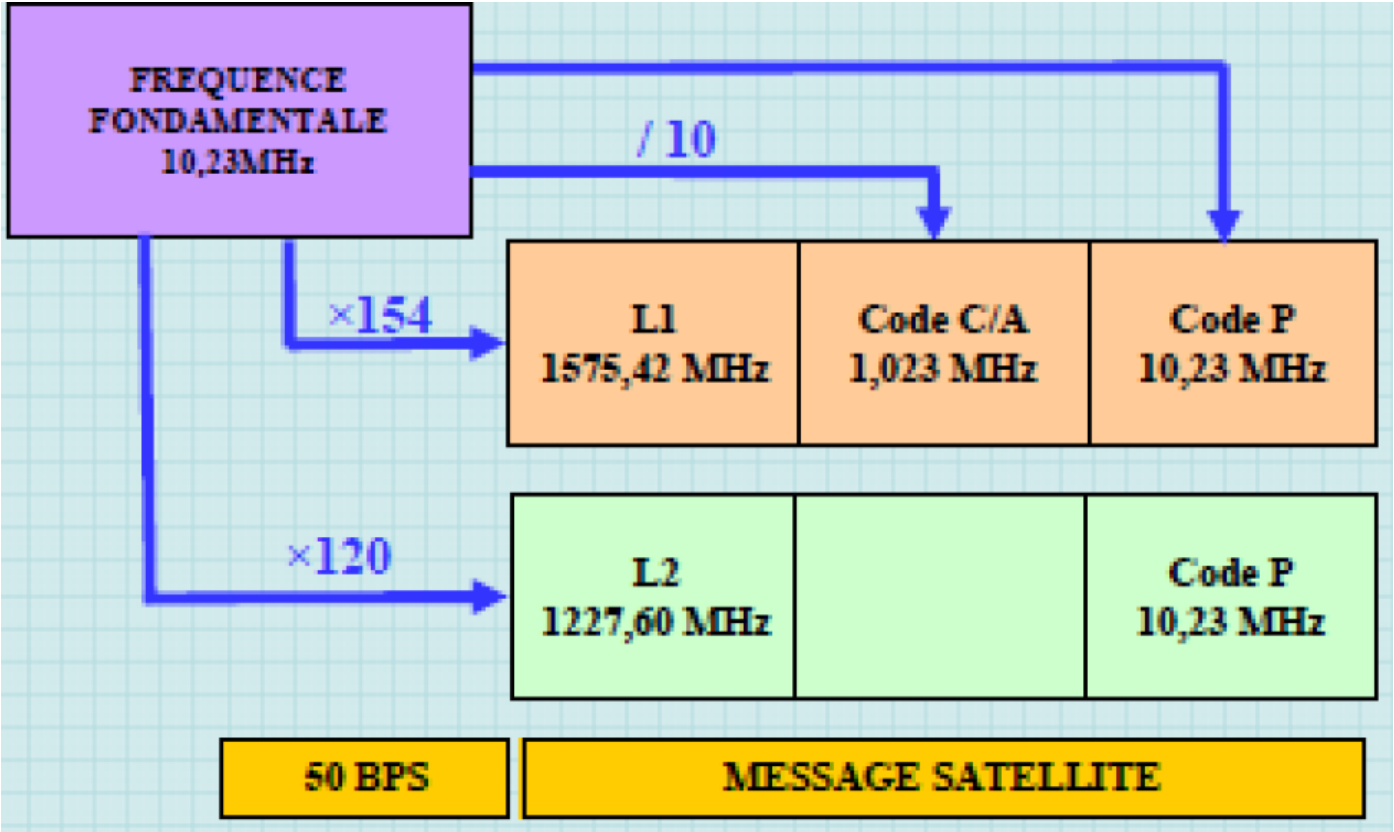
Different frequencies
for each constellation

Message **encoded in carrier** with BPSK* modulation



*Bi-Phase Shift Keying

Frequencies



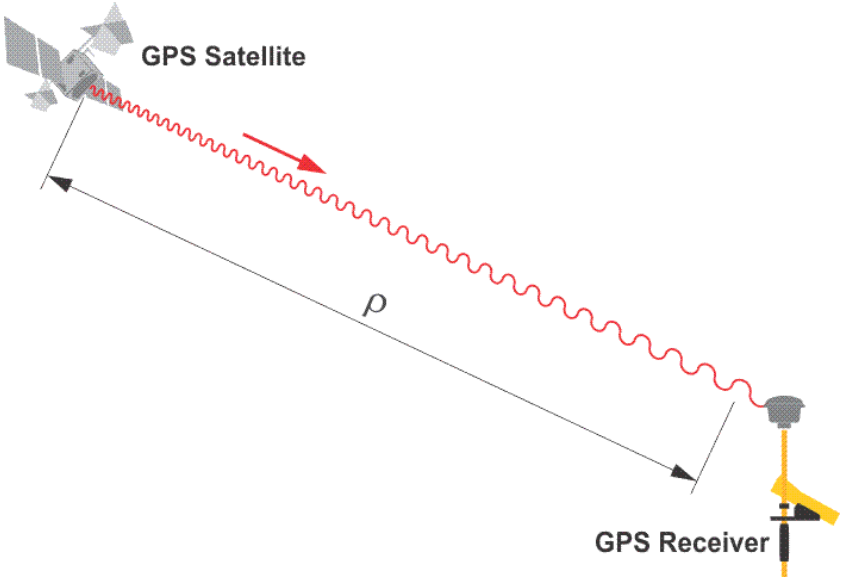
Message Content

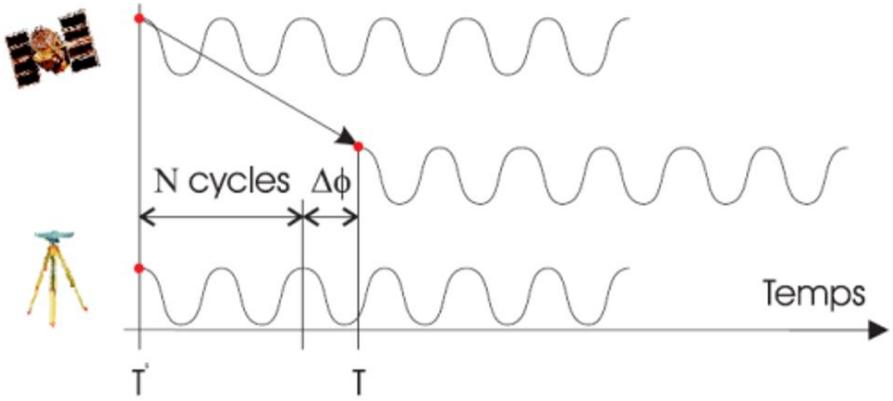
Navigation message:

- ✓ **Ephemeris** data: precise orbital and clock correction of where each satellite should be at specific time.
- ✓ **Almanac** data: general orbital data of all the satellites & clock parameters.
- ✓ **Atmospheric** and propagation **models**: correct signal's time propagation

Observation message: carrier phase and code measurement, clock

Code vs carrier phase measurements



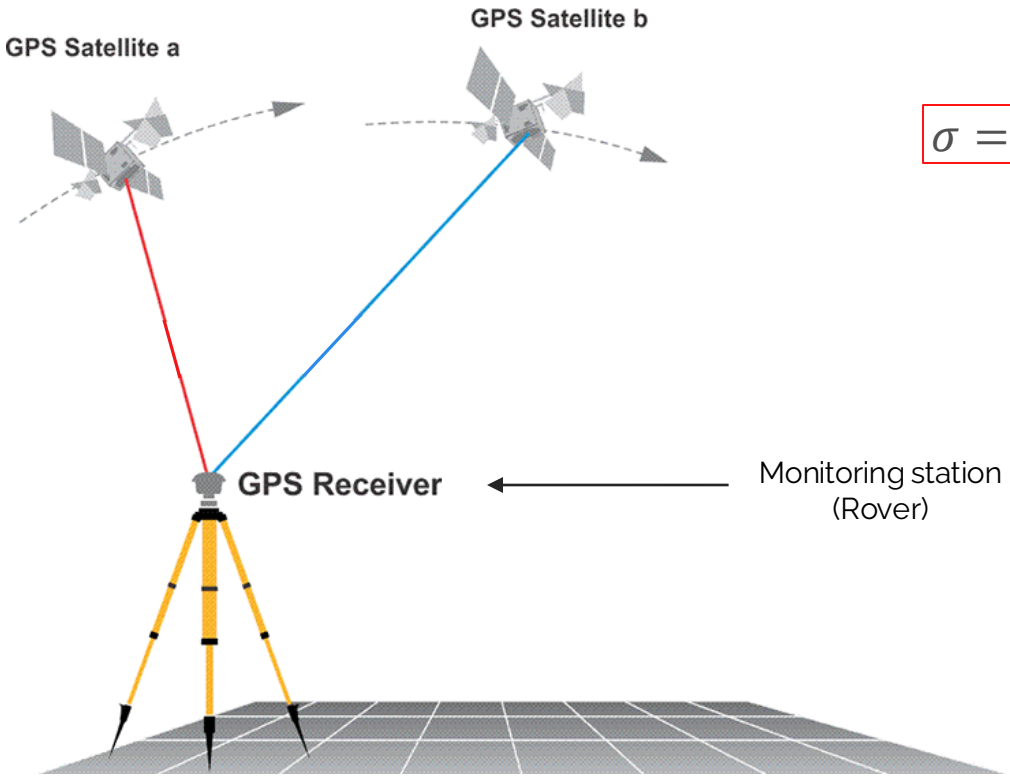


Pseudo-range (code): distance between receiver and satellite based on time of flight measurement.

Carrier phase: phase modulo the wavelenth of the carrier. Ambiguity: how many complete cycle have occured ?

a. Real time positioning methods

Positioning method: Absolute positioning (standalone)

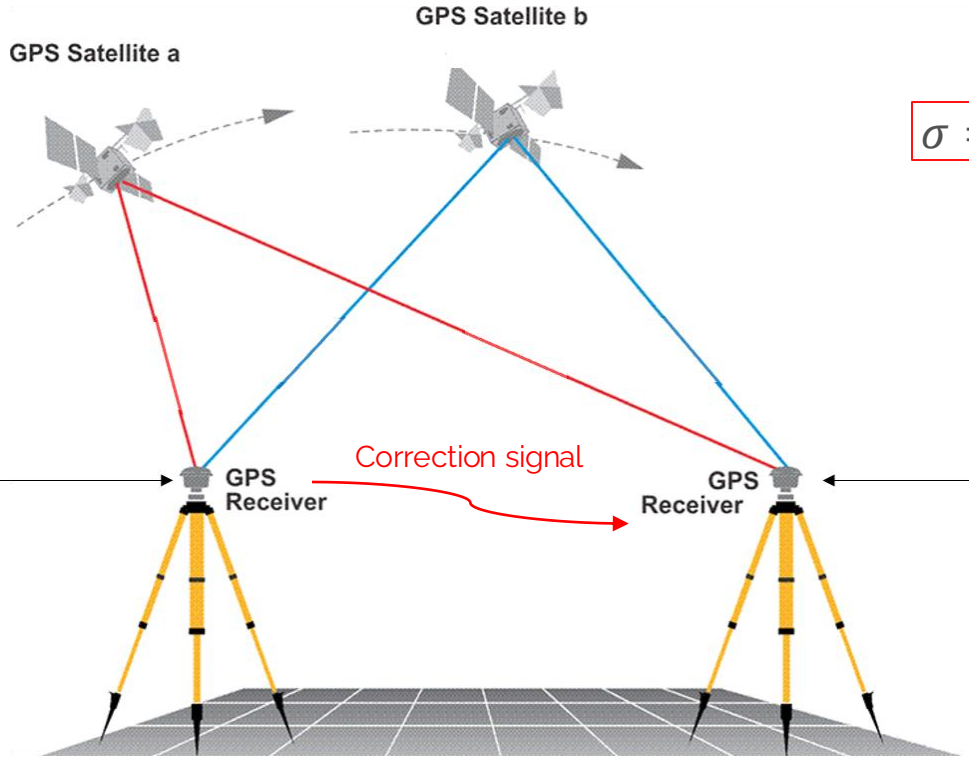


$$\sigma = 5 - 10\ m$$

Positioning method: DGPS

DGPS: Differential GPS

$$\sigma = 30 \ - 100 \ cm$$

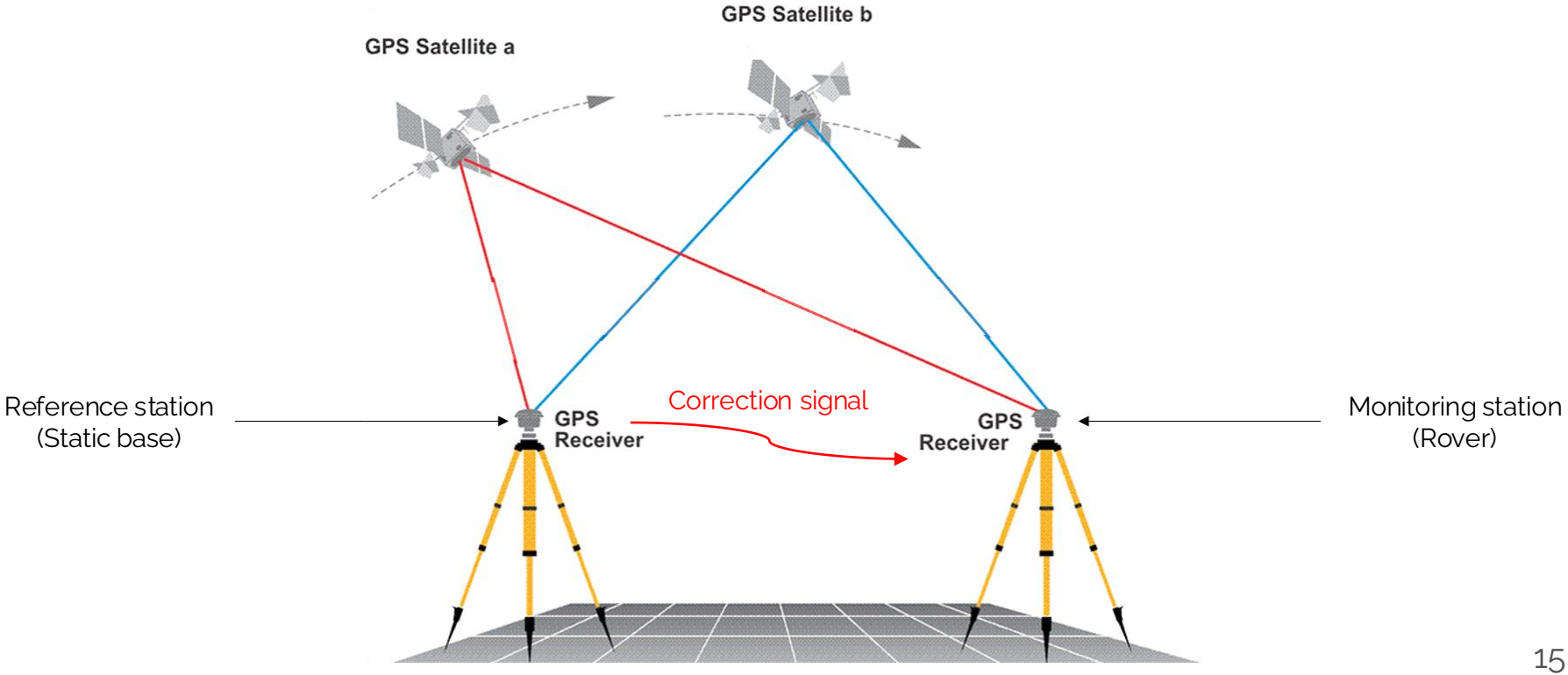


Reference station (Static base)

Monitoring station (Rover)

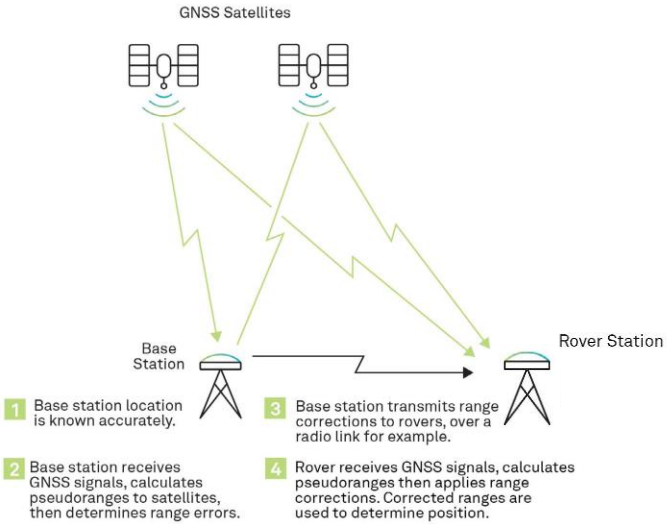
Positioning method: RTK

RTK: Real Time Kinematic

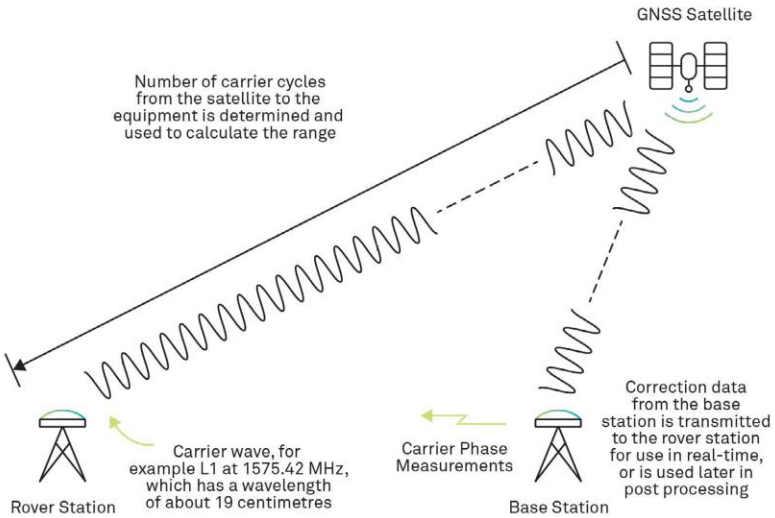


What’s the difference between DGPS and RTK ?

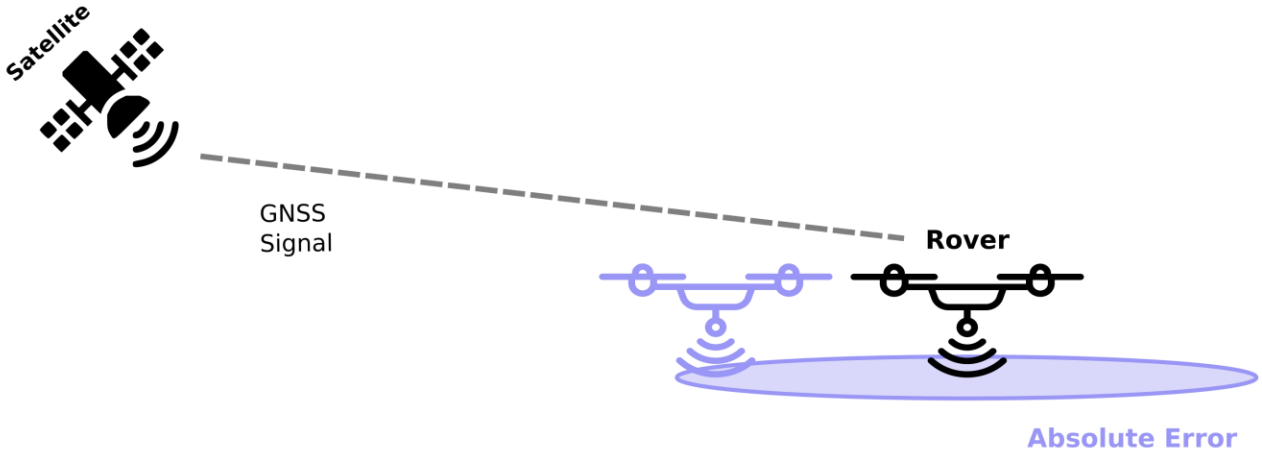
DGPS: code based



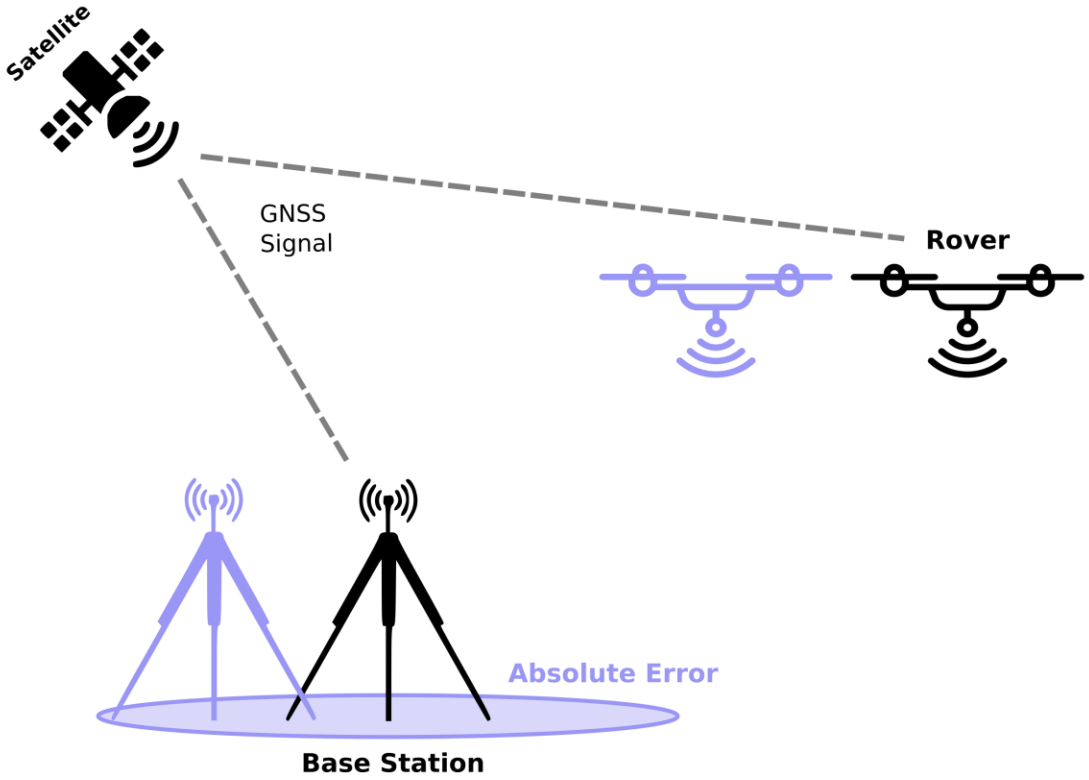
RTK: carrier-phase based



Positioning method: RTK



Positioning method: RTK

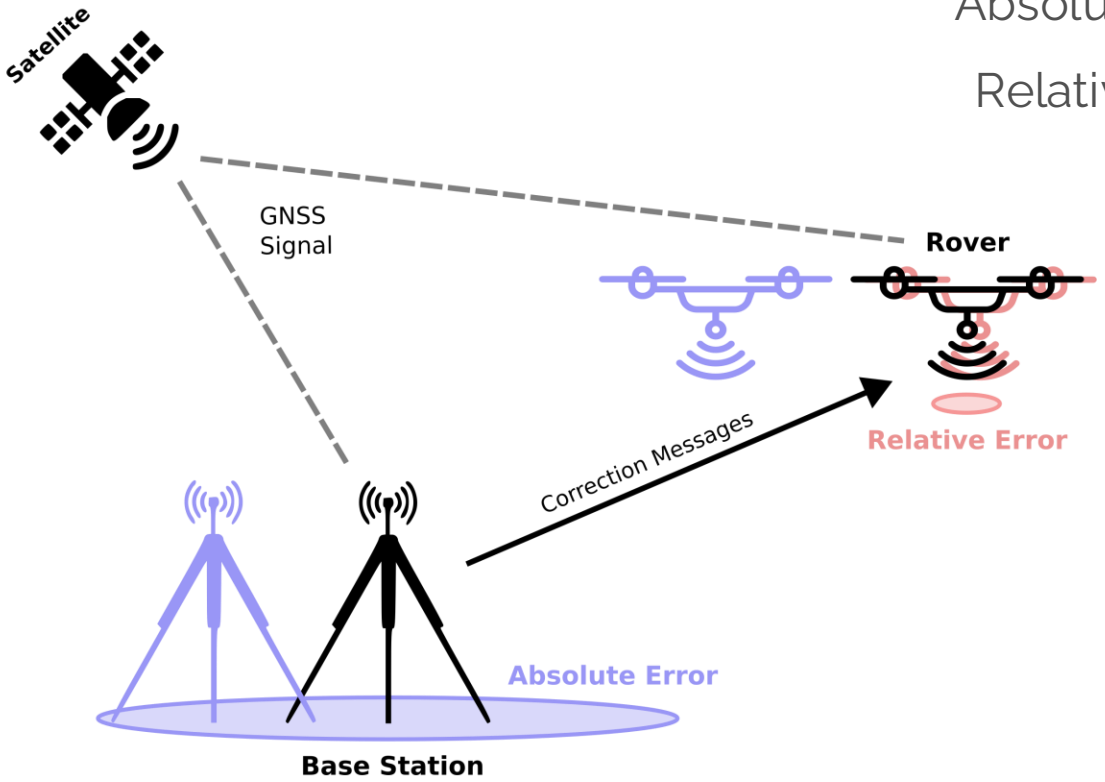


Positioning method: RTK

Absolute vs relative error

Absolute: $\sigma = 5 - 10\ m$

Relative: $\sigma = 1 - 5\ cm$



NMEA format

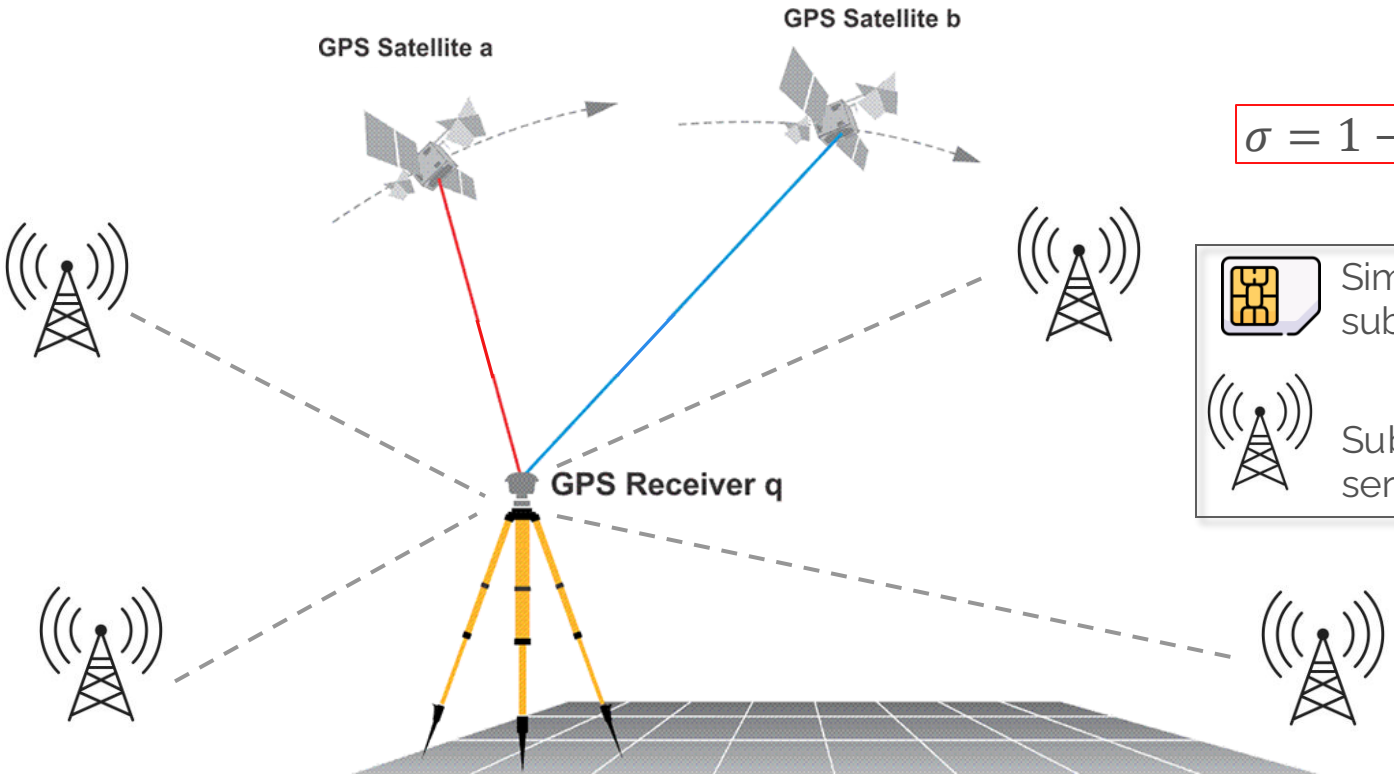
NMEA (National Marine Electronics Association)

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M, ,*47

GPGGA - The Global Positioning Fix Data
123519 - UTC Time Data in hhmmss.ss
4807.038,N - Latitude data in DegreesMinutes.decimalofMinutes, North/South of Equator
01131.000,E - Longitude data in DegreesMinutes.decimalofMinutes, East/West of Prime Meridian
1 - GPS Quality Indicator (0=No Fix, 1=GPS Fix)
08 - Number of Satellites
0.9 - Horizontal Dilution of Precision
545.4,M - Antenna Altitude above sea level in meters
46.9,M - Geoidal separation in meters
Gap - Age of differential GPS data in seconds
*47 - Checksum

Positioning method: NRTK

NRTK: Network Real Time Kinematic

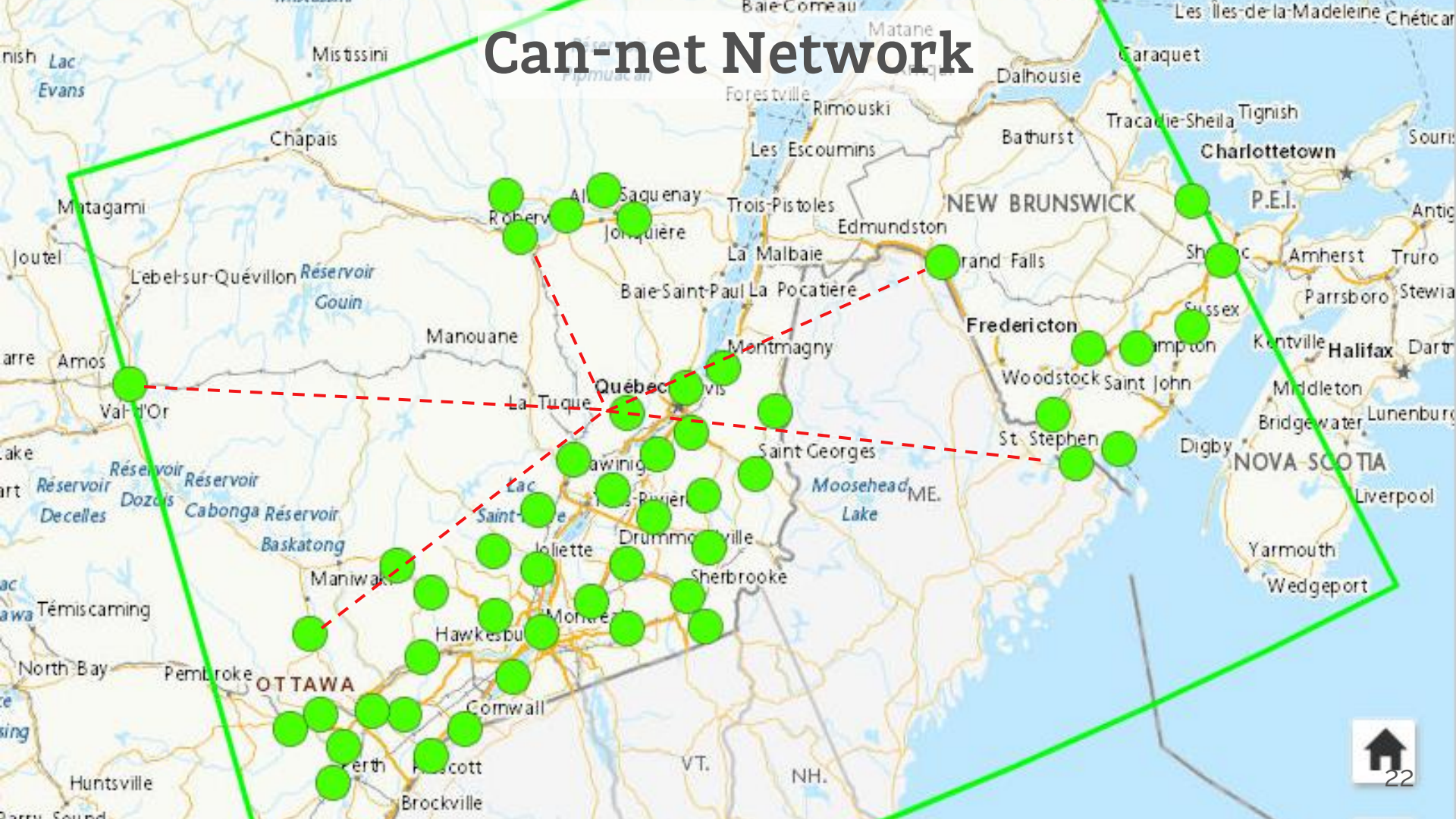


$\sigma = 1 - 5\ cm$

Sim card with internet subscription

Subscribe to a network service (Can-Net)

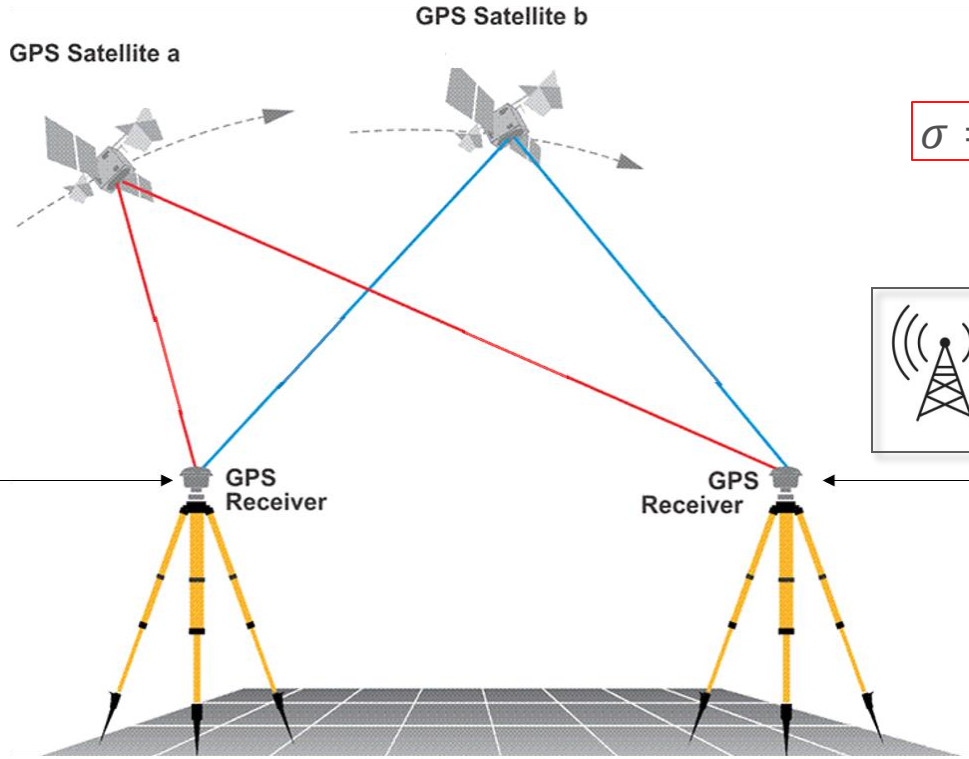
Can-net Network



b. Post-processed positioning methods

Positioning method: PPK

PPK: Post Processed Kinematic



$$\sigma = 1 - 5\ cm$$

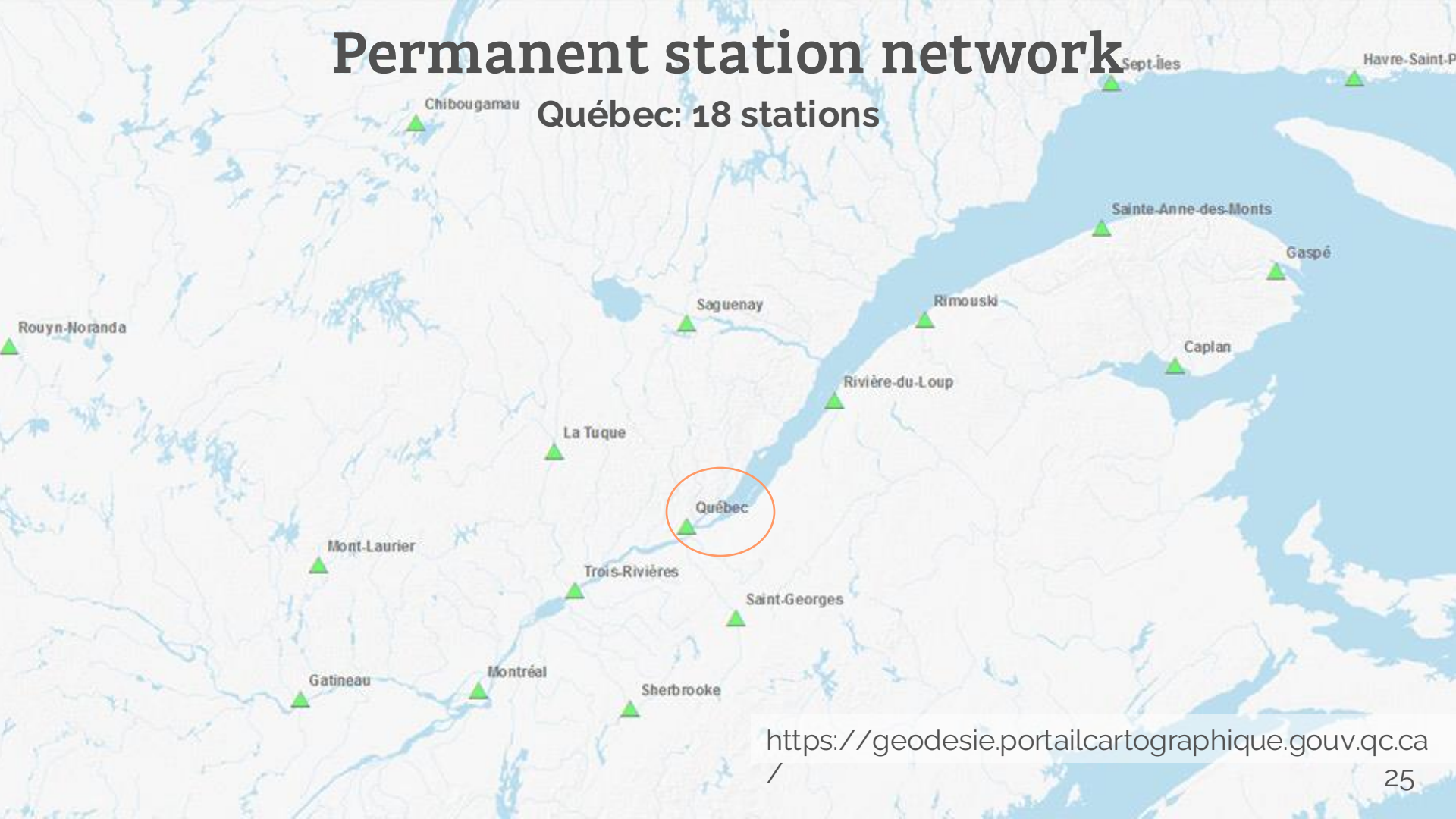
Free download for permanent stations

Base station

Measuring receiver

Permanent station network

Québec: 18 stations



https://geodesie.portailcartographique.gouv.qc.ca/

Required inputs

Base station

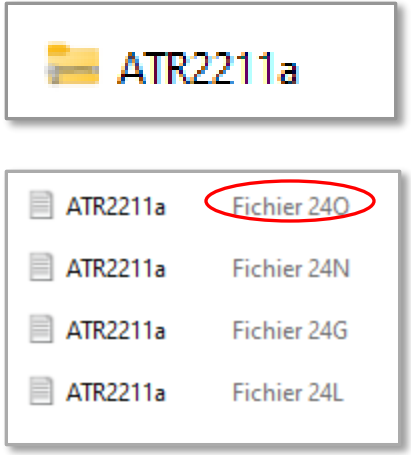
- ✓ Precise coordinates
- ✓ Navigation message
- ✓ Observation message
- ✓ Antenna type (type, height)

Rover

- ✓ Observation message
- ✓ Antenna type (type, height)

RINEX format

RINEX: Receiver Independant Exchange Format

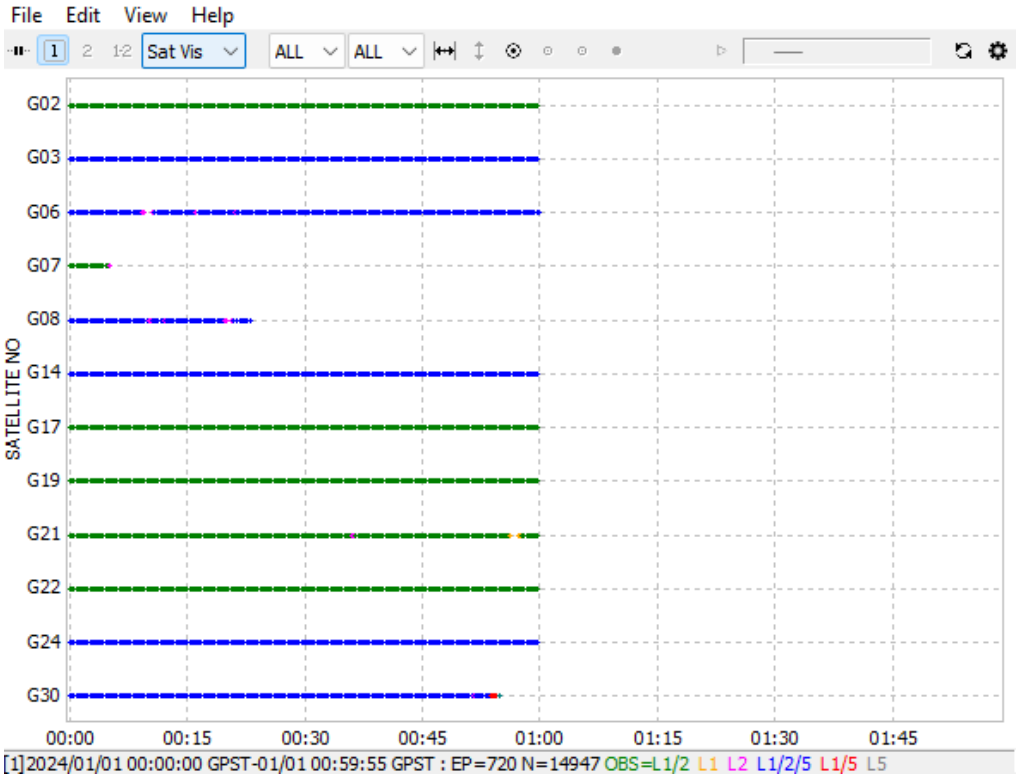


Code on L1 frequency

Carrier-phase on L1 frequency

```
     2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
NetR9 5.45          Receiver Operator   20240101 000000 UTC PGM / RUN BY / DATE
ATR2                                                        MARKER NAME
M23K2000                                                    MARKER NUMBER
SGLG                Energie et Ressources naturelles Qc     OBSERVER / AGENCY
5302K56172          TRIMBLE NETR9       5.45                REC # / TYPE / VERS
5323361230          TRM59900.00     SCIS                    ANT # / TYPE
  1403869.5429 -4138424.9678  4630209.6630                  APPROX POSITION XYZ
        0.0620        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
    17    C1    L1    S1    P1    C2    L2    S2    P2    C5# / TYPES OF OBSERV
          L5    S5    C7    L7    S7    C8    L8    S8      # / TYPES OF OBSERV
     5.000
  2024     1     1     0     0    0.0000000     GPS
L2C CARRIER PHASE MEASUREMENTS: PHASE SHIFTS REMOVED
L2C PHASE MATCHES L2 P PHASE
GLONASS C/A & P PHASE MATCH: PHASE SHIFTS REMOVED

 24  1  1  0  0  0.0000000  0 26R12G 7R23G17G14G 6G21R11G 2G22R22G24 0.000000000
                                R 5R 4G30G 3R13G19R21G 8E30E36E 2E34
                                E15E27
  19487418.859 9 104098413.254 9        51.600    19487417.969 9  19487421.578 9
  80965480.444 9        49.500    19487421.453 9


  24873694.766 5 130712296.574 5        35.700                    24873702.695 3
 101853755.91045        16.300    24873702.59445


  23252440.391 6 124384938.402 6        40.100    23252439.746 6



  20760832.195 9 109099026.621 9        50.600                    20760836.145 9
  85012342.67249        43.700    20760836.37149


  20100114.484 9 105626805.252 9        50.400                    20100118.406 9
  82306825.95349        46.800    20100118.76249  20100121.813 9  78877397.005 9
        59.300

  24908201.398 2 130893505.925 2        31.900                    24908212.113 5
 101994952.84145        16.300    24908211.33645  24908210.926 6  97745175.329 6
        40.600
```

RINEX format



RTK *versus* PPK

GeoOne

YOUTUBE.COM/LEANDROFRANÇA

@GEOLEANDROFRANCA

What's the difference between NMEA & RINEX format ?

NMEA

- Real-time applications
- Processed output less detailed
- Lower precision
- Small data file
- Low precision applications

RINEX

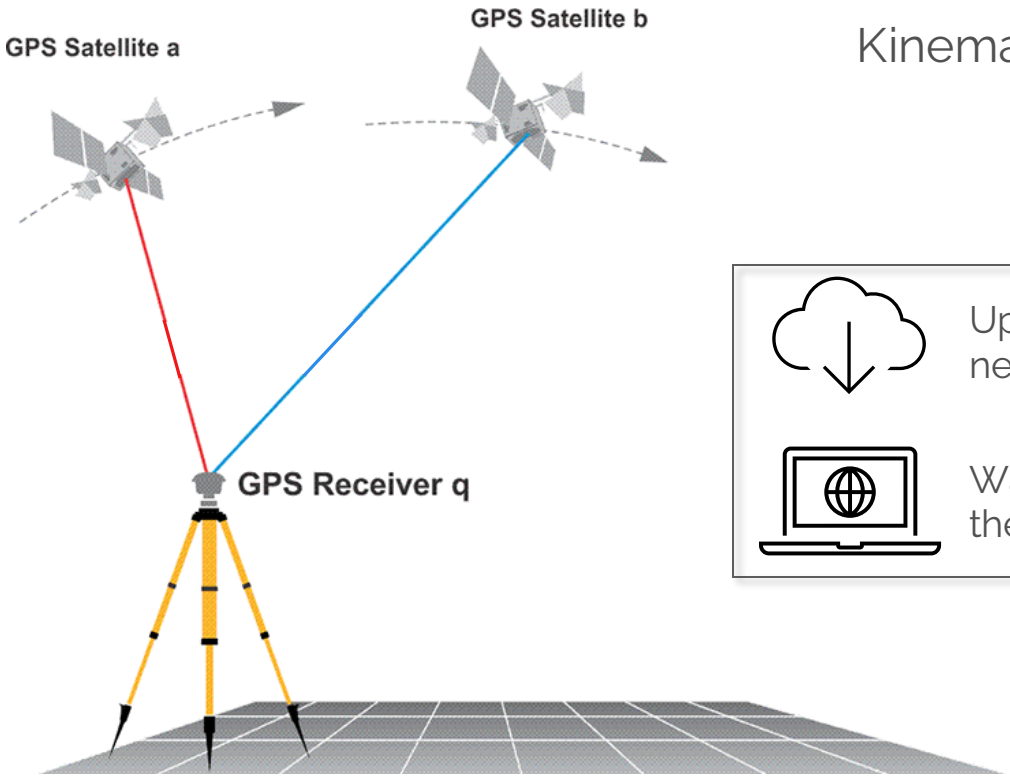
- Post-processed applications
- Raw data more detailed
- Higher precision
- Larger data file
- High precision applications

Positioning method: PPP

PPP: Precise Point Positioning

Static: $\sigma = 1 - 5\ cm$

Kinematic: $\sigma = 5 - 10\ cm$

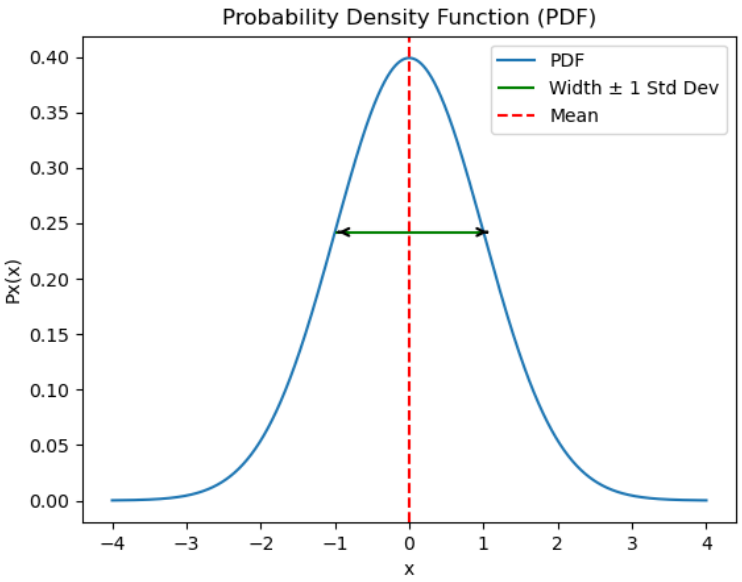


Upload data on NRCan network service

Wait for 2 weeks to receive the processed data

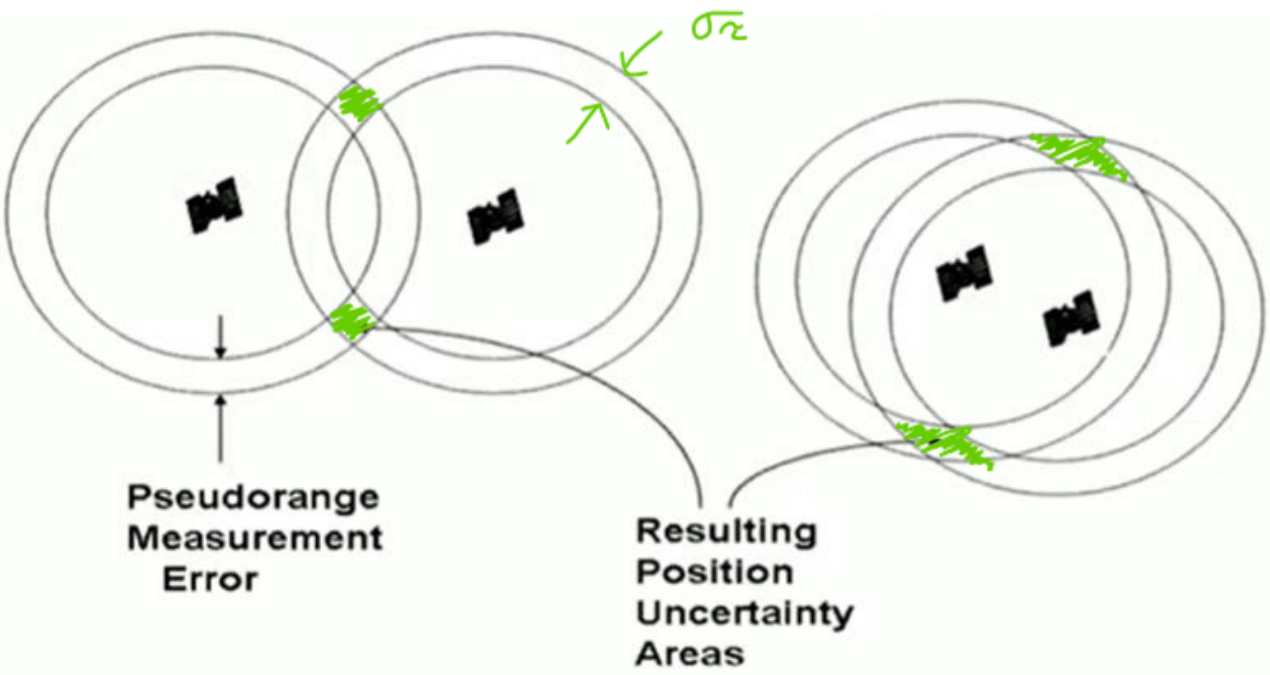
II. GDOP (Geometric Dilution of Precision)

DOP (Dilution of Precision)

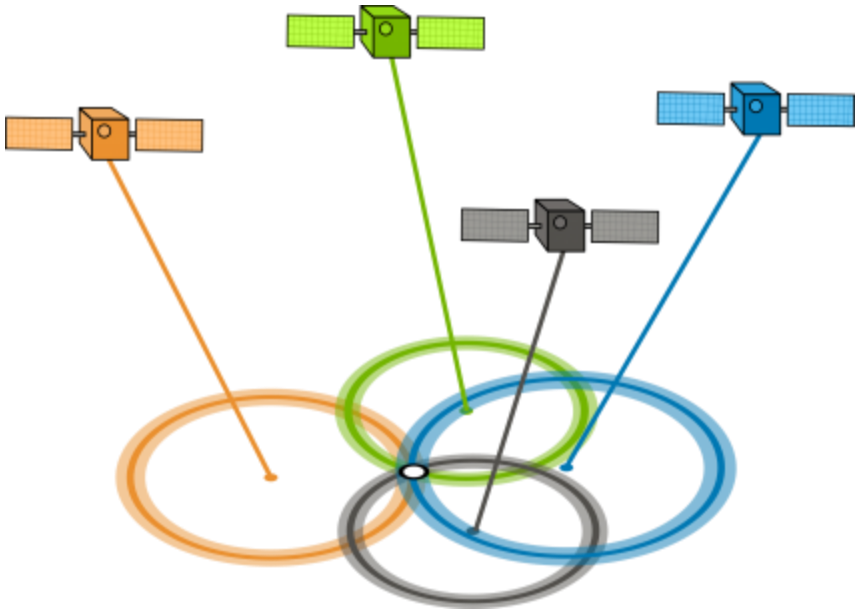


$$(\mathrm{G}^{\mathrm{T}}\mathrm{G})^{-1} = \begin{bmatrix} \mathrm{XDOP}^2 = \frac{\sigma^2_{\mathrm{x}-\hat{\mathrm{x}}}}{\sigma^2_{\tau}} & & & \\ & \mathrm{YDOP}^2 = \frac{\sigma^2_{\mathrm{y}-\hat{\mathrm{y}}}}{\sigma^2_{\tau}} & & \\ & & \mathrm{ZDOP}^2 = \frac{\sigma^2_{\mathrm{z}-\hat{\mathrm{z}}}}{\sigma^2_{\tau}} & \\ & & & \mathrm{TDOP}^2 = \frac{\sigma^2_{\mathrm{t}-\hat{\mathrm{t}}}}{\sigma^2_{\tau}} \end{bmatrix}$$

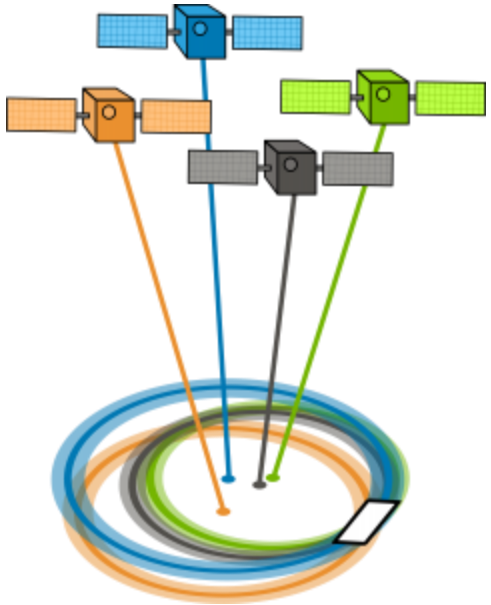
GDOP (Geometric Dilution of Precision)



GDOP (Geometric Dilution of Precision)



Low GDOP < 3 → **good** precision



High GDOP > 5 → **poor** precision

GDOP (Geometric Dilution of Precision)

$$(\tilde{\mathrm{G}}^{\mathrm{T}}\tilde{\mathrm{G}})^{-1} = \begin{bmatrix} \mathrm{EDOP}^2 = \frac{\sigma^2_{\mathrm{E}-\hat{\mathrm{E}}}}{\sigma^2_\tau} & & & \\ & \mathrm{NDOP}^2 = \frac{\sigma^2_{\mathrm{N}-\hat{\mathrm{N}}}}{\sigma^2_\tau} & & \\ & & \mathrm{VDOP}^2 = \frac{\sigma^2_{\mathrm{V}-\hat{\mathrm{V}}}}{\sigma^2_\tau} & \\ & & & \mathrm{TDOP}^2 = \frac{\sigma^2_{\mathrm{t}-\hat{\mathrm{t}}}}{\sigma^2_\tau} \end{bmatrix}$$

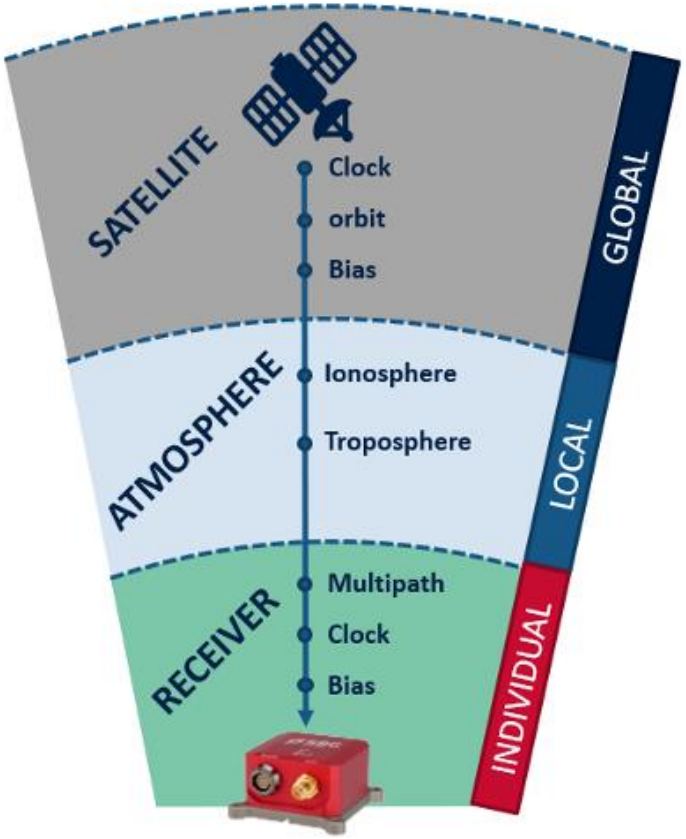
$$\mathrm{GDOP} = \sqrt{\mathrm{EDOP}^2 + \mathrm{NDOP}^2 + \mathrm{VDOP}^2 + \mathrm{TDOP}^2}$$

Satellites positioning

GDOP value	Rating	Description
<1	Ideal	Highest confidence level.
1-2	Excellent	Accurate for most applications.
2-5	Good	Mostly reliable.
5-10	Moderate	Potential for improved accuracy.
10-20	Fair	Low confidence level.
>20	Poor	Measurements should be discarded due to low reliability.

III. Sources of GNSS noise and solutions

Causes of GNSS noise and degradation



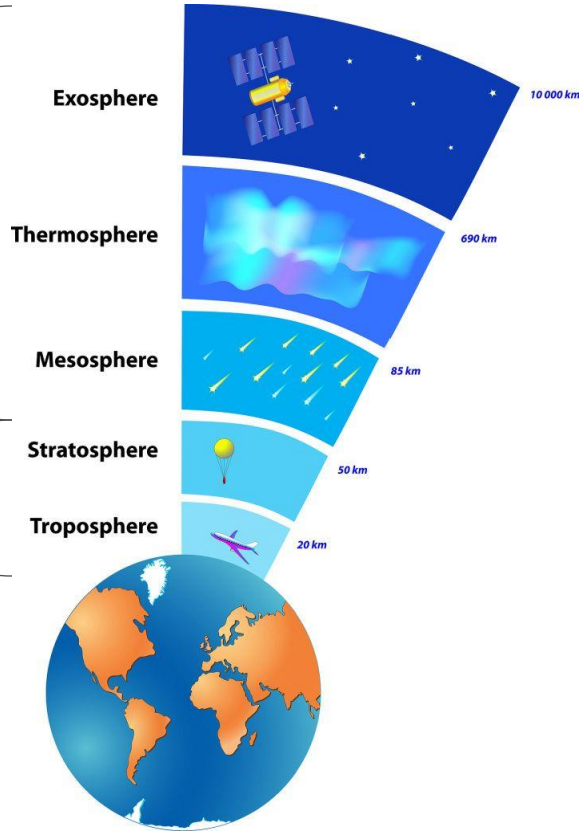
1. Atmospheric refraction
2. Multipath
3. Satellite's ephemeris precision
4. Phase ambiguity resolution
5. Antenna phase offset

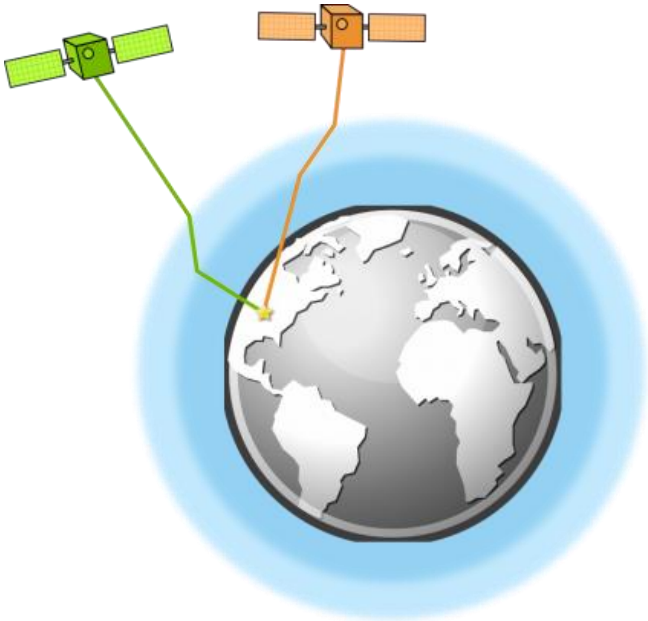
1. Atmospheric refraction

Atmosphere: several **layers** wih different physical properties

ionosphere

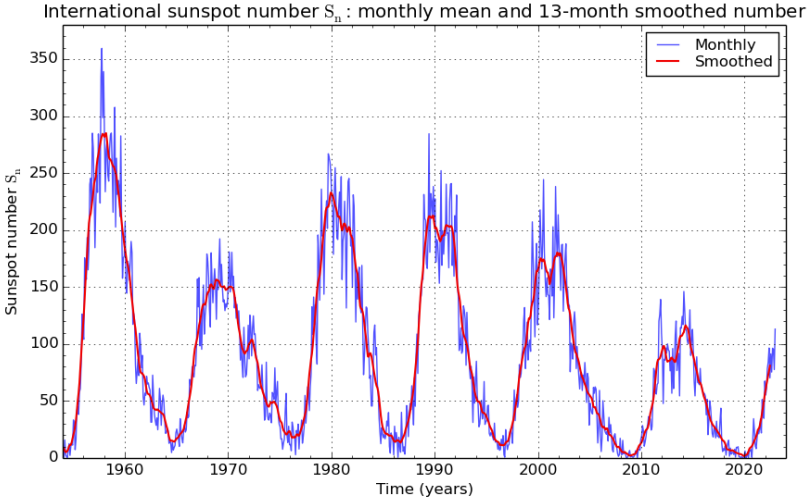
neutral atmosphere



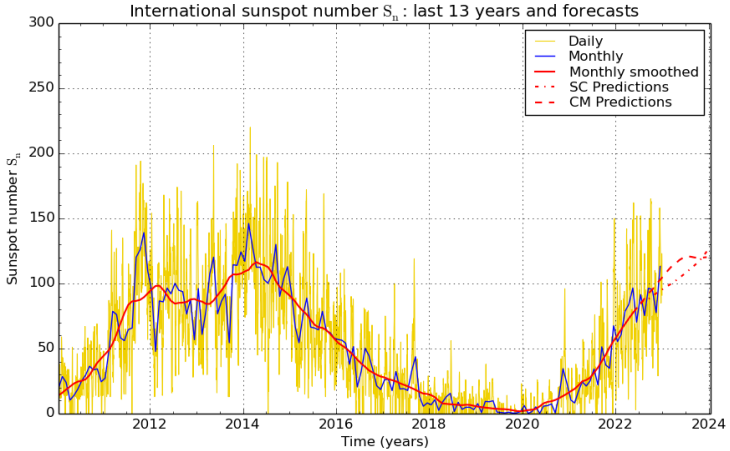


1. Ionospheric refraction

Proportional to the number of electrons encountered by the electromagnetic wave:



Last 5 solar cycles



Last solar cycle

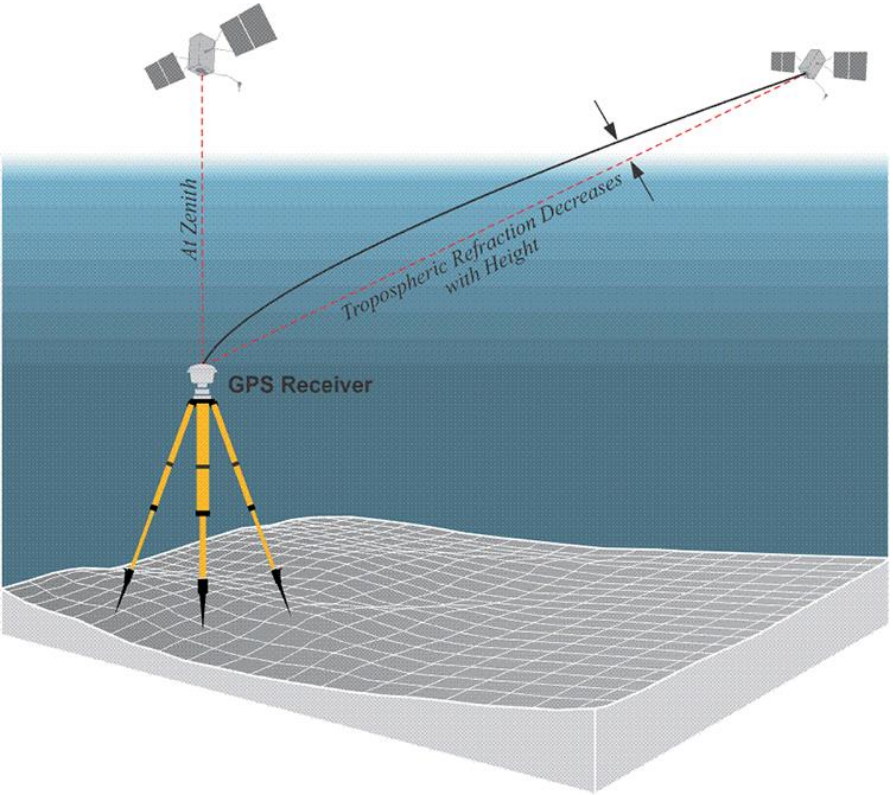
Geomagnetic storms

Black hole radio

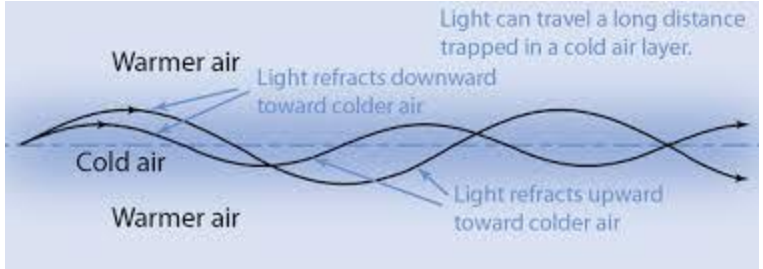
main source of error (up to 100 meters)

1. Tropospheric refraction

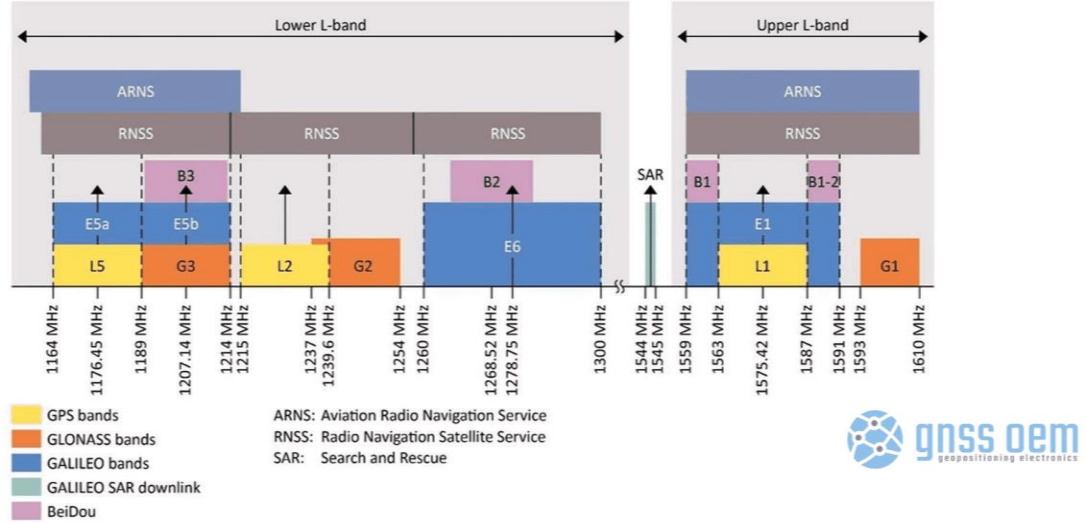
Delay up to 3 meters (elevation angle)



Refrection depends on temperature, pressure and humidity conditions.



1. Atmospheric refraction



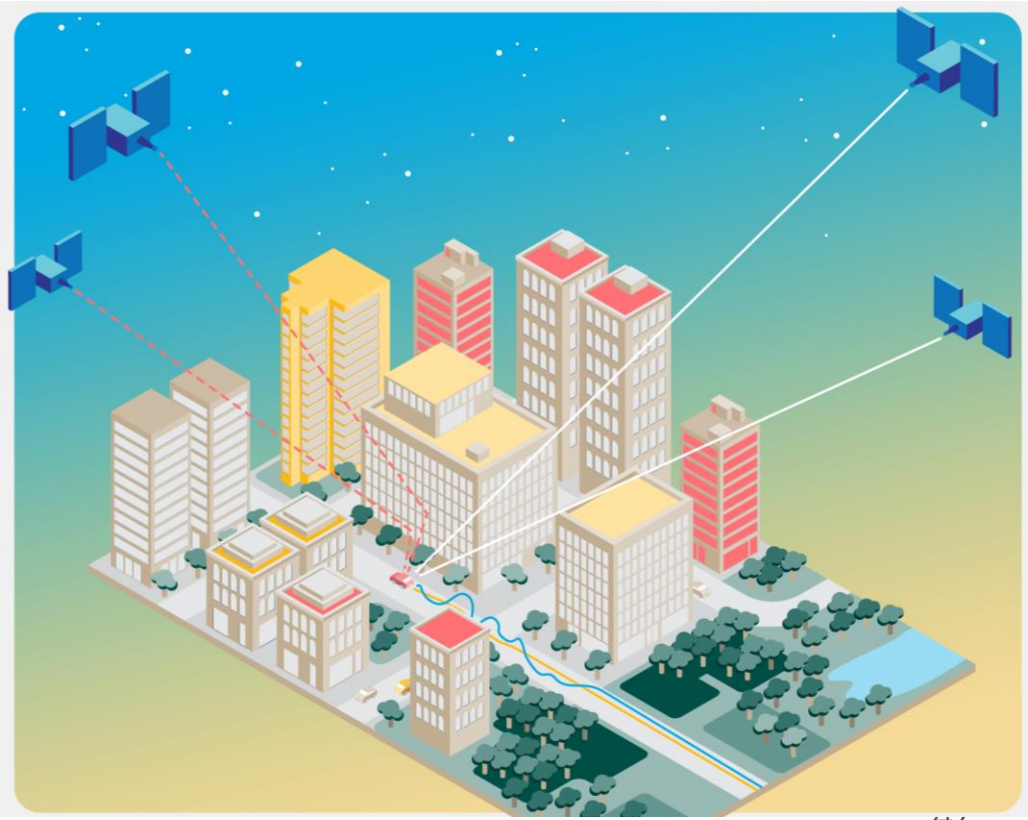
GPS signal bands
L1: 1575.42 MHz
L2: 1227.60 MHz
L5: 1176.45 MHz

L3 band is utilized for the United States Nuclear Detonation Detection System (USNDS)

Solution: Bi-frequency (L1,L2) / multifrequency (L1,L2,L5) receivers, Double difference (more later)

2. Multipath

Reflective surface (buildings, trees, etc): bouncing signal leading to inaccurate distance measurements to satellites

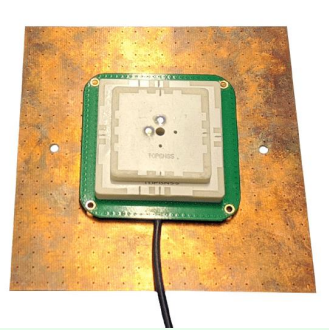


2. Multipath

Environment solution:

Avoid reflective surface

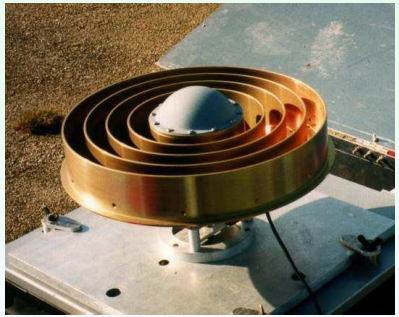
Ground plane



Antenna solution:

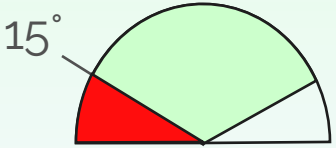
Larger one

Choke ring



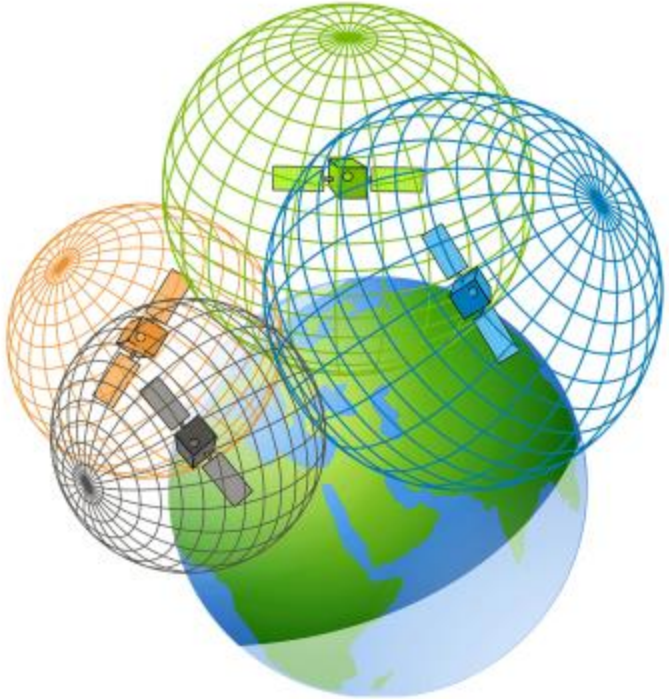
Computation solution:

Set elevation mask angles:
ignore low-elevation satellites



3. Satellite's ephemeris precision

Ephemeris provided by the satellites received by the GNSS to calculate position: Broadcast Orbits.

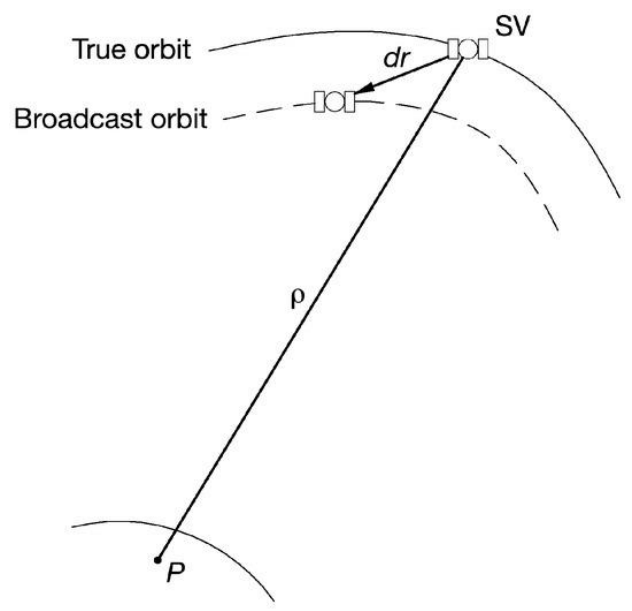


Broadcasted: $\sigma = 1\ m$

3. Satellite's ephemeris precision

IGS Orbit Products: The International GNSS Service (IGS) provides GNSS orbit products, precise ephemeris (true orbit)

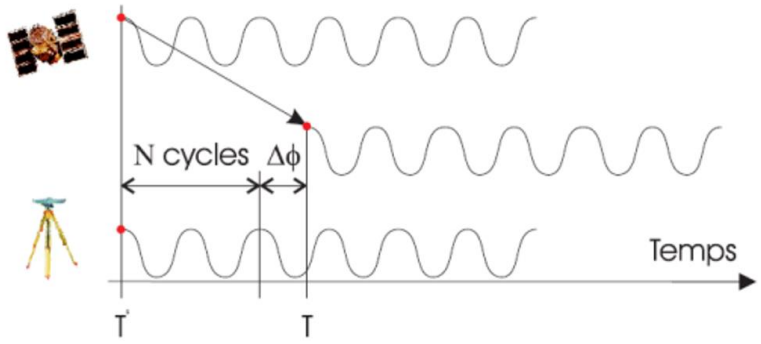
Precise ephermeris: $\boxed{\sigma = 2.5\ cm}$



ρ: pseudo-distance
dr: orbital error

4. Phase ambiguity resolution

Ambiguity: how many complete cycle have occured ?

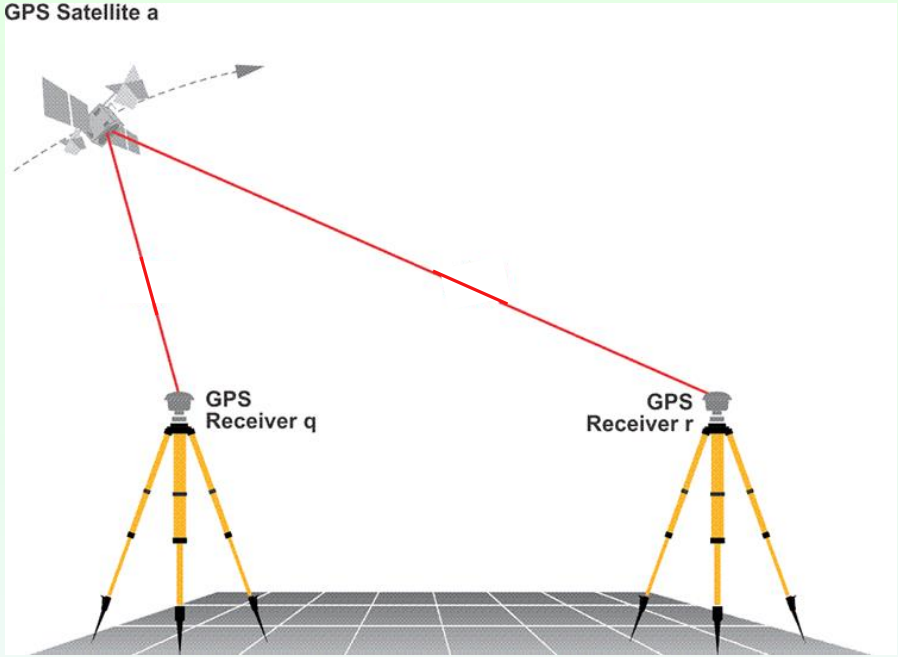


Initialisation phase: The receiver resolves phase ambiguities through an initialization phase, which is why it's necessary to wait a few minutes before taking measurements.

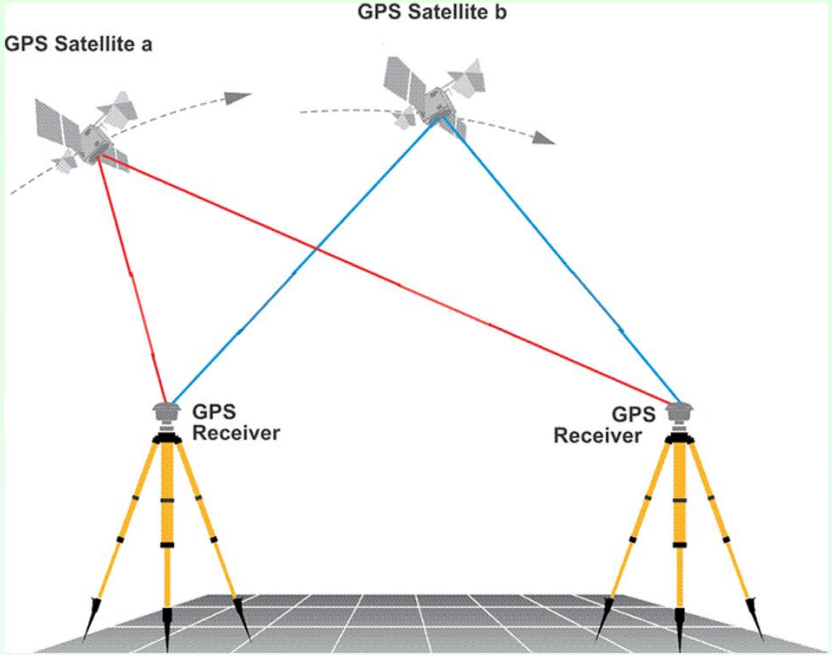
Carrier phase: phase modulo the wavelenth of the carrier.

4. Phase ambiguity resolution

Subtract one measurement from the other: simplifies integer ambiguities resolution, eliminates clock error, atmospheric refraction.



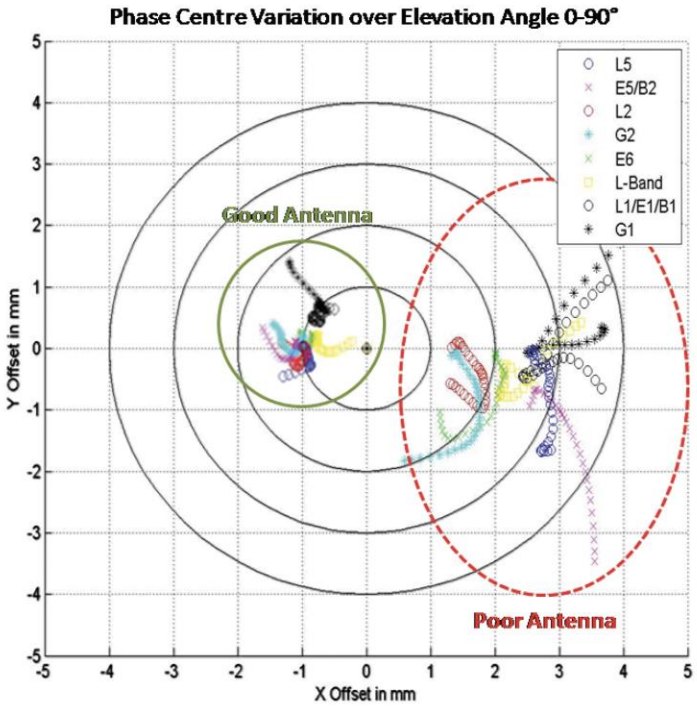
Single difference

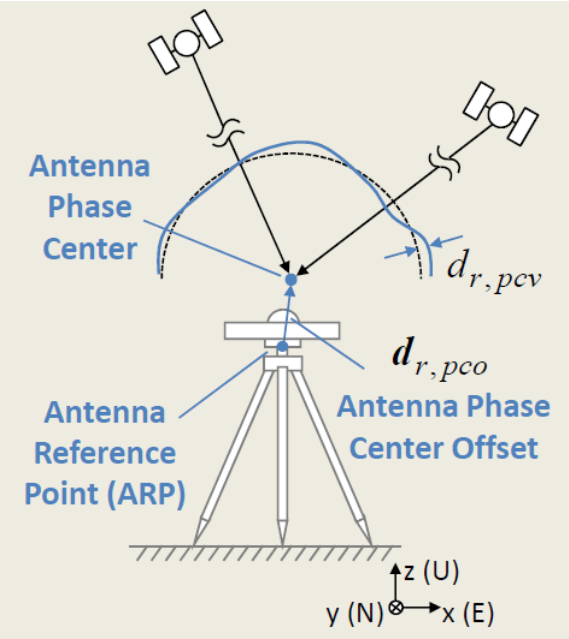


Double difference

GNSS base station within 20km

5. Antenna phase offset





5. Antenna phase offset

Antenna Calibration file: ANTenna EXchange format (ANTEX)

Calibration is applied to determine the best general phase corrections for a given antenna model.

```
     1.4            M                                       ANTEX VERSION / SYST
A                                                           PCV TYPE / REFANT
This calibration extracted from composite ngs20.atx.  See   COMMENT
the composite file ngs20.atx for more information.          COMMENT
                                                            END OF HEADER
                                                            START OF ANTENNA
EML_REACH_RS2   NONE                                        TYPE / SERIAL NO
ROBOT               Geoscience Australia     0    07-SEP-22 METH / BY / # / DATE
     5.0                                                    DAZI
     0.0  90.0   5.0                                        ZEN1 / ZEN2 / DZEN
     4                                                      # OF FREQUENCIES
IGS20_2233                                                  SINEX CODE
# Number of Calibrated Antennas GPS:      005               COMMENT
# Number of Individual Calibrations GPS:  052               COMMENT
# Number of Calibrated Antennas GLO:      005               COMMENT
# Number of Individual Calibrations GLO:  052               COMMENT
# GLONASS PCV (metric)                                      COMMENT
#  derived from Delta PCV per 25.0 MHz                      COMMENT
#  for frequency channel number  k=0                        COMMENT
   G01                                                      START OF FREQUENCY
     -0.98     +1.92   +134.92                               NORTH / EAST / UP
   NOAZI   +0.00   +0.20   +0.75   +1.44   +2.02   +2.26   +2.03   +1.39   +0.56
     0.0   +0.00   +0.15   +0.65   +1.35   +1.96   +2.23   +2.01   +1.37   +0.55
     5.0   +0.00   +0.15   +0.66   +1.35   +1.95   +2.21   +2.00   +1.36   +0.54
    10.0   +0.00   +0.16   +0.67   +1.35   +1.94   +2.20   +1.98   +1.35   +0.53
    15.0   +0.00   +0.17   +0.68   +1.35   +1.93   +2.18   +1.97   +1.34   +0.51
    20.0   +0.00   +0.18   +0.69   +1.35   +1.92   +2.17   +1.96   +1.33   +0.49
    25.0   +0.00   +0.19   +0.70   +1.36   +1.92   +2.16   +1.95   +1.32   +0.47
```

Recommendations

Relative positioning: RTK

- ✓ Trajectory evaluation
- ✓ Relative mapping

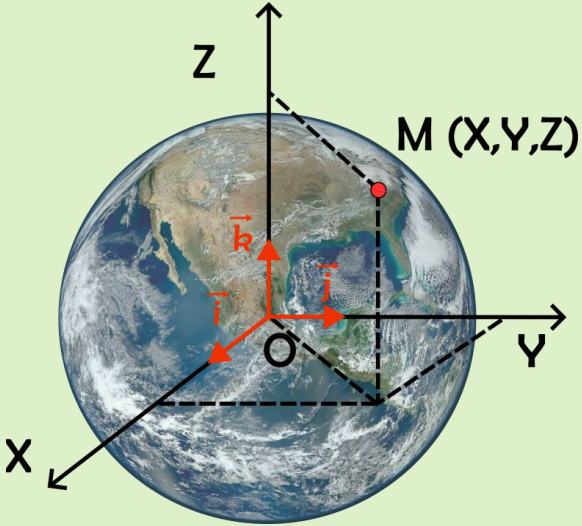
Absolute positioning: NRTK

- ✓ Legal application
- ✓ Trees cutting

IV. Coordinate system

A coordinate system

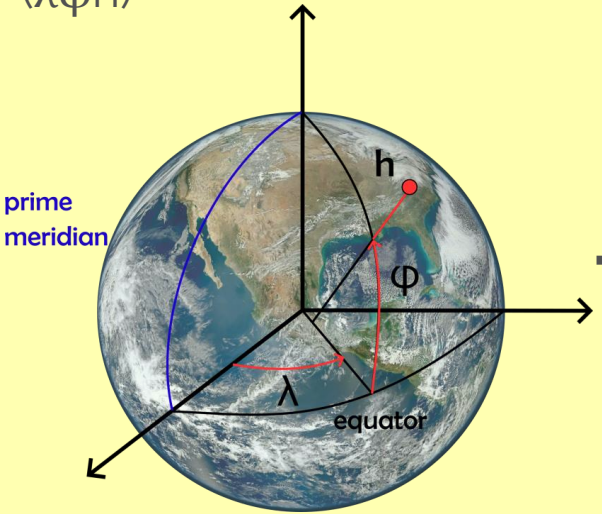
Reference system (XYZ)



Unit: meters

+

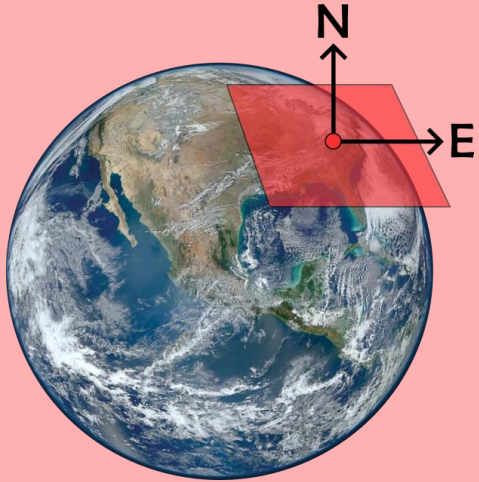
Reference Ellipsoïde (λφh)



Unit: degrees

+

Reference projection (EN)



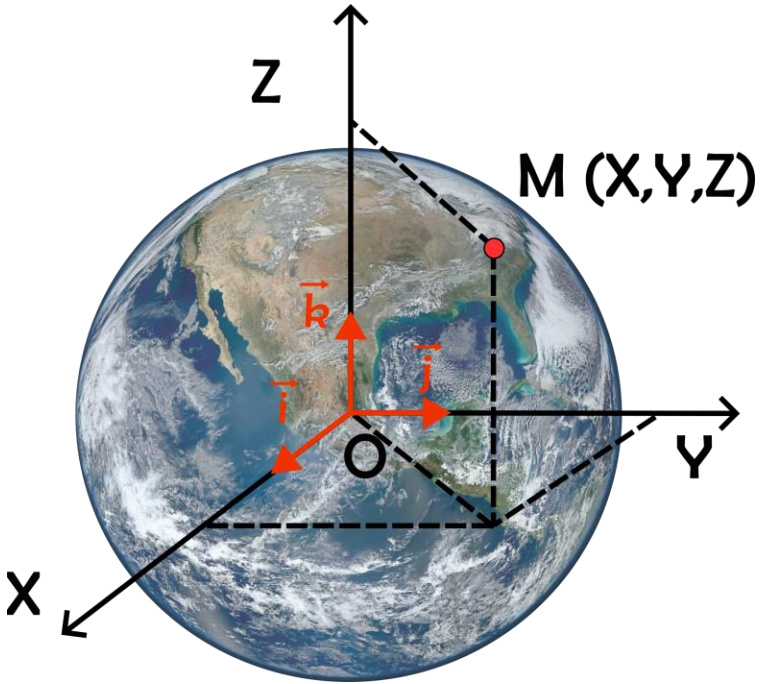
Unit: meters

Reference system (XYZ)

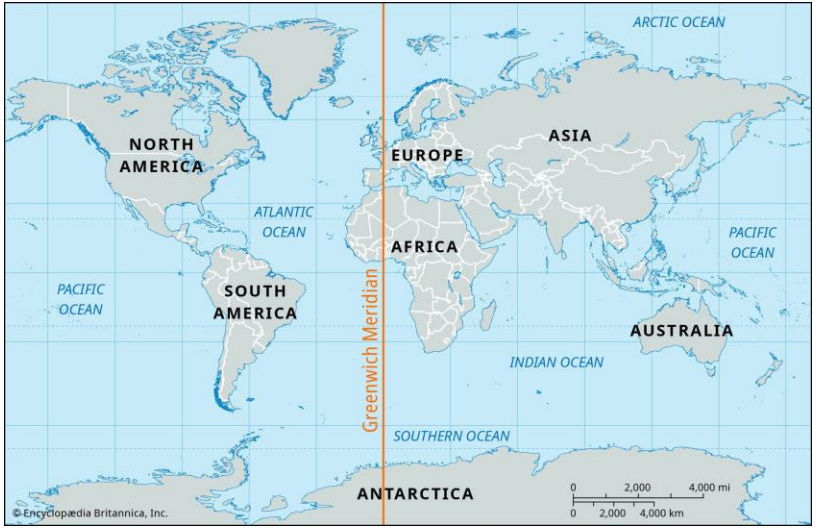
Unit: meters

NAD83 (North American Datum 1983) is the current horizontal datum used to define the geodetic network in North America.

- Geocentric datum, referenced to the Earth's center of mass
- released in 1986
- more accurate than its predecessor (NAD27)

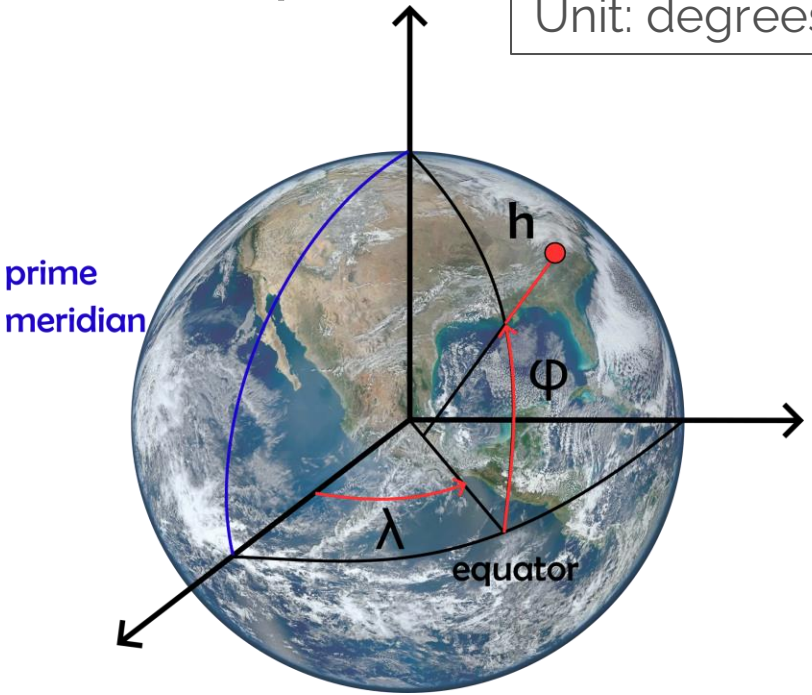


Reference ellipsoïde (λφh)



Prime meridian: Greenwich

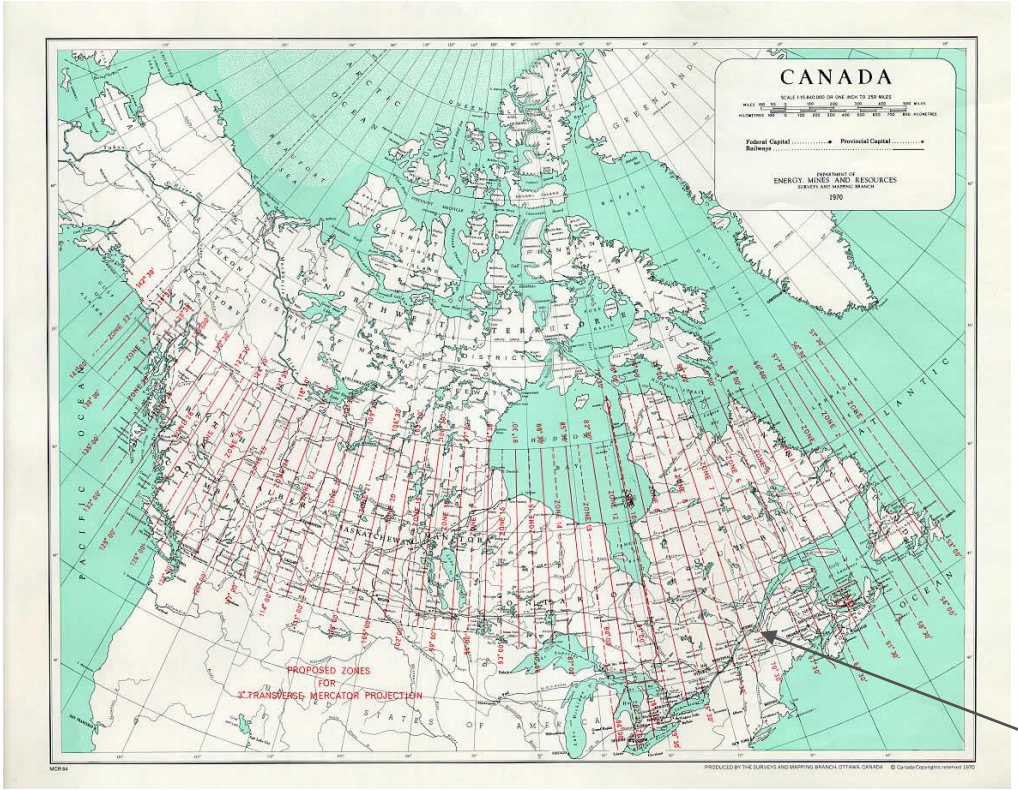
Unit: degrees

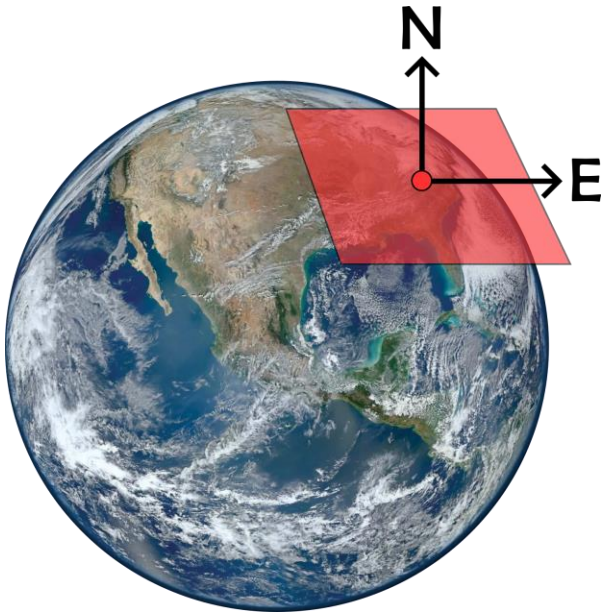


In Québec : GRS80 (Geodetic Reference System 1980)

Reference projection (EN)

Unit: meters





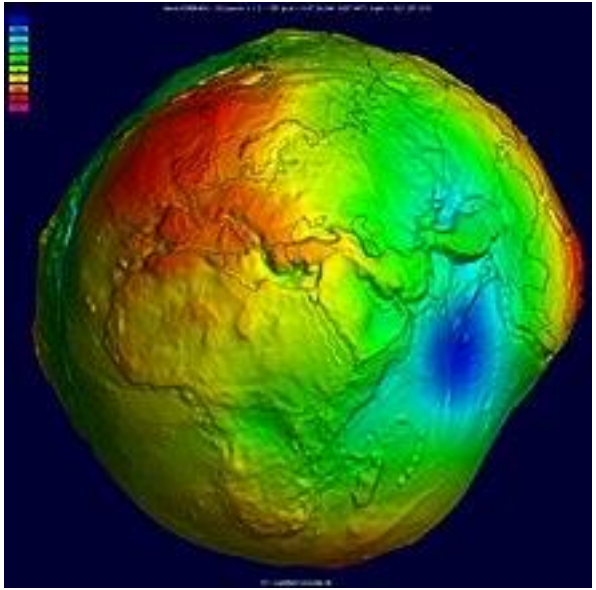
MTM (Modified Transverse Mercator) Zone 7* projection

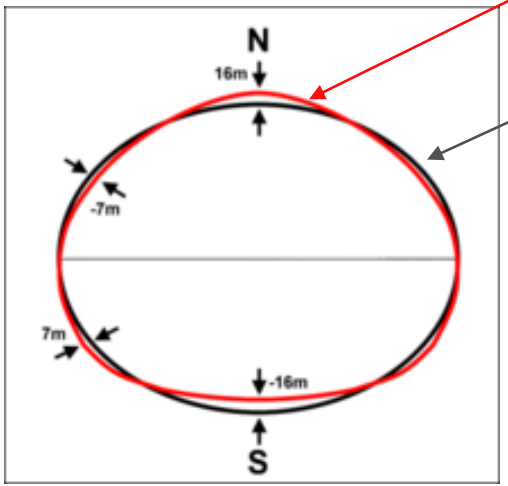
*Between 72° W and 69°W in longitude

Questions ?

Geoid ondulation (N)

Geoid



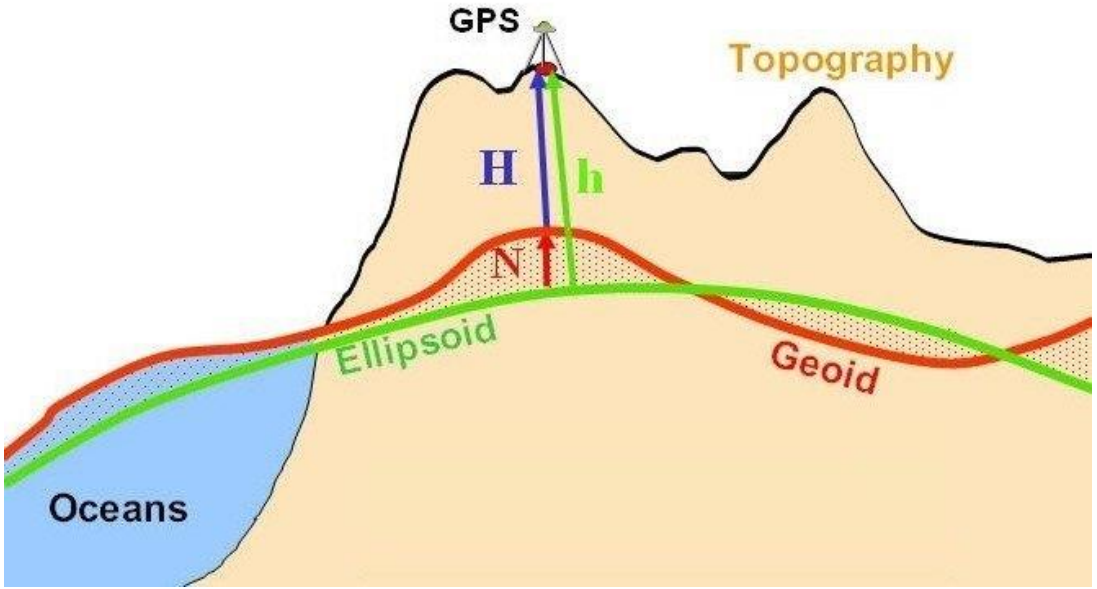


Geoid undulation

Reference ellipsoide

Altimetric system (H)

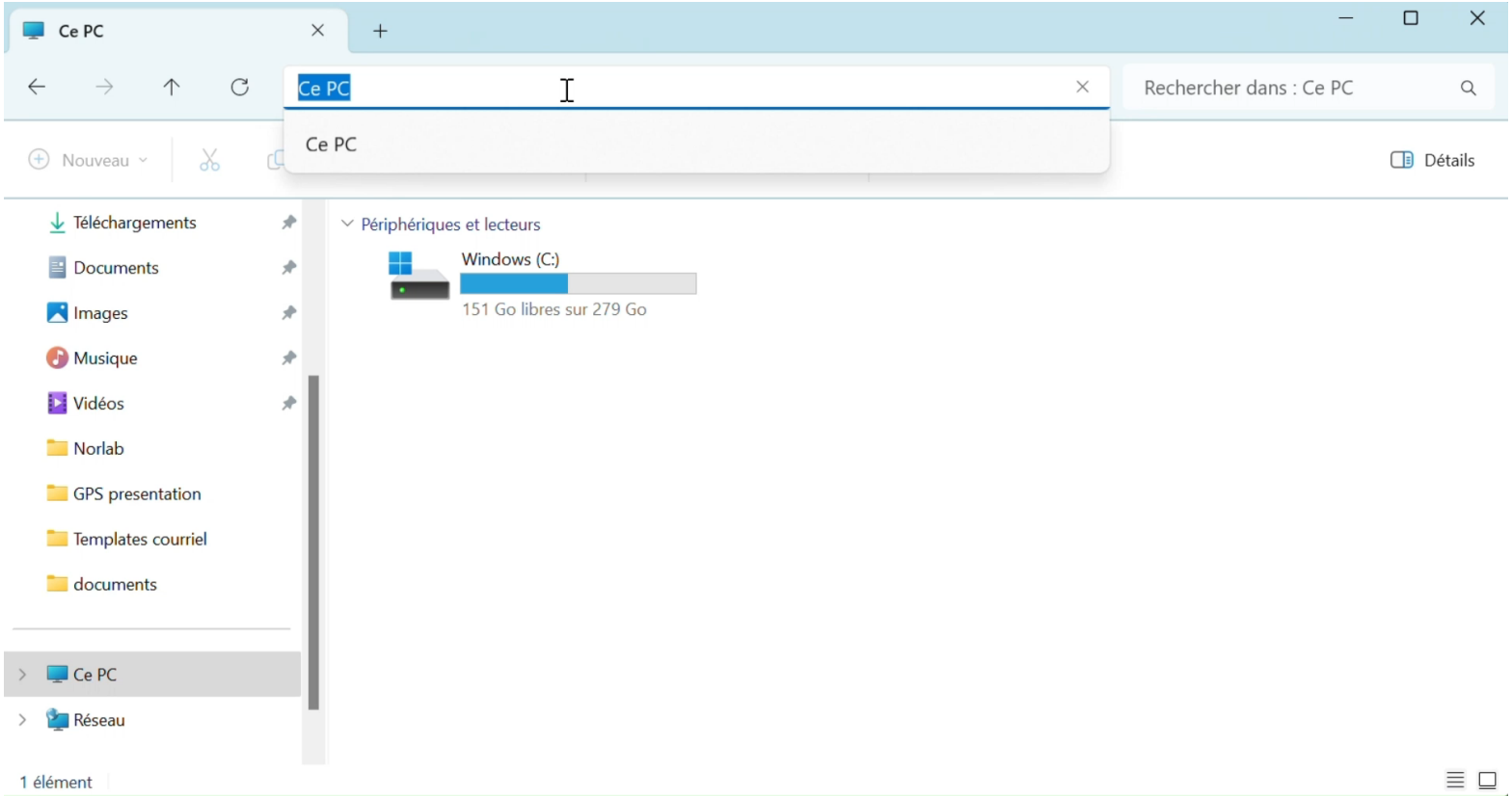
Canadian Geodetic Vertical Datum of 1928 (CGVD28)

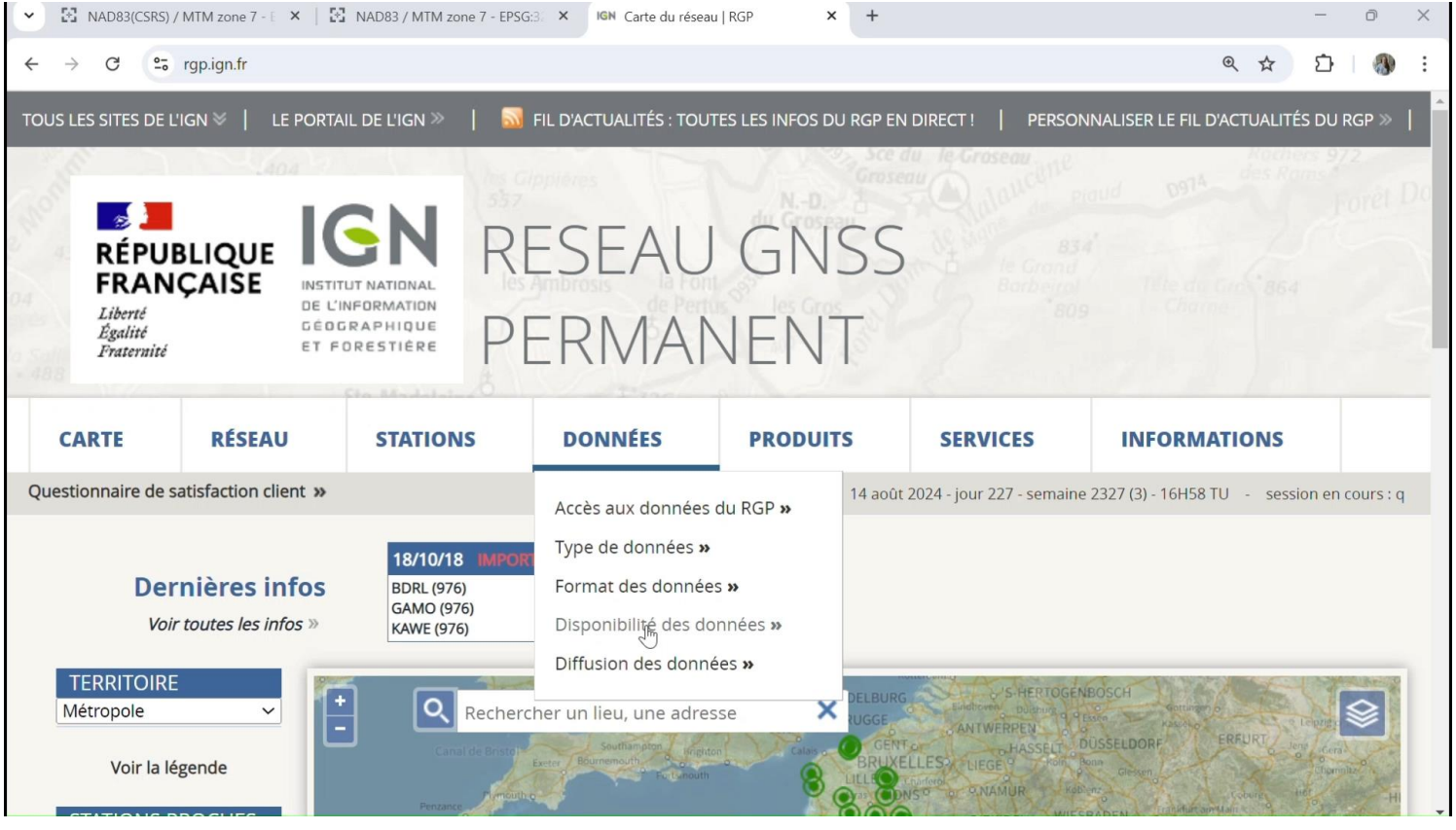


$$H = h - N$$

Download free permanent stations data

Québec: 18 stations



Download free permanent stations data

France: 525 stations