MULTIPATH EFFECT ON GNSS POSITIONING:

mitigate or apply it?

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Overview

1. Introduction
2. Multipath
3. Some results from B&H:
    - Detection and localisation of multipath
    - Soil monsture content from GNSS multipath
4. Conclusions and future plan

Introduction and motivation

- Multipath is one of the most dominant and unpredictable error sources in high-accuracy GNSS positioning and navigation.

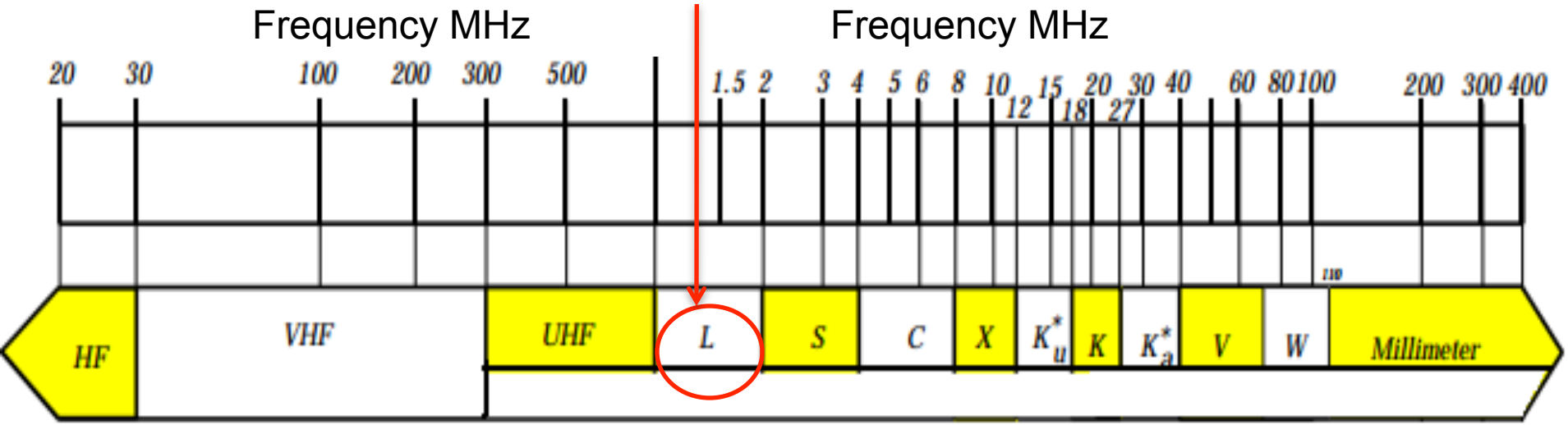
What is it? How to mitigate it? Could we use it?

Analise of the multipath anable to:

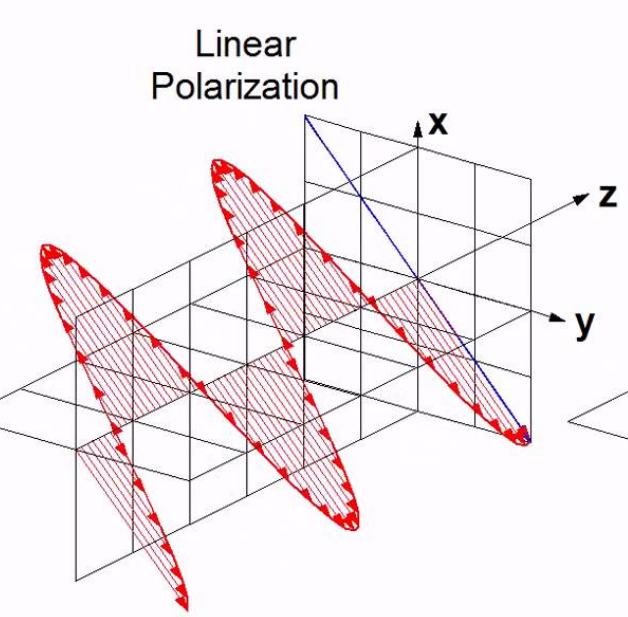
- ✓ Determine reflector (surfaces) characteristics
- ✓ Measure soil moisture,
- ✓ Monitor snow depth,
- ✓ Monitor vegetation growth, …

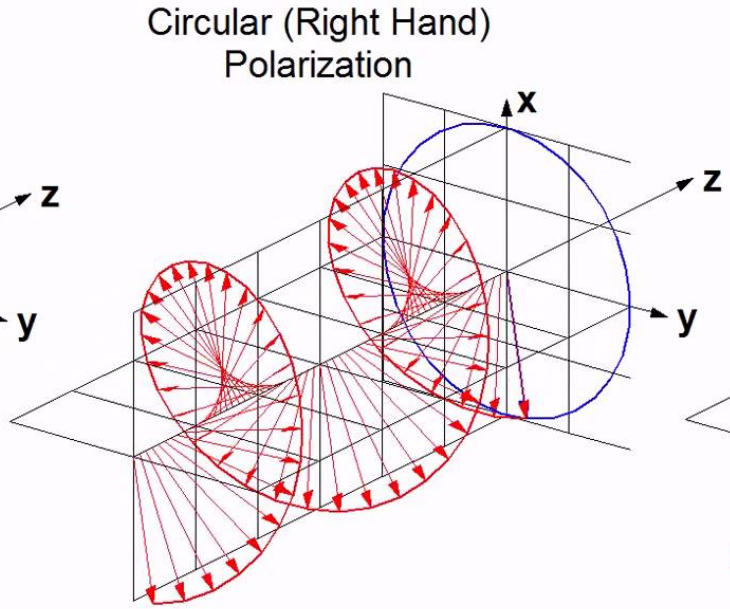
GPS signal

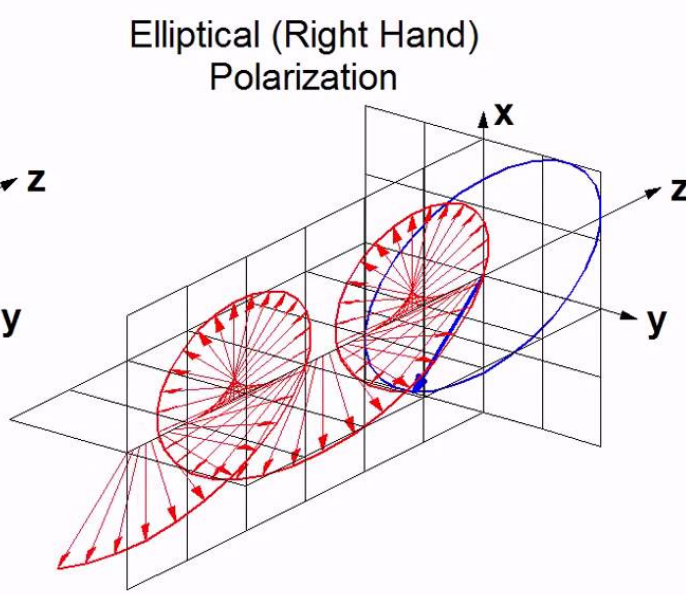
- GPS segments:
  - Space
  - Control
  - User
- Signal Structure:
  - L-band frequency



ELECTROMAGNETIC WAVE POLARISATION

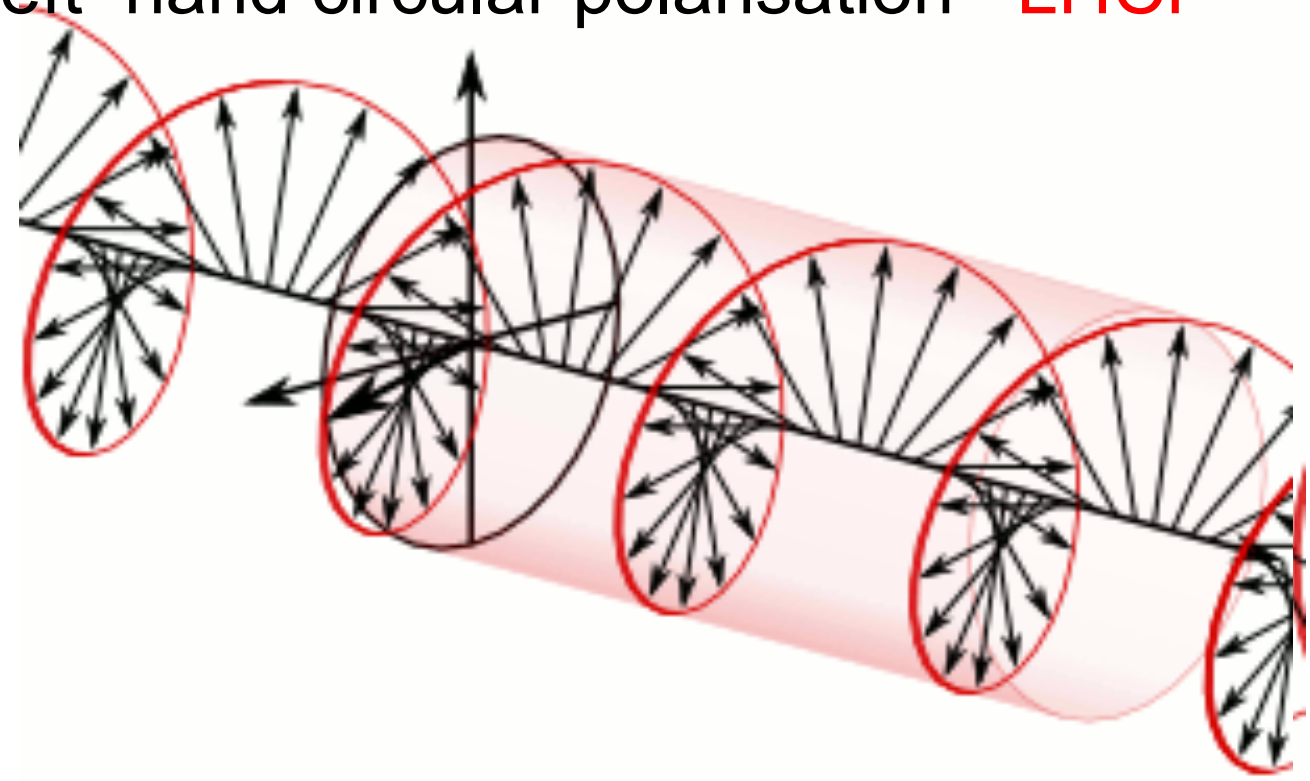






GPS signal polarisation

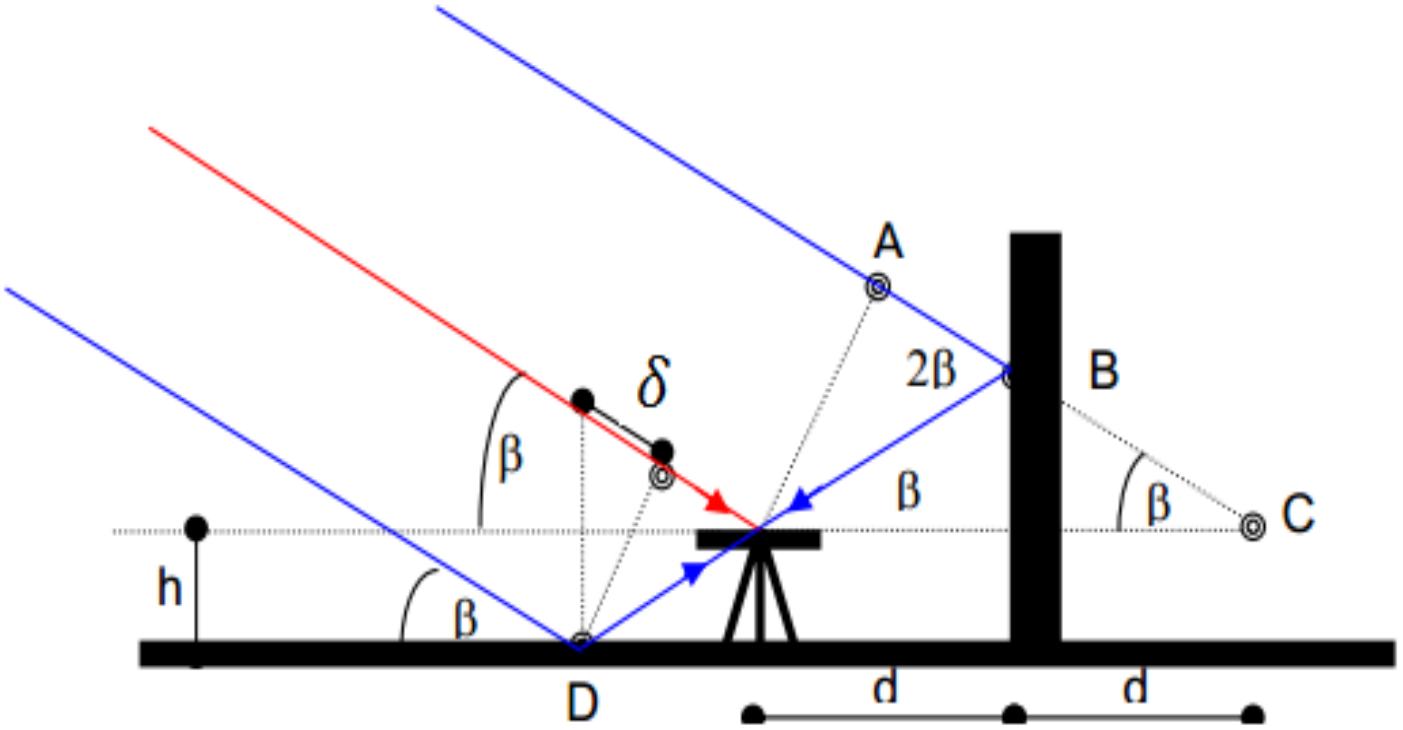
- Right hand circular polarization-RHCP
- Left hand circular polarisation –LHCP



MULTIPATH

- Beside direct signal, GNSS antenna receives the reflected signal.
- Reflected -”multipath signal” is delayed.
- Pseudorangs from reflected signals are longer than thuse from direct paths ⇨ user position biased.
- Multipath depends on the environment of GNSS antenna.
- Reflecting surfaces can be vertical, horizontal, or slanted.
- Reflectors can be at different distances from antenna
- Close reflectors effects strogner impact.

MULTIPATH



$$\delta = 2h \sin\beta$$

$$\delta = 2d \cos\beta$$

MULTIPATH

- User positions biased by multipath:
  - code pseudoranging: 10 -20 m (100 to ~300 m)
  - carrier phase mesurement: ~1cm
    - theoretically: λ/4 (~ 5 or 6 cm for L1 and L2)

SNR

- SNR (Signal to Noise Ratio) is a measure used to quantify how much a signal has been corrupted by noise.
- It is defined as the ratio of received signal power to the noise power corrupting the signal.
- SNR – is function of A_m, A_d i ψ
  - Amplitudes of reflected and direct signals, and relative phase multipath

$$\mathrm{SNR}^2 \equiv \mathrm{A}_\mathrm{C}^2 = \mathrm{A}_\mathrm{d}^2 + \mathrm{A}_\mathrm{m}^2 + 2\mathrm{A}_\mathrm{d}\mathrm{A}_\mathrm{m}\cos\psi$$

How to mitigate multipath?

- Differencing of the obesrvation equations or their linear cominations, many biases could be reduced, but not multipath.
- Multipath – still dominating errors.
- Different techniques developed to detect, estimate, filter, and reduce multipathe.
- Receivers architecture on the market apply various multipath mitigation techniques, as:
  - discriminator function shaping or
  - correlation function shaping

How to mitigate multipath?

Antennas designed to reduce multipath

Double polariside antennas

Choke-ring antenna

System of antennas

Example: Multipath investigation in B&H

WaSoft / Multipath

- detects and localizes multipath effects on phase measurements

- **Multipath map legend:**

(empty space) –no mesurements

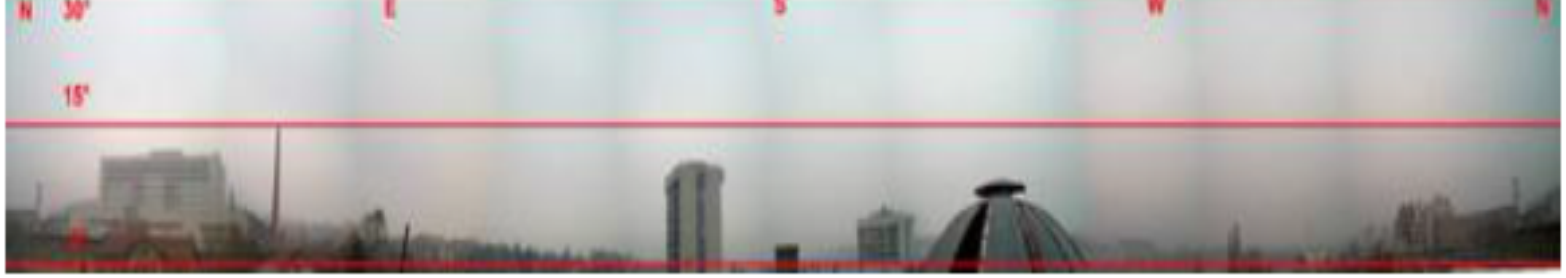
. (small) RMS up to 5 mm

1 (moderate) RMS up to 15 mm

2 (strong) RMS <15 mm.

Implementation for:

- CERGOP2/Environment and planned CORS-**BIHPOS**
- Year 2005
- **Results shows:**
- Simple maps
- Vector map



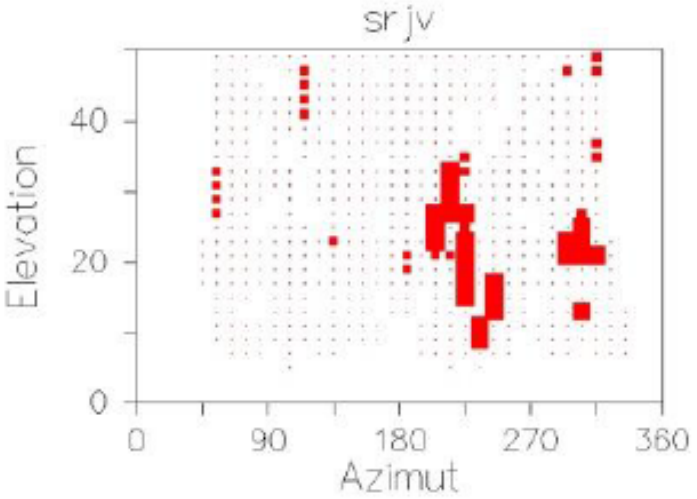
```
      .... .1 ............ ...1.1      47
      ....  1............. ... ..      45
      ......1............. ......      43
      ......1.......... .  . ....      41
      ... .... ........ . .. ....      39
      ... . ........... . ......1      37
      ..... ...........1........1      35
     1..... .........21..... ...      33
     1..... .........2..........      31
     1... . .........2..........      29
    .1... . ........222... ...1.      27
    ........ .......2.1.......2.      25
    .........1......2.2......22..      23
    ..............1.112......222.      21
    ........ .....1...2.... .....      19
    ...................2.2........      17
    ...................2.2........      15
    ... ..................2.....2...      13
     ............  ....2..........      11
     ............  ....2.. .......       9
      ... . ..     .......  .. ...       7
          .          . .              5
                                        3
                                        1

az        11111111112222222222333333  el
 123456789012345678901234567890123456  .
5555555555555555555555555555555555555  .
    srjv.map                           .

 Input files, multipath index:
  1  srjv171.map    12
  2  srjv172.map    21
  3  srjv173.map    15
  4  srjv174.map     7
  5  srjv175.map     5
 Mean index         12 +/- 2.8
```

MULTIPATH MAP (by WaSoft)

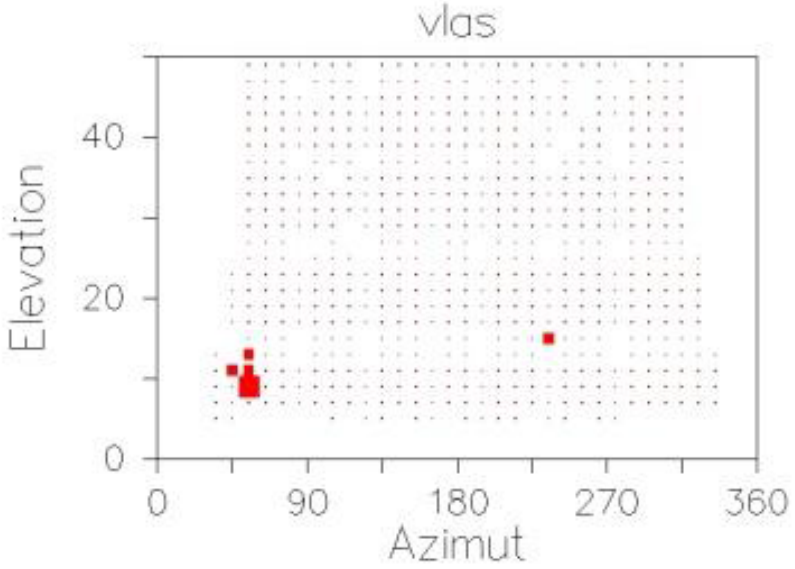
- SRJV EPN Station
  - Sarajevo, UNSA
  - Established 1999
- ⇦ Simple map; vector map ⇩



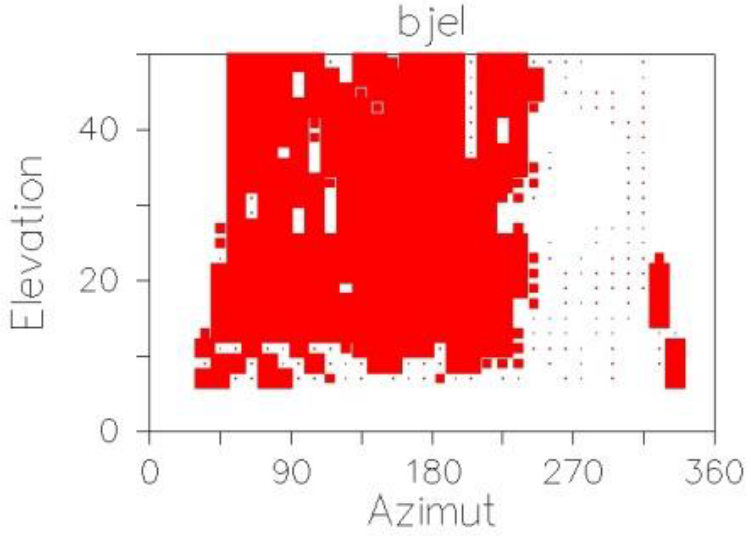
More data of MULTIPATH investigation in B&H

Examples of good and bad station multipath environment

Station on the mountain Vlašić



Olimpic Bjelašnica mountain



Can MULTIPATH be usefull?

- Manuel Martin-Neira: 1993, idea to use GPS reflected signals as tool for remote sensing.
- Specially designed instruments for remote sensing.
- SMOS (soil moisture and ocean salinity) satellite.
- GNSS-interferometric reflectometry, GNSS-IR
- Based on multipath effect: reflected GNSS signals
- GNSS-IR uses geodetic instruments

soil moisture

- *In situ* mesurement (area 1 m sq.)
- Satellite missions (1000 km sq.)
- GNSS-IR (area 1 km sq.)

SMOS satellite mission

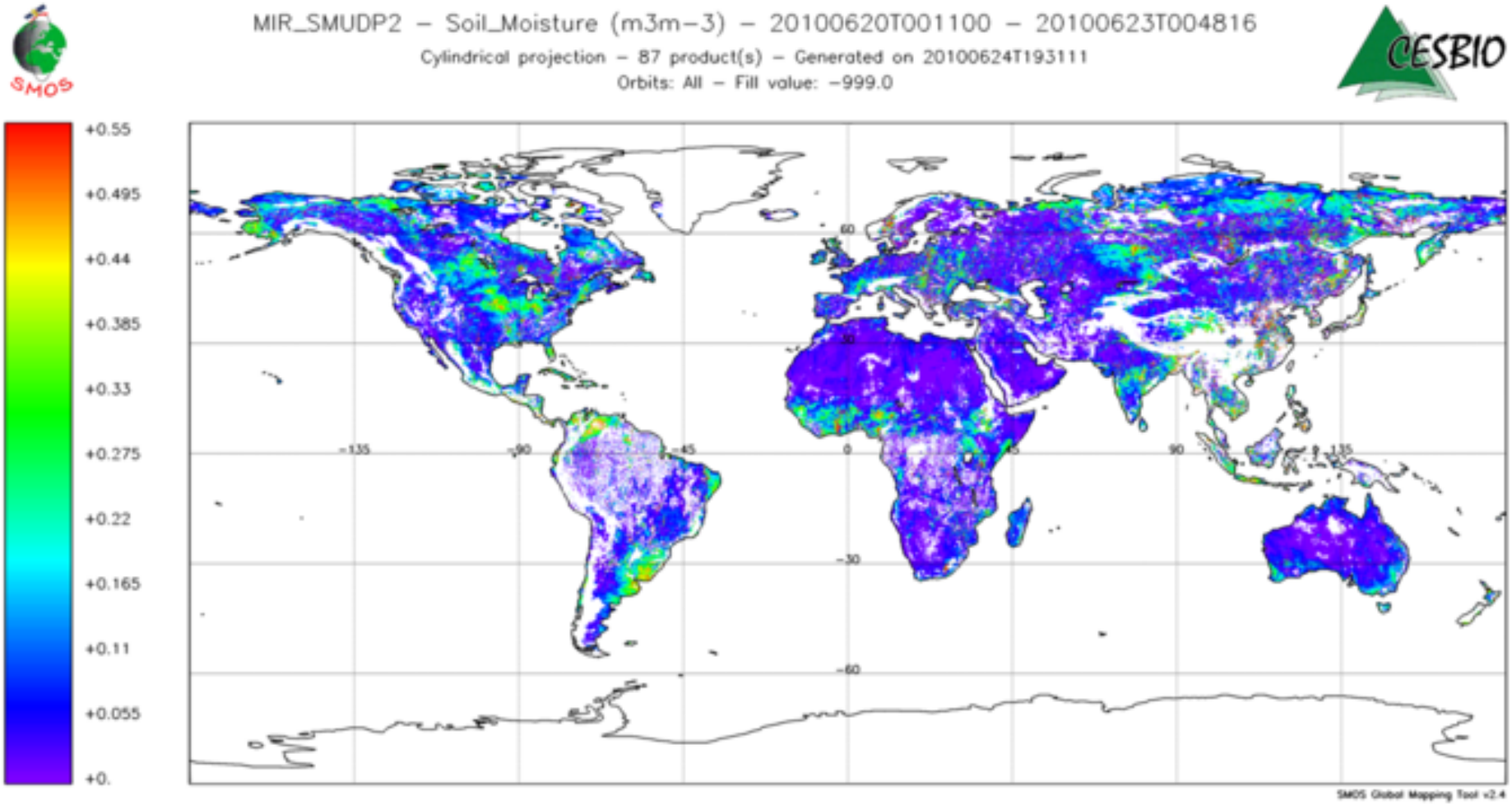
SMOS lunched 2009:

- Global maps of soil moisture every three days
- Altitude of 758 km
- SMOS antenna view an area almost 3000 km in diameter.

- Figure: ESA

SMOS- First map of global soil moisture retrievals

30/06/2010



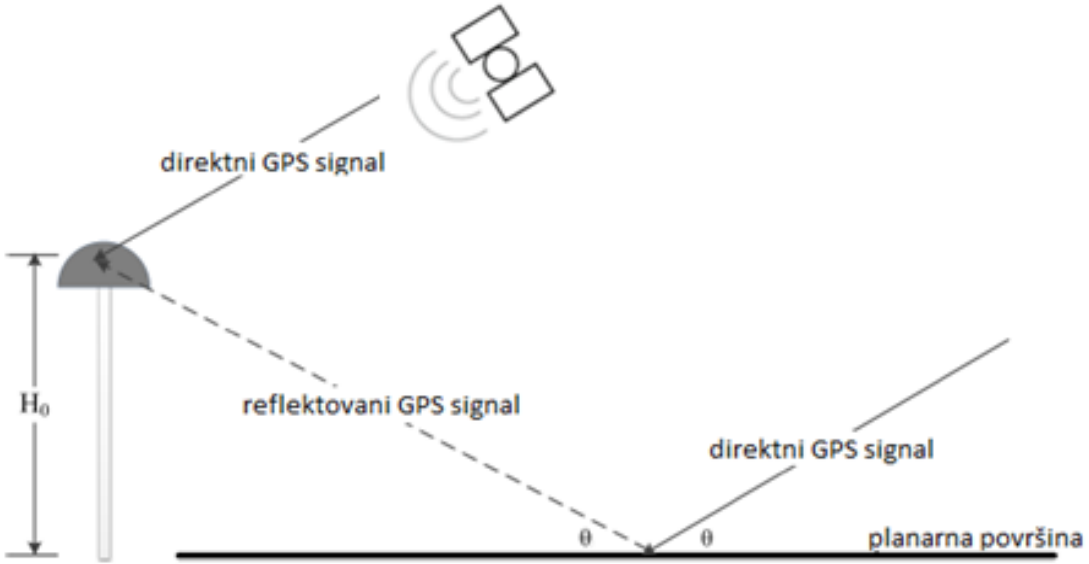
Credit by ESA

GNSS-IR

- GNSS (geodetic) receivers not designed to measure reflections, but it sowed that provide consistent measurements of:
  - Soil moistures (5 cm layer),
  - Measurement of snow depth,
  - Measurement of sea level changes (Larson, at.al., 2008, 2009, 2013)
  - Monitoring vegetation growing
  - Monitoring water content in the plants. (Wan at.al., 2014)
- GNSS-IR uses SNR data to provide information about environment characteristics.
- Interferences between direct and reflected signal produces characteristic pattern of SNR data.

GNSS-IR geometry: bi-static radar

- SNR pattern depend on antenna hight, reflective coeficient of the reflective surfaces, and for monitoring of plants it depend on the wather content in the plants.
- Significant possibility for the application in the precise firming.
- GNSS-IR has geometry of the bi-static radar



How to apply GNSS MULTIPATH effect ?

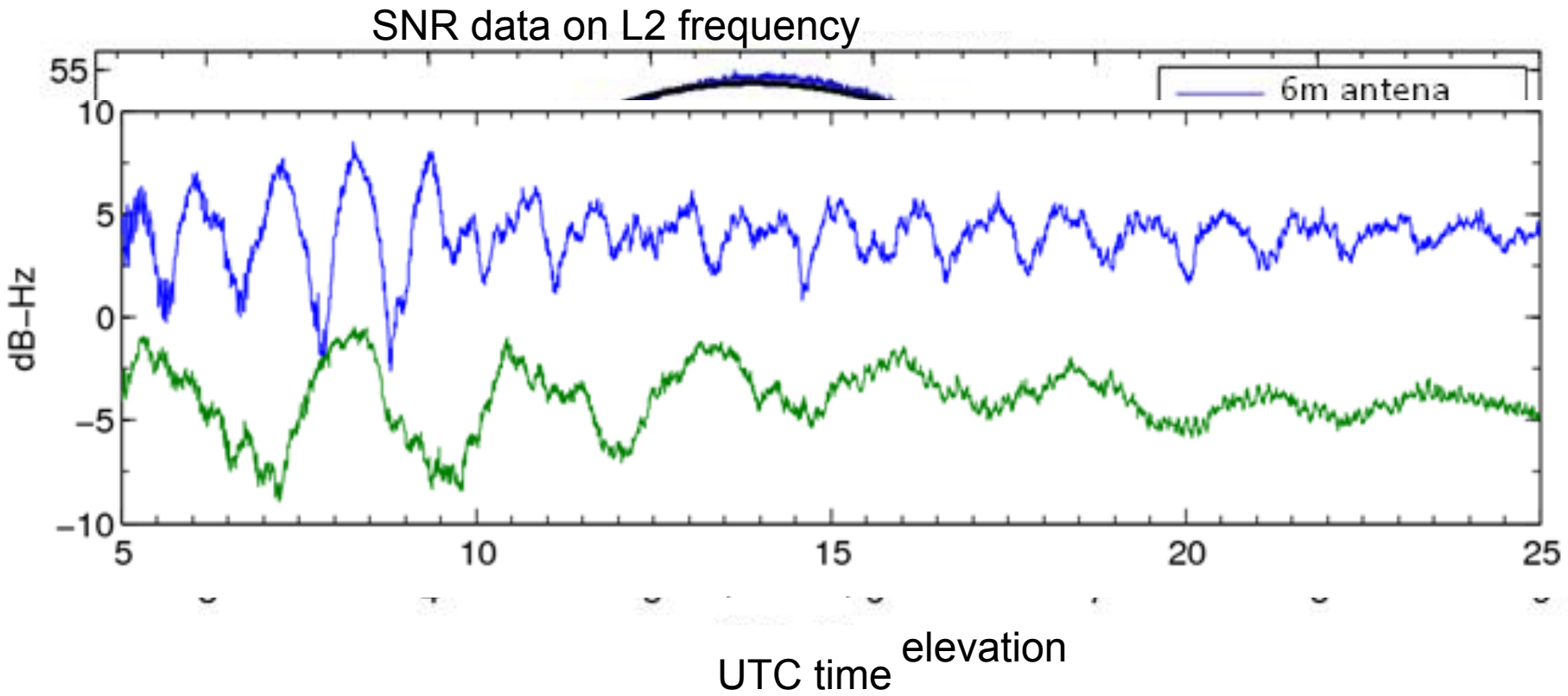
Methodology: Larson at al., (2007, 2010)

- SNR is sensitive to changes in the antenna environment
- GPS metrics:
  - Phase φ
  - Amplitude A
  - Frequency f of SNR oscillations
- Interference between direct and reflected signals has characteristic pattern of SNR.
- Direct signal separated from the reflected using the lower order polynomial.

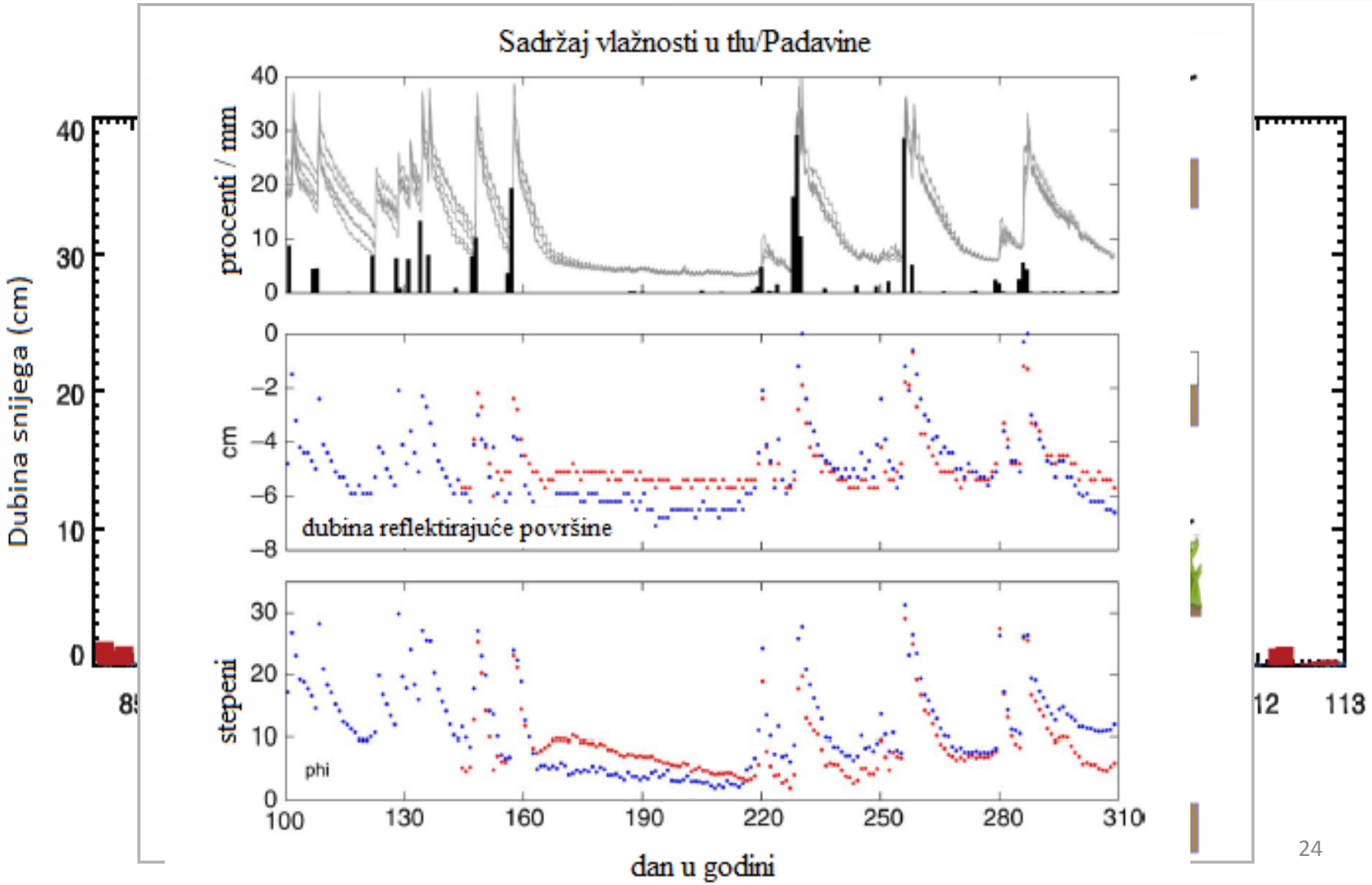
SOIL MOISTURE from SNR DATA

SNR after lower order polinomial applied

Lower order polynomial to apply



Researche results (Larson at al. 2010)

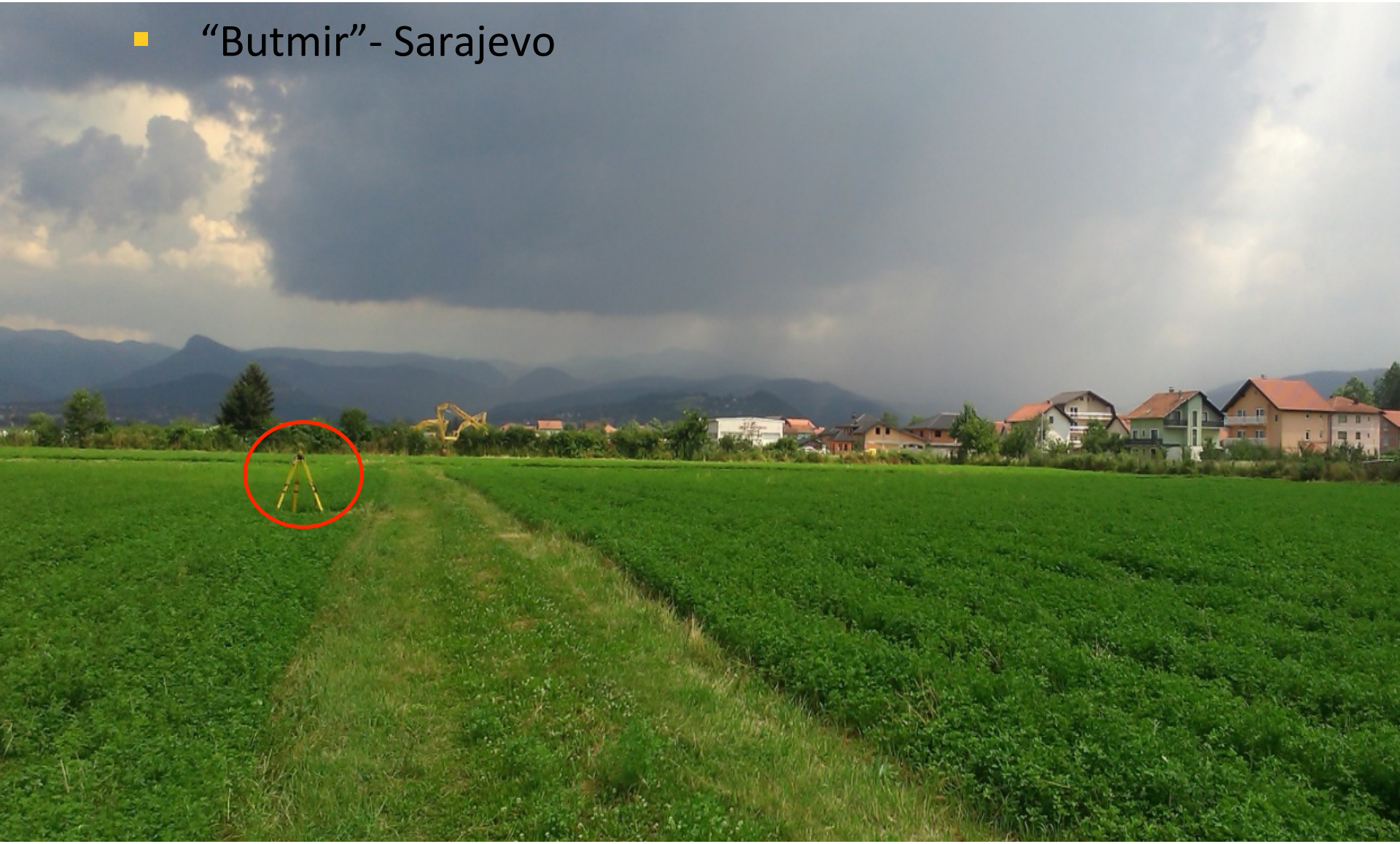


Implementation in Sarajevo

- Difficulties at the beginning: BIHPOS stations at the roofs
- Location for GPS test station:
  - to fulfill specific conditions
- Location established:
  - in cooperation with Faculty of the Agriculture of University of Sarajevo
- Observation in period from 15.7. to 19.7. 2014.
  - 196, 197, 198, 199 DOY 2014

Test field environment

- “Butmir”- Sarajevo



Opservations at the test field

Opservations at the test field

SNR values at L1 and L2 for PRN 12

SNR data extracted from RINEX

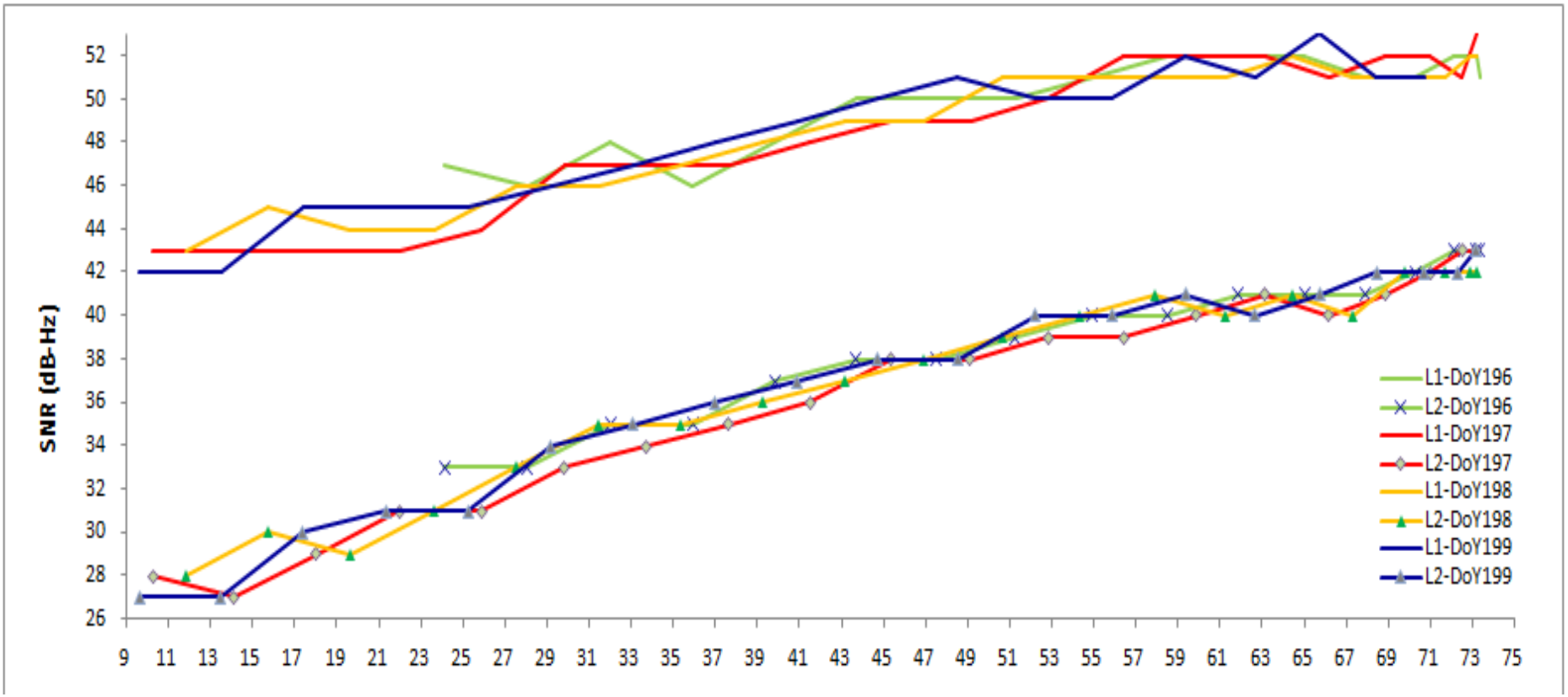
- teqc sofware used (UNAVCO)
- HERE presented data of (10 min):
- **PRN 12 (Block IIR-M)**
- **lounched 2006**
- Second civil L2C at L2,
- more strength for SNR data.
- **PRN 22 (BLOCK IIR)**
- **lounched 2003**
- Civil signala C/A at L1
- SNR data from new satellites more sensitive on SNR changes

PRN 12 (Block IIR-M)		
Elevation [deg]	S1 [dB-Hz]	S1 [dB-Hz]
24,097	47,0	33,0
28,034	46,0	33,0
31,968	48,0	35,0
35,889	46,0	35,0
39,789	48,0	37,0
43,655	50,0	38,0
47,473	50,0	38,0
51,225	50,0	39,0
54,889	51,0	40,0
58,434	52,0	40,0
61,818	52,0	41,0
64,981	52,0	41,0
67,835	51,0	41,0
70,259	51,0	42,0
72,090	52,0	43,0
73,149	52,0	43,0
73,303	51,0	43,0

SNR analyses

PRN 12 Block IIR-M: launched 17/11/ 2006

SNR for L1 and L2 frequencies: 196, 197, 198, 199 DOY 2014

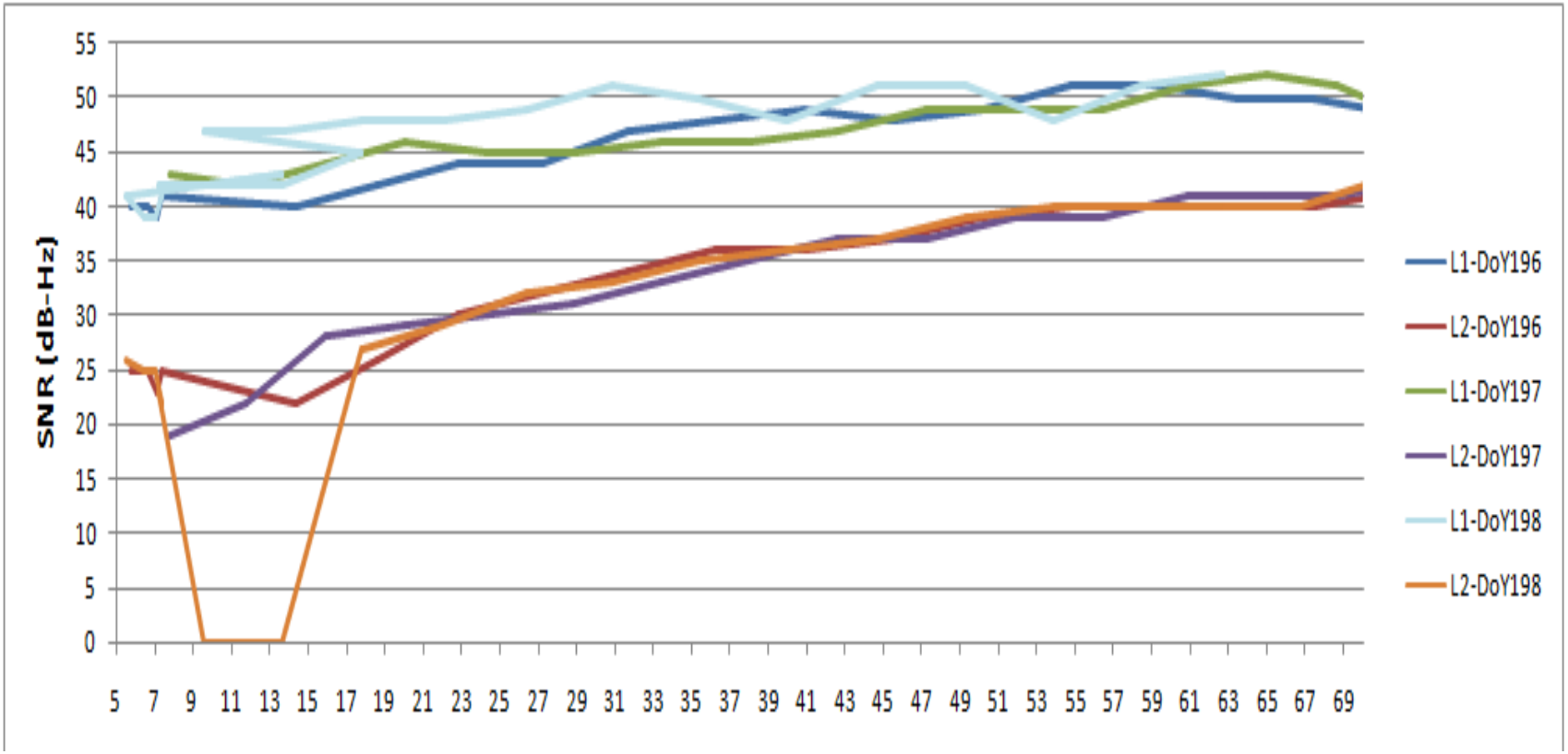


elevations (deg)

SNR analyses

PRN 22 Block IIR: **launched 21/Dec/2003**

SNR for L1 and L2 frequencies: 196, 197, 198, 199 DOY 2014



Conclusions

- Multipath is the dominant error source in high precision GNSS applications.
- Geodetic and navigation communities are focused to mitigate multipath.
- Multipath effect can be useful, for example:
  - to mesure soil moistures, ...what can be applied for agriculure and precisse farming.

Conclusions

- Soil moisture from GNSS multipath has some advantage over *in site* measurements.
- Data from new satellites (BLOCK IIR-M) more sensitive on SNR changes and more convenient for this tasks.
- Established project area in Bosnia and Herzegovina.

Future plan

- Plan to make an effort to develop a software to calculate soil moisture from GPS SNR data.
- Plannned to do it usung MatLab (to provide it first)
- Plan to establishe “Laboratory for atmosphere and space weather investigation”.

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Thank you for your attention!

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