



New GNSS Signals and Ambiguity Resolution

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Outline



- New GNSS and Modernization
- New Signals and Ambiguity Resolution
 - Basic Relations
 - Linear Combinations of Signals and their Properties
- Satellite Availability
- Simulations
- Standards for RTK
 - RTCM2, RTCM3
- Do we still need RTK Networks ?
- Summary

New GNSS and Modernization



- GPS will provide 3 carrier frequencies and new (civil) codes (L2C, L5, L1C)
- GLONASS will have „Full Constellation“ in 2007/2008 ?
- GLONASS will provide third frequency L3, $f_{L_3}(i) = 94/125 f_{L_1}(i)$?
- Galileo will be operational in 2011/2012 ?
- Galileo will provide up to 5 frequencies with different signals
- China announced the Compass GNSS 30 ? MEO's and 3 GEO's
- All together more than 75+ GNSS satellites will be available
- RINEX 3.0 defines 40+ different Code Signals and Combinations on 7+ Carrier Frequencies
- SBAS Augmentation's with L1/L5 (Egnos, WAAS, MSAS, QZSS...)

New GNSS and Modernization



- Modernized Codes have better noise and multipath characteristics
- Challenges for precise DGNSS and RTK Operation:
 - Interoperability of receivers/systems
 - Conventional Double Differencing may not be possible, due to different signals tracked by different receivers and channels
 - Each signal component will have its individual bias (group delay / hardware delay) induced by the satellite hardware (today: Differential Code Bias C1-P1) and receiver hardware
 - Biases will vary with time/temperature (Carrier Phase, Precise Codes)
 - Systems/Software more complex, higher computational load
- Development, Improvement and Application of Ambiguity Resolution Algorithms for Multiple Carrier Frequencies and Multiple Code Signals

Basic Relations between Different Signal Components



- Different Signals are effected by different Error Components
 - Satellite Induced Delays (Biases)
 - Delays within Satellite Hardware
 - Varying with Time/Temperature
 - Satellite Antenna PCV (Ground Calibration ?)
 - Calibration / Estimation / Elimination through Differencing
 - Dispersive Ionospheric Effects
 - First Order Effect:
 - Codes are delayed $\sim(1/f^2)$
 - Carrier Phases are advanced $\sim -(1/f^2)$
 - Higher order Effects
 - Order of Magnitude: Centimeters
 - Important for Global Applications
 - Effects Code-Carrier Combinations !

Basic Relations between Different Signal Components



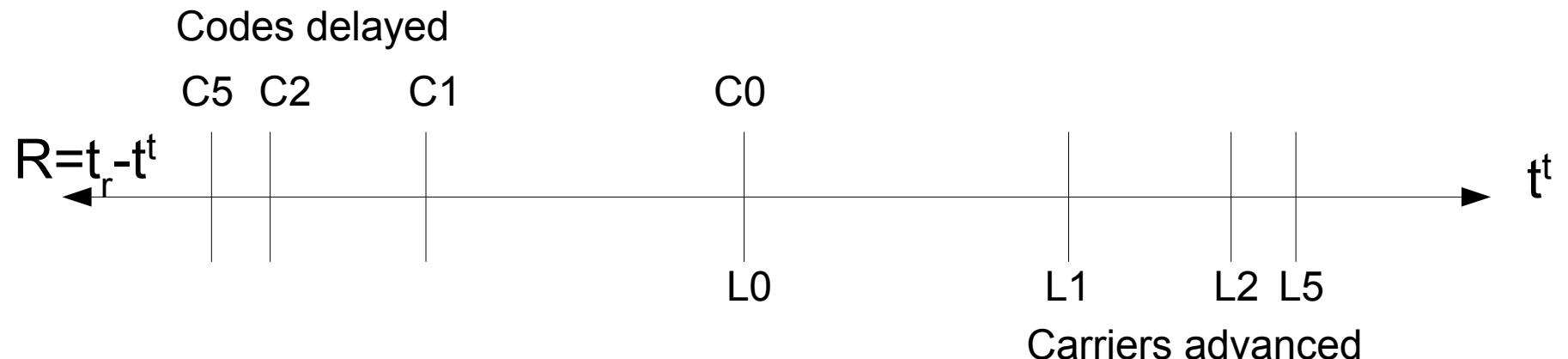
- Different Signals are effected by different error components
 - Tropospheric Delay
 - Non-Dispersive Effect, assumed to be **identical** for all Signal Components at Frequencies of interest.
 - Multipath Effects
 - Different for different Frequencies and Signal Components
 - Receiver Antenna PCV
 - Different for different Frequencies and Signal Components
 - Calibration
 - Receiver Hardware induced Delays
 - Varying with Time/Temperature
 - Elimination through Differencing between Satellites or
 - Parameters to be estimated within Applications

First Order Ionospheric Effect on Signal Components



- Signal Components received at the same time have different „apparent“ transmission times
 - Biases, Higher order Ionospheric effects, Multipath ignored:

Apparent GPS Signal transmission Time (First order Iono Effect):



- C1, C2, C5 – Code Epochs on L1, L2, L5 Carrier
- L1, L2, L5 – Carrier Phase Epochs
- C0, L0 – Ionospheric free (First Order) Linear Combination for Code (C0) and Carrier (L0)

Ambiguity Resolution Techniques (1)



- Geometry Free Ambiguity Resolution (GFAR)
 - Make use of Linear Combinations between Code and Carrier observables to resolve carrier ambiguities
 - All errors, except dispersive Ionosphere and individual errors for different signal components are eliminated
 - Technique in use since more than 20 years (Melbourne-Wübbena)
 - Higher performance with more frequencies and better code multipath rejection expected
 - In recent years known as TCAR, MCAR for more than 2 frequencies

Ambiguity Resolution Techniques (2)



- Geometry Based Ambiguity Resolution (GBAR)
 - Use Redundancy (more Satellites than needed for Position) to resolve Ambiguities
 - Adjustment or Filter Model: estimates all necessary Parameters (Coordinates, Orbits, Clock, Troposphere, Ionosphere, Biases,...) including the Carrier Phases Ambiguities
 - “Float” solutions -> fix to nearest integers
 - Ambiguity Search Algorithms (Lambda method etc.)
 - ...
- Combinations of GFAR and GBAR

Linear Combinations of Carrier Phases



Linear Combination with Integer Coefficients (n,m,k,...)

(==> Integer Ambiguity in resulting Phase)

$$\Phi_{n,m,k,\dots} = n * \Phi_1 + m * \Phi_2 + k * \Phi_3 \dots$$

Apparent Frequency:

Condition: Phases shall represent the same oscillator (if no Iono, Biases, Ambiguities, ...):

$$t = \frac{\Phi_{n,m,k,\dots}}{f_{n,m,k,\dots}} = \frac{\Phi_1}{f_1} = \frac{\Phi_2}{f_2} = \frac{\Phi_3}{f_3} = \dots$$

==>

$$f_{n,m,k,\dots} = n * f_1 + m * f_2 + k * f_3 \dots$$

Apparent Wavelength:

$$\lambda_{n,m,k,\dots} = \frac{c}{f_{n,m,k,\dots}} = \frac{1}{\frac{n}{\lambda_1} + \frac{m}{\lambda_2} + \frac{k}{\lambda_3} + \dots}$$

Linear Combinations of Carrier Phases



First Order Ionospheric Influence relative to L1

$$dI_{\phi,n,m,k,\dots}[m] = \left(\frac{n}{f_1} + \frac{m}{f_2} + \frac{k}{f_3} + \dots \right) * \frac{f_1^2}{f_{n,m,k,\dots}} * dI_{\phi,1}[m]$$

$$dI_{\phi,n,m,k,\dots}[m] = (n\lambda_1 + m\lambda_2 + k\lambda_3 + \dots) * \frac{\lambda_{n,m,k,\dots}}{\lambda_1^2} * dI_{\phi,1}[m]$$

First Order Ionospheric Amplification Factor (rel. to L1)

$$vI_{n,m,k,\dots} = \left(\frac{n}{f_1} + \frac{m}{f_2} + \frac{k}{f_3} + \dots \right) * \frac{f_1^2}{f_{n,m,k,\dots}} = (n\lambda_1 + m\lambda_2 + k\lambda_3 + \dots) * \frac{\lambda_{n,m,k,\dots}}{\lambda_1^2}$$

First Order Ionospheric Influence relative to L1 in Cycles

$$dI_{\phi,n,m,k,\dots}[cycles] = (n\lambda_1 + m\lambda_2 + k\lambda_3 + \dots) * \frac{1}{\lambda_1} * dI_{\phi,1}[cycles]$$

Noise: Phase Noise s [radians or cycles]:

(assumed to be the same for all original phases)

$$s_{n,m,k,\dots} = \sqrt{(n*n + m*m + k*k + \dots)} * s$$

Linear Combinations of Carrier Phases



- Caution: Amplification of Biases
 - A bias in one original phase will be amplified by the linear combination coefficient.
 - MP (Near Field, Far Field)
 - Biases 0.1 cycles or more
 - Antenna Phase Center Variations (PCV)
 - Calibration!
 - Keep n, m, k, etc. small for short observation times (Max. Coefficient 2, .3 ?)

Basic GPS Linear Combinations:



L1	L2	L5	Lambda [m]	VI1 [-]	VI1 [Cyc]	S [m]	S [Cyc]
Original							
1	0	0	0.1903	1.0000	1.0000	0.0019	0.0100
0	1	0	0.2442	1.6469	1.2833	0.0024	0.0100
0	0	1	0.2548	1.7933	1.3391	0.0025	0.0100
Narrow Lanes							
1	1	0	0.1070	1.2833	2.2833	0.0015	0.0141
1	0	1	0.1089	1.3391	2.3391	0.0015	0.0141
0	1	1	0.1247	1.7186	2.6225	0.0018	0.0141
Wide Lanes							
1	-1	0	0.8619	-1.2833	-0.2833	0.0122	0.0141
1	0	-1	0.7514	-1.3391	-0.3391	0.0106	0.0141
0	1	-1	5.8610	-1.7186	-0.0558	0.0829	0.0141

Some More GPS Linear Combinations:



L1	L2	L5	Lambda [m]	VI1 [-]	VI1 [Cyc]	S [m]	S [Cyc]
Low Ionosphere							
4	0	-3	0.1081	-0.0099	-0.0174	0.0054	0.0500
4	-1	-2	0.1102	0.0222	0.0384	0.0050	0.0458
Big Wavelength							
1	-2	1	1.0105	-1.2083	-0.2275	0.0248	0.0245
1	-3	2	1.2211	-1.1020	-0.1717	0.0457	0.0374
1	-4	3	1.5424	-0.9397	-0.1159	0.0786	0.0510
1	-5	4	2.0932	-0.6616	-0.0601	0.1357	0.0648

Some GLONASS Linear Combinations



L1	L2	L3	Lambda [m]	VI1 [-]	VI1 [Cyc]	S [m]	S [Cyc]
Original							
1	0	0	0.1871	1.0000	1.0000	0.0019	0.0100
0	1	0	0.2406	1.6531	1.2857	0.0024	0.0100
0	0	1	0.2489	1.7683	1.3298	0.0025	0.0100
Narrow Lanes							
1	1	0	0.1053	1.2857	2.2857	0.0015	0.0141
1	0	1	0.1068	1.3298	2.3298	0.0015	0.0141
0	1	1	0.1223	1.7097	2.6155	0.0017	0.0141
Wide Lanes							
1	-1	0	0.8421	-1.2857	-0.2857	0.0119	0.0141
1	0	-1	0.7546	-1.3298	-0.3298	0.0107	0.0141
0	1	-1	7.2596	-1.7097	-0.0441	0.1027	0.0141
Low Ionosphere							
4	0	-3	0.1073	0.0061	0.0106	0.0054	0.0500
Big Wavelength							
1	-3	2	1.0965	-1.1576	-0.1976	0.0410	0.0374
1	-4	3	1.2916	-1.0594	-0.1535	0.0659	0.0510
1	-5	4	1.5711	-0.9187	-0.1094	0.1018	0.0648

Basic Galileo Linear Combinations



L1	E6	E5b	E5	E5a	Lambda [m]	VI [-]	VI1 [Cyc]	S [m]	S [Cyc]
Original									
1	0	0	0	0	0.1903	1.0000	1.0000	0.0019	0.0100
0	1	0	0	0	0.2344	1.5178	1.2320	0.0023	0.0100
0	0	1	0	0	0.2483	1.7032	1.3051	0.0025	0.0100
0	0	0	1	0	0.2515	1.7474	1.3219	0.0025	0.0100
0	0	0	0	1	0.2548	1.7933	1.3391	0.0025	0.0100
Narrow Lanes									
1	1	0	0	0	0.1050	1.2320	2.2320	0.0015	0.0141
1	0	1	0	0	0.1077	1.3051	2.3051	0.0015	0.0141
1	0	0	1	0	0.1083	1.3219	2.3219	0.0015	0.0141
1	0	0	0	1	0.1089	1.3391	2.3391	0.0015	0.0141
0	1	1	0	0	0.1206	1.6079	2.5371	0.0017	0.0141
0	1	0	1	0	0.1213	1.6286	2.5539	0.0017	0.0141
0	1	0	0	1	0.1221	1.6498	2.5711	0.0017	0.0141
0	0	1	1	0	0.1250	1.7252	2.6270	0.0018	0.0141
0	0	1	0	1	0.1258	1.7477	2.6442	0.0018	0.0141
0	0	0	1	1	0.1266	1.7702	2.6610	0.0018	0.0141

Galileo Wide Lanes



L1	E6	E5b	E5	E5a	Lambda [m]	VI [-]	VI1 [Cyc]	S [m]	S [Cyc]
Wide Lanes									
1	-1	0	0	0	1.0105	-1.2320	-0.2320	0.0143	0.0141
1	0	-1	0	0	0.8140	-1.3051	-0.3051	0.0115	0.0141
1	0	0	-1	0	0.7815	-1.3219	-0.3219	0.0111	0.0141
1	0	0	0	-1	0.7514	-1.3391	-0.3391	0.0106	0.0141
0	1	-1	0	0	4.1865	-1.6079	-0.0731	0.0592	0.0141
0	1	0	-1	0	3.4477	-1.6286	-0.0899	0.0488	0.0141
0	1	0	0	-1	2.9305	-1.6498	-0.1071	0.0414	0.0141
0	0	1	-1	0	19.5368	-1.7252	-0.0168	0.2763	0.0141
0	0	1	0	-1	9.7684	-1.7477	-0.0340	0.1381	0.0141
0	0	0	1	-1	19.5368	-1.7702	-0.0172	0.2763	0.0141

Some other Galileo Linear Combinations



L1	E6	E5b	E5	E5a	Lambda [m]	VI [-]	VI1 [Cyc]	S [m]	S [Cyc]
Low Ionosphere									
5	-3	1	-4	2	0.1058	-0.0001	-0.0002	0.0078	0.0742
4	0	1	-3	-1	0.1087	0.0002	0.0003	0.0057	0.0520
4	0	0	-1	-2	0.1087	-0.0001	-0.0001	0.0050	0.0458
3	3	0	0	-5	0.1119	0.0002	0.0003	0.0073	0.0656
1	-3	1	-3	4	3.9074	-0.0012	-0.0001	0.2344	0.0600
Big Wavelength									
1	-3	1	-3	4	3.9074	-0.0012	-0.0001	0.2344	0.0600
0	2	-5	-2	5	14.6526	-0.7352	-0.0095	1.1159	0.0762
0	1	-1	-4	4	29.3052	-0.6340	-0.0041	1.7088	0.0583
0	1	-2	-1	2	11.7221	-1.3427	-0.0218	0.3707	0.0316

Linear Combinations of Code Phases



Divide Codes by Wavelength of corresponding Carrier Frequency
Apply Formulas for Linear Combination of Carrier Phases

Linear Combination with Integer Coefficients (n,m,k,...)

$$C_{n,m,k,\dots} = \lambda_{n,m,k,\dots} * (n * \frac{C_1}{\lambda_1} + m * \frac{C_2}{\lambda_2} + k * \frac{C_3}{\lambda_3} \dots)$$

First Order Ionospheric Influence relative to C1 [m]

$$dI_{C,n,m,k,\dots} = (\frac{n}{f_1} + \frac{m}{f_2} + \frac{k}{f_3} + \dots) * \frac{f_1^2}{f_{n,m,k,\dots}} * dI_{C,1}$$

Code Noise [m]:

$$s_{Code,n,m,k,\dots} = \sqrt{(\frac{n^2}{\lambda_1^2} s_{Code,1}^2 + \frac{m^2}{\lambda_2^2} s_{Code,2}^2 + \frac{k^2}{\lambda_3^2} s_{Code,3}^2 + \dots) * \lambda_{n,m,k,\dots}}$$

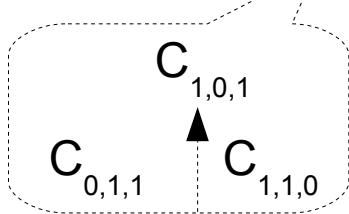
GPS Narrow and Wide Lanes



Apparent Signal Transmission Times:

Low Noise

Code Narrow Lanes



C5 C2 C1

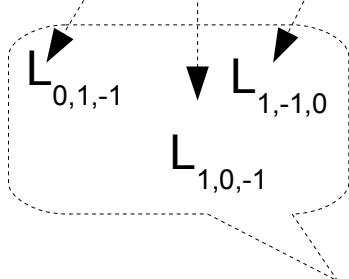
C0

L0

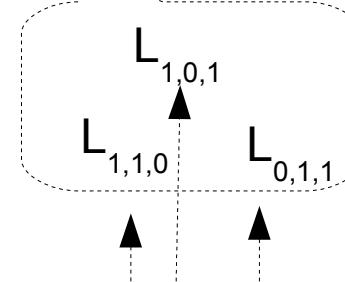
Originally
Non-Integer
LC

High
WL

Carrier Wide Lanes



Carrier Narrow Lanes

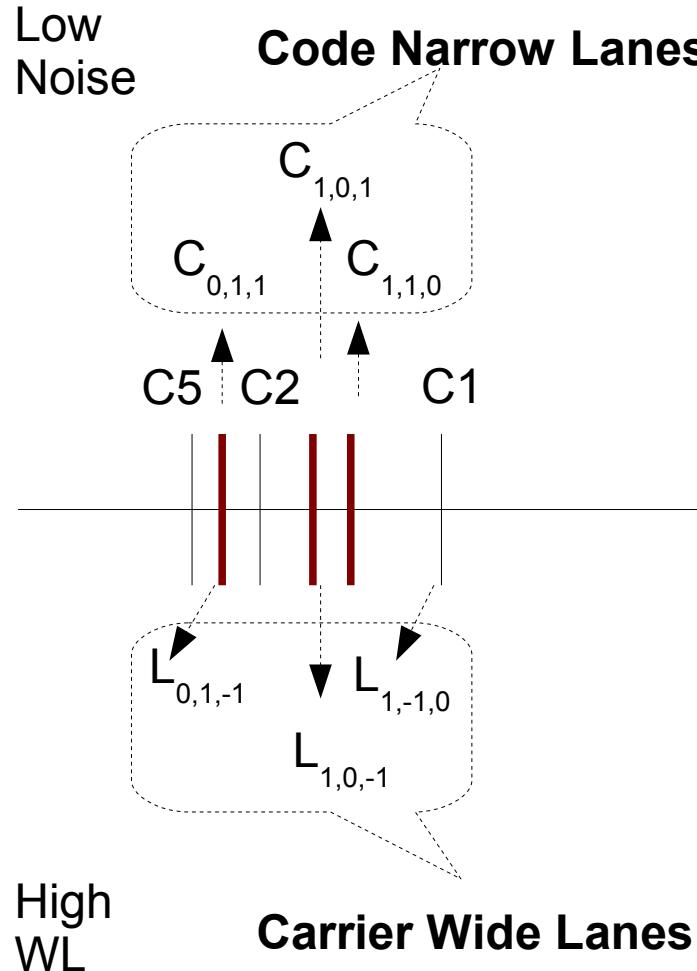


L1 L2 L5

Low Noise
WL ~ 11 cm

Code Wide Lanes with
big noise + MP amplification
not shown

GFAR Principle: Step 1: Solve n-1 Wide Lanes



Difference of Code Narrow Lanes and Carrier Wide Lanes directly provides Wide Lane Ambiguity

**Code MP+Noise Sufficient ?
HW Delays ==> Double Differences or Estimation**

GFAR Principle: After Step 1: Even-Odd Condition



If $N_i - N_j$ is even
then $N_i + N_j$ is even

Effective Narrow Lane WL increases by Factor: 2

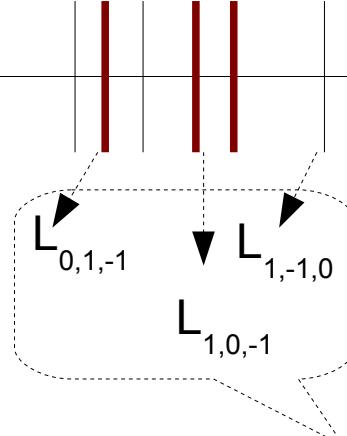
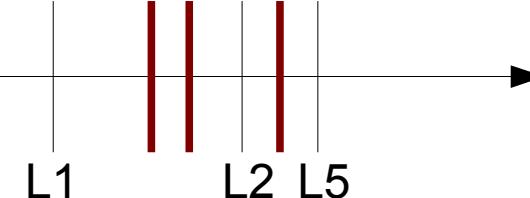
If $N_i - N_j$ is odd
then $N_i + N_j$ is odd

Carrier Narrow Lanes

Low Noise
WL ~ 21 cm

C5 C2 C1

C0



High
WL

**Carrier Wide Lanes
Ambiguities Resolved**

**Integer LC:
WL ~ 11 cm!**

**Same Ambiguity for all Narrow Lanes
And Ionospheric Free L0**

GFAR Principle: Step 2: Solve L0 Ambiguity



- Problem:
 - Code noise and MP too big to fix L0 or Narrow Lane Ambiguities
 - Knowledge of ionospheric effect can improve the estimation
 - Still no geometry involved

GFAR: Fixing Performance, No Iono Constraints



- Parameters used:
 - Phase Noise+MP: 0.01 cycles
 - Code Noise+MP: 0.2 m
 - S_i – Standard Deviation for Ambiguity before Fixing
 - WL_0 – effective Wavelength for L0 after Wide Lane Fixing
 - S . Standard Deviation of fixed L0

GNS S	Signals	S1 [Cyc]	S2 [Cyc]	S3 [Cyc]	S4 [Cyc]	S0 [Cyc]	WL_0 [m]	S [m]
G	L1+L2+L5	0.037	0.153			2.986	0.1086	0.0101
R	L1+L2+L3	0.034	0.157			3.278	0.1065	0.0100
E	E1+E5a+E5 b	0.032	0.163			3.272	0.1087	0.0099
E	E1+E6+E5a	0.055	0.131			2.363	0.1086	0.0104
E	E1+E6+E5a +E5ab+E5b	0.029	0.026	0.034	0.130	2.057	0.1091	0.0094

GFAR: Fixing Performance, No Iono Constraints



- Success Rates for Ambiguity Fixing:

GNSS	Signals	Rate1	Rate2	Rate3	Rate4	Rate0
G	L1+L2+L5	100.000	99.888			13.297
R	L1+L2+L3	100.000	99.854			12.121
E	E1+E5a+E5b	100.000	99.786			12.147
E	E1+E6+E5a	100.000	99.986			16.758
E	E1+E6+E5a+ E5ab+E5b	100.000	100.000	100.000	99.988	19.207

- High Success Rates for Wide Lanes
 - Low Multipath
- Very Low Success Rates for L0:
 - No solution! -> Iono constraints

GFAR: Fixing Performance, Iono Constraints: 0.1 m



GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	1.133	34.111	0.1091	0.0101
R	L1+L2+L3	1.161	33.330	0.1071	0.0100
E	L1+E5a+E5b	1.149	33.654	0.1093	0.0099
E	L1+E6+E5a	1.085	35.498	0.1092	0.0104
E	L1+E6+E5b+E5ab+E5a	1.054	36.493	0.1095	0.0094

GFAR: Fixing Performance, Iono Constraints: 0.05 m

GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	0.604	59.236	0.1108	0.0100
R	L1+L2+L3	0.614	58.441	0.1087	0.0099
E	L1+E5a+E5b	0.607	58.978	0.1108	0.0098
E	L1+E6+E5a	0.596	59.844	0.1110	0.0103
E	L1+E6+E5b+E5ab+E5a	0.591	60.257	0.1109	0.0094

GFAR: Fixing Performance, Iono Constraints: 0.02 m



GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	0.258	94.742	0.1211	0.0096
R	L1+L2+L3	0.262	94.396	0.1188	0.0095
E	L1+E5a+E5b	0.258	94.737	0.1207	0.0094
E	L1+E6+E5a	0.259	94.683	0.1222	0.0098
E	L1+E6+E5b+E5ab+E5a	0.254	95.055	0.1198	0.0090

GFAR: Fixing Performance, Iono Constraints: 0.01 m

GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	0.149	99.920	0.1461	0.0084
R	L1+L2+L3	0.151	99.906	0.1434	0.0083
E	L1+E5a+E5b	0.148	99.926	0.1451	0.0083
E	L1+E6+E5a	0.152	99.901	0.1483	0.0085
E	L1+E6+E5b+E5ab+E5a	0.144	99.949	0.1429	0.0081

GFAR: Fixing Performance, Iono Constraints: 0.005 m



GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	0.105	100.000	0.1840	0.0062
R	L1+L2+L3	0.107	100.000	0.1806	0.0062
E	L1+E5a+E5b	0.104	100.000	0.1831	0.0062
E	L1+E6+E5a	0.109	100.000	0.1852	0.0062
E	L1+E6+E5b+E5ab+E5a	0.098	100.000	0.1826	0.0061

GFAR: Fixing Performance, Iono Constraints: 0.001 m

GNSS	Signals	S0 [cyc]	Rate0 [%]	WL_0 [m]	S [m]
G	L1+L2+L5	0.087	100.000	0.2197	0.0029
R	L1+L2+L3	0.088	100.000	0.2158	0.0029
E	L1+E5a+E5b	0.085	100.000	0.2205	0.0029
E	L1+E6+E5a	0.092	100.000	0.2176	0.0029
E	L1+E6+E5b+E5ab+E5a	0.077	100.000	0.2269	0.0025



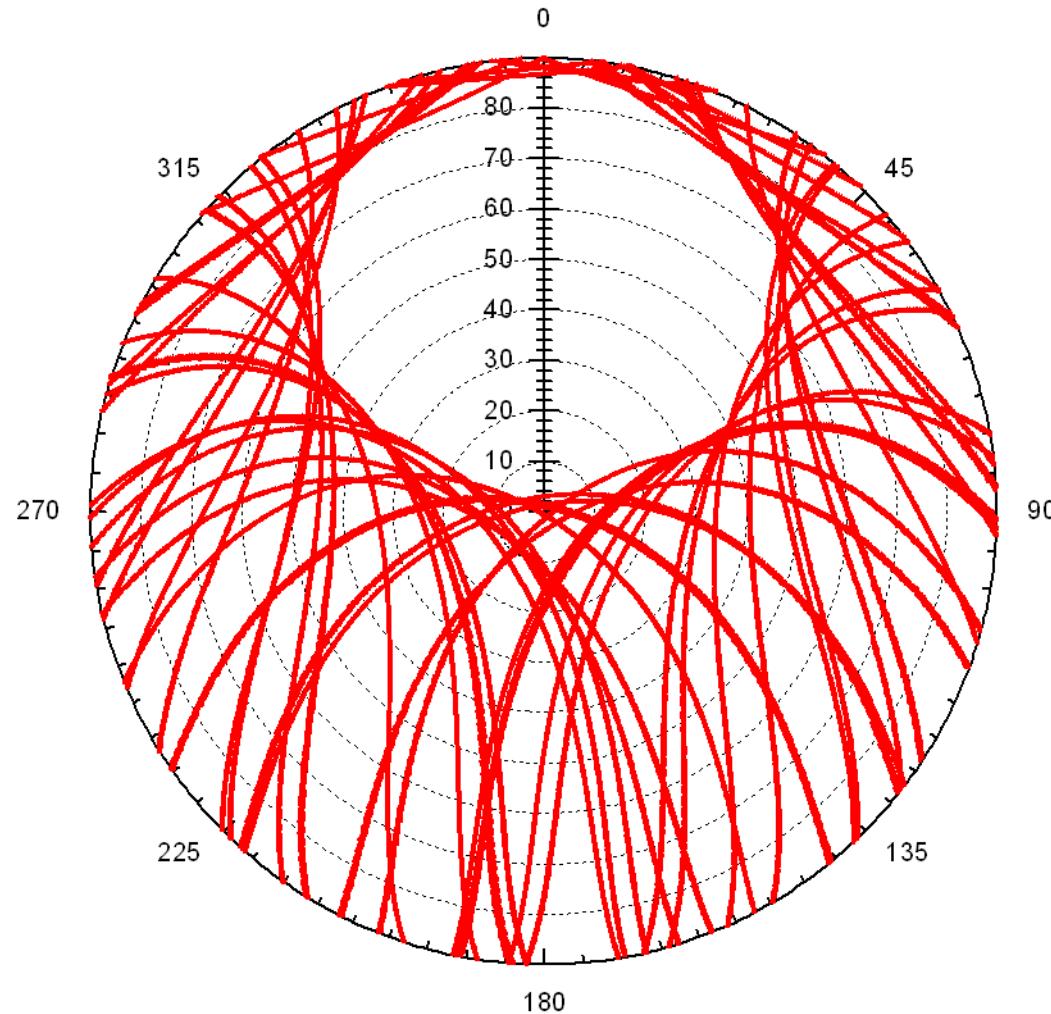
- Geometry Free Ambiguity Resolution resolves L0 Ambiguity only if the Ionospheric Influence is known with approx. 1 cm or better
- ==> use on short baselines
- ==> use in dense reference station networks
- A combination of Geometry Free and Geometry Based algorithm is necessary for other applications
- ==> Use Ambiguity Search Algorithms with GBAR
- Search Algorithms make use of Redundancy!
- More Satellites provide more Redundancy
- Effective Wavelength for L0 approx. 11 cm!

Satellite Availability

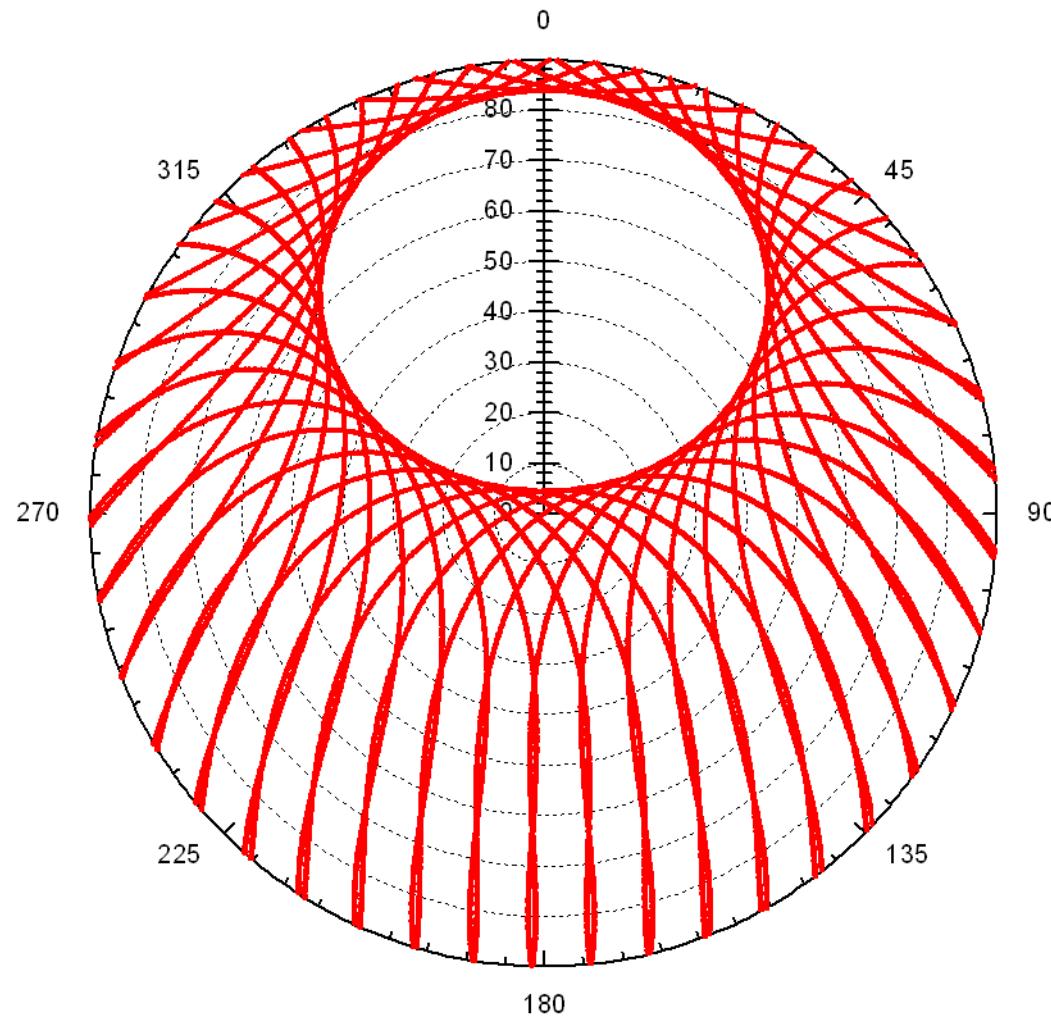


- Satellite Visibility Plots for Hannover, June 14, 2006 using
 - Current GPS Almanac
 - Galileo Constellation (Walker 27/3/1):
 - 3 Orbit Planes with 9 Satellites each
 - Altitude: 23616 km
 - Inclination: 56°
 - Ground Track repeating every 10 siderial days
 - GLONASS Constellation (Nominal Constellation)
 - 3 Orbit Planes with 8 Satellites each
 - Altitude: 19100 km
 - Inclination: 64.8°
 - Ground Track repeating every 8 siderial days

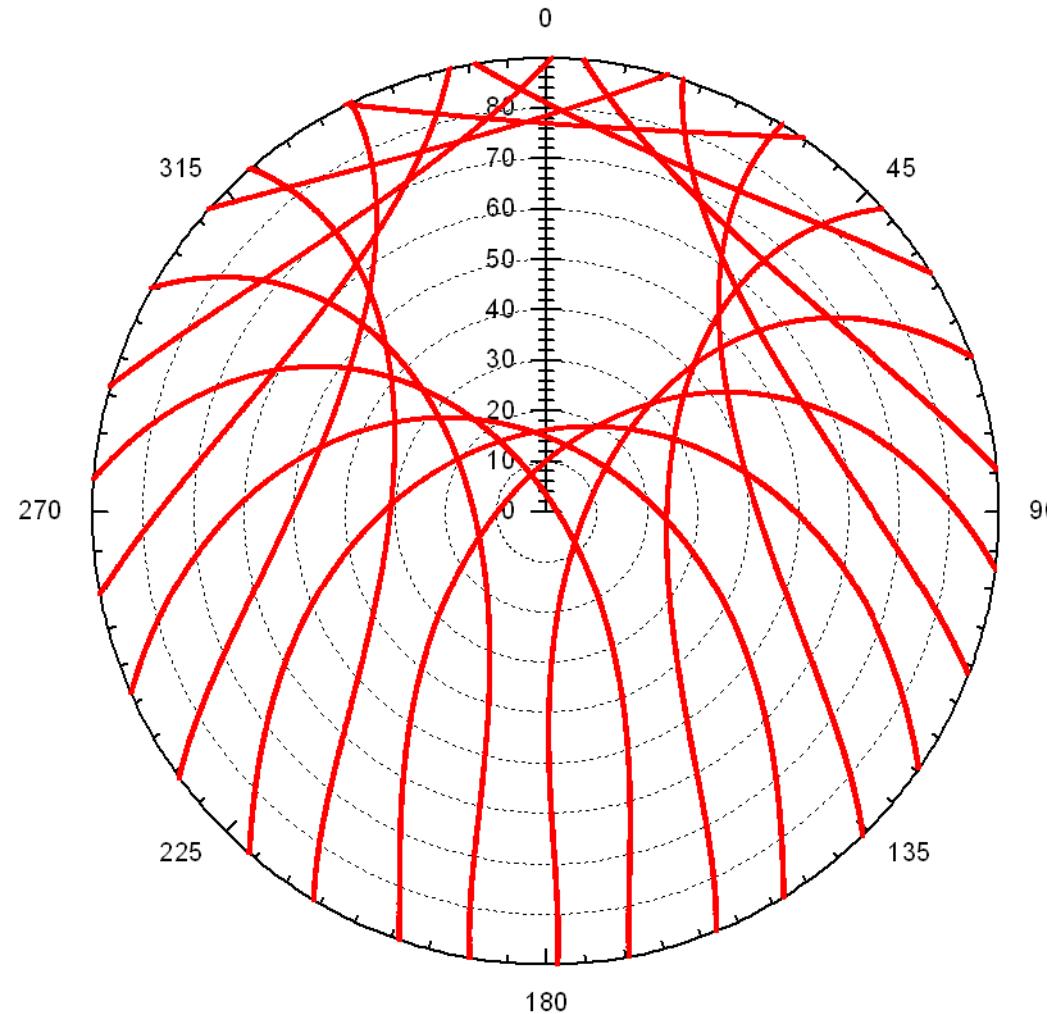
GPS Sky-Plot for Hannover 2006-06-14



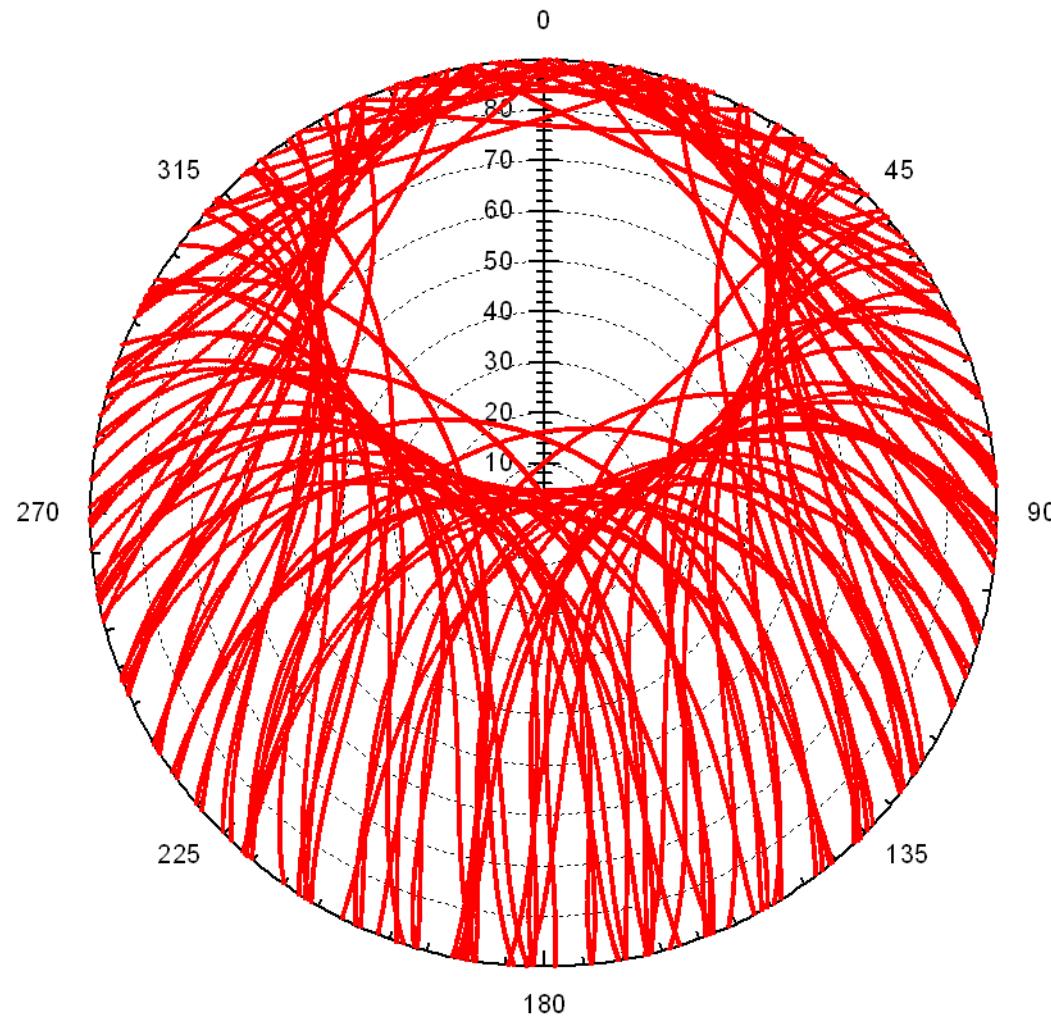
Galileo Sky-Plot for Hannover 2006-06-14



GLONASS Sky-Plot for Hannover 2006-06-14



GNSS Sky-Plot for Hannover 2006-06-14

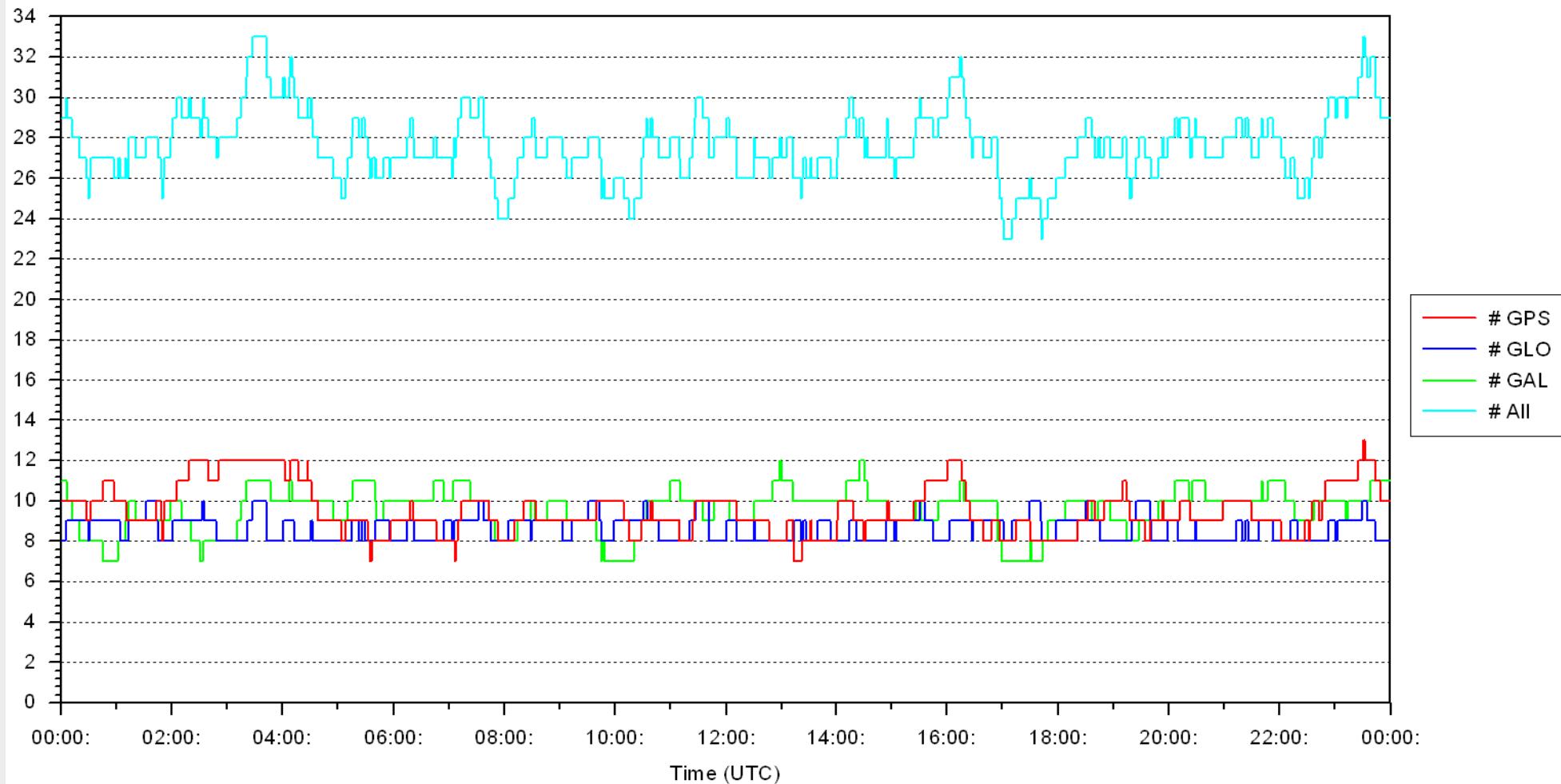


GNSS Visible Satellites for Hannover 2006-06-14



of Visible Satellites

Full GNSS Constellations (GPS,GLONASS,Galileo)



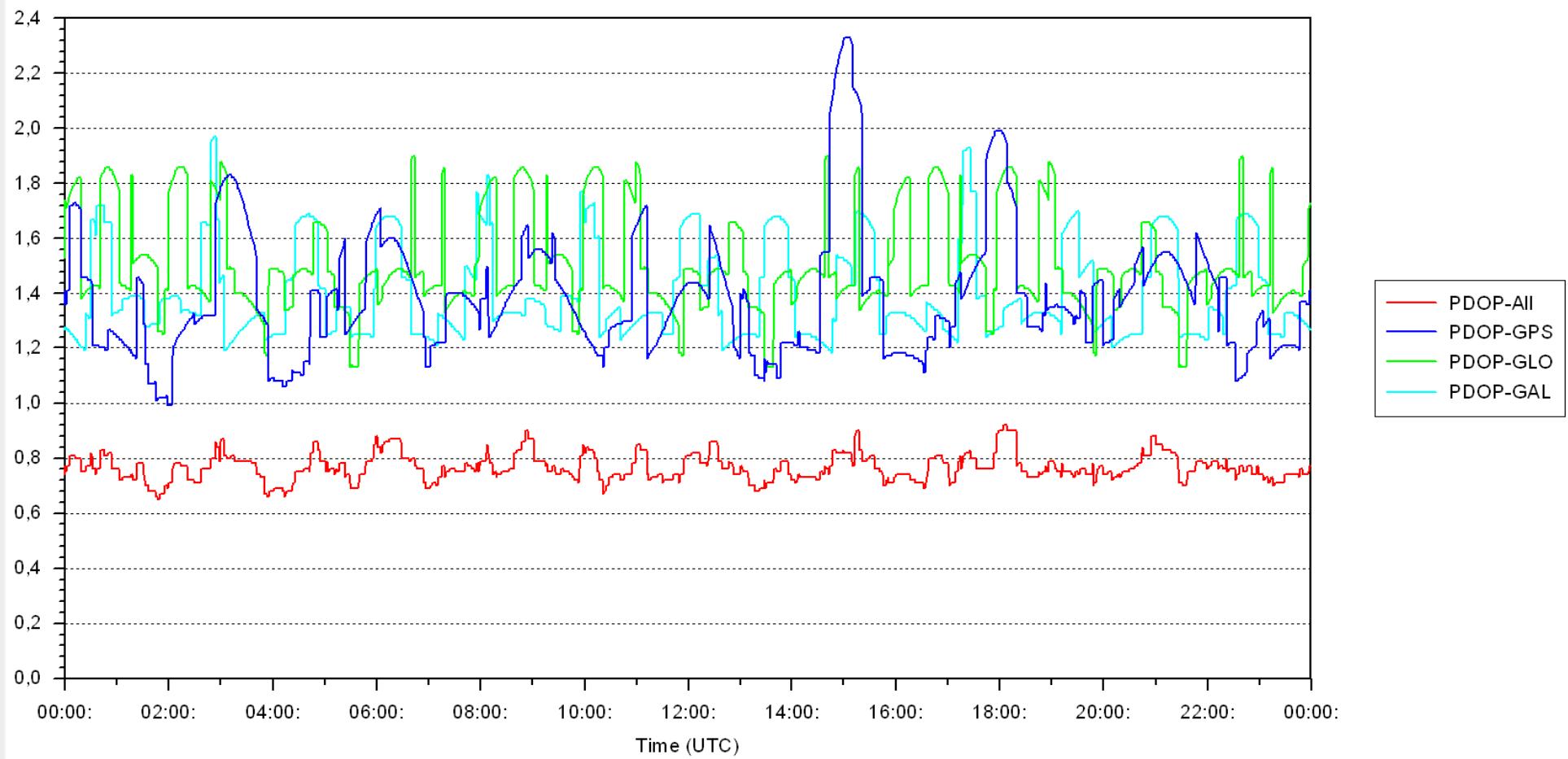
Hannover 2006-06-14 Elevation Mask: 5°

GNSS PDOP for Hannover 2006-06-14



PDOP

Full GNSS Constellations (GPS,GLONASS,Galileo)

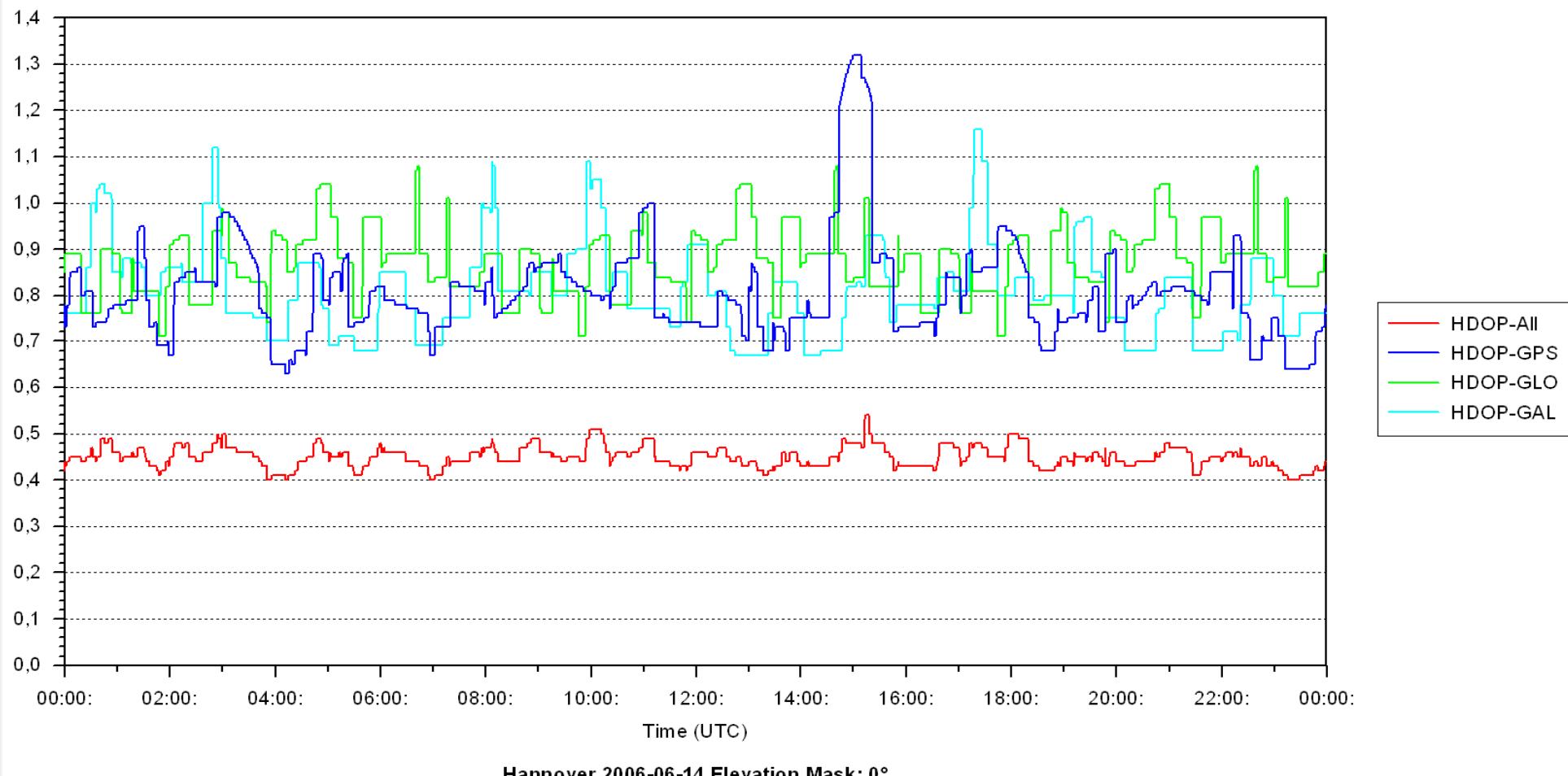


GNSS HDOP for Hannover 2006-06-14



HDOP

Full GNSS Constellations (GPS,GLONASS,Galileo)

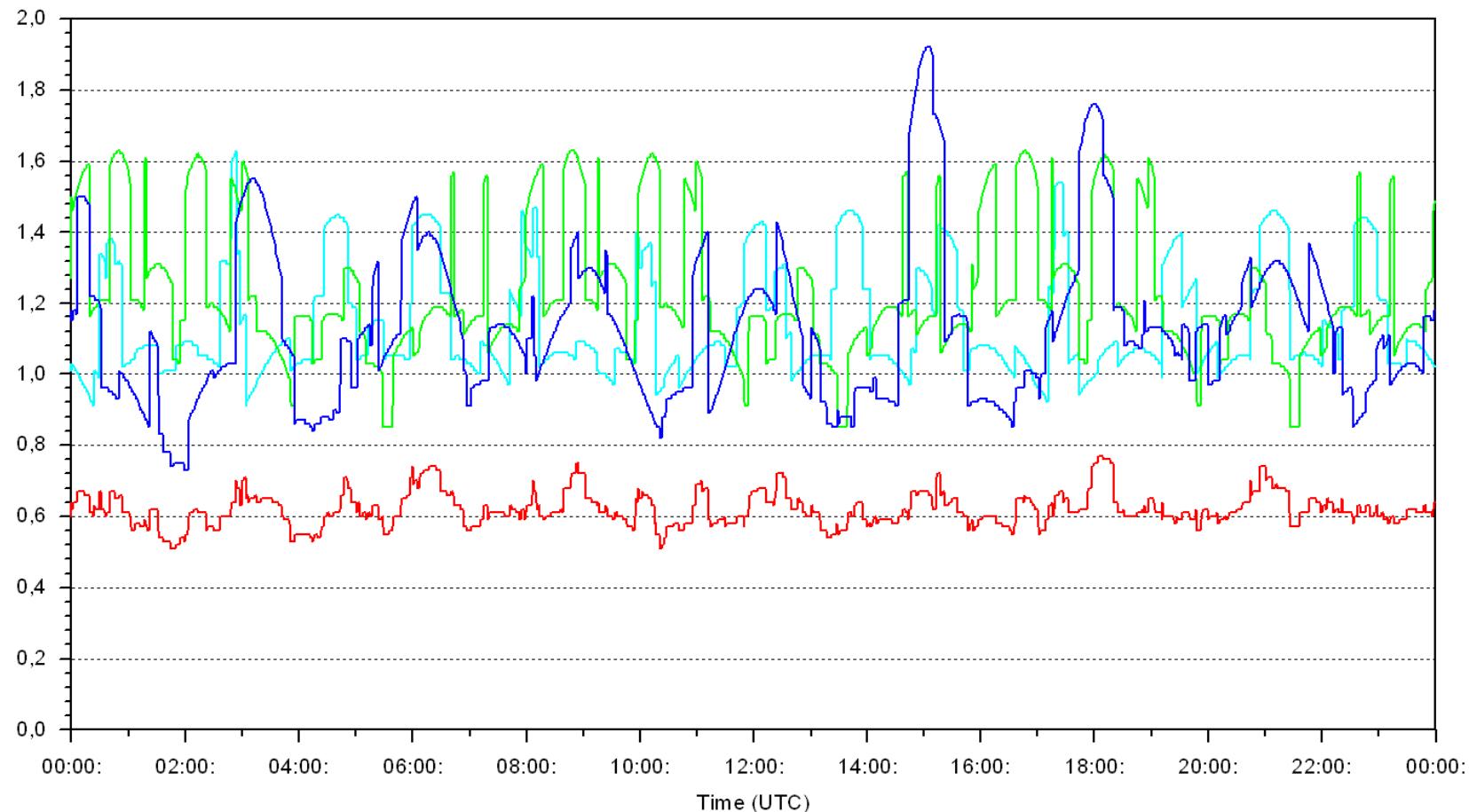


GNSS VDOP for Hannover 2006-06-14



VDOP

Full GNSS Constellations (GPS,GLONASS,Galileo)



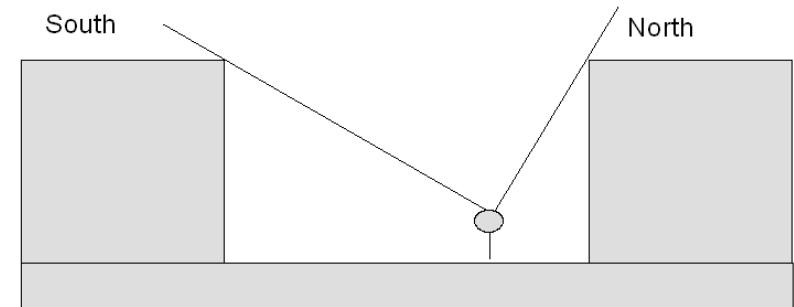
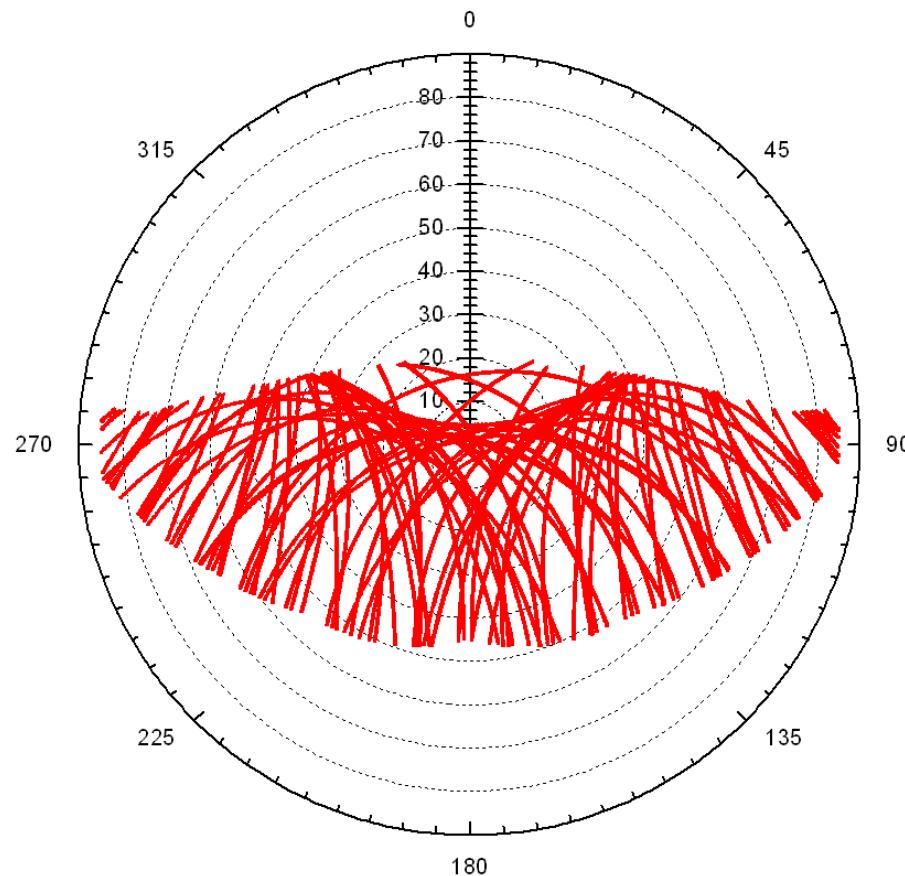
Hannover 2006-06-14 Elevation Mask: 0°

GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (East-West)

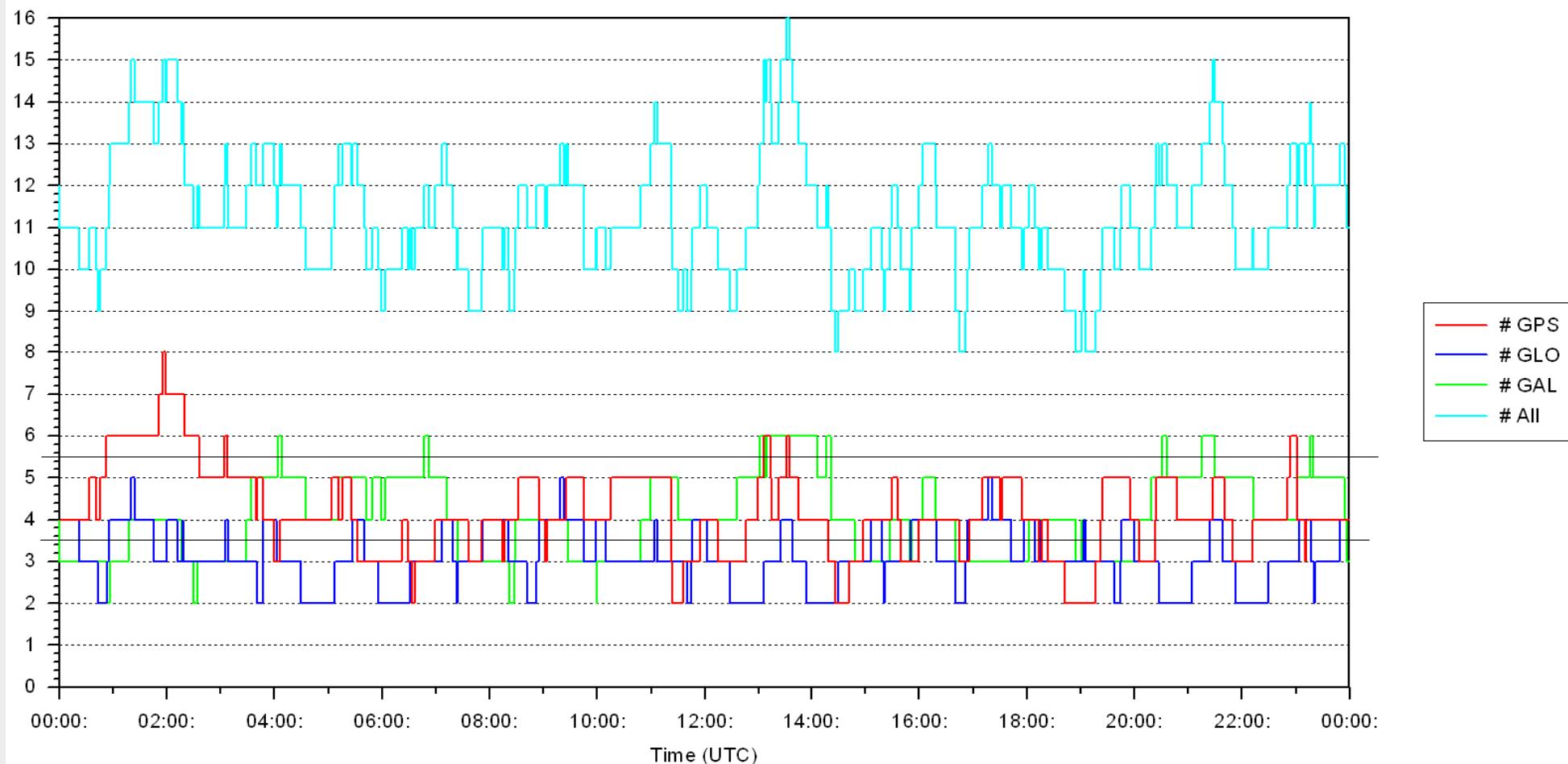


GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (East-West)

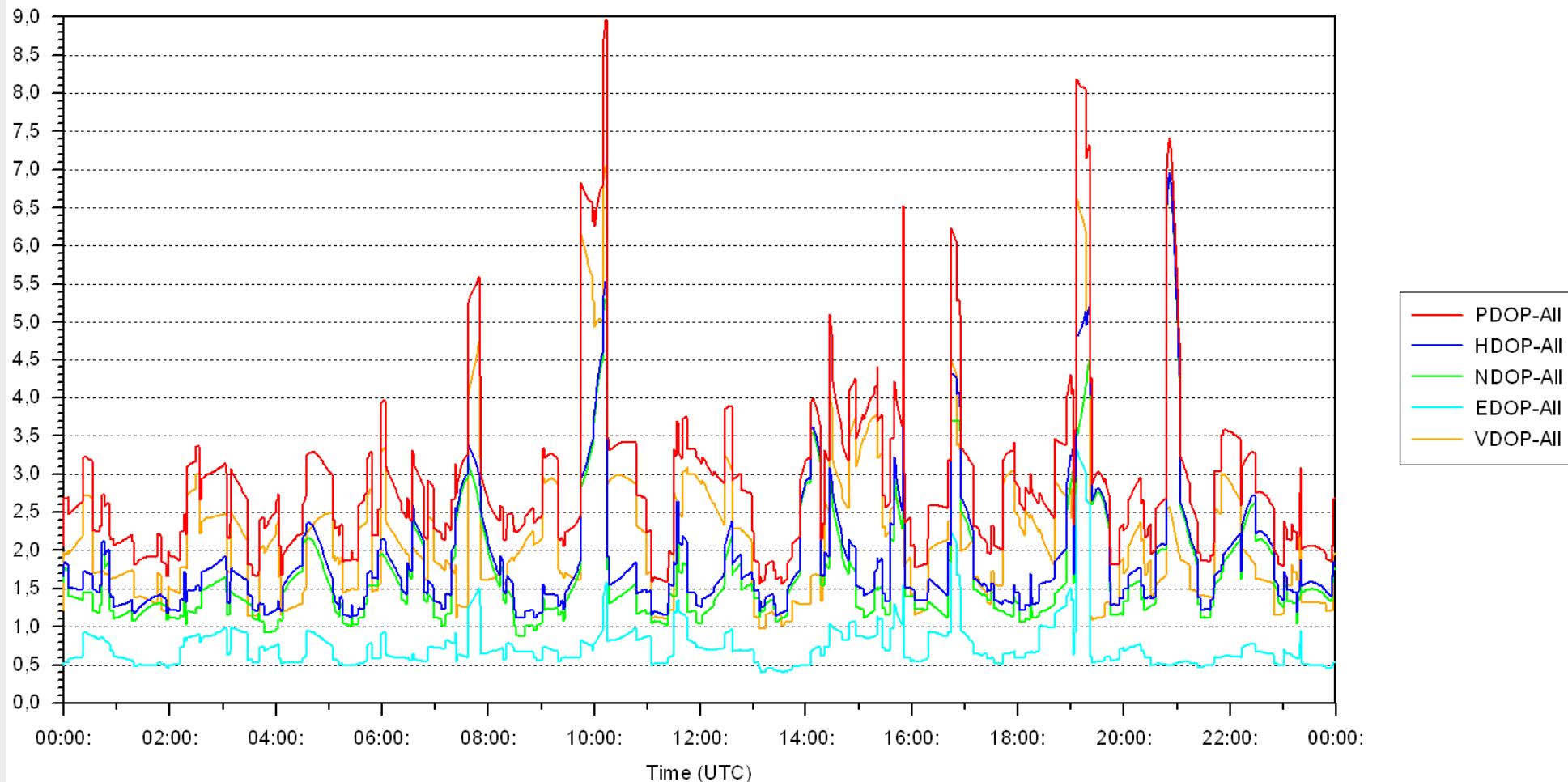


GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (East-West)

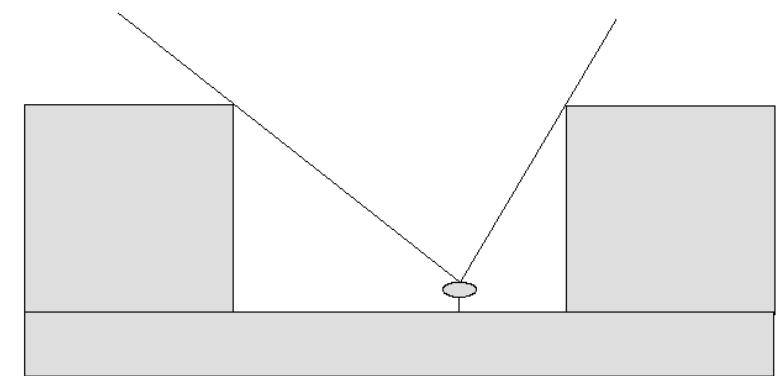
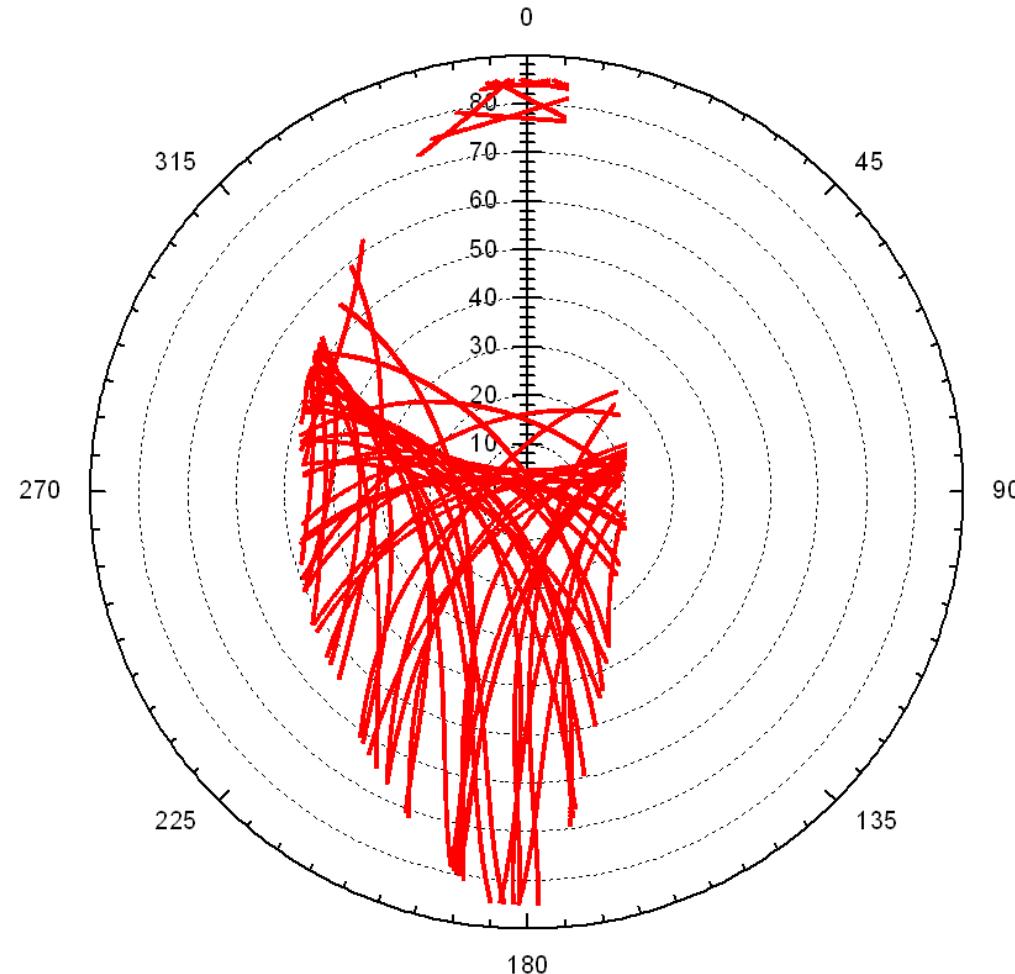


GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (North-South)

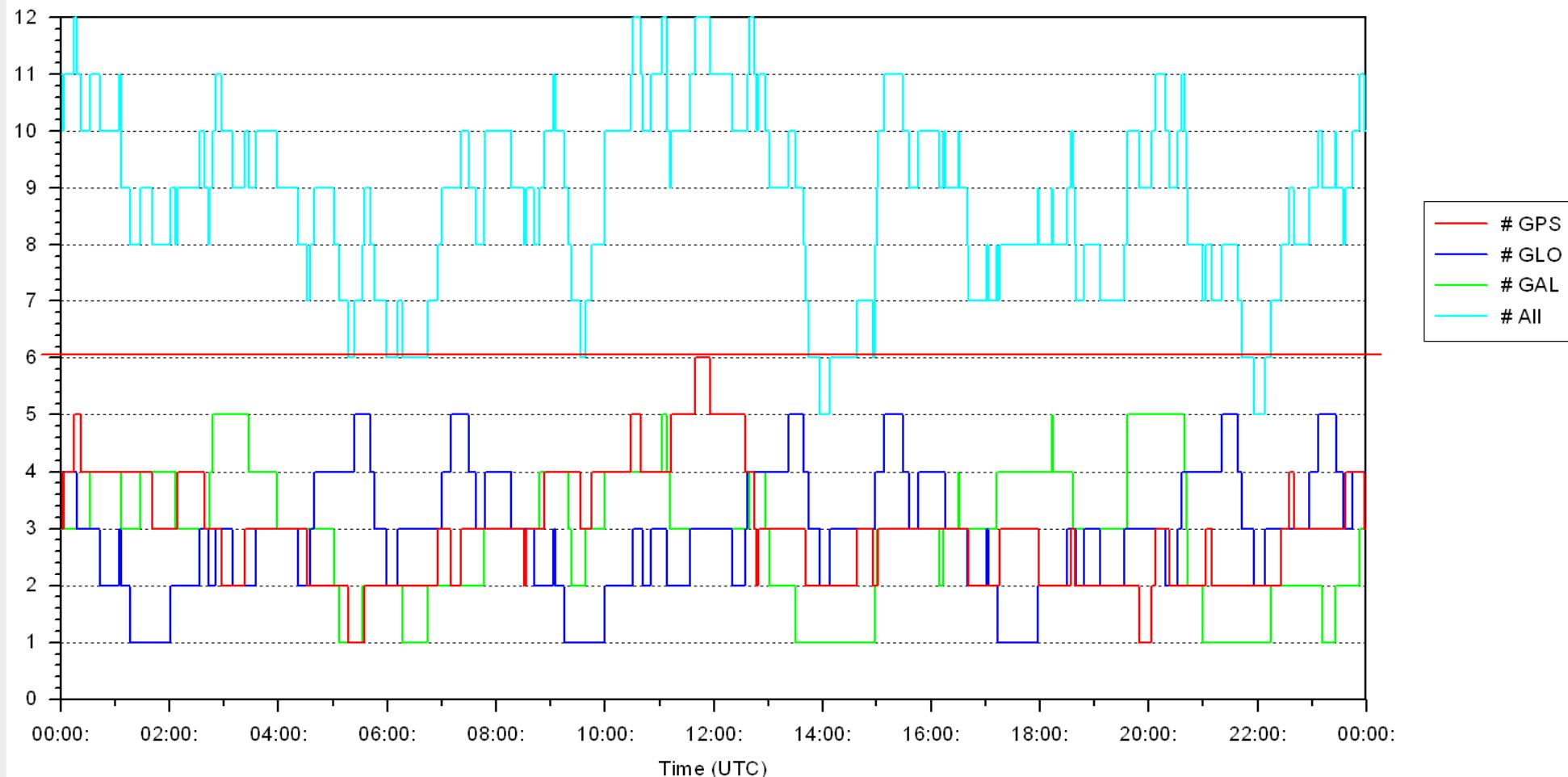


GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (North-South)

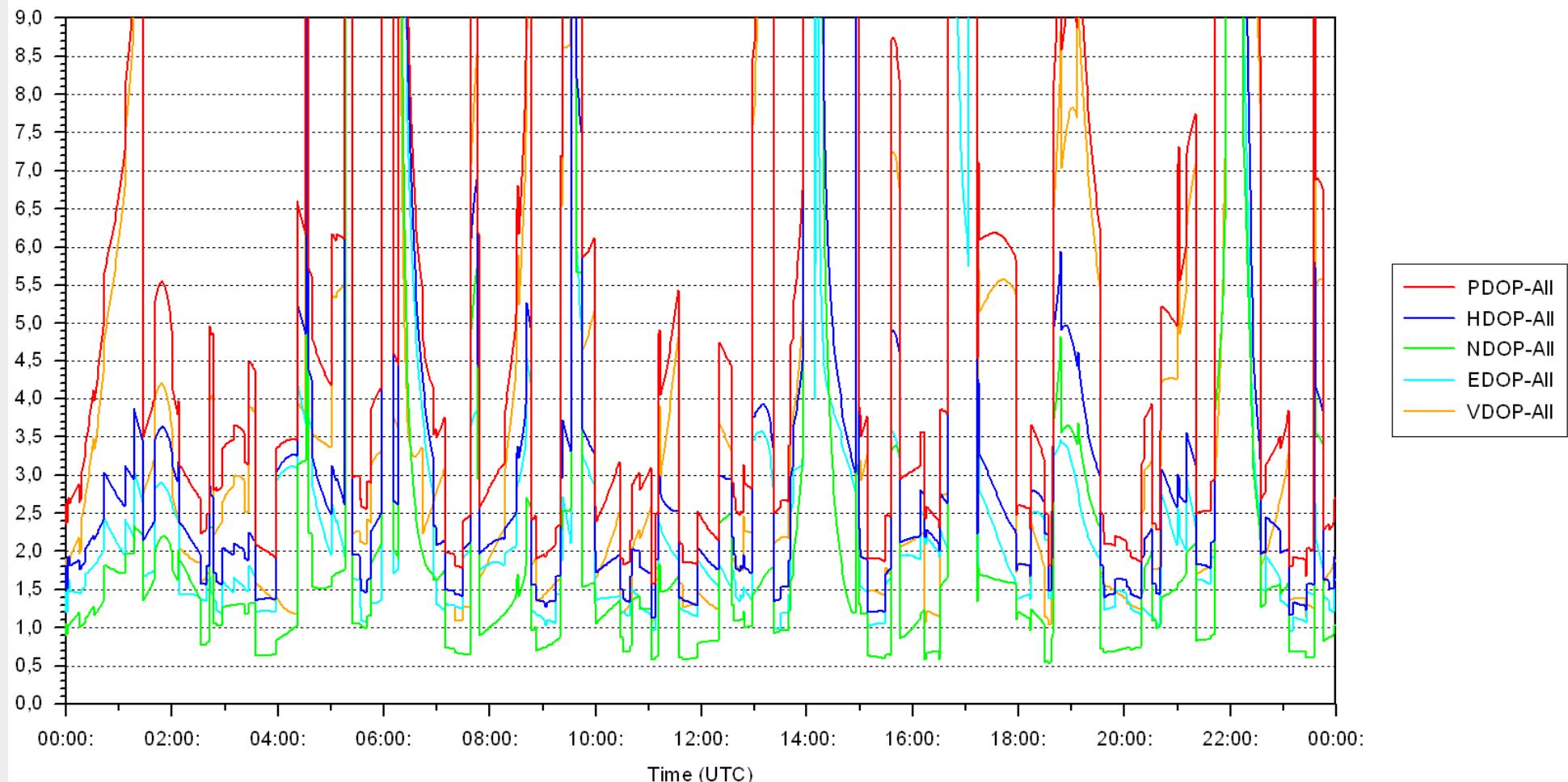


GNSS Improvement of Availability in Obstructed Areas



Obstructions

Urban Canyon (North-South)





- General Properties
 - Simulation of residual errors for Ionosphere and Troposphere
 - Individual residual Ionosphere for all satellites
 - Random walk process (0.01 m variation RMS per Second)
 - tropospheric Zenith Delay residuals as Gauss-Marcov process
 - No residual orbit errors
 - Precise RT orbits from RT network
 - Simulation of white noise for observations
 - Simulation of Multipath as Gauss-Markov processes for all individual signals (Phase: 2mm/60 s, Code 0.2m/60s)
 - Kalman filter for all simultaneous observations
 - Estimation of Coordinates, Ambiguities, ZD, Individual IONO, Signal Delays
 - Ambiguity resolution with Ambiguity Search algorithm



- Signal Variations

- Signal Set 1:

- GPS: L1, L2 and L5
 - Galileo: L1,E6,E5b,E5a+b,E5a
 - GLONASS: L1,L2,L3

- Signal Set 2:

- GPS: L1, L2 and L5
 - Galileo: L1,E5b,E5a
 - GLONASS: L1,L2,L3

- Signal Set 3:

- GPS: L1 and L5
 - Galileo: L1 and E5a
 - GLONASS: L1 and L3b



- Signal Variations
 - Signal Set 4:
 - GPS: L1, L2 and L5
 - Galileo: L1, E5b and E5a
 - Signal Set 5:
 - GPS: L1 and L5
 - Galileo: L1 and E5a

Simulations



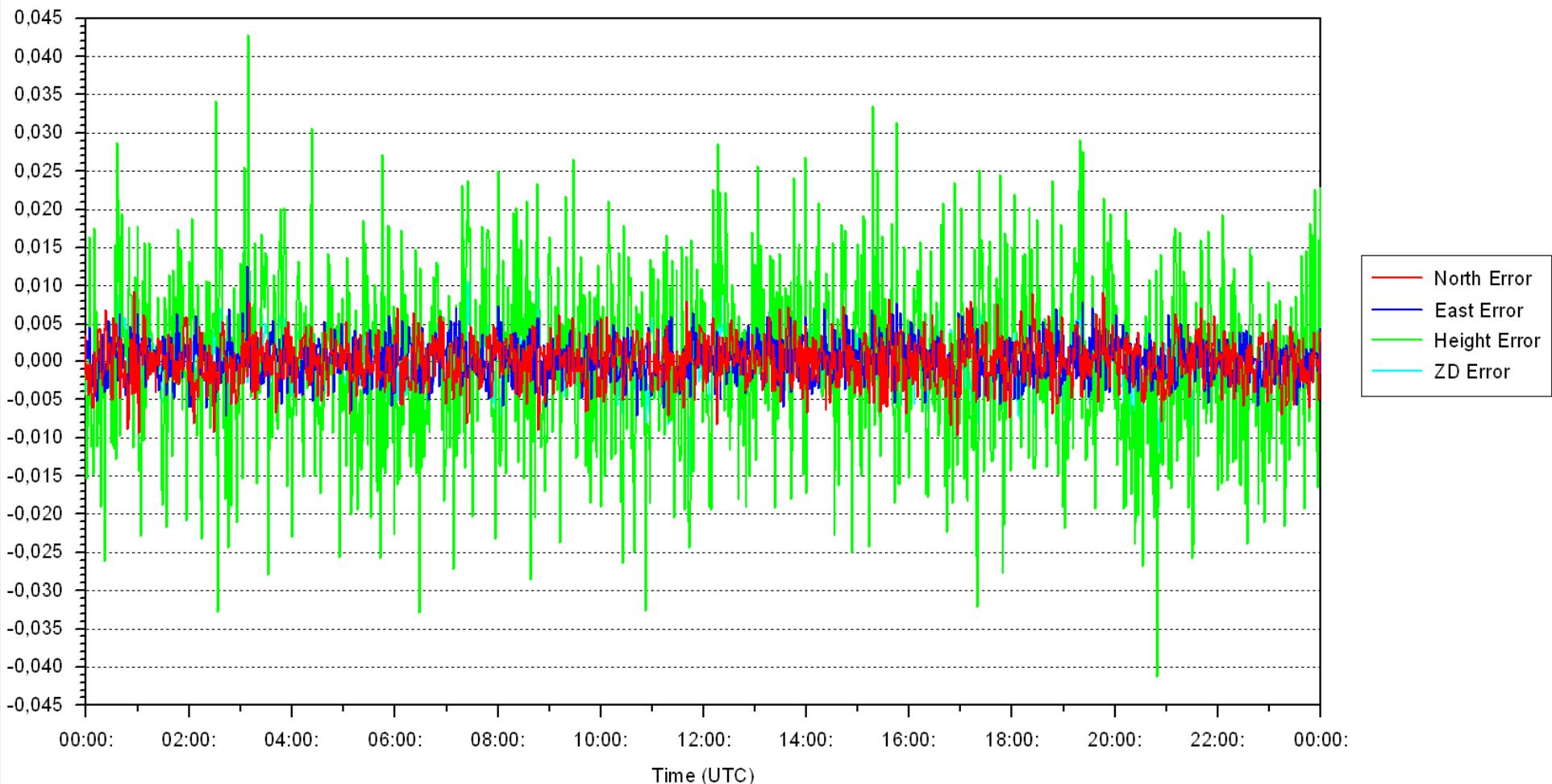
- Residual Ionosphere and Troposphere Simulation
 - Atmosphere Set 1:
 - 0.5 m Residual Ionosphere
 - 0.1 m Residual Tropospheric ZD
 - Atmosphere Set 2:
 - 0.1 m Residual Ionosphere
 - 0.02 m Residual Tropospheric ZD
 - Atmosphere Set 3:
 - 0.05 m Residual Ionosphere
 - 0.004 m Residual Troposphere
 - Atmosphere Set 4:
 - 0.01 m Residual Ionosphere
 - 0.002 m Residual Troposphere
 - Atmosphere Set 5: No Residual Atmosphere

Accuracy (Sparse Network, 0.5 m Iono, 0.1m Tropo)



Simulation: Network Interstation Distance 500 km

RMS (N,E,h,ZD) 3.0, 2.6, 10.9, 3.8 mm

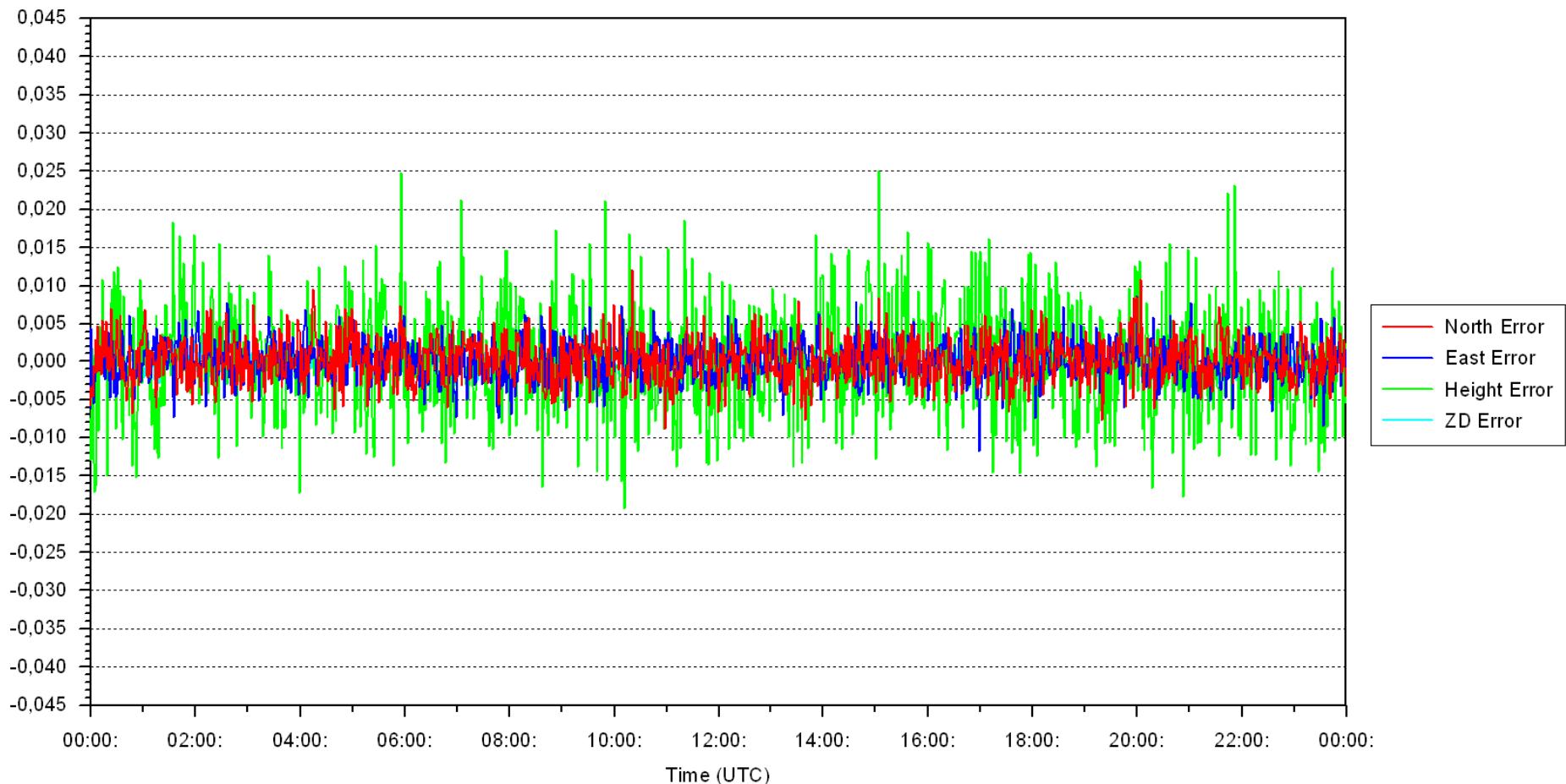


Accuracy (Network 100 km, 0.05 m Iono, 0.004 m Tropo)



Simulation: Network Interstation Distance 100 km

RMS (N,E,h,ZD) 2.8, 2.6, 6.6, 1.1 mm



Fixing Times



Signals	TTF WL [s]	TTF L0 [s]	# Fixes
All Signals GPS, Galileo, GLONASS			
G123R123E12345I500T100	1.0	5.6	288
G123R123E12345I100T020	1.0	4.9	288
G123R123E12345I050T004	1.0	3.8	289
G123R123E12345I010T002	1.0	1.4	289
G123R123E12345I000T000	1.0	1.0	289
GPS L1+L2'+L5, Galileo L1,E5b,E5a, GLONASS L1,L2,L3			
G123R123E135I500T100	1.0	5.6	287
G123R123E135I100T020	1.0	5.3	288
G123R123E135I050T004	1.0	4.0	288
G123R123E135I010T002	1.0	1.4	288
G123R123E135I000T000	1.0	1.0	289
GPS L1+L2'+L5, Galileo L1,E5b,E5a			
G123E135I500T100	1.0	18.6	281
G123E135I100T020	1.0	13.6	283
G123E135I050T004	1.0	6.4	289
G123E135I010T002	1.0	1.2	288
G123E135I000T000	1.0	1.0	288

Fixing Times



Signals	TTF WL [s]	TTF L0 [s]	# Fixes
Dual Frequency GPS L1+L5, Galileo L1+E5a, GLONASS L1+L3			
G13R13E15I500T100	16.0	26.6	253
G13R13E15I100T020	13.2	23.3	250
G13R13E15I050T004	6.9	12.1	272
G13R13E15I010T002	1.0	1.3	287
G13R13E15I000T000	1.0	1.0	289
Dual Frequency GPS L1+L5, Galileo L1+E5a			
G13E15I500T100	15.4	26.9	279
G13E15I100T020	13.4	21.4	282
G13E15I050T004	7.0	10.9	288
G13E15I010T002	1.0	1.1	288
G13E15I000T000	1.0	1.0	289

Fixing Times



Signals	TTF WL [s]	TTF L0 [s]	# Fixes
Dual Frequency GPS L1+L2			
G12I500T100	12.2	46.2	98
G12I100T020	9.7	39.7	132
G12I050T004	5.9	26.7	238
G12I010T002	1.5	2.5	289
G12I000T000	1.0	1.0	289

Fixing Times



Signals	TTF WL [s]	TTF L0 [s]	# Fixes
Urban Canyon East-West			
G123R123E12345I0T0_ew	1.0	1.0	285
G123R123E135I0T0_ew	1.0	1.1	282
G13R13E15I0T0_ew	1.1	1.1	288
G13E15I0T0_ew	1.3	1.3	288
Urban Canyon North-South			
G123R123E12345I0T0_ns	1.9	1.9	242
G123R123E135I0T0_ns	2.0	2.1	240
G13R13E15I0T0_ns	2.8	2.9	4
G123E135I0T0_ew	1.1	1.1	4

Standards for RTK



- RTK and Network RTK standards are available with RTCM 2.3 and RTCM 3.1
 - Observation Space Representation (OSR)
 - Corrections (Code and Carrier) (RTCM2.3)
 - Raw Observations (RTCM2.3, RTCM3.0)
 - FKP (AdV: de facto Standard) (RTCM 2.3)
 - MAC (Master-Auxiliary Concept) (RTCM 3.1)
 - Ambiguity resolved carrier phase correction differences between network reference stations
 - VRS/FKP in preparation (RTCM 3.1)
 - OSR will become complicated and interoperability of Rovers and Reference Station will be difficult in case of heterogeneous tracking of signal components

Standards for RTK



- Solution (new RTCM SC104 Working Group established):
 - State Space Representation (SSR) or mixed OSR/SSR
 - Like PPP state, but maintaining Integer nature for Ambiguity resolution
 - Requirement for State Vector Parameter:
 - Orbits + Clocks must have approx. 1 cm or better accuracy in order to allow reliable ambiguity fixing in L0 (10-11 cm Wavelength)

Do we still need RTK Networks with full GNSS Constellations



- Answer: YES
 - Height Accuracy
 - Support for Rovers with Single / Dual Frequency Receivers
 - Support for Rovers in Areas with Obstructions
 - Many years with heterogeneous signals ahead
 - Redundancy
- Network Density may be Reduced
 - Rovers should estimate Residual Troposphere

Summary



- Full GNSS Constellations Provide
 - Improved Availability
 - Improved Accuracy
 - Fast Ambiguity Fixing over longer Distances using new Signals and high number of Satellites
- RTK Networks will still be necessary
- Complexity of Network Setup and Software will increase

