Extension of RTKLIB for the calculation and validation of protection levels

Bence TAKÁCS[1,2], Zoltán SIKI[1,2], Rita MARKOVITS-SOMOGYI[3]

[1]Budapest University of Technology and Economics,
Department of Geodesy and Surveying

[2]GeoForAll Lab at Budapest

[3]Hungarocontrol, Hungarian Air Navigation Service Provider

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Content

- Why?

  Plans to introduce GPS based flight procedures in Hungary

- Compare RTKLIB to proprietary programs
- Application: flight validation at Debrecen airport

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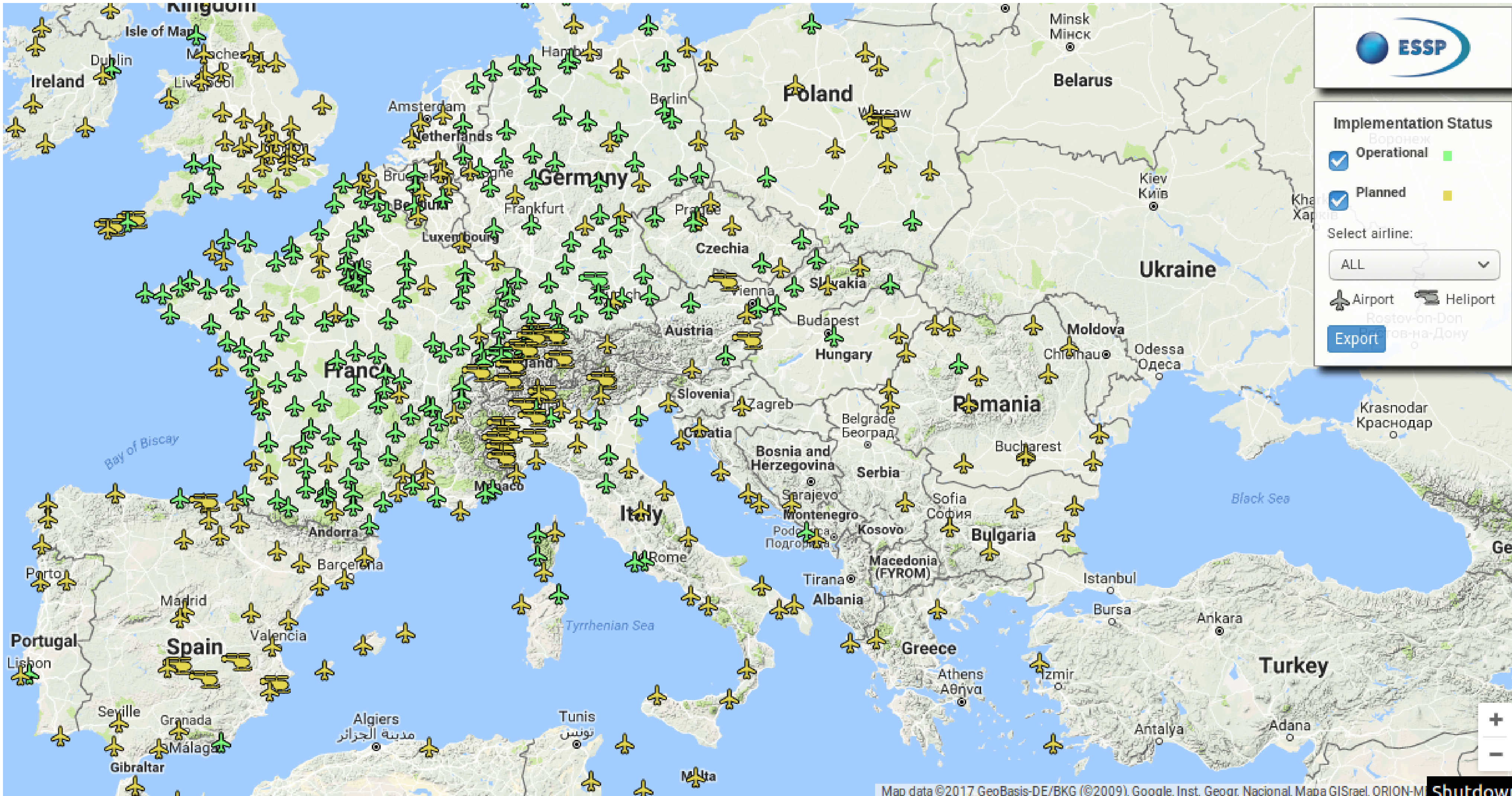
Rationale



ESSP
Implementation Status
Operational
Planned
Select airline:
ALL
Airport
Heliport
Export
Ireland
Dublin
Isle of Man
Amsterdam
Netherlands
Germany
Frankfurt
Hamburg
Berlin
Poland
Warsaw
Minsk
Минск
Belarus
Kiev
Київ
Ukraine
Moldova
Chișinău
Odessa
Одеса
Krasnodar
Краснодар
Luxembourg
Prague
Czechia
Slovakia
Vienna
Austria
Budapest
Hungary
Slovenia
Zagreb
Croatia
Belgrade
Београд
Bosnia and Herzegovina
Serbia
Sarajevo
Montenegro
Kosovo
Romania
Bucharest
Sofia
София
Bulgaria
Macedonia (FYROM)
Tirana
Albania
Istanbul
Bursa
Ankara
Turkey
Izmir
Antalya
Adana
Greece
Athens
Αθήνα
Black Sea
Bay of Biscay
Andorra
Barcelona
Madrid
Valencia
Spain
Porto
Portugal
Lisbon
Seville
Granada
Málaga
Gibraltar
Algiers
مدينة الجزائر
Tunis
تونس
Tyrrhenian Sea
Italy
Rome
Monaco
Malta
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Shutdown

EGNOS improves GPS over Europe

EGNOS improves GPS over Europe

European Commission

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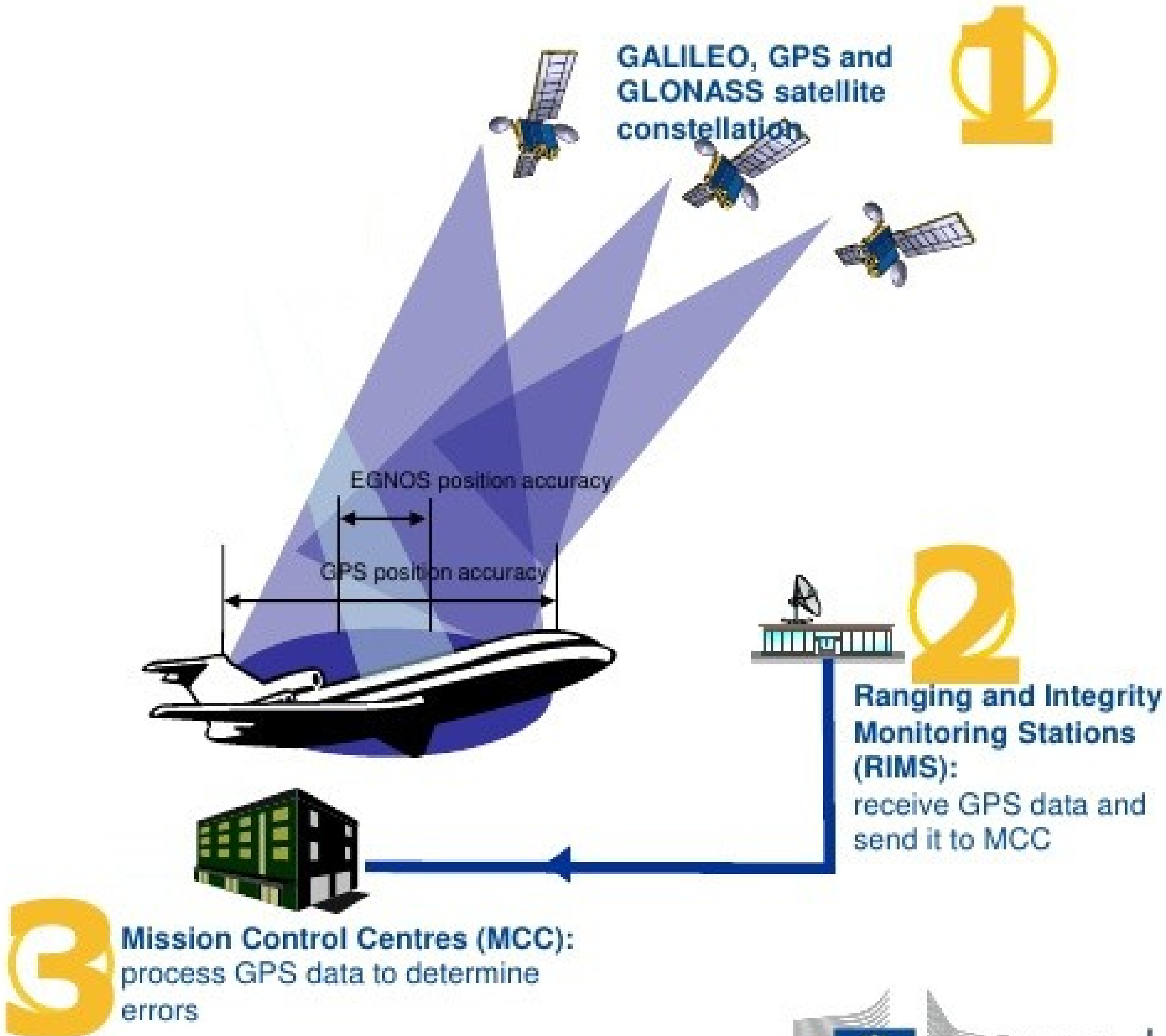
EGNOS improves GPS over Europe



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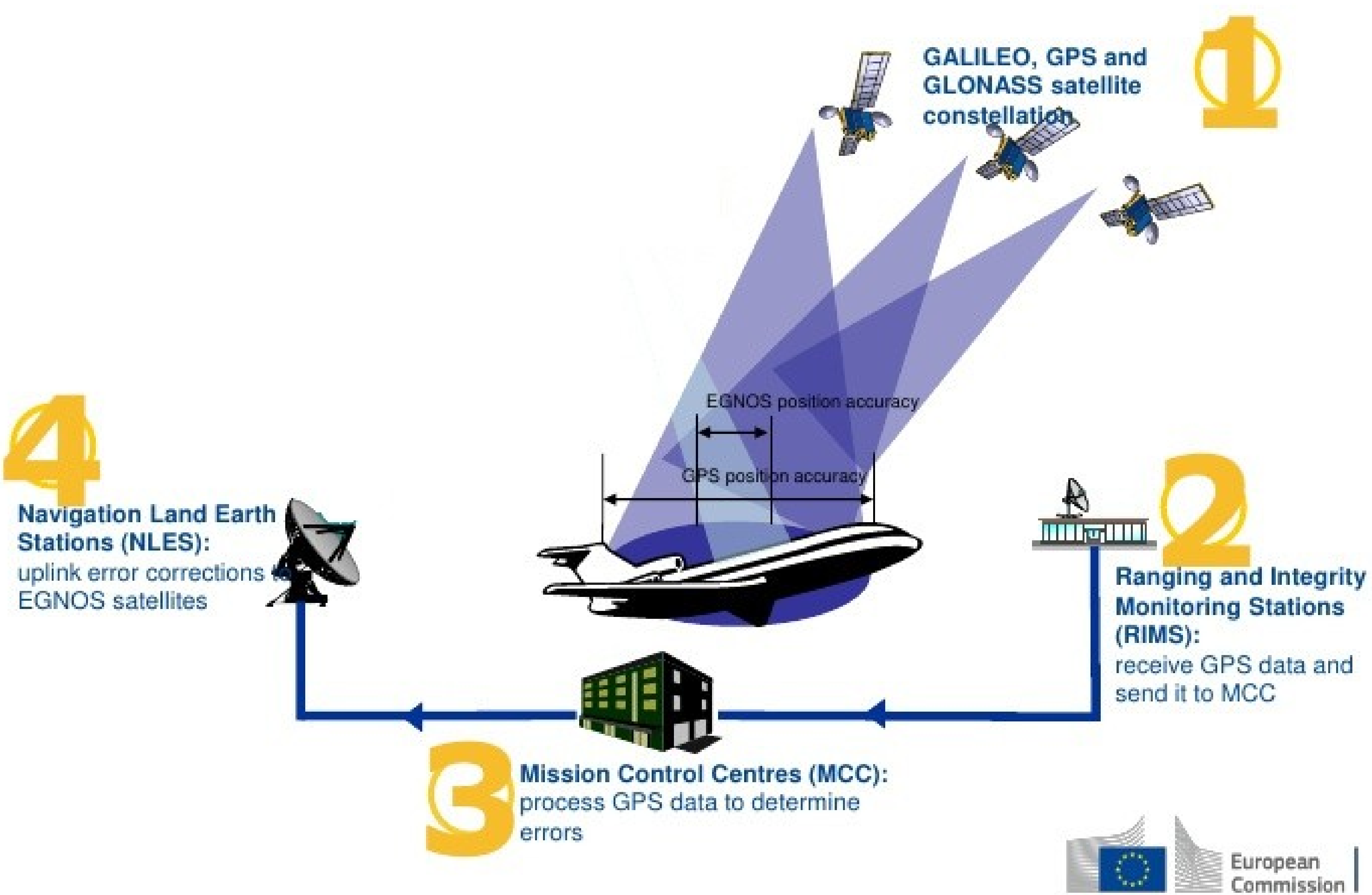
European Commission

EGNOS improves GPS over Europe



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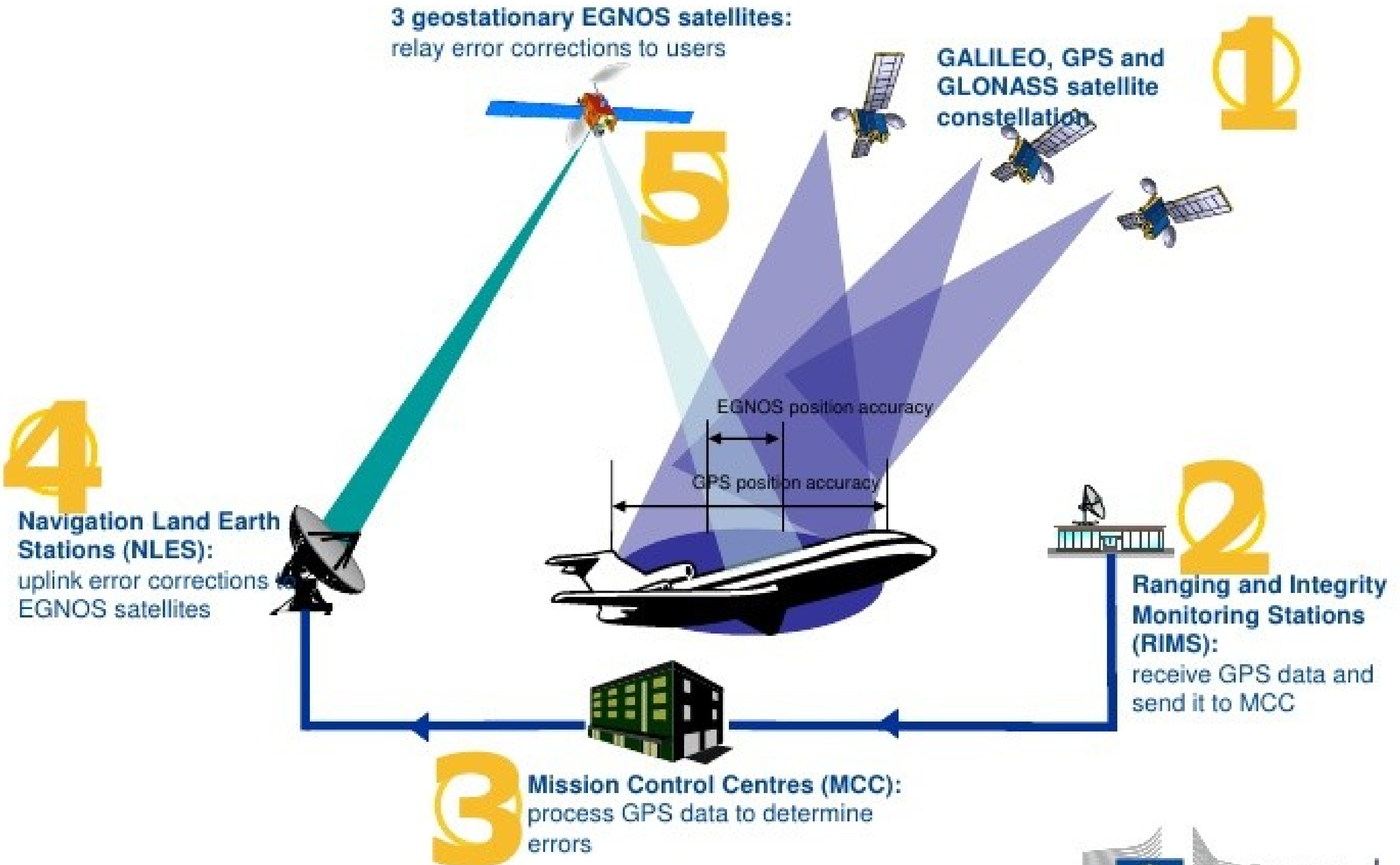
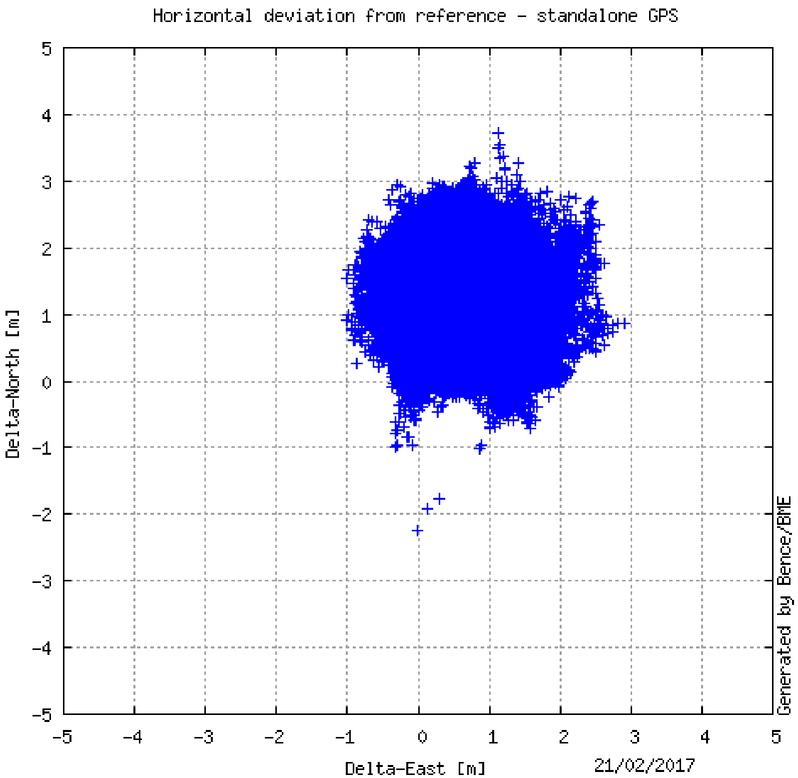
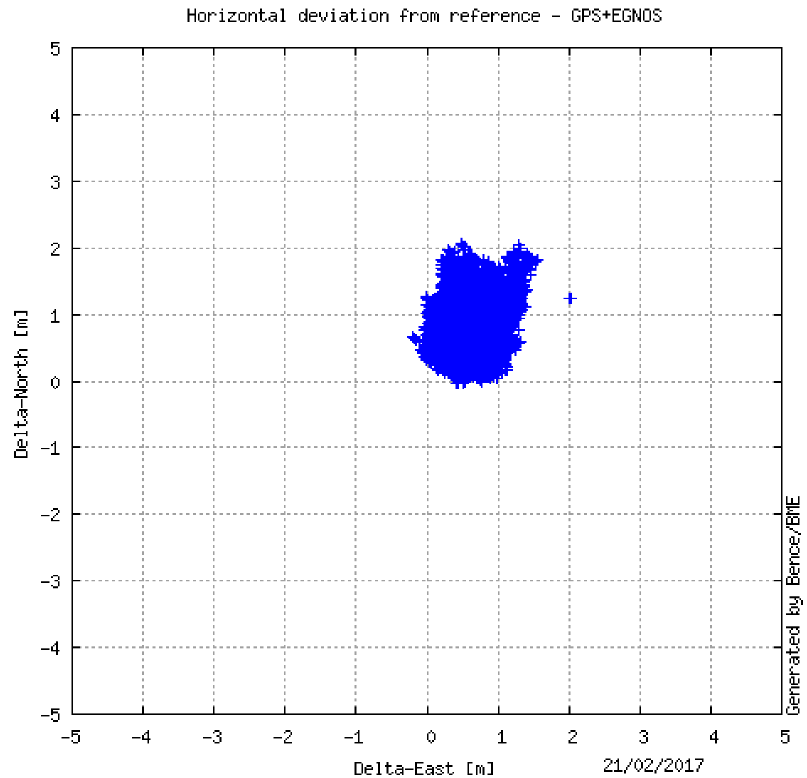
EGNOS improves GPS over Europe



Accuracy



Standalone GPS



GPS with EGNOS corrections

EGNOS monitor station at BME
www.agt.bme.hu/egnos

Aircraft moving in 3D?

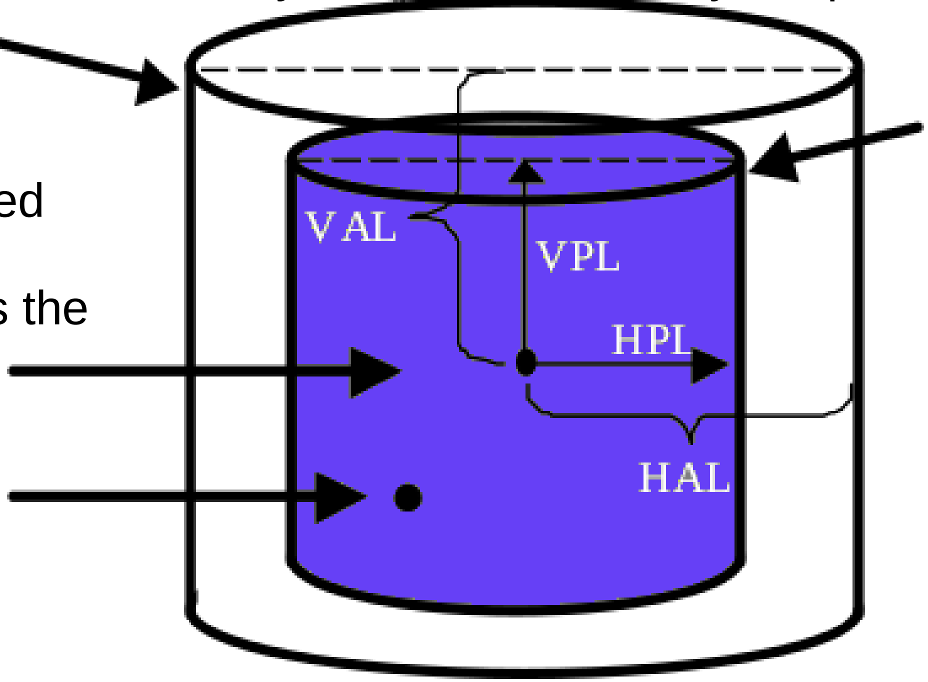
Integrity protection cylinder

Vertical and Horizontal Alert Limit cylinder are defined by the phase of flight

Protection level cylinder:
VPL and HPL

The aircraft's calculated position based on the EGNOS corrections is the center of cylinder

The aircraft's true position: not known



Source: http://www.gps.gov/technical/ps/2008-WAAS-performance-standard.pdf

Protection level (PL) calculation

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,iono}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$$

variance of i[th] satellite has 4 components

$$\mathbf{W}^{-1} = \begin{bmatrix} \sigma_1^2 & 0 & \dots & 0 \\ 0 & \sigma_2^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_n^2 \end{bmatrix}$$

Inverse of the weight matrix

$$\mathbf{G}_\mathbf{i}^\mathbf{T} = \begin{bmatrix} \cos(El_i)\cdot\cos(Az_i) \\ \cos(El_i)\cdot\sin(Az_i) \\ \sin(El_i) \\ 1 \end{bmatrix}$$

Geometry matrix

$$\mathbf{D} = \begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT} \\ d_{ET} & d_{NT} & d_{UT} & d_t^2 \end{bmatrix} = (\mathbf{G}^\mathbf{T}\mathbf{W}\mathbf{G})^{-1}$$

Variance/covariance matrix

$$d_{major} = \sqrt{\frac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\frac{d_{east}^2 - d_{north}^2}{2} + d_{EN}^2}}$$

$$K_H = 6.00$$
$$K_V = 5.33$$

Factor bounding users horizontal / vertical position with a probability of 10^{-9} / 0.5 x 10^{-7}

$$HPL = K_H \cdot d_{major}$$
$$VPL = K_V \cdot d_U$$

Horizontal and vertical protection level

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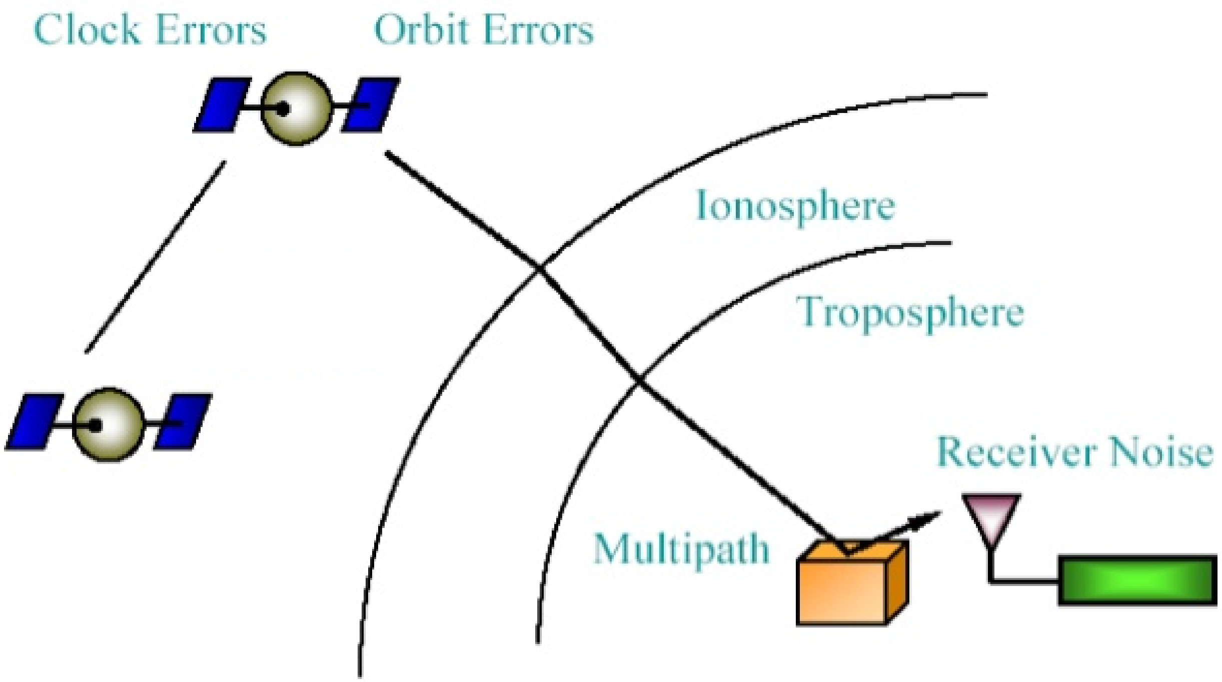
Source: RTCA MOPS DO-229-C "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System airborne equipment"

Variance includes

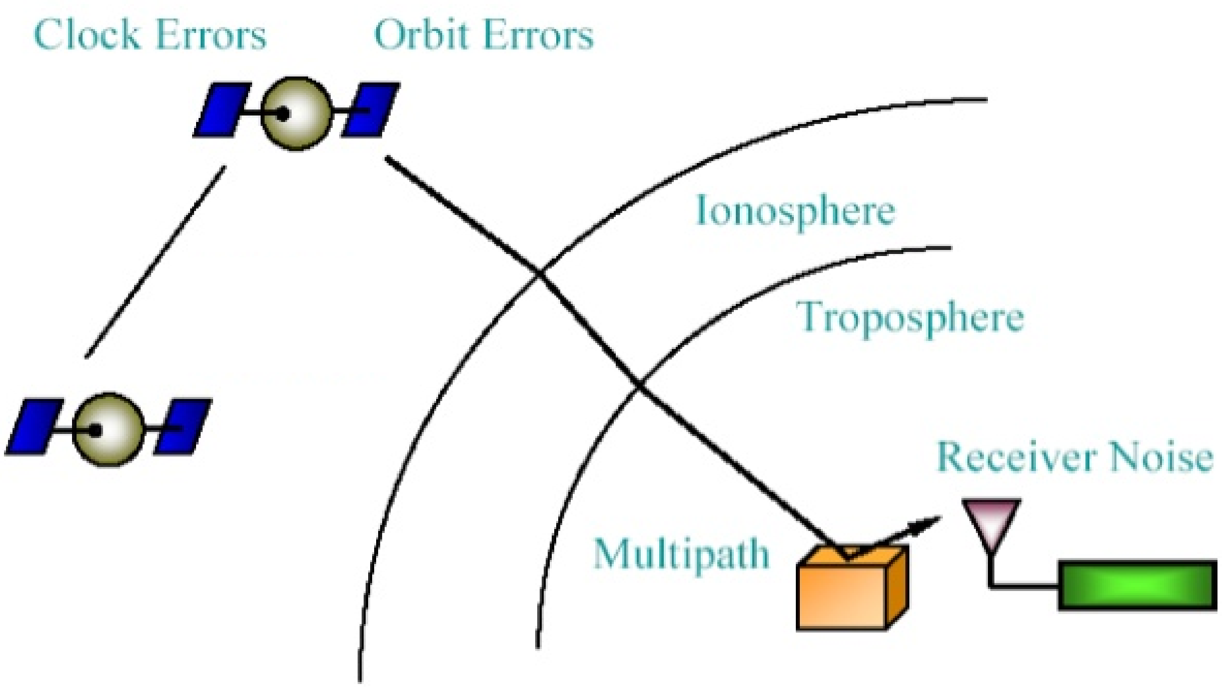
$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,iono}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$$



Variance includes

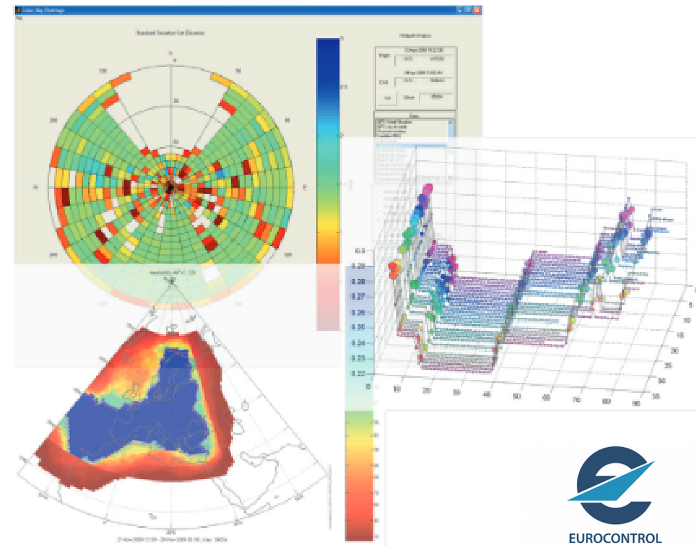
$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,iono}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$$

- Fast and long term correction
- Ionospheric delay
- Tropospheric delay
- Airborne error

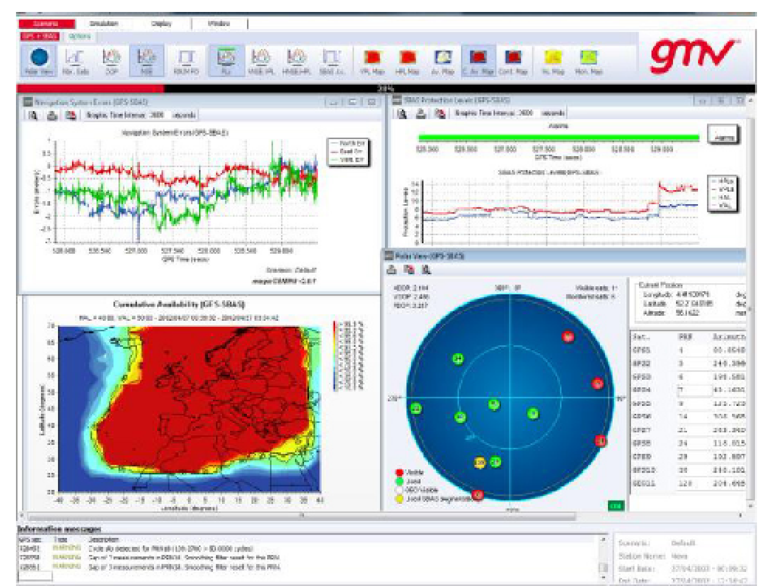


Software to calculate PL

- Eurocontrol: Pegasus



- GMV: magicGemini



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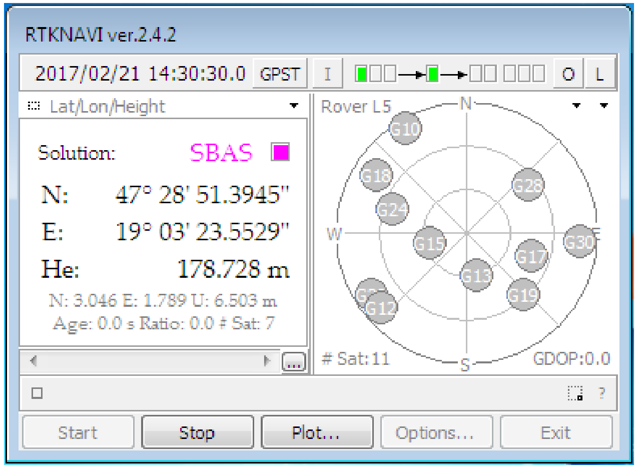
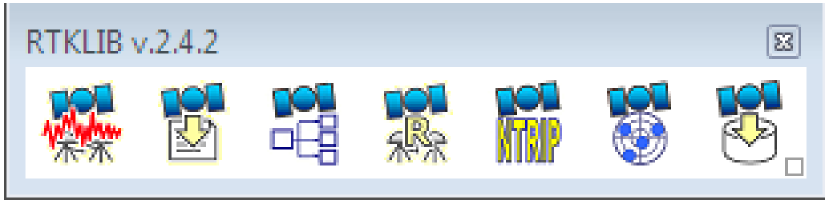
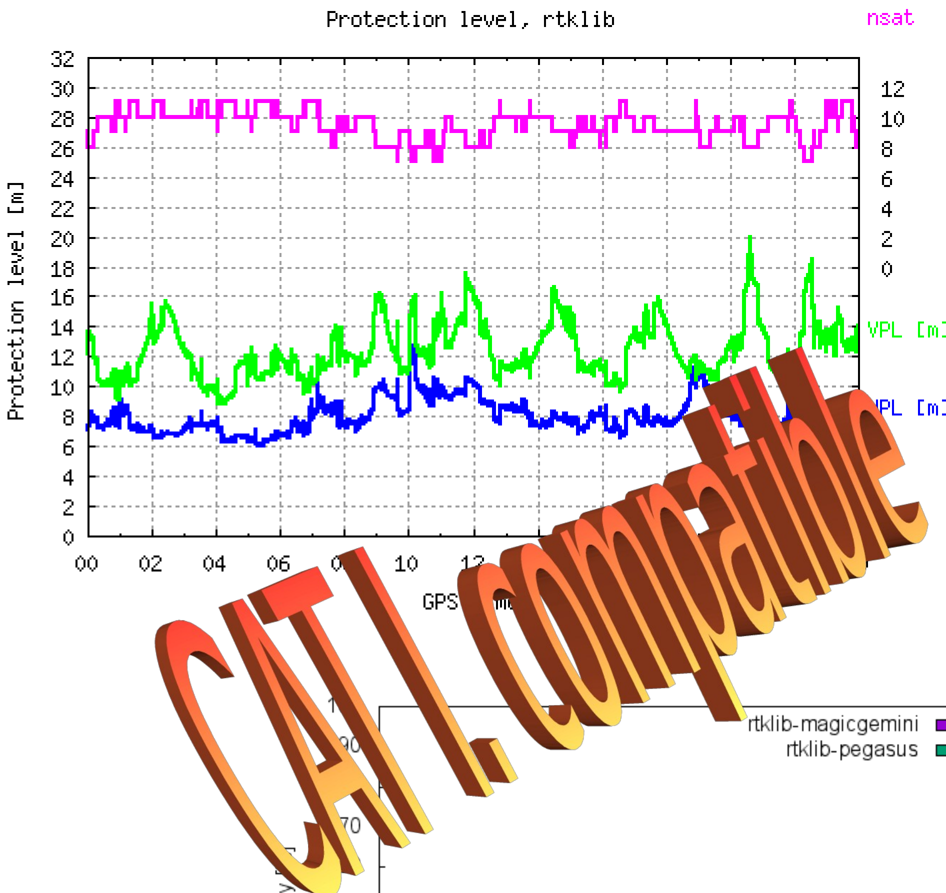
Open source solution: RTKLIB

- RTKLIB
  - SBAS positioning mode
  - no PL calculation
- Houghton Assoc Inc. fork of RTKLIB
  - PL calculation available
- Our enhanced version
  - https://github.com/zsiki/RTKLIB/tree/rtklib_2.4.3

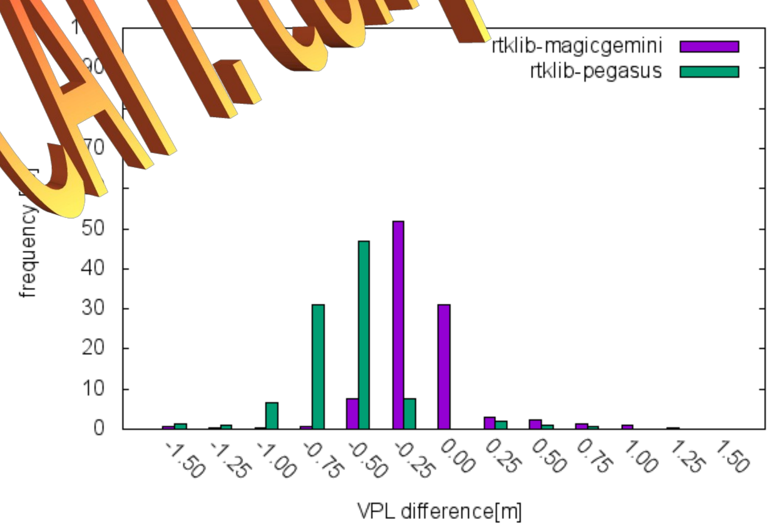


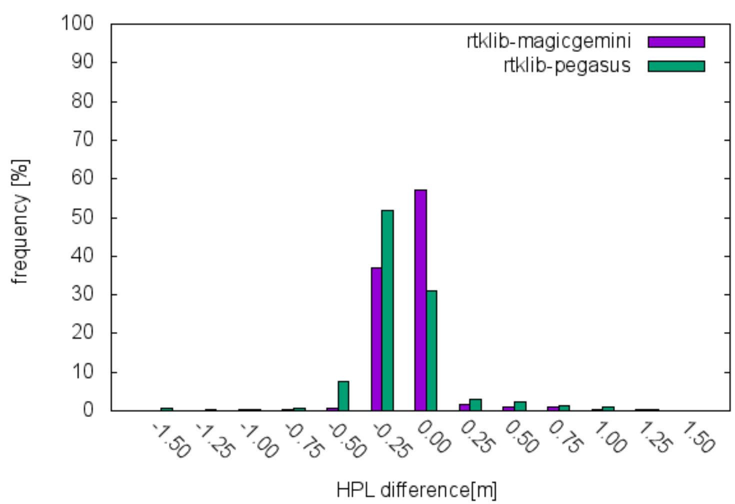


PL calculated by different programs



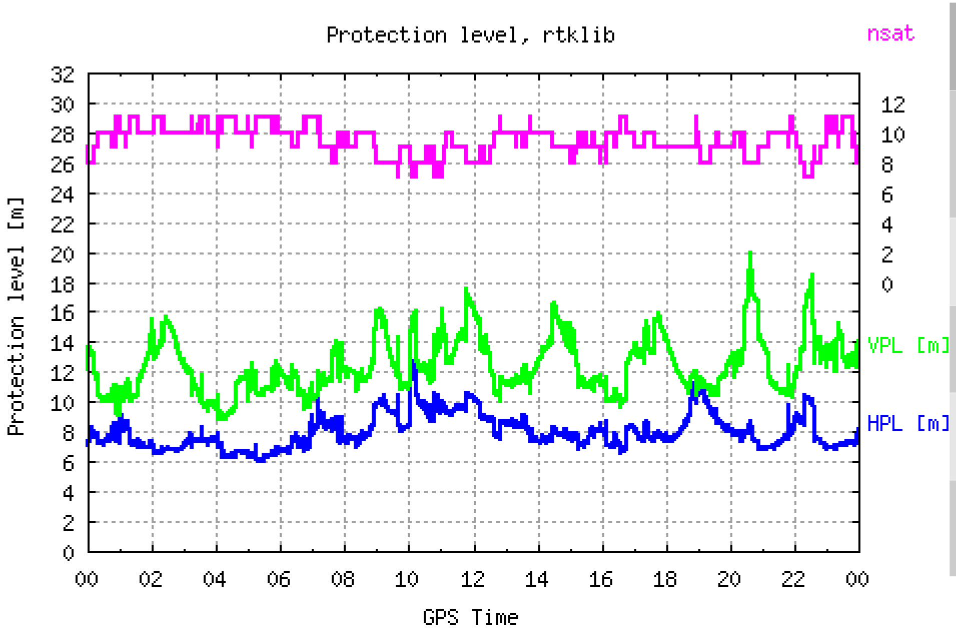
	RTKLIB-mGemini		RTKLIB-pegasus	
	ΔHPL [m]	ΔVPL [m]	ΔHPL [m]	ΔVPL [m]
min	-0.86	-1.65	-1.18	-1.85
max	+1.68	+1.66	+1.57	+1.40
mean	-0.08	-0.14	-0.32	-0.55
std. dev.	±0.18	±0.24	±0.21	±0.28





What is Cat. I – II – III?

PL calculated by different programs



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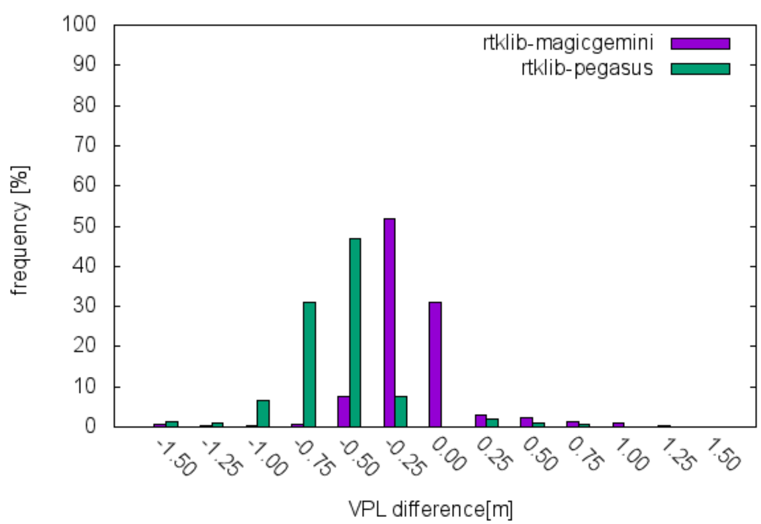
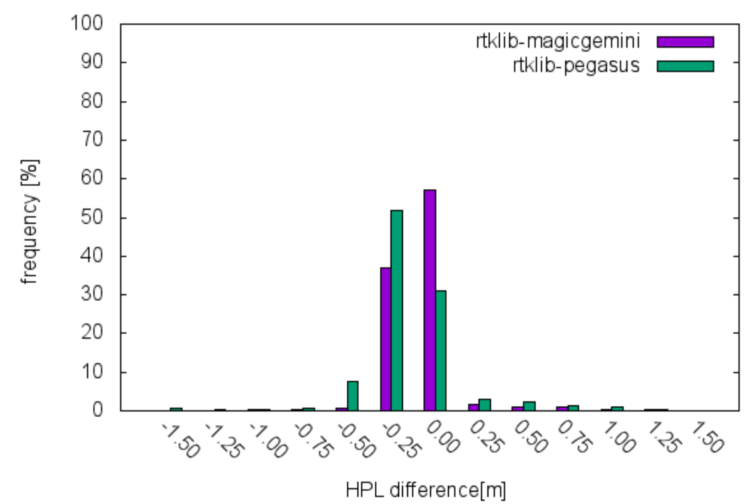
Different results





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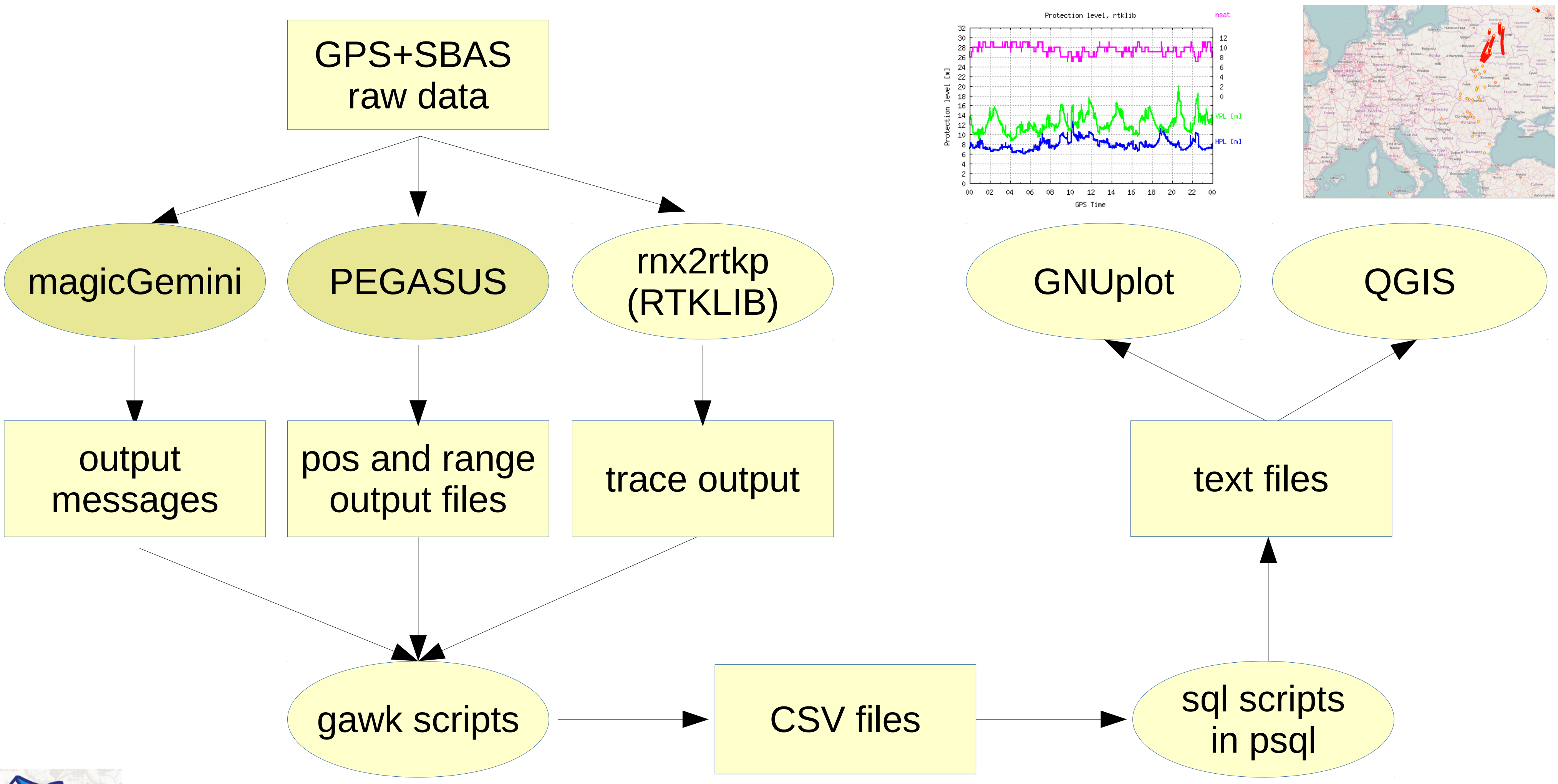
Data processing scheme



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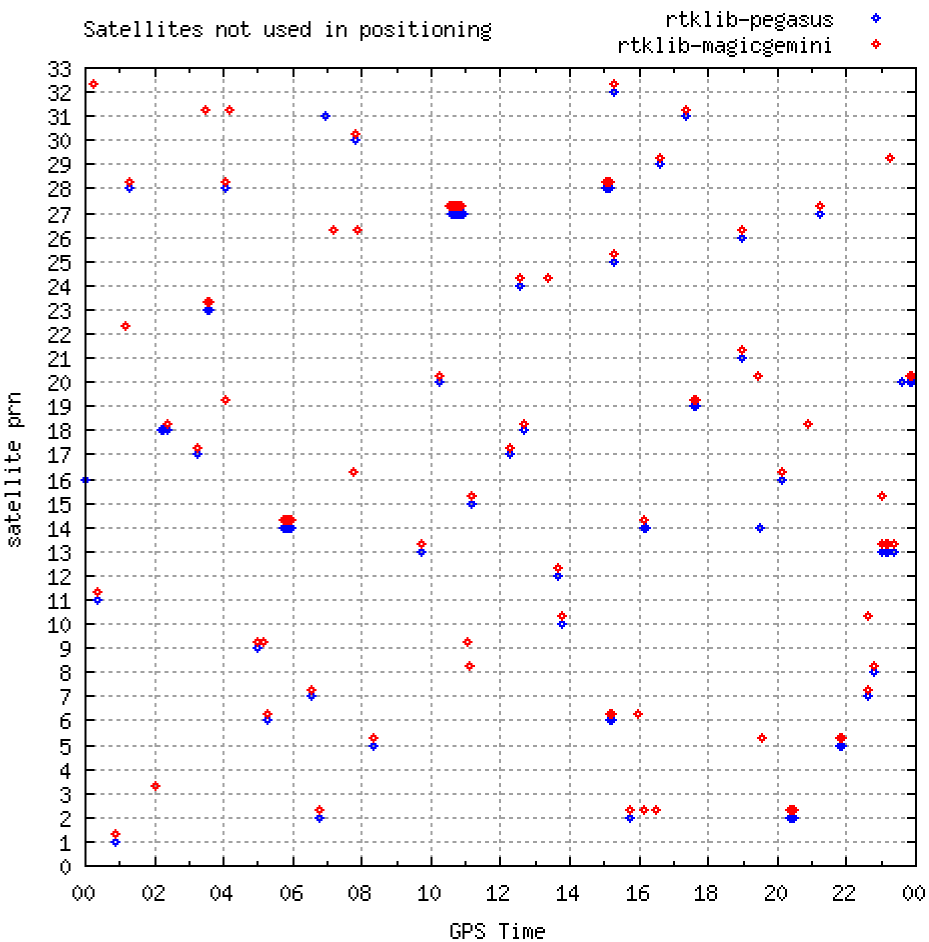
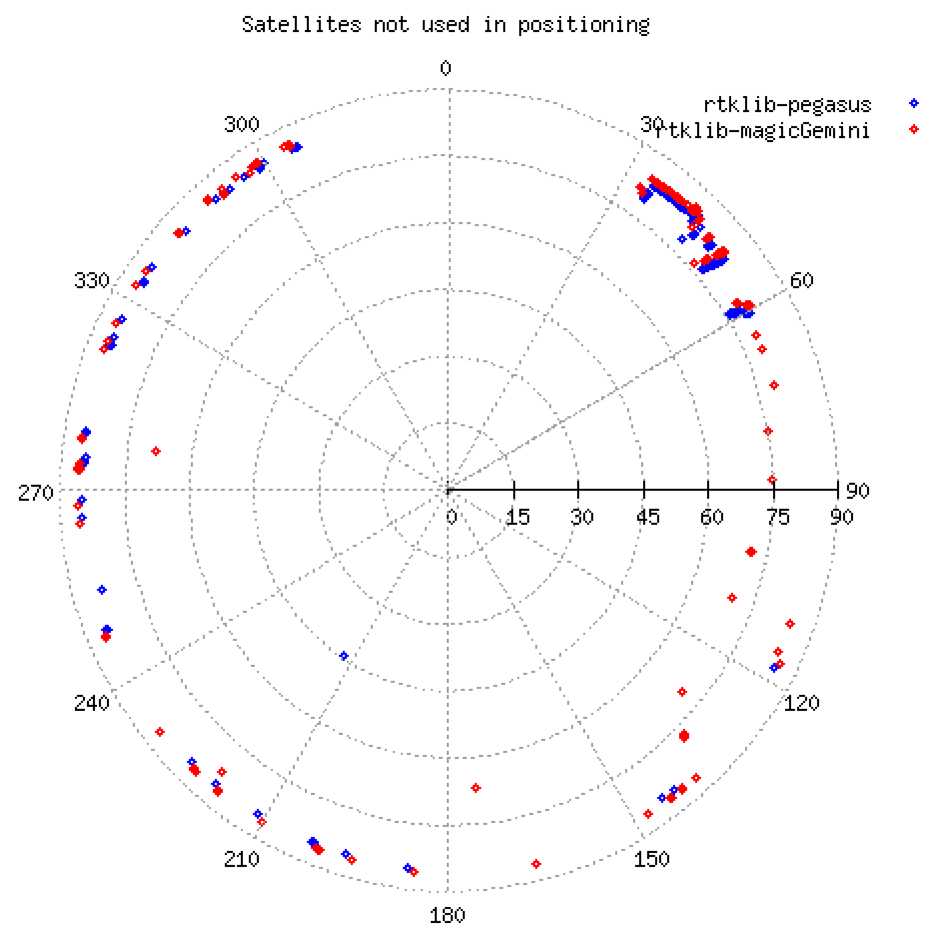
1st reason: Some of the measurements are filtered out





2^{nd} reason: Differences of variances

	magicGemini vs. RTKLIB	Pegasus vs. RTKLIB
differences of fast and long term correction variance [m]		
minimum	-2.14	+0.04
maximum	+2.42	+0.29
mean	+0.09	+0.13
std. dev.	±0.04	±0.04
differences of airborne variance [m]		
minimum	-0.18	0.00
maximum	0.00	0.00
mean	-0.15	0.00
std. dev.	±0.04	0.00
differences of ionospheric delay variance [m]		
minimum	-26.23	-26.23
maximum	+10.47	+0.22
mean	-0.02	-0.02
std. dev.	±0.41	±0.38

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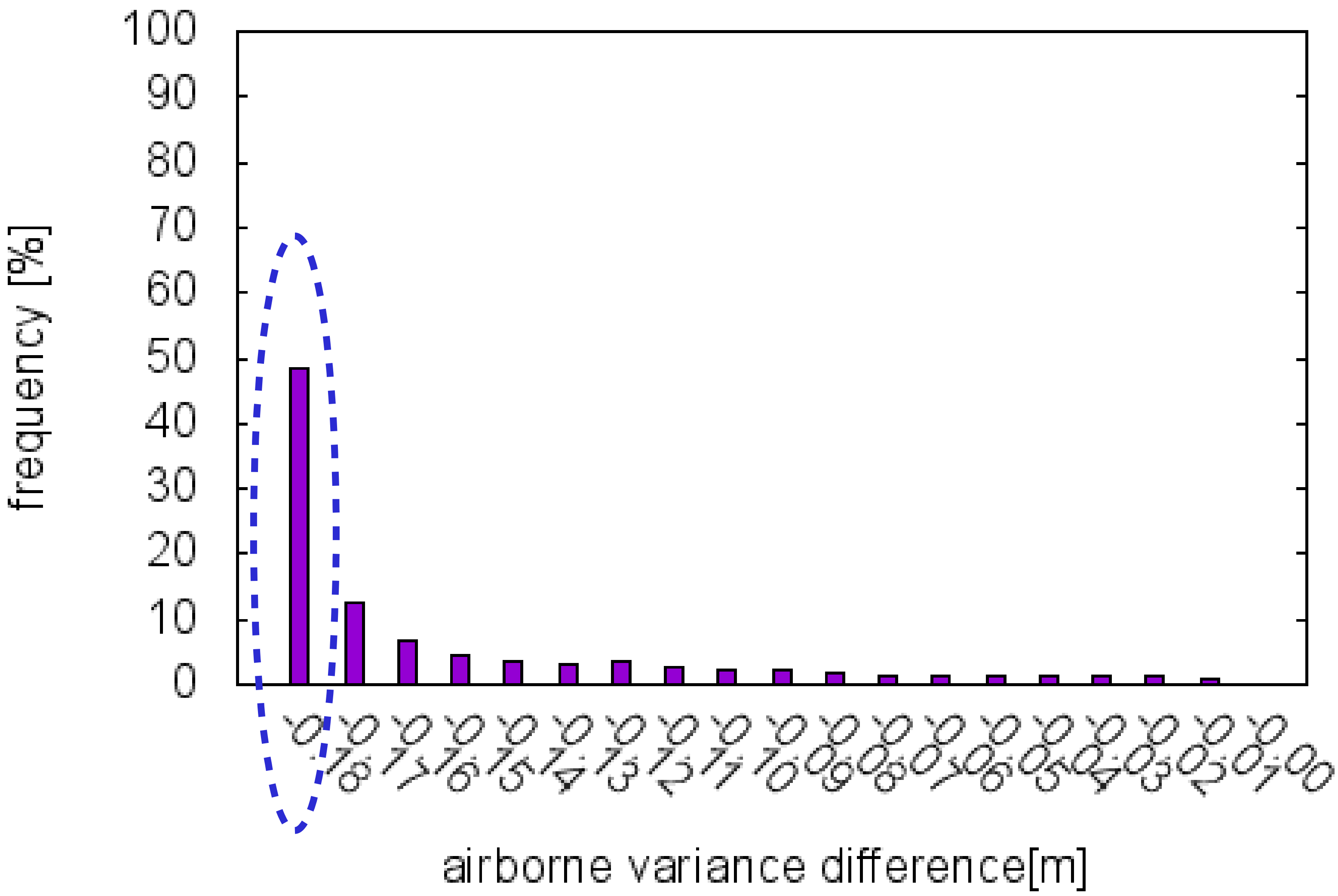
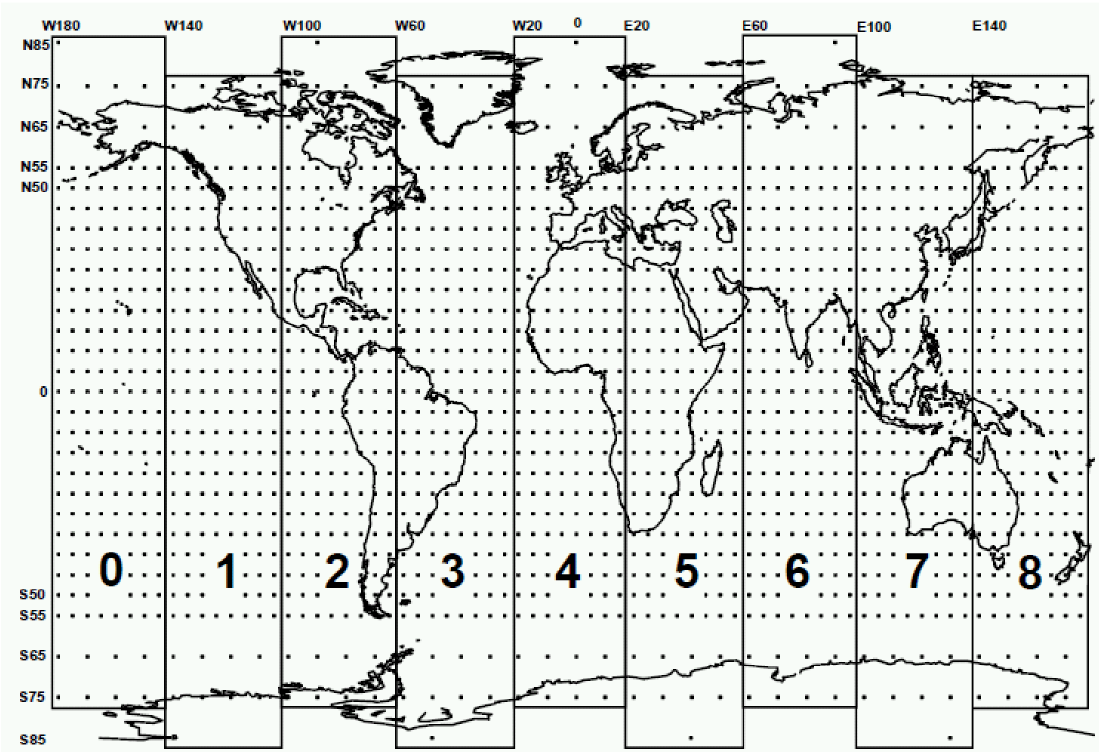
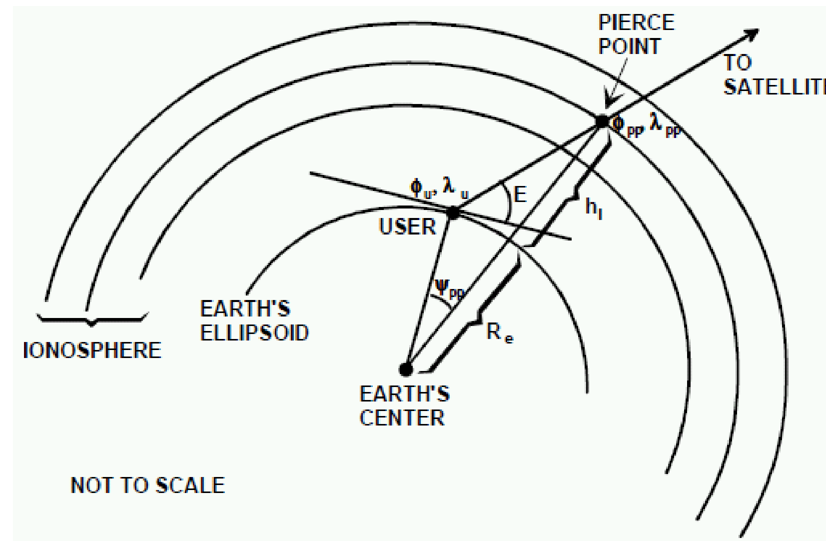
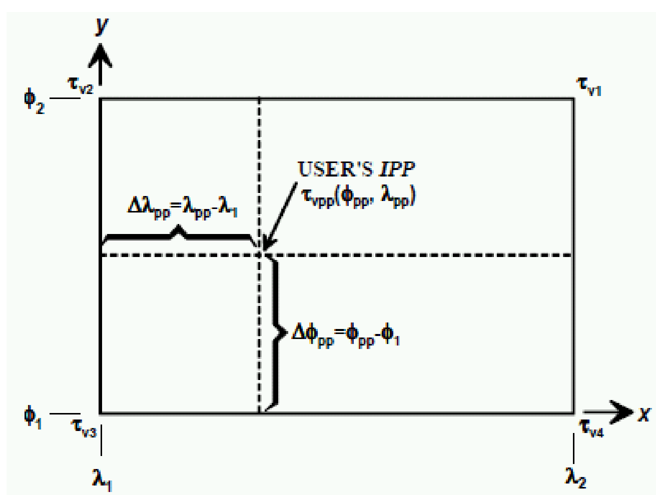
Airborne variance

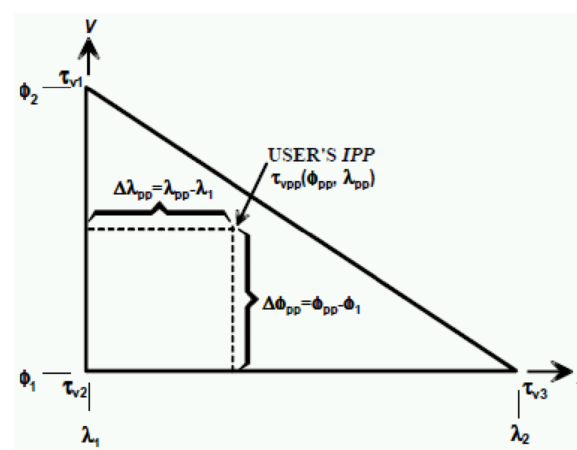


Largest component: Ionosphere









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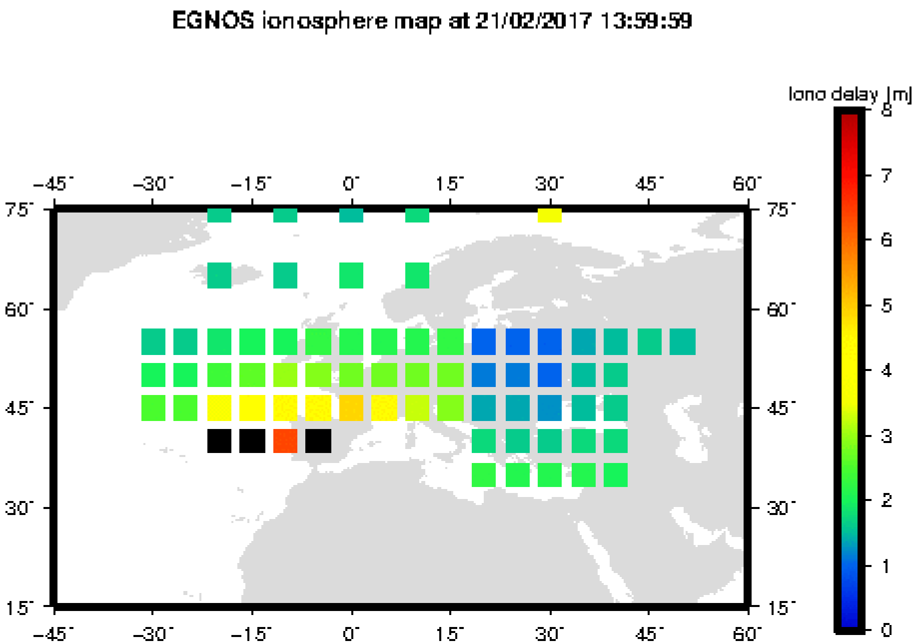
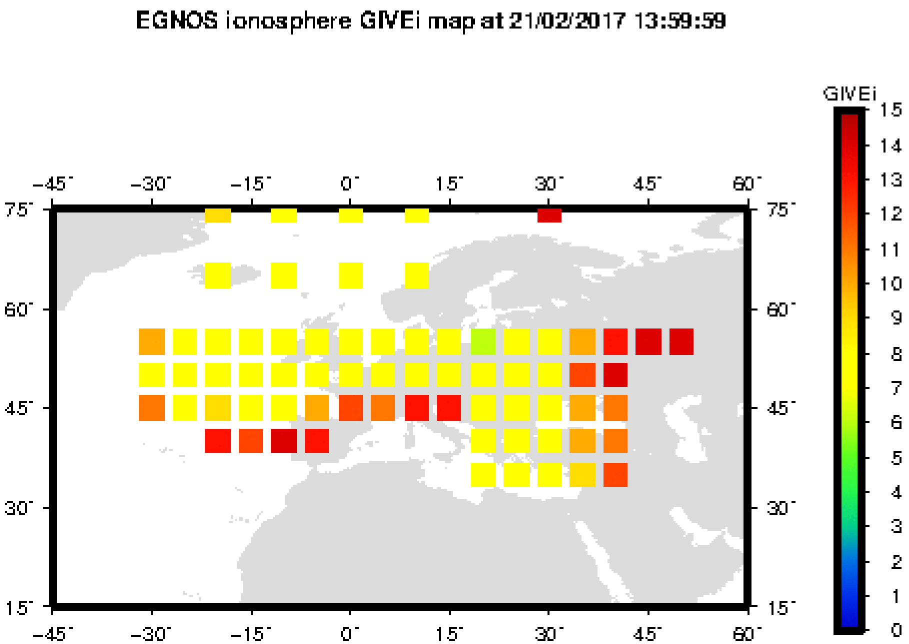
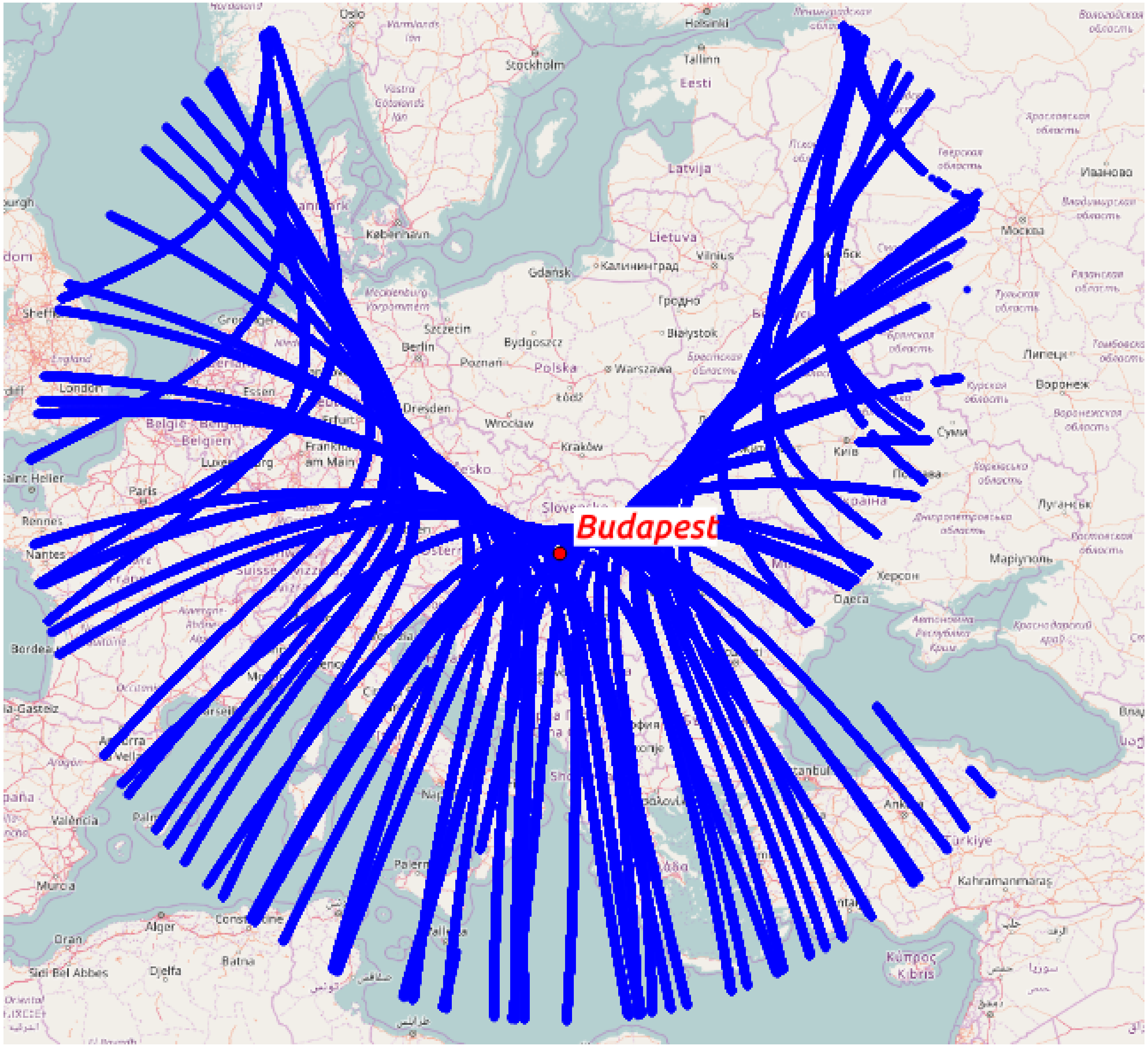
Ionosphere grid models





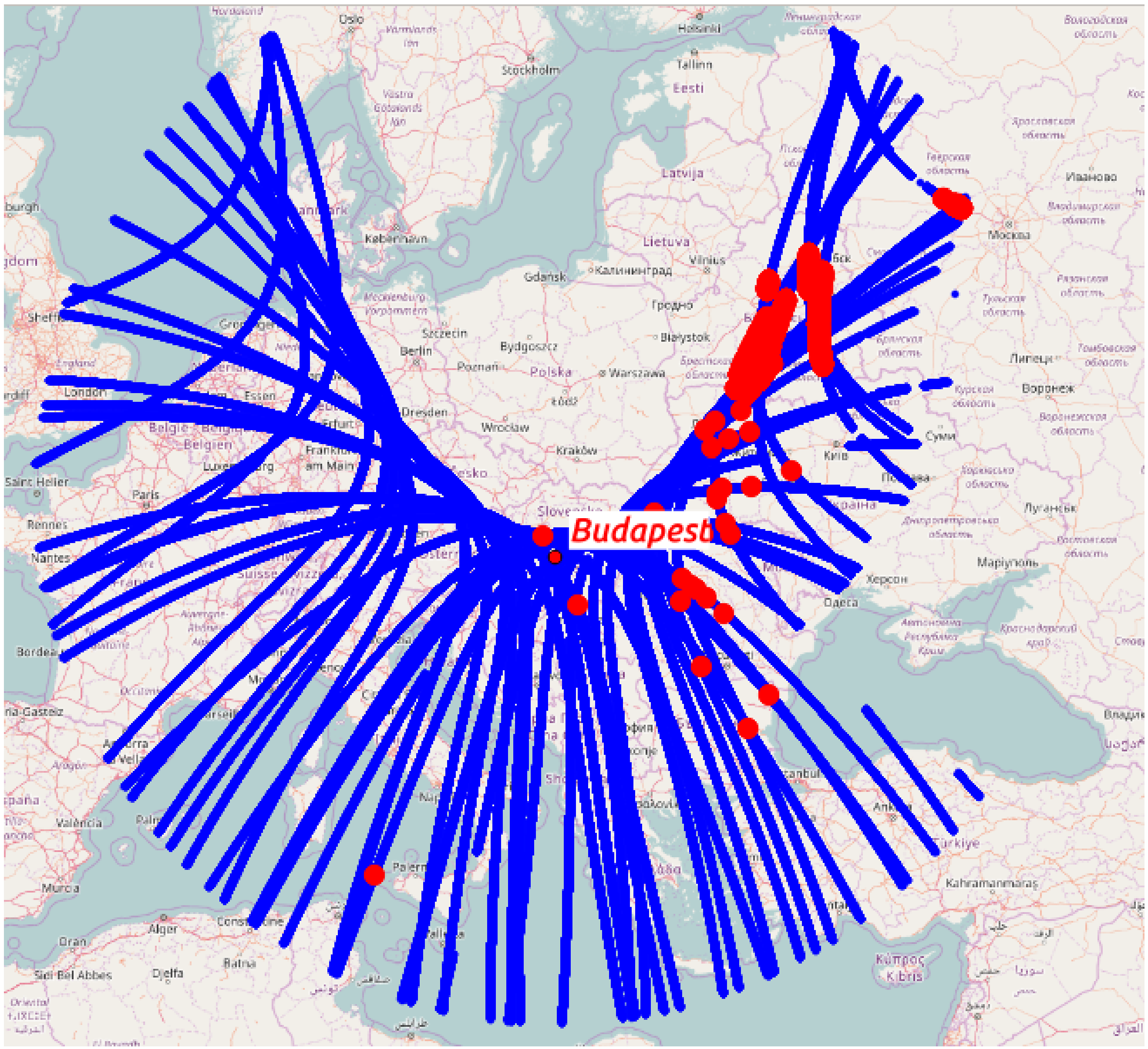
IPP positions

all measurements during a 24 hour session at Budapest



IPP positions

Large ionosphere variance differences!
(RTKLIB vs. mGemini)



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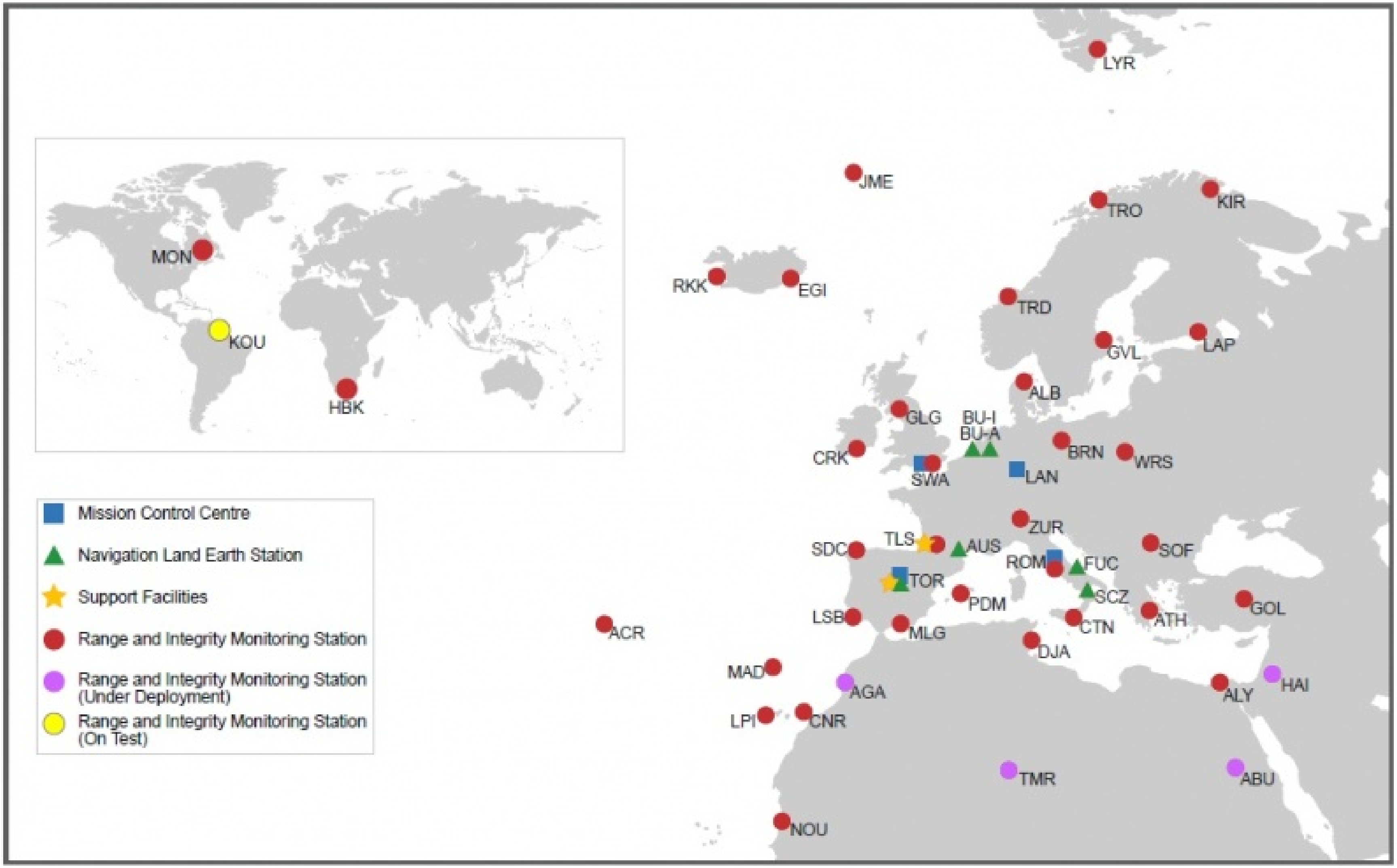
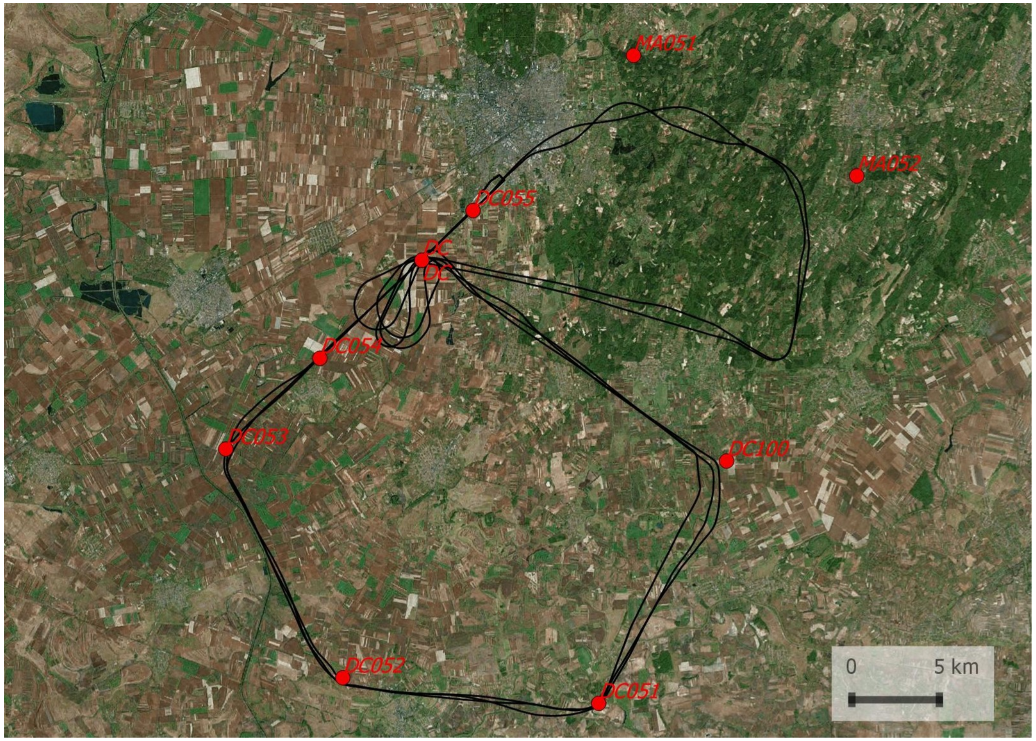
Range and Integrity Monitor Stations (RIMS)



Flight validation at Debrecen airport

12/13th July 2016



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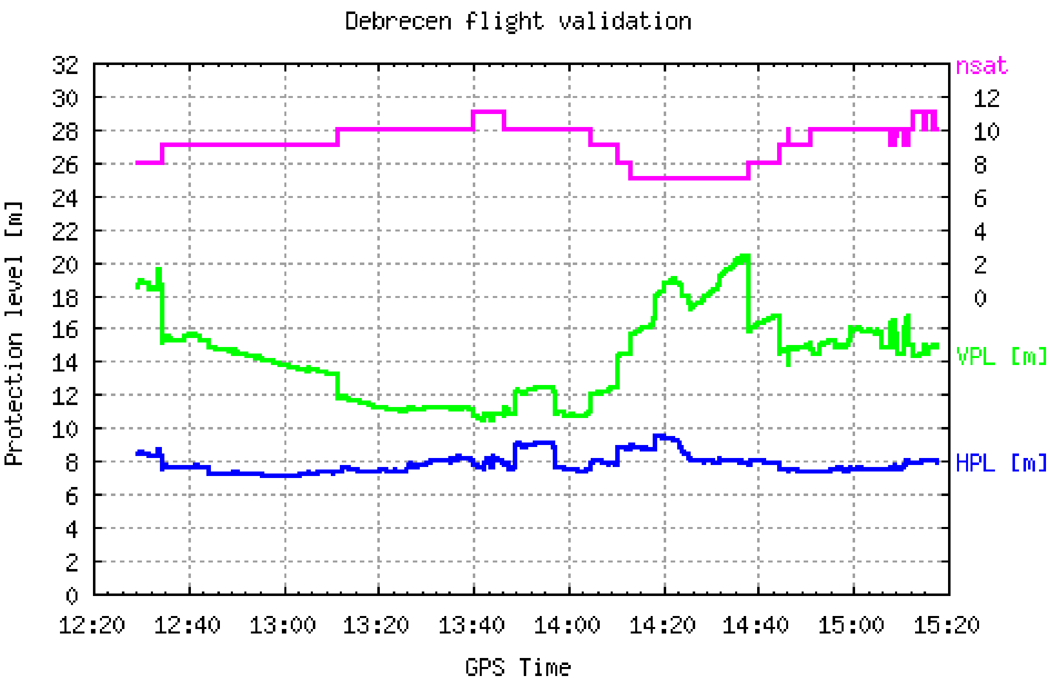
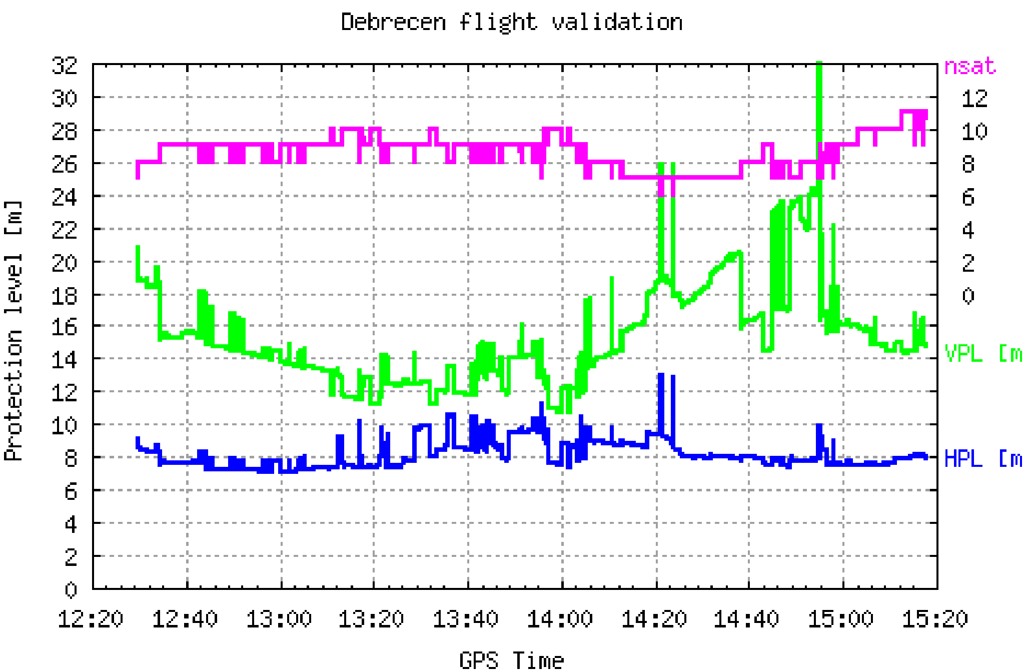
PL during flight validation



On a permanent station close to the airport

On the aircraft



To sum it up

- Open source SW compared to proprietary

  https://github.com/zsiki/RTKLIB/tree/rtklib_2.4.3
- Protection levels
- Reason behind the differences

What for?...


GPS SAYS...
TURN LEFT NOW!