GSA Raw GNSS Measurements Task Force Workshop

Innovative work results using raw measurements

Prague, Czechia, 27 – 28 May, 2020 (virtual *Webex* meeting)

RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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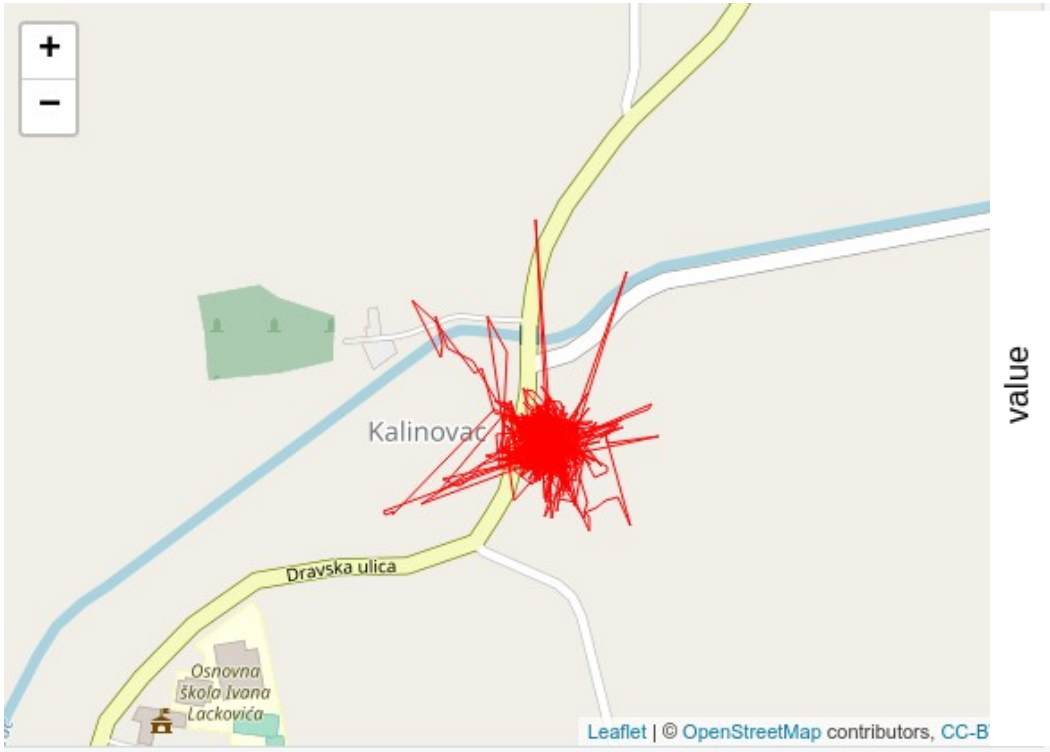
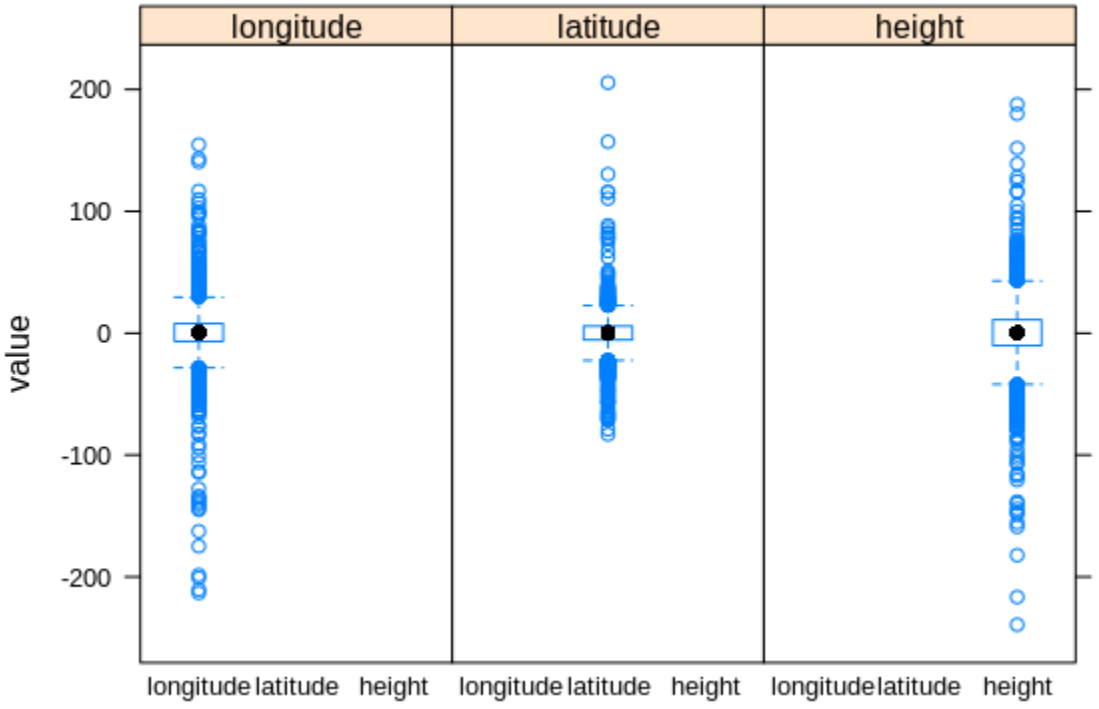
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance**
- Foundation and enabling technology for GNSS applications

- GPS only





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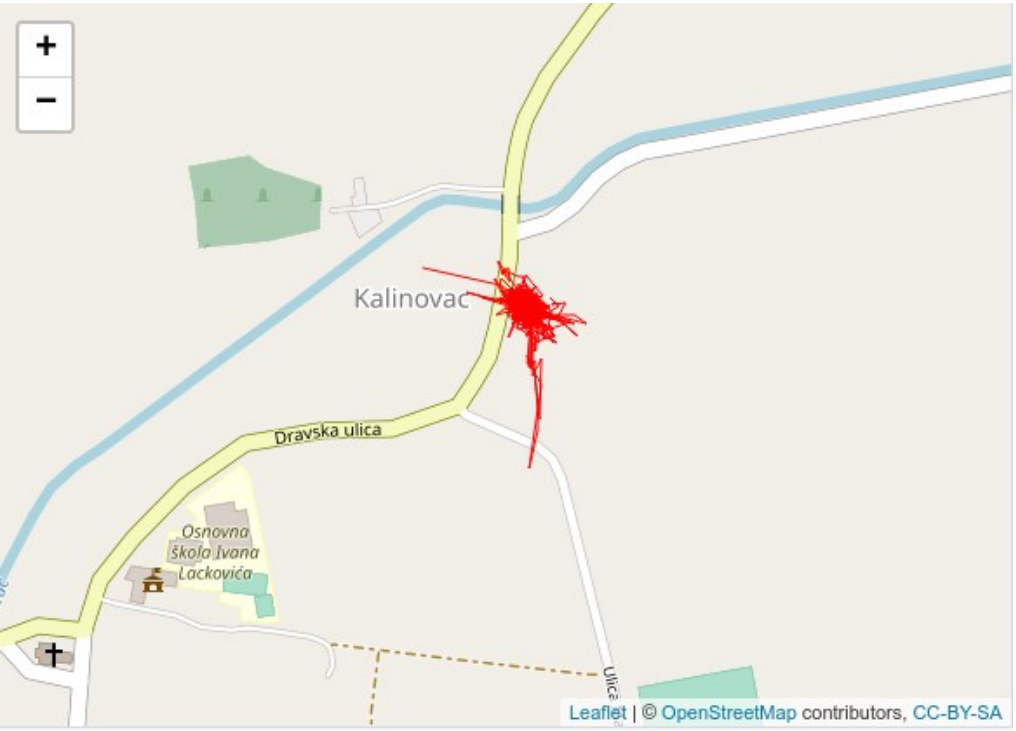
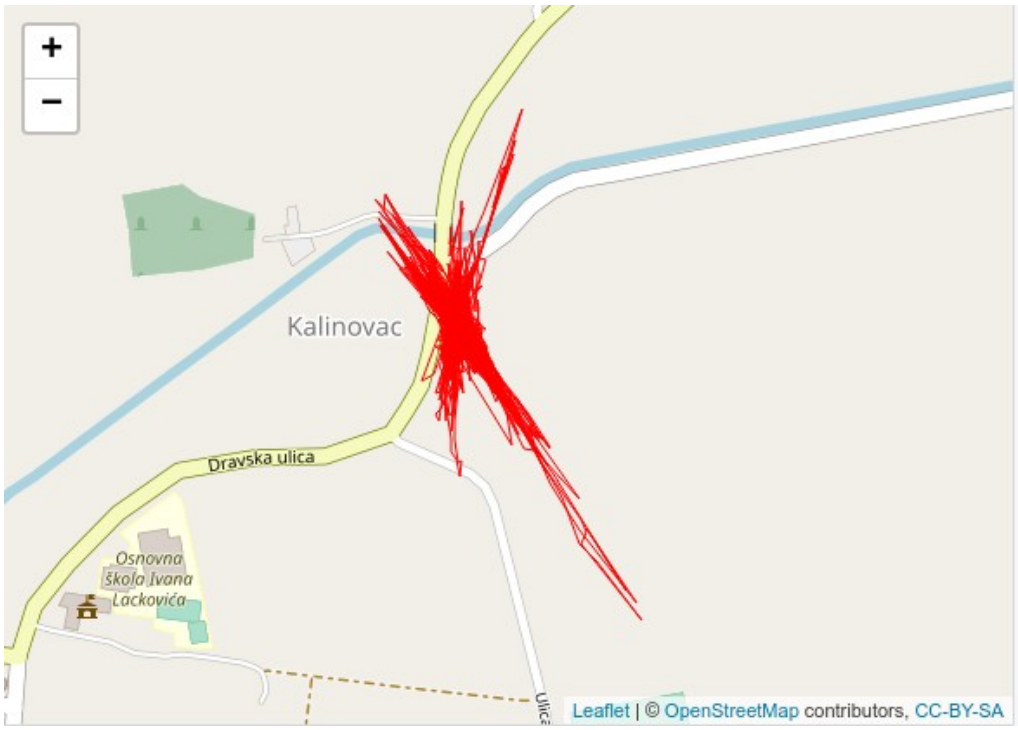
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance**
- Foundation and enabling technology for GNSS applications

Galileo only



Beidou only



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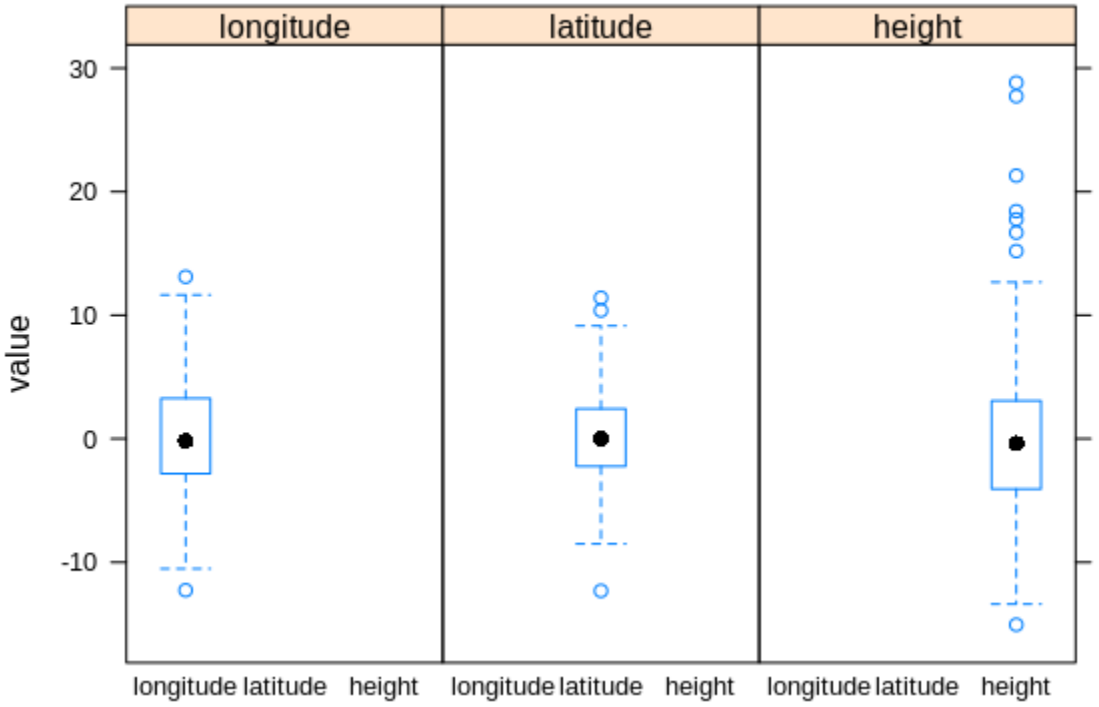
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance**
- Foundation and enabling technology for GNSS applications

- All four (single-frequency)



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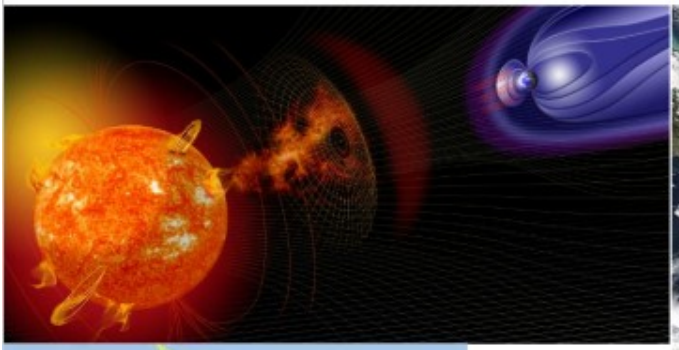
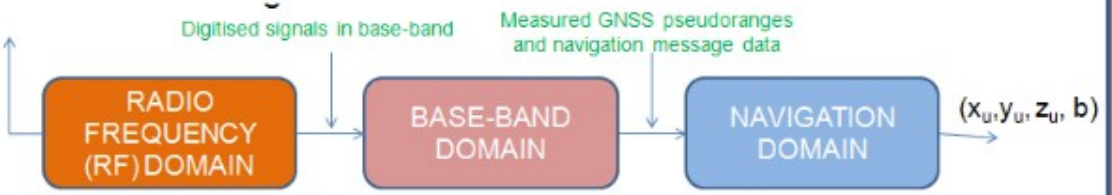
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning environment**
- Challenges of the impact of natural and artificial effects on the core GNSS positioning performance





GNSS-BASED APPLICATIONS:

NAVIGATION

AND

NON-NAVIGATION

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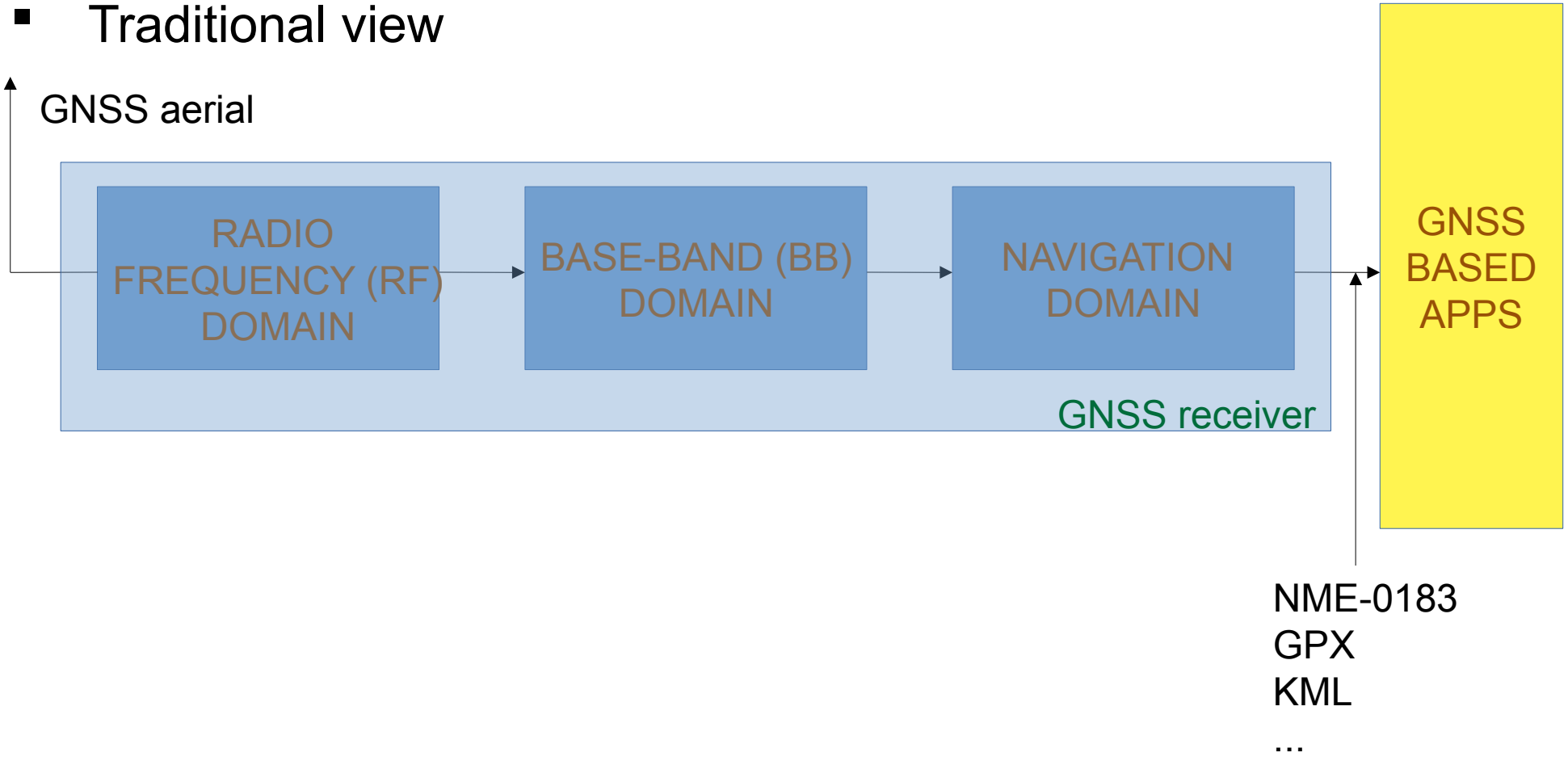
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- Traditional view



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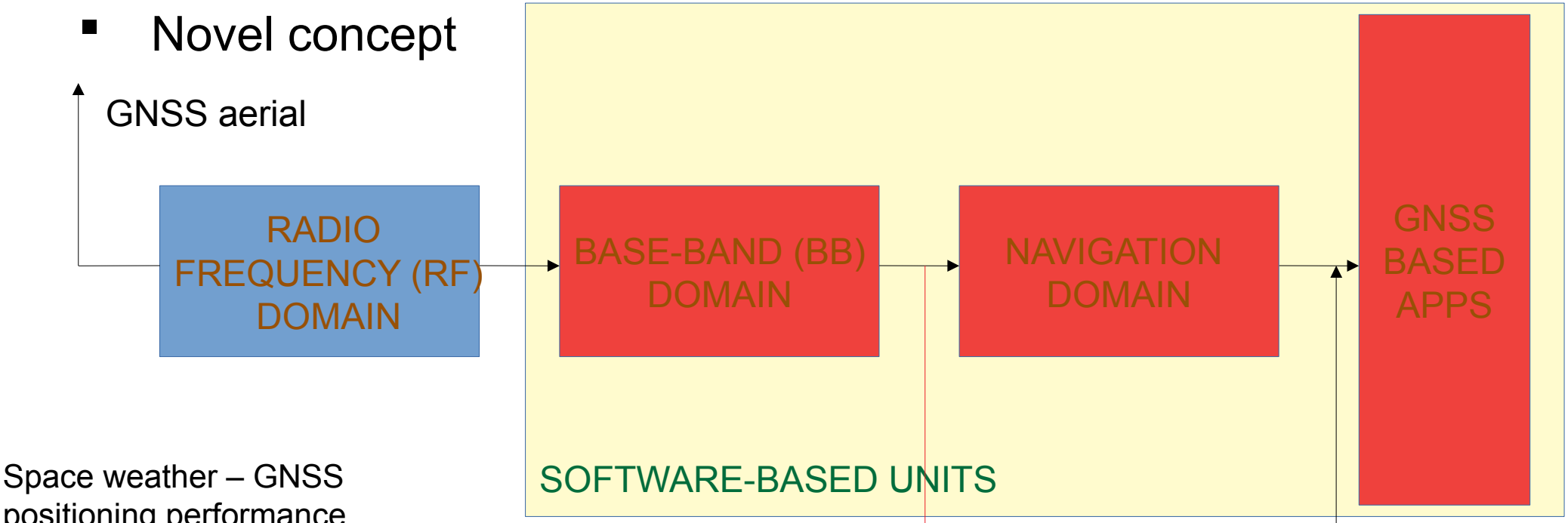
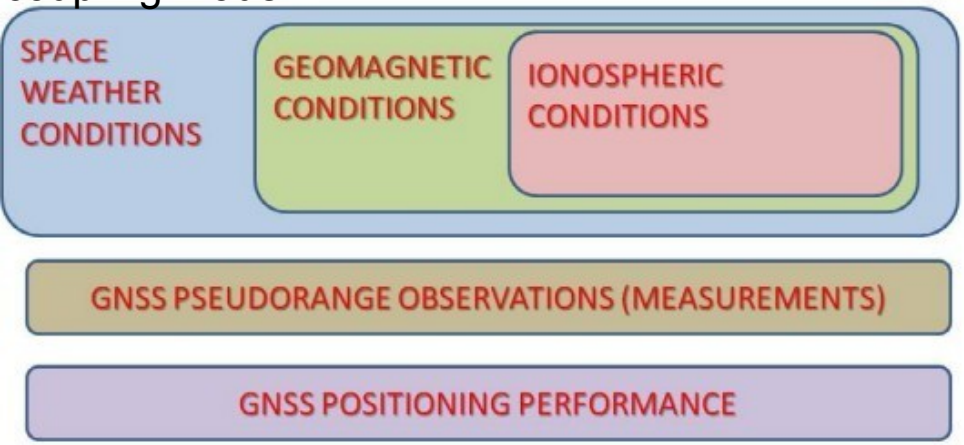
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- Novel concept



Space weather – GNSS positioning performance coupling model



ANDROID LOCATION API
RINEX o
RINEX n
RINEX p

NMEA-0183
GPX
KML
...

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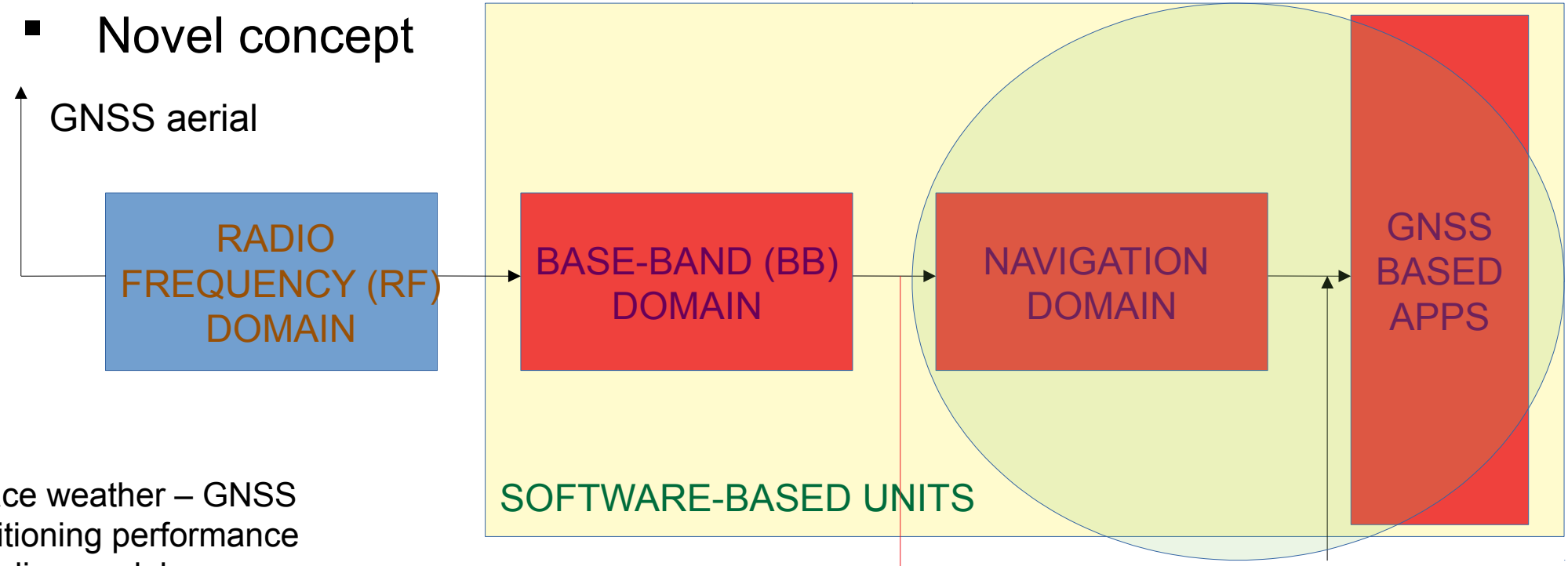
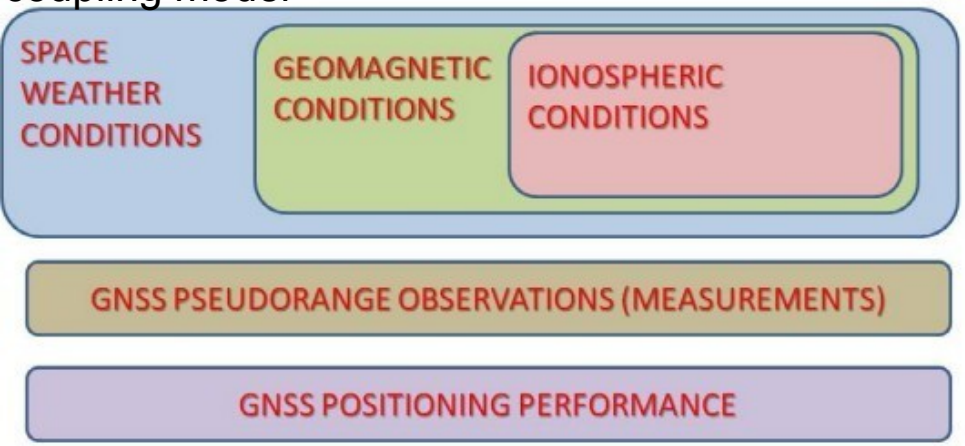
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- Novel concept



Space weather – GNSS positioning performance coupling model



ANDROID LOCATION API
RINEX o
RINEX n
RINEX p

NMEA-0183
GPX
KML
...

The GNSS positioning environment effects are detectable in the Navigation Domain!

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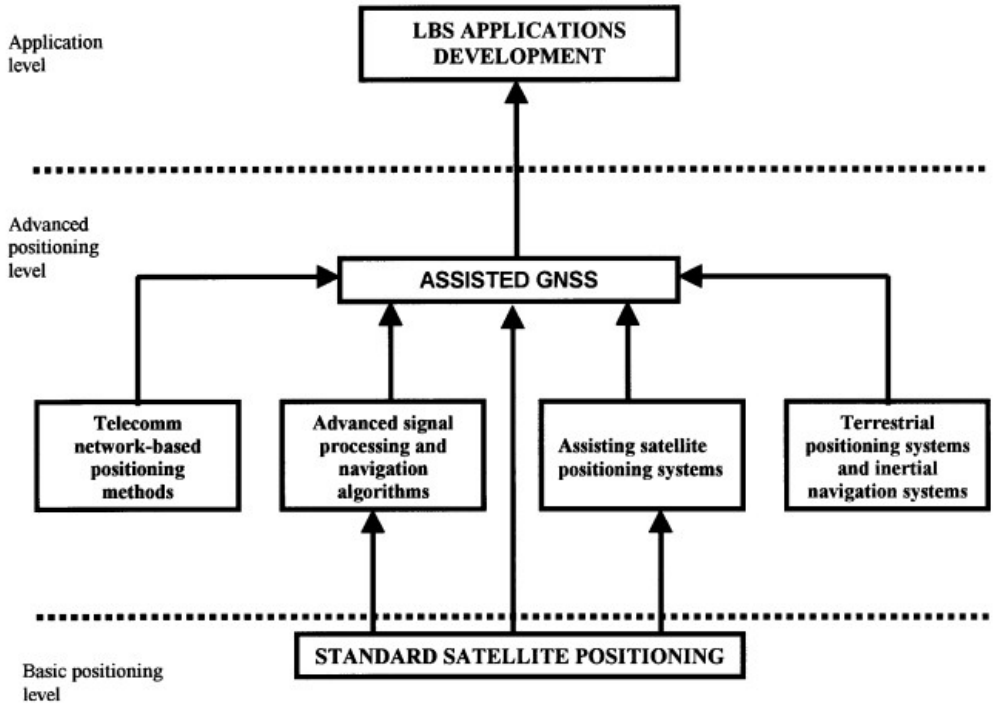
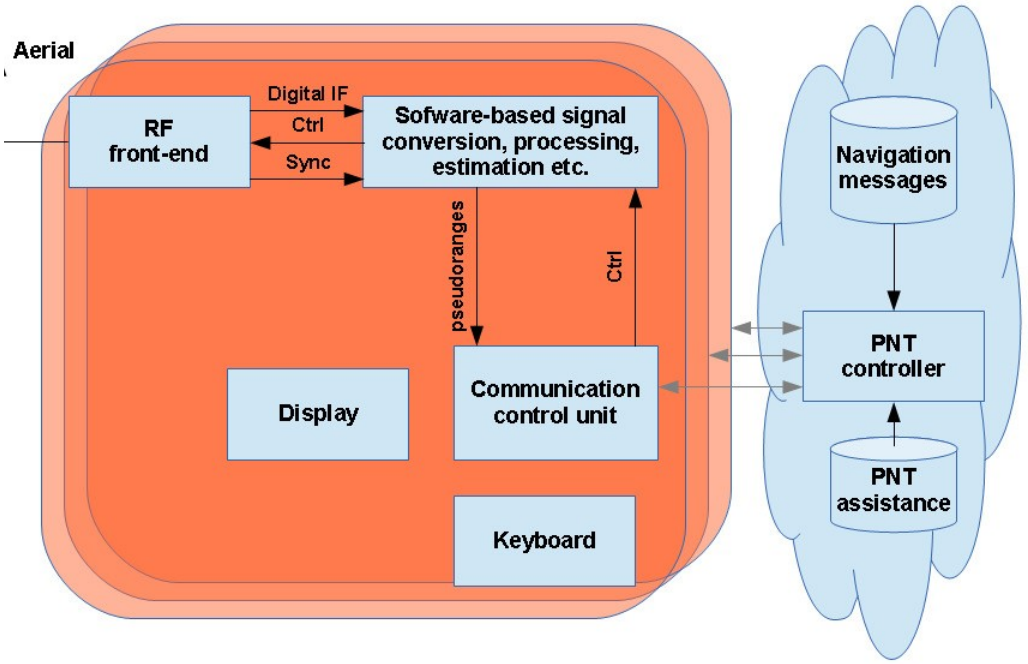
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- Evolution of the concept





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Filjar, R, Huljenić, D, and Lenac, K. (2013). Enhancing performance of GNSS position estimator by cloud-based GNSS SDR reciver architecture utilisation. Proc ELMAR-2013, 315-319. Zadar, Croatia

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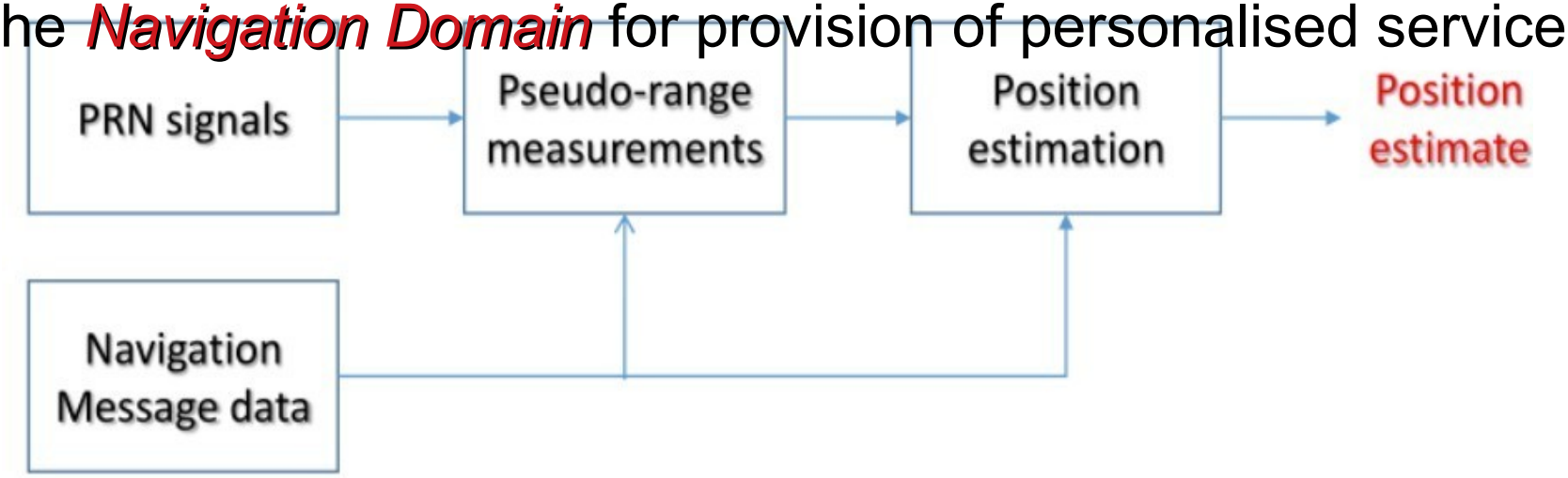
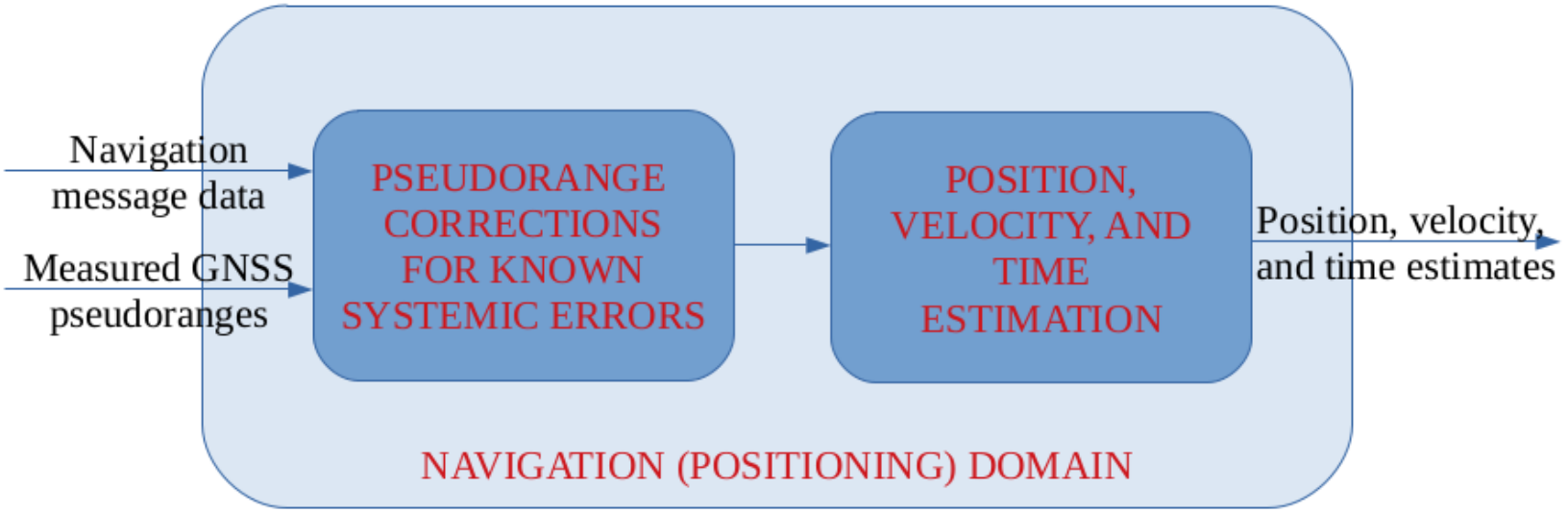
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- The problem we target: compromised raw GNSS pseudoranges in the *Navigation Domain* for provision of personalised service





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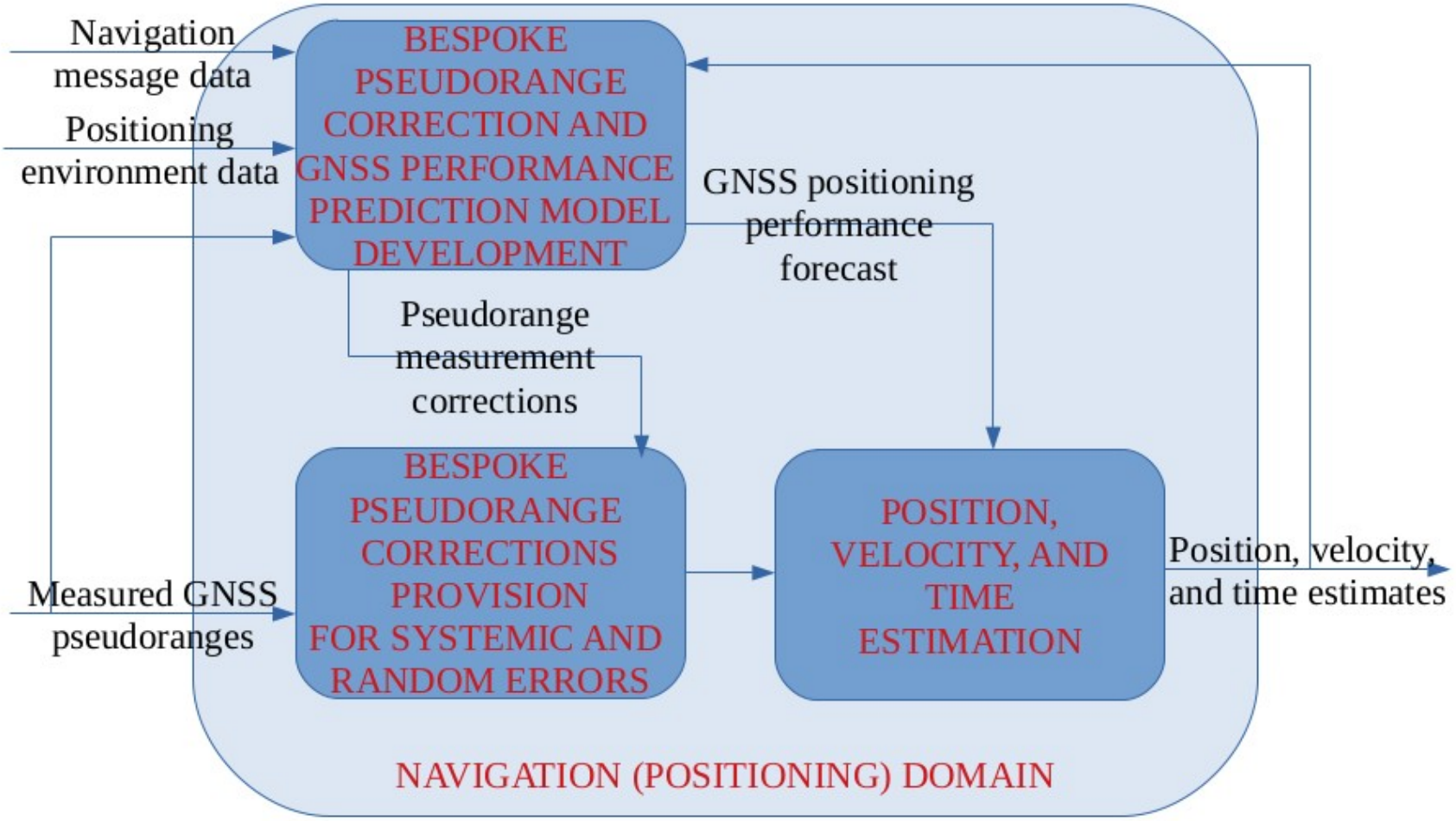
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- The approach we take: the GNSS positioning process that self-adapts to the GNSS positioning environment conditions

In preparation for publication:
Filjar, R, and Jukić, O. (2020). Self-Adaptive GNSS Position Estimation Process Improves Mitigation Of GNSS Ionospheric Effects. Proc of International Colloqium on Equatorial and Low Latitude Ionosphere. University of Lagos, Akoka, Nigeria.



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **Theoretical foundations of the self-adaptive GNSS position estimation method – Weighted Least-Square Solution (WLSS)of the Single-Point GNSS positioning problem**
- Weights as the results of the model of variance for a particular GNSS positioning environment conditions

WLSS is determined through condition:

$$min \, \|y - \hat{y}\|_W^2$$

Estimate of vector of unknowns

$$\widehat{x_w} = (G^\tau W G)^{-1} G^\tau W y$$

If ***W*** is a diagonal matrix:

$$\|y - \hat{y}\|_W^2 = \sum w_i (y_i - \hat{y}_i)^2$$

Covariance matrix:

$$P_w = (G^\tau W G)^{-1} G^\tau W R W G (G^\tau W G)^{-1}$$

Filić, M, Grubišić, L, and Filjar, R. (2018). Improvement of standard GPS position estimation algorithm through utilization of Weighted Least-Sqaure approach. Proc of 11th Annual Baška GNSS Conference, 7-19. Baška, Krk Island, Croatia. Available at: https://www.pfri.uniri.hr/web/hr/dokumenti/zbornici-gnss/2018-GNSS-11.pdf

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **WLSS-based positioning process demonstrated in the scenario of the GNSS ionospheric effects mitigation**

- **Self-adaptove GNSS positioning process**
- Bespoke GNSS pseudorange error model

$$\Delta\vec{\rho} = \boldsymbol{A}\cdot\vec{l}_{pos-env} + \boldsymbol{B}\cdot\vec{l}_{exper} \qquad (18)$$
$$\vec{\rho} = \vec{\rho}_{meas} - \Delta\vec{\rho}$$

where:

$\Delta\vec{\rho}$ … denotes GNSS pseudorange measurement error vector estimated from known positioning conditions and experience from similar previous cases

$\boldsymbol{A}$ … denotes the transform matrix between vector description of positioning environment conditions and the resulting GNSS pseudorange measurement error

$\vec{\rho}_{meas}$ … denotes measured GNSS pseudorange vector

$\vec{l}_{pos-env}$ … denotes vector description of positioning environment conditions

$\boldsymbol{B}$ … denotes the transform matrix between vector description of previous experience and the resulting GNSS pseudorange measurement error

$\vec{l}_{exper}$ … denotes vector description of previous experience

- **Self-adaptive GNSS positioning process**
- Bespoke GNSS positioning error model

$$\Delta\vec{x} = \boldsymbol{C}\cdot\vec{l}_{pos-env} + \boldsymbol{D}\cdot\vec{l}_{exper} \qquad (19)$$
$$\vec{x} = \vec{x}_{est} - \Delta\vec{x}$$

where:

$\Delta\vec{x}$ … denotes GNSS position estimation error vector estimated from known positioning conditions and experience from similar previous cases

$\boldsymbol{C}$ … denotes the transform matrix between vector description of positioning environment conditions and the resulting GNSS position estimation error

$\vec{l}_{pos-env}$ … denotes vector description of positioning environment conditions

$\vec{x}_{est}$ … denotes GNSS position estimation vector estimated from corrected pseudoranges

$\boldsymbol{D}$ … denotes the transform matrix between vector description of previous experience and the resulting GNSS position estimation error

$\vec{l}_{exper}$ … denotes vector description of previous experience

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **Improvement of the GNSS positioning process may be rendered bespoke for targeted application and a particular GNSS positioning environment conditions**
- **A successful model balances bias and variance**
- **Bias, trend, and seasonality are usually mitigated well with the standard correction models, thus leaving variance as the key target to tackle!**

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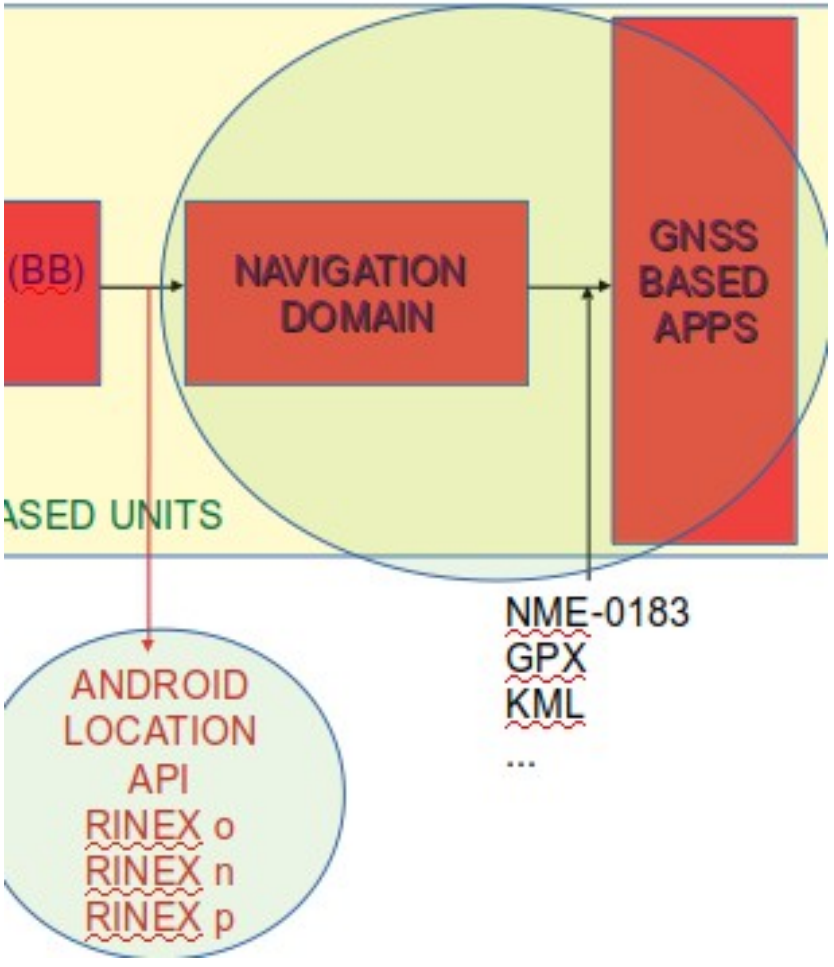
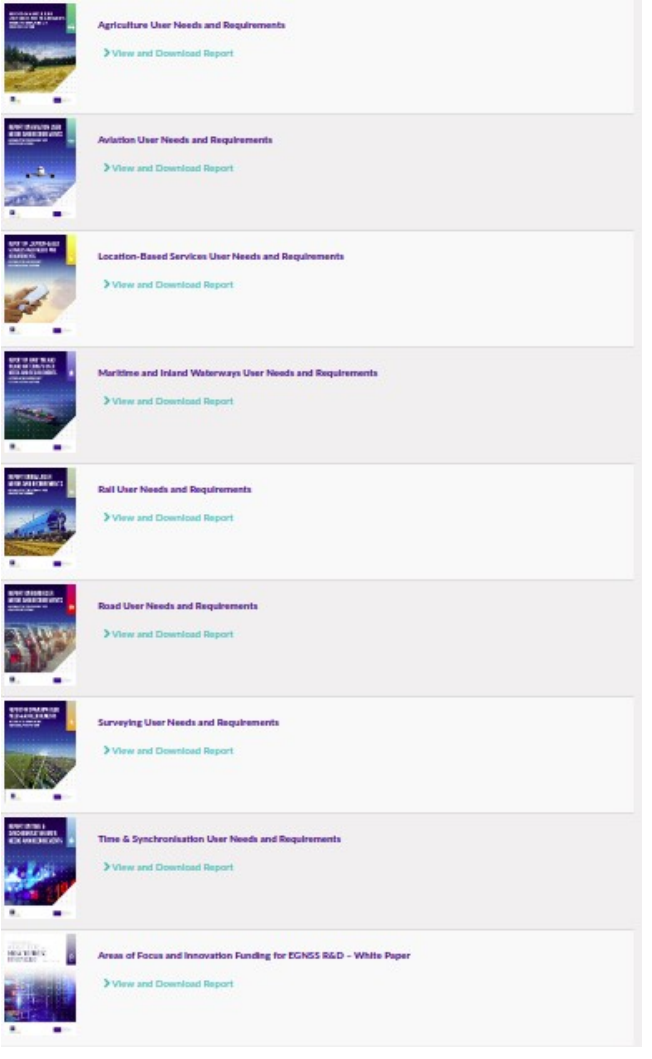
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **Positioning-as-a-(Personalised) Service through integration between the Navigation Domain of the GNSS positioning process and a related GNSS application**



GNSS User Needs and Requirements → *Ask GSA!*

https://www.gsa.europa.eu/gnss-applications/user-needs-and-requirements



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **Global Navigation Satellite System (GNSS)**
- **50th anniversary to be celebrated soon**
- Attraction and fascination to stay with researchers, developers, operators, users, society, and civilisation!

Dr Renato Filjar, FRIN
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Faculty of Engineering, University of Rijeka, Croatia
Zagreb University of Applied Sciences, Croatia

E-mail: renato.filjar@gmail.com

SELECTED PUBLICATIONS

Journal manuscripts (I)

Filić, M, and Dimc, F. (2019). Logistic map-encrypted PRN code as a proposed alternative to GNSS PRN pseudo-range code. TransNav, 13(3), 587-590. doi: 10.12716/1001.13.03.14
Filić, M, and Filjar, R. (2019). GNSS positioning error change-point detection in GNSS positioning performance modelling. TransNav, 13(3), 575-579. doi: 10.12716/1001.13.03.12
Filić, M. (2018). Foundations of GNSS spoofing detection and mitigation with distributed GNSS SDR receiver. TransNav, 12(4), 649-656. doi: 10.12716/1001.12.04.01
Filić, M, and Filjar, R. (2018). A South Pacific Cyclone-Caused GPS Positioning Error and Its Effects on Remote Island Communities. TransNav, 12(4), 663-670. doi: 10.12716/1001.12.04.03
Filić, M, Filjar, R, and Ševrović, M. (2018). Expression of GNSS Positioning Error in Terms of Distance. Promet - Traffic & Transportation, 30(3), 305-310. doi:10.7307/ptt.v30i3.2304
Filic, M, Filjar, R, and Ruotsalainen, L. (2016). An SDR-based Study of Multi-GNSS Positioning Performance During Fast-developing Space Weather Storm. TransNav, 10(3), 395-400. doi: 10.12716/1001.10.03.03

SELECTED PUBLICATIONS

Journal manuscripts (II)

Filić, M, Filjar, R. (2019). A Considerable Level of Correlation Between SID-Monitoring Time Series and GPS-Derived TEC Observations Taken During Development of a Massive Ionospheric Storm. URSI Radio Science Bulletin, 2019(370), 27-33. doi: 10.23919/URSIRSB.2019.8956141

Rumora, I, Jukić, O, Filić, M, and Filjar, R. (2018). A study of GPS positioning error associated with tropospheric delay during Numa Mediterranean cyclone. Int J for Transp and Traff Eng, 8(3), 282-293. doi: 10.7708/ijtte.2018.8(3).03

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SELECTED PUBLICATIONS

Conference papers (I)

Filić, M. (2019). GNSS Navigation Message Authentication Using TESLA. Proc 13th Baška GNSS Conference, 29-45. Baška, Krk Island, Croatia. Available at: https://www.pfri.uniri.hr/web/hr/dokumenti/13-GNSS-2019_Final.pdf

Filić, M, and Filjar, R. (2019). On correlation between SID monitor and GPS-derived TEC observations during a massive ionospheric storm development. Student Paper Competition Award at URSI AP-RASC 2019. New Delhi, India. doi: 10.23919/URSIAP-RASC.2019.8738664

Jukić, O, Sikirica, N, Rumora I, and Filić, M. (2019). Seven Days in Chile: Impact of the 2011 Puyehue-Cordon Caulle Volcanic Eruption on the GPS Ionospheric Delay. Proc of International Symposium on Global Navigation Satellite System 2018 (ISGNSS 2018), Bali, Indonesia. E3S Web Conf, 94, Article No. 01001 (4 pages). doi: https://doi.org/10.1051/e3sconf/20199401001

Špoljar, D, Črnjarić-Žic, N, Sikirica, N, Lenac, K. (2020). Statistical analysis of ionospheric scintillation S4 index time-series during development of an ionospheric storm. Proc ISGNSS 2019 Conference. Juju Island, South Korea. Available at: https://bit.ly/3d9aCae

Filić, M, and Filjar, R. (2018). Modelling the Relation between GNSS Positioning Performance Degradation, and Space Weather and Ionospheric Conditions using RReliefF Features Selection. Proc of 31st International Technical Meeting ION GNSS+ 2018, 1999-2006. Miami, FL. doi: https://doi.org/10.33012/2018.16016

SELECTED PUBLICATIONS

Conference papers (II)

Filić, M, and Filjar, R. (2018). Smartphone GNSS positioning performance improvements through utilisation of Google Location API. Proc of 41 st International Convention MIPRO/CTI, 507-510. Opatija, Croatia. doi: 10.23919/MIPRO.2018.8400087

Filić, M. (2018). On development of the forecasting model of GNSS positioning performance degradation due to space weather and ionospheric conditions. Proc 2 nd URSI AT-RASC (4 pages, electronic format). Gran Canaria, Spain. Available at: http://www.atrasc.com/content/stick/papers/URSISummaryPaperMFilic.pdf

Filić, M, Grubišić, L, and Filjar, R. (2018). Improvement of standard GPS position estimation algorithm through utilization of Weighted Least-Sqaure approach. Proc of 11th Annual Baška GNSS Conference, 7-19. Baška, Krk Island, Croatia. Available at: https://www.pfri.uniri.hr/web/hr/dokumenti/zbornici-gnss/2018-GNSS-11.pdf

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Filjar, R, Filić, M, and Mirmakhmudov, E. (2018). Categorisation of space weather and GNSS positioning quality indicators for estimation of GNSS positioning quality degradation. Proc of 11th Annual Baška GNSS Conference. Baška, Krk Island,Croatia. Available at: https://www.pfri.uniri.hr/web/hr/dokumenti/zbornici-gnss/2018-GNSS-11.pdf