

GSA Raw GNSS Measurements Task Force Workshop

Innovative work results using raw measurements

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



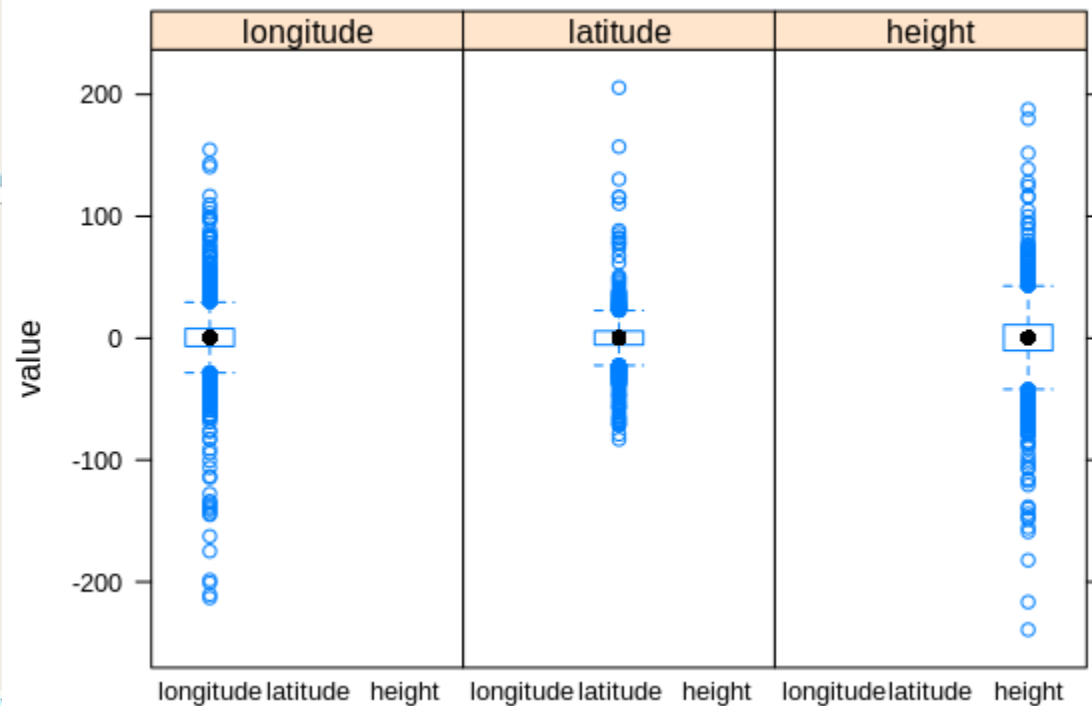
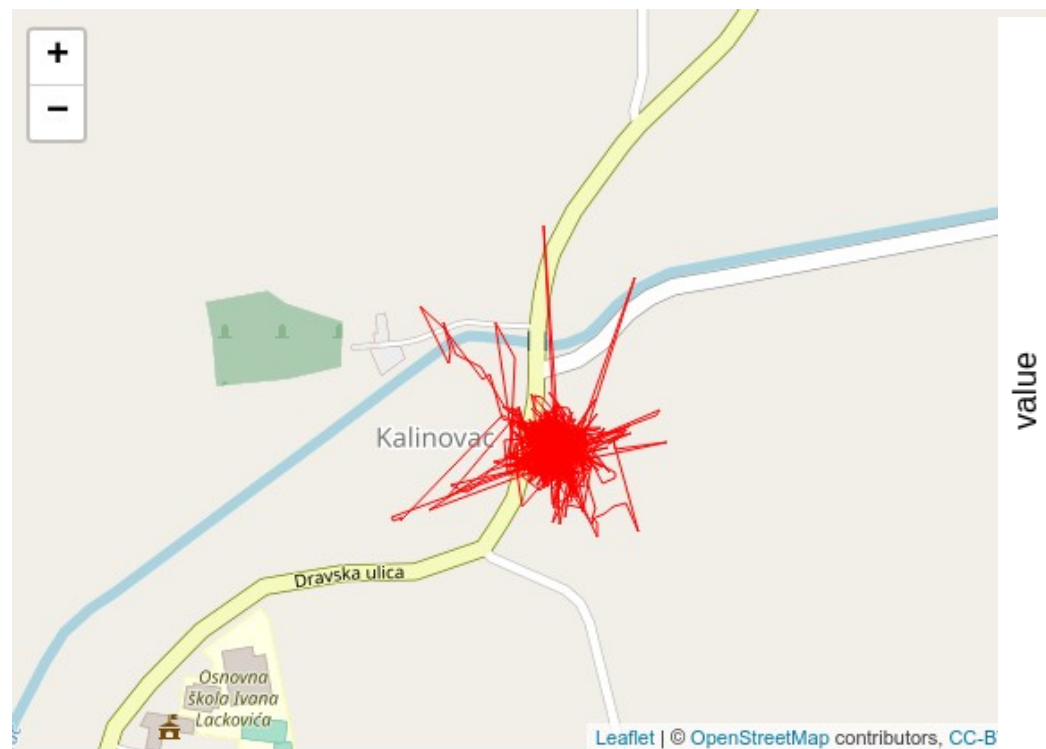
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

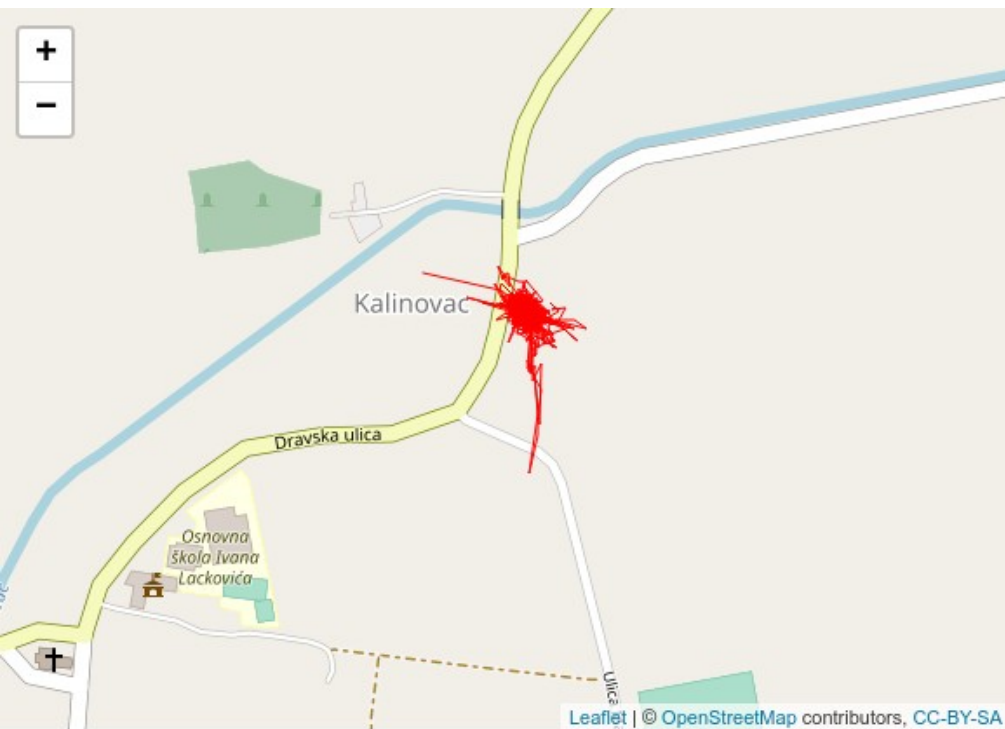


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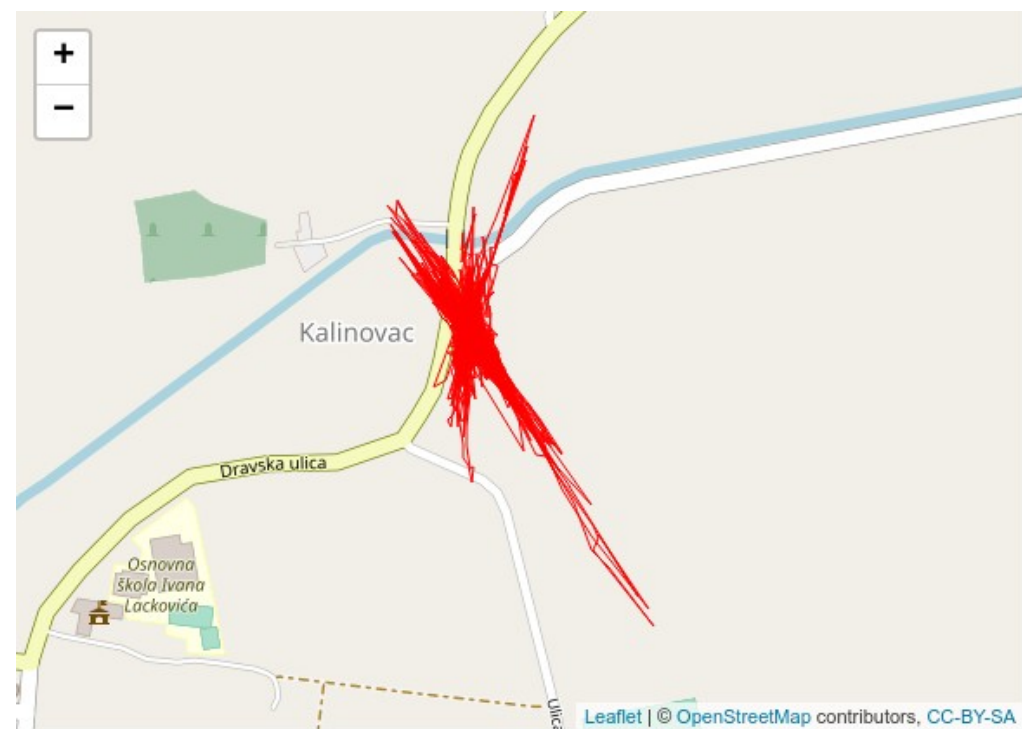
RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

Galileo only



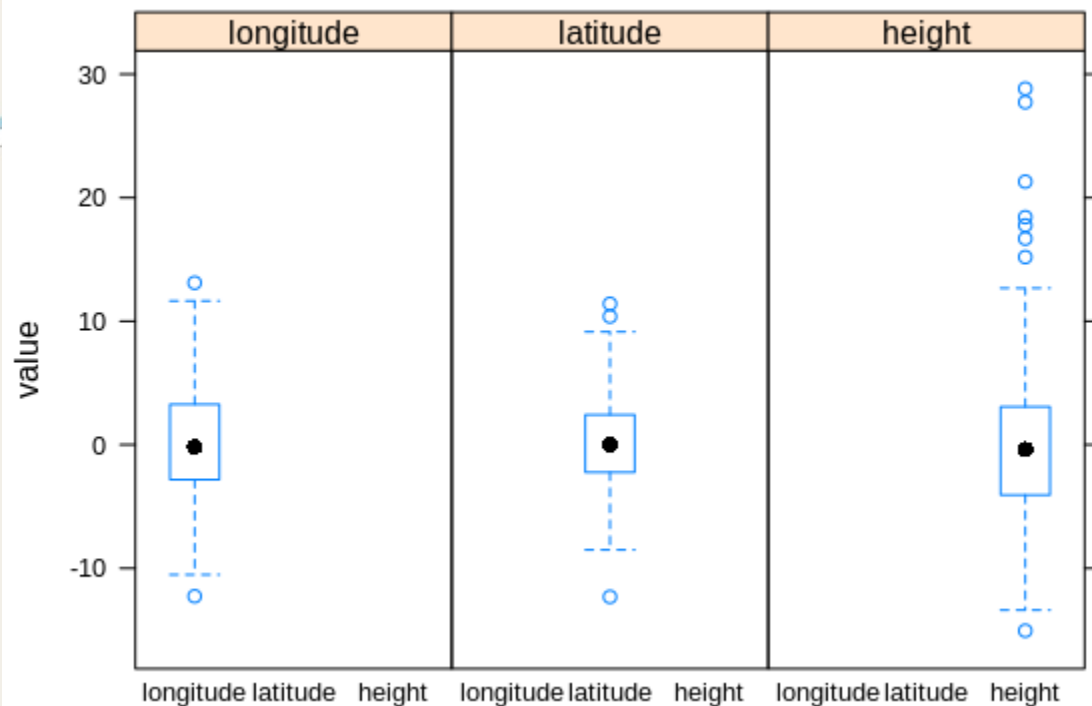
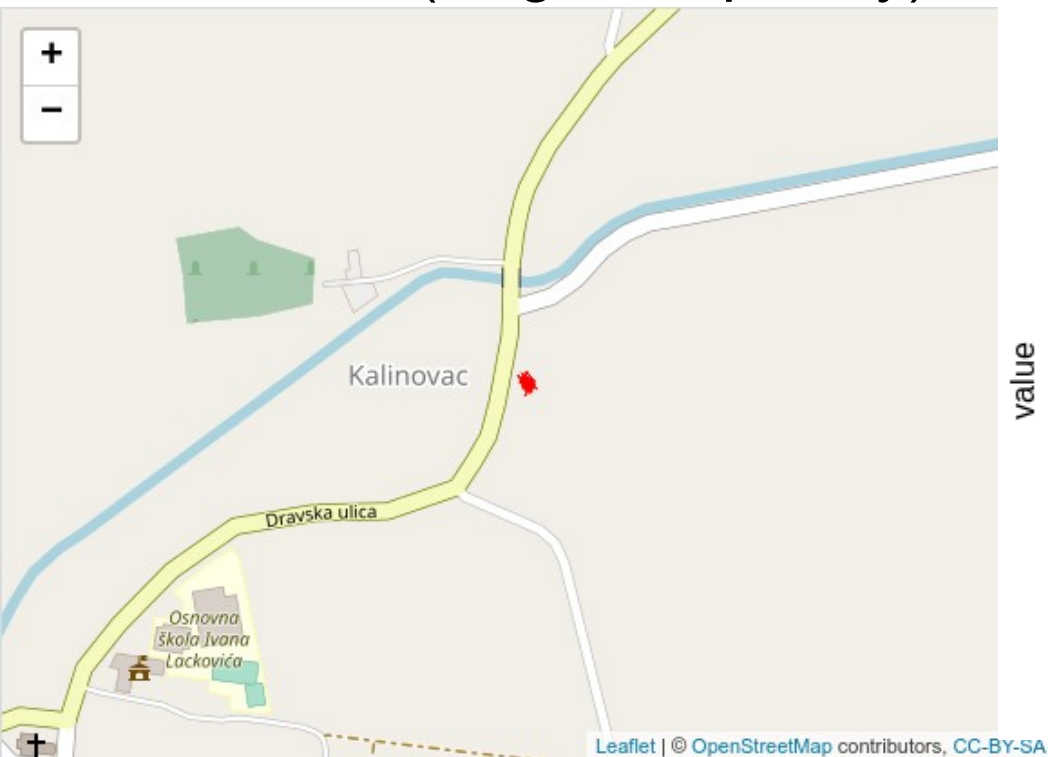
Beidou only



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

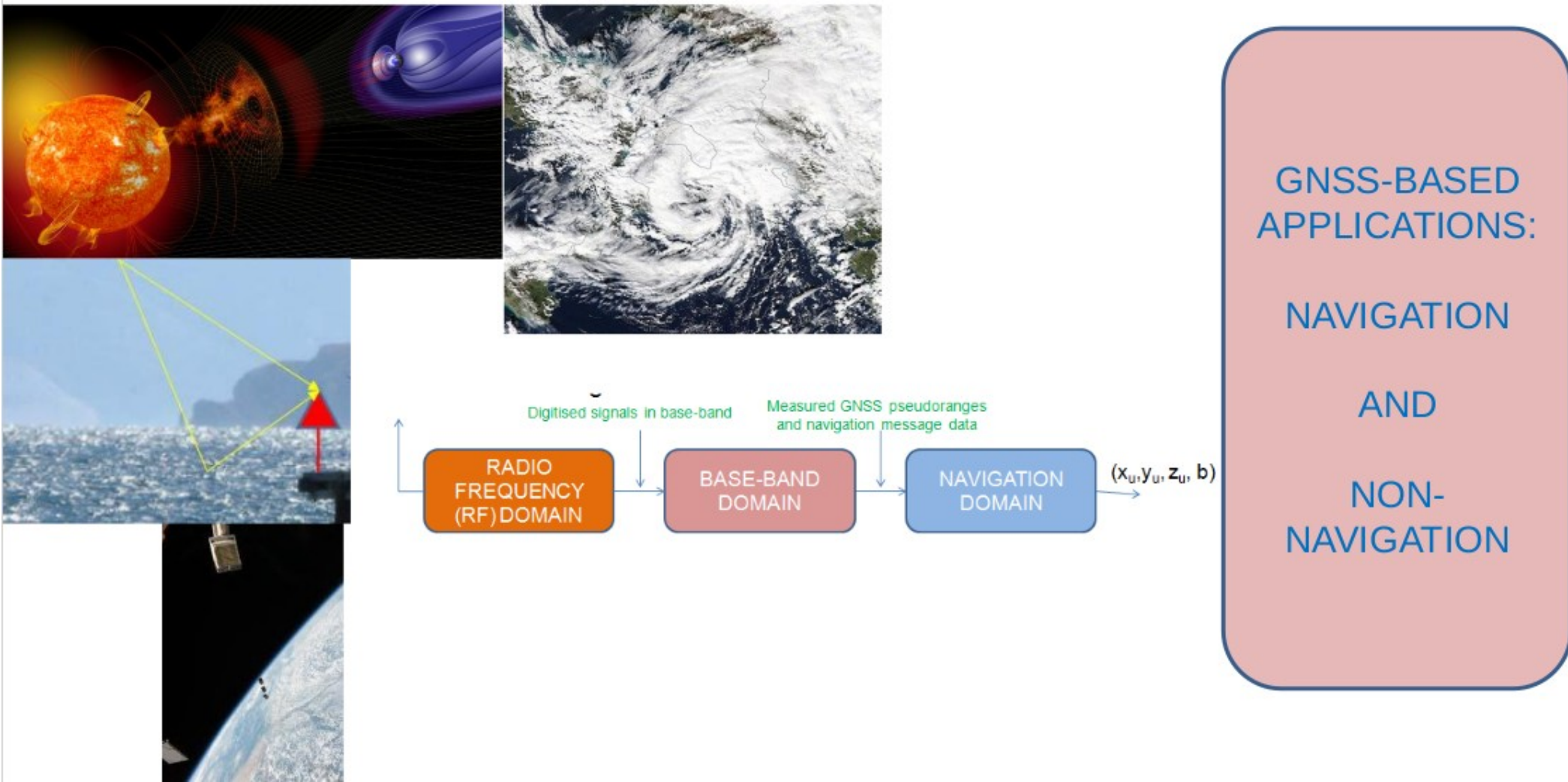
- **GNSS positioning performance**
- Foundation and enabling technology for GNSS applications
- All four (single-frequency)



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

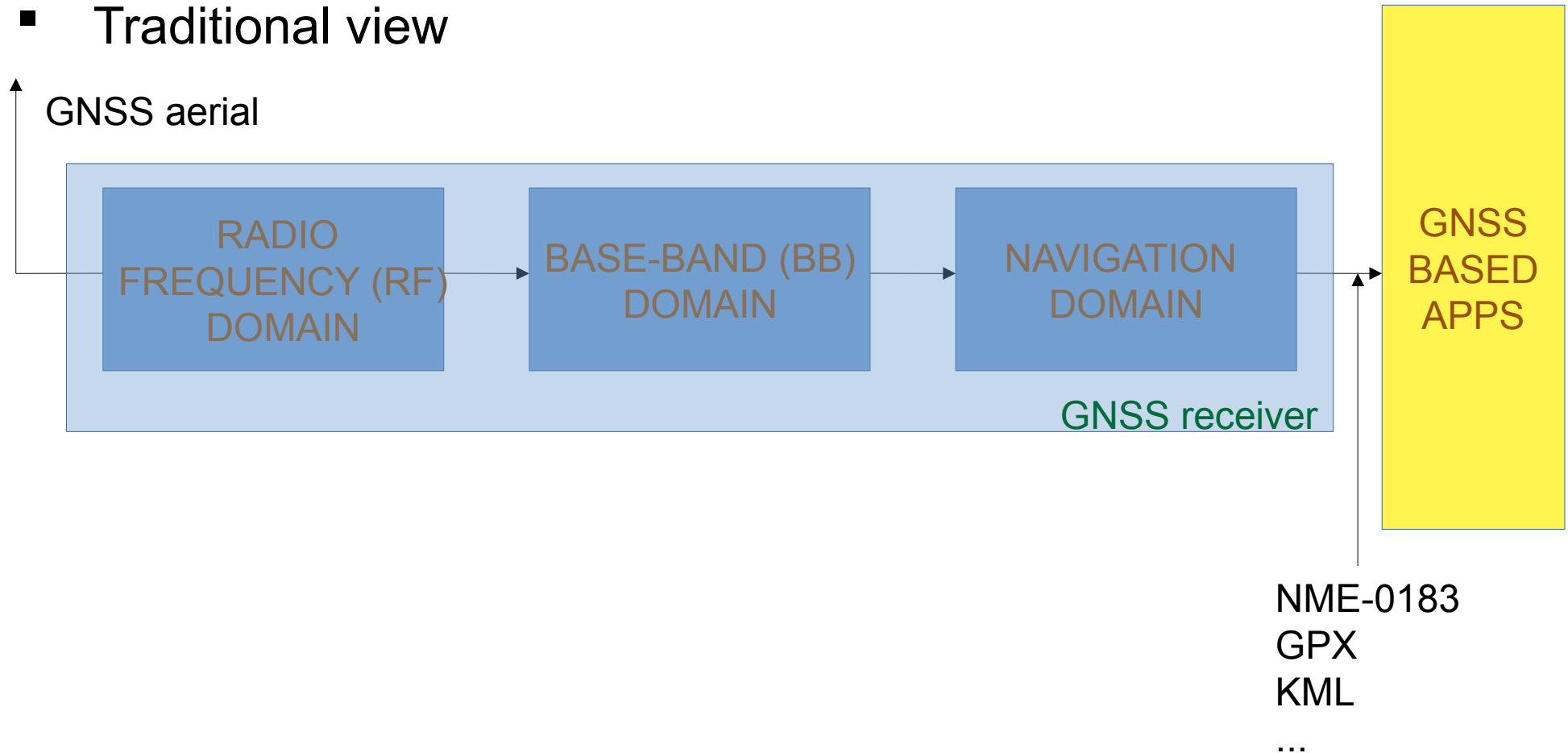
- **GNSS positioning environment**
- Challenges of the impact of natural and artificial effects on the core GNSS positioning performance



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

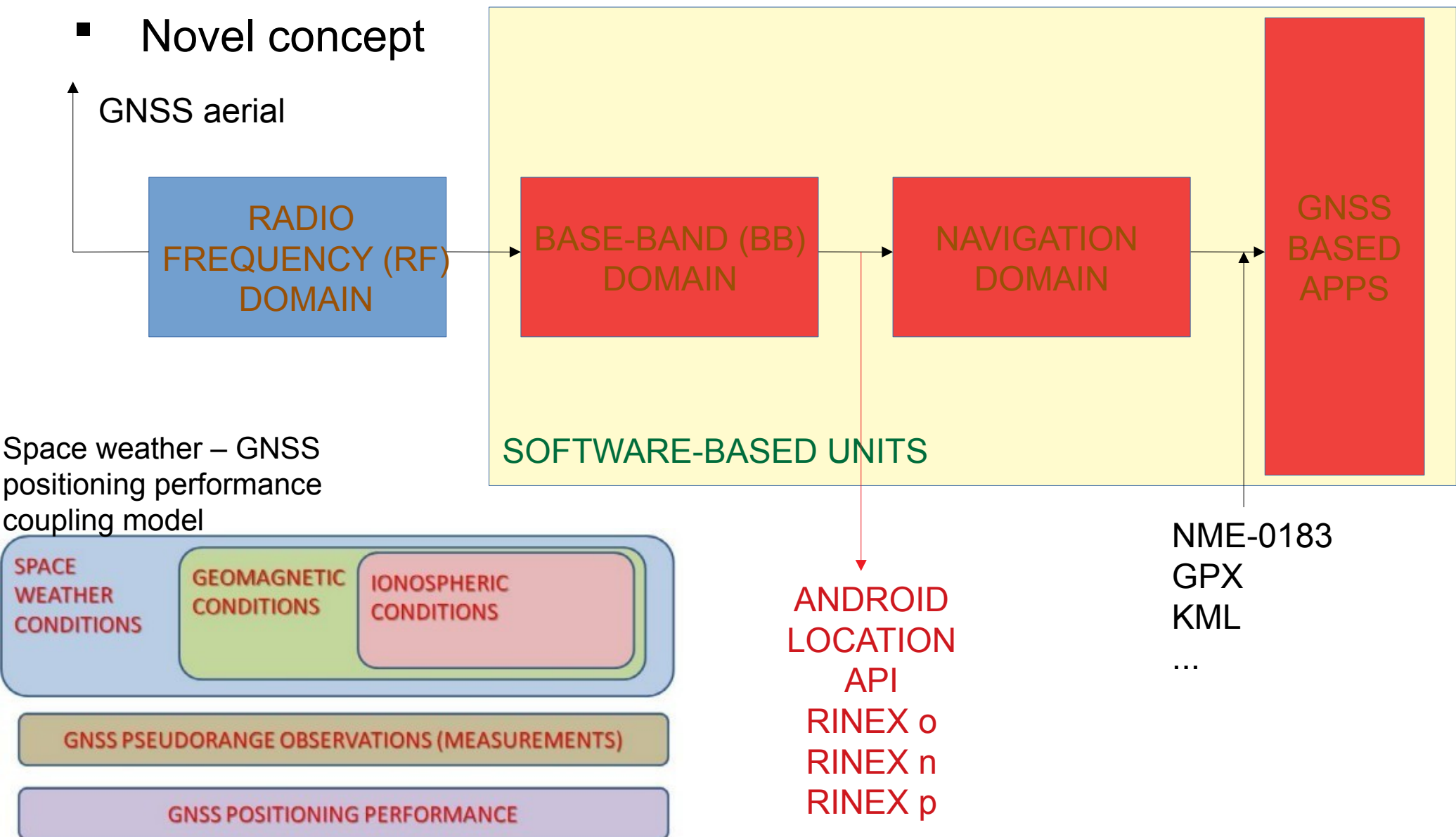


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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**

- Novel concept

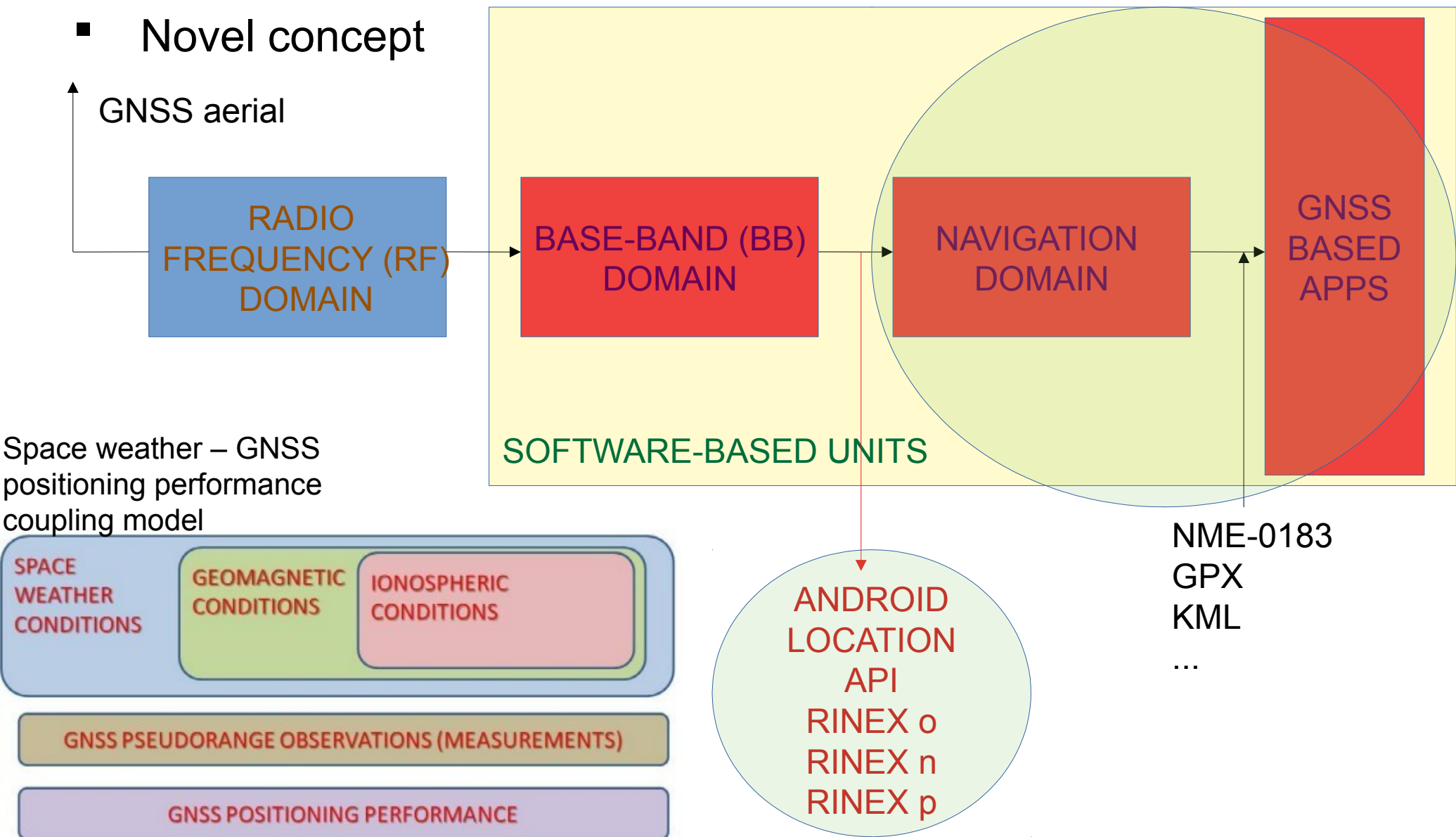


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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**

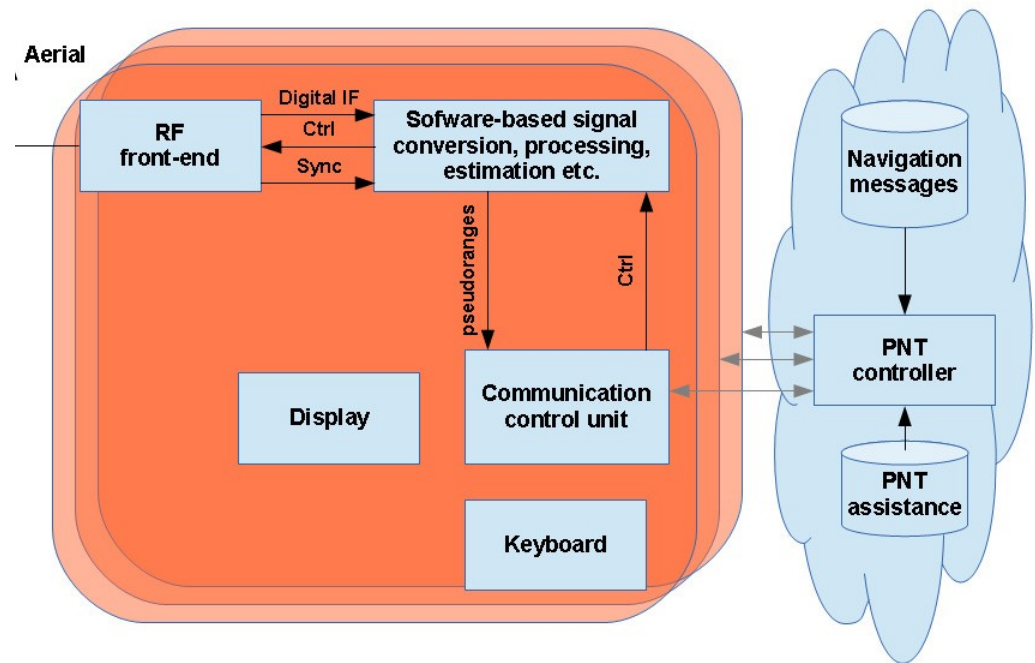
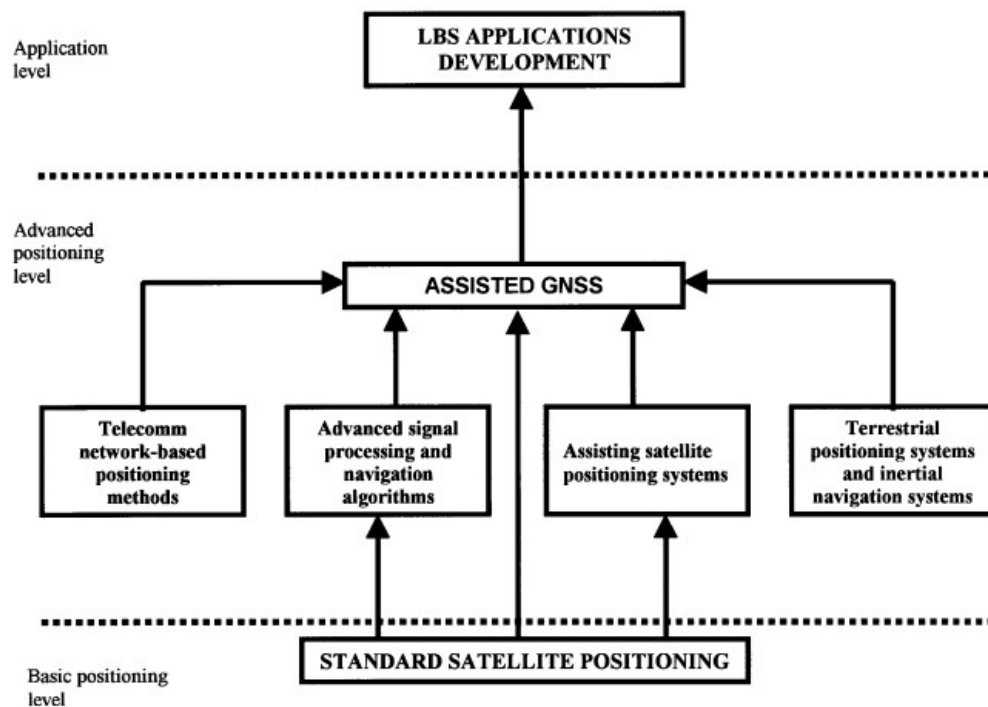
- Novel concept



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **GNSS positioning performance sustainability**
- Evolution



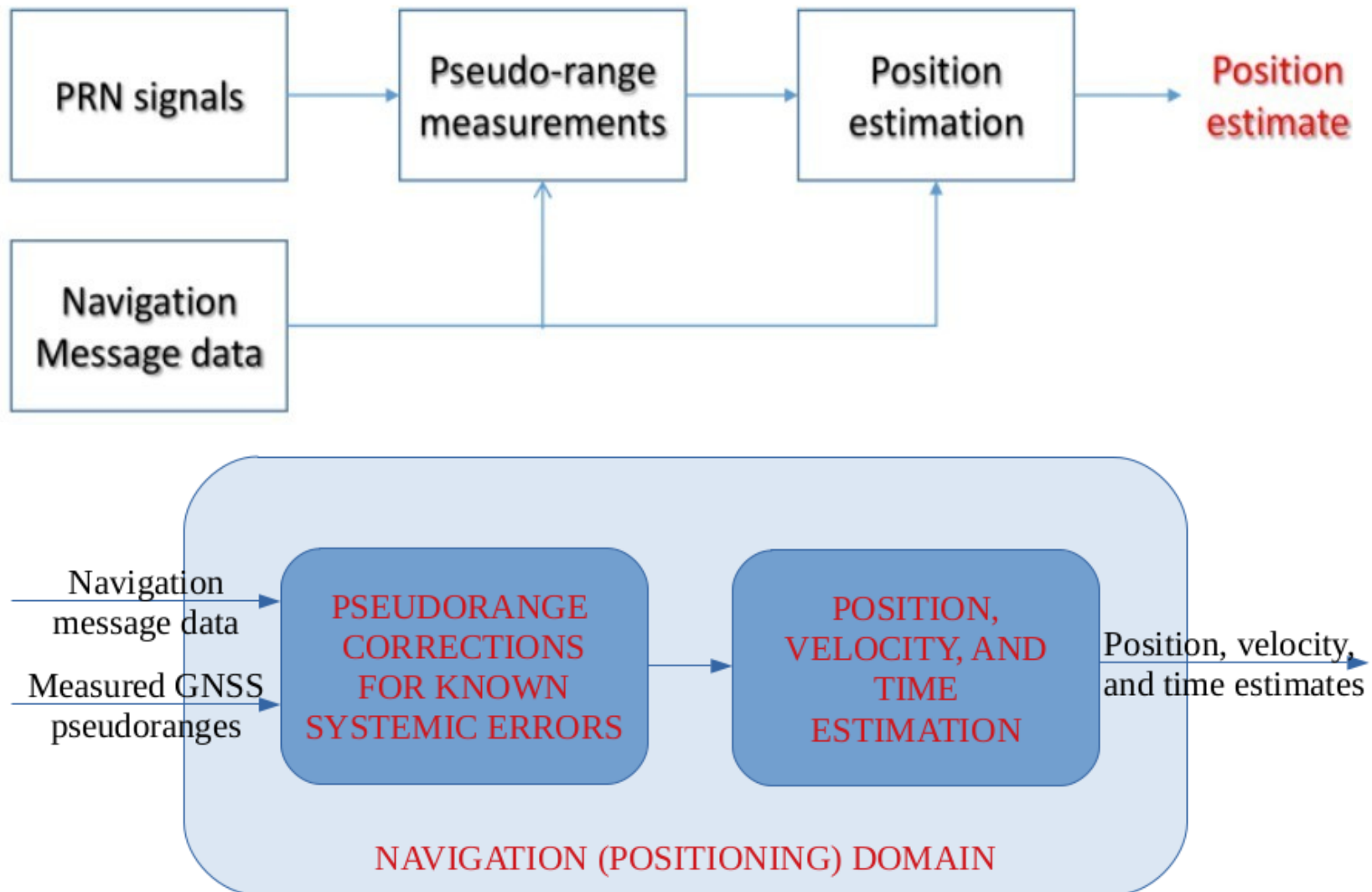
Filjar, R, Huljenic, D, and Desic, S. (2002). Distributed Positioning: A Network-Supported Method for Satellite Positioning Performance. Journal of Navigation, 55, 477-484. doi: 10.1017/S0373463302001996

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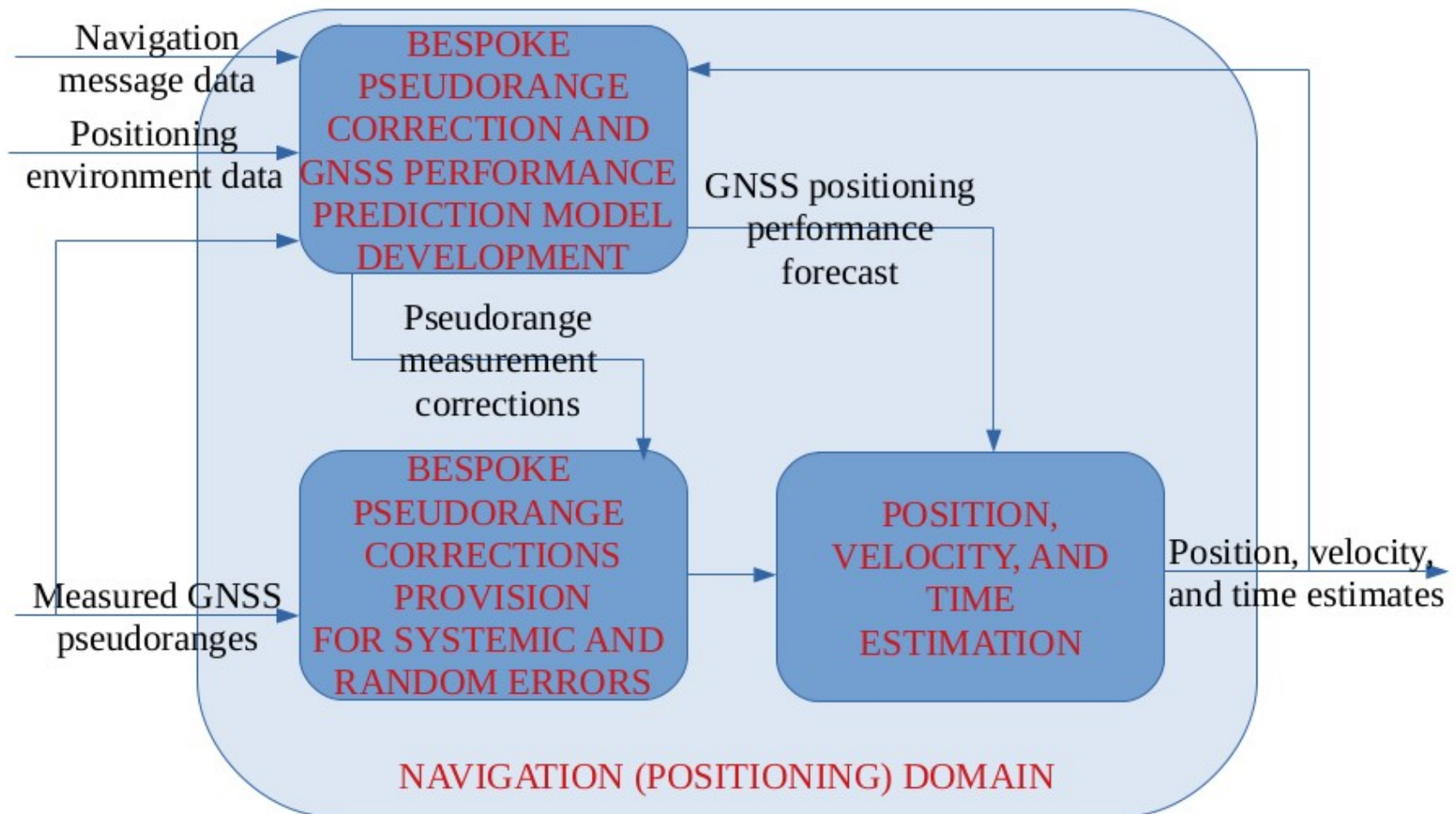
- **GNSS positioning performance sustainability**
- The problem we target: compromised raw GNSS pseudoranges



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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 Colloquium 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:

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

If W is a diagonal matrix:

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

Estimate of vector of unknowns

$$\hat{x}_w = (G^T W G)^{-1} G^T W y$$

Covariance matrix:

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

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

Space weather effects on Global Navigation Satellite System (GNSS) positioning performance are well-understood. However, a numerical model capable of forecasting the extent of GNSS positioning performance deterioration due to space weather, geomagnetic and ionospheric effects remains a scientific challenge. This monograph addresses the challenge through introduction of the space weather – GNSS positioning performance coupling model, and utilisation of selected machine learning methods for model development in selected scenario of quiet space weather conditions. Based on the assembled database of experimental observations, several forecasting models were developed using machine learning methods selected according to statistical properties of observations. Models were compared and their performance assessed from both the modelling and computational perspectives. Presented results contribute to the effort of generalised model development. The monograph will benefit scientists in the fields of machine learning, space weather and satellite navigation, GNSS receiver designers, and a growing population of interested GNSS users.

Space weather-driven GNSS degradation



Mia Filić
Renato Filjar

Mia Filić, mag. inf. et math. MRIN: Studied computer science and mathematics at Department of mathematics, Faculty of Science, University of Zagreb, Croatia. Independent statistical and machine learning, satellite navigation and space weather scientist. She received USRI Young Scientist Award in 2018.

Forecasting model of space weather-driven GNSS positioning performance

Forecasting model of space weather-driven GNSS
positioning performance degradation



978-613-9-90118-0

Filić, Filjar

LAP LAMBERT
Academic Publishing

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

$$\begin{aligned}\Delta \vec{\rho} &= \mathbf{A} \cdot \vec{\mathbf{l}}_{pos-env} + \mathbf{B} \cdot \vec{\mathbf{l}}_{exper} \\ \vec{\rho} &= \vec{\rho}_{meas} - \Delta \vec{\rho}\end{aligned}\tag{18}$$

where:

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

\mathbf{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

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

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

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

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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

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

$$\begin{aligned}\Delta \vec{x} &= \mathbf{C} \cdot \vec{I}_{pos-env} + \mathbf{D} \cdot \vec{I}_{exper} \\ \vec{x} &= \vec{x}_{est} - \Delta \vec{x}\end{aligned}\tag{19}$$

where:

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

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

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

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

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

\vec{I}_{exper} ... denotes vector description of previous experience

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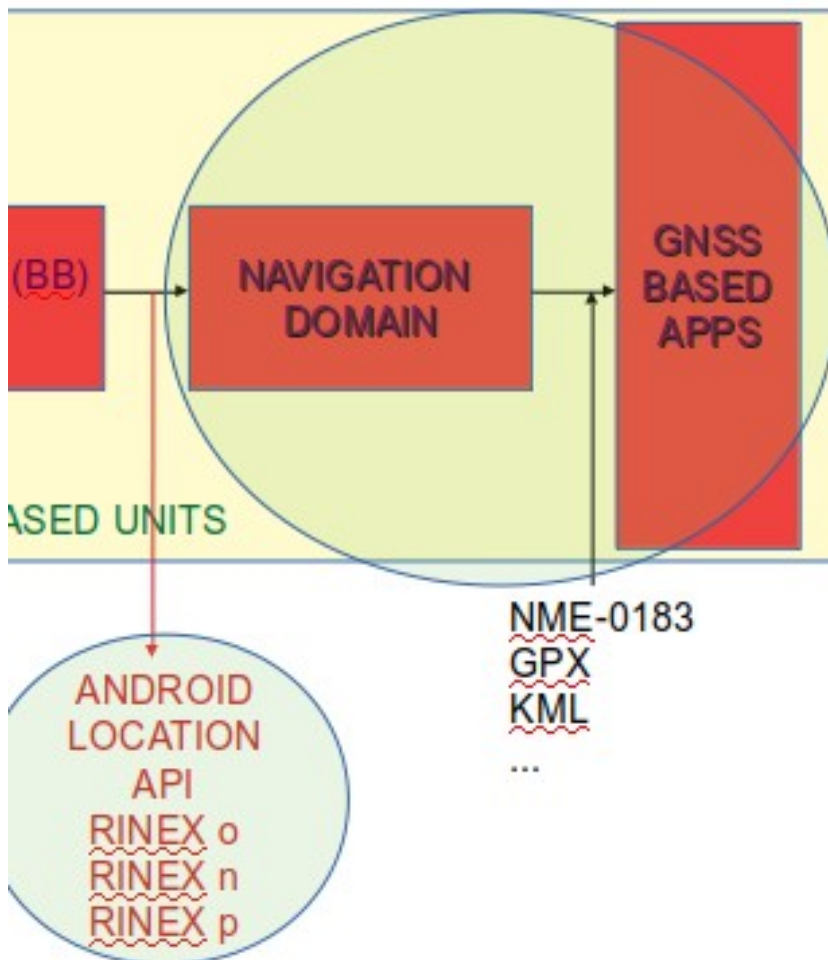
- Improvement of the GNSS positioning process may be rendered bespoke for targeted application and a particular GNSS positioning environment conditions
- Bias, trend, and seasonality are usually mitigated well with the standard correction models, thus leaving **variance** as the key target to tackle!



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RESILIENT GNSS POSITIONING PERFORMANCE: IS THE PROBLEM SOLVED?

- **Positioning-as-a-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>

	Agriculture User Needs and Requirements View and Download Report
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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!





APPRECIATE VERY MUCH
YOUR KIND ATTENTION!

Dr Renato Filjar, FRIN
Professor of Electronics Engineering
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

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SELECTED PUBLICATIONS

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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>

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Conference papers (II)

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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/URSI_SummaryPaperMFilic.pdf

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