United Nations/Azerbaijan Workshop on the International Space Weather Initiative: The Sun, Space Weather and Geosphere

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Statistical learning TEC predictive model for GNSS ionospheric delay mitigation in self-adaptive environment-aware SDR GNSS position estimation algorithm

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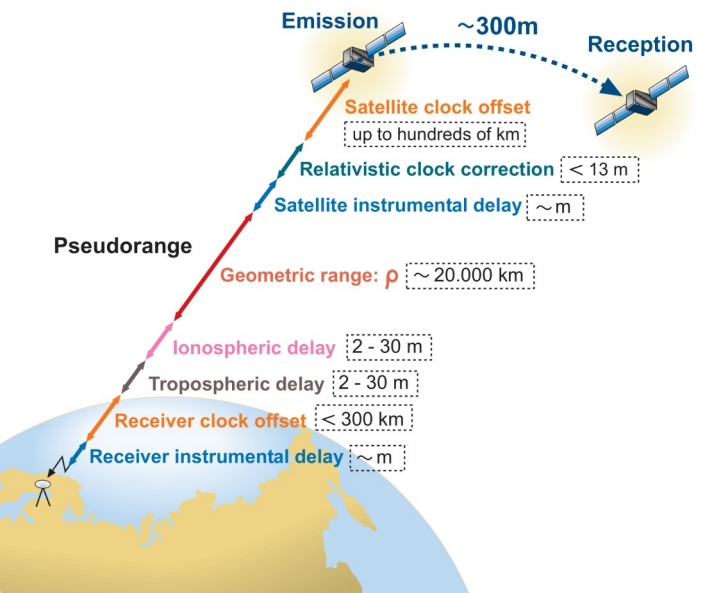
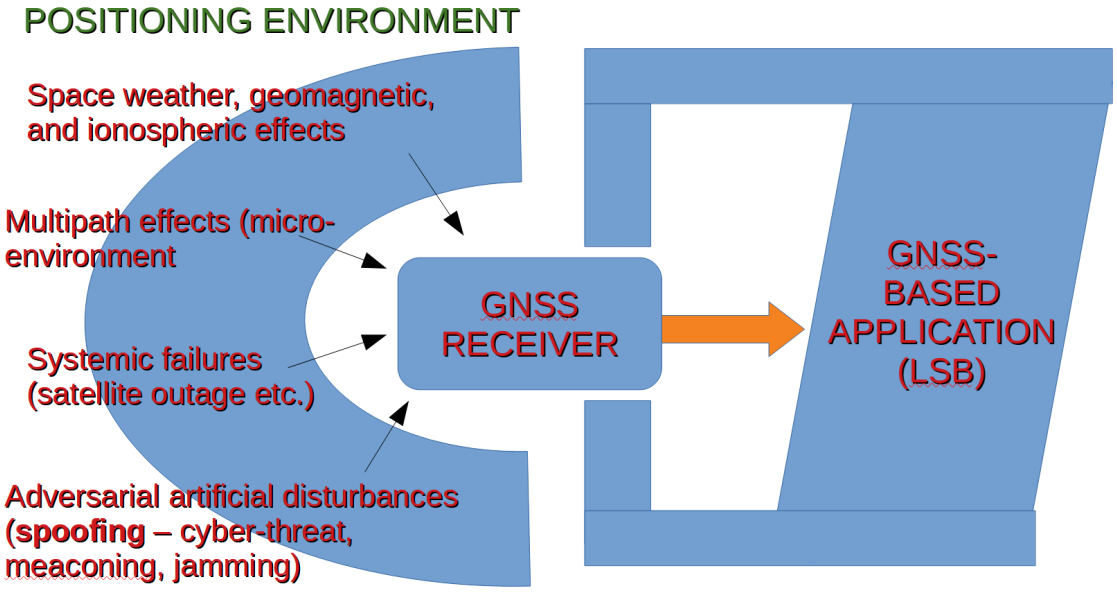
Problem statement and motivation

- **Natural and artificial interference in the positioning environment** (space weather/ionospheric, multipath, spoofing etc. effects) cause degradation of GNSS PNT performance
- **Standard GNSS ionsopheric correction models are inefficient**:
  - **Generalised**, not addressing geographically constrained effects
  - **Inflexible** to mitigate rapid and short-term effects

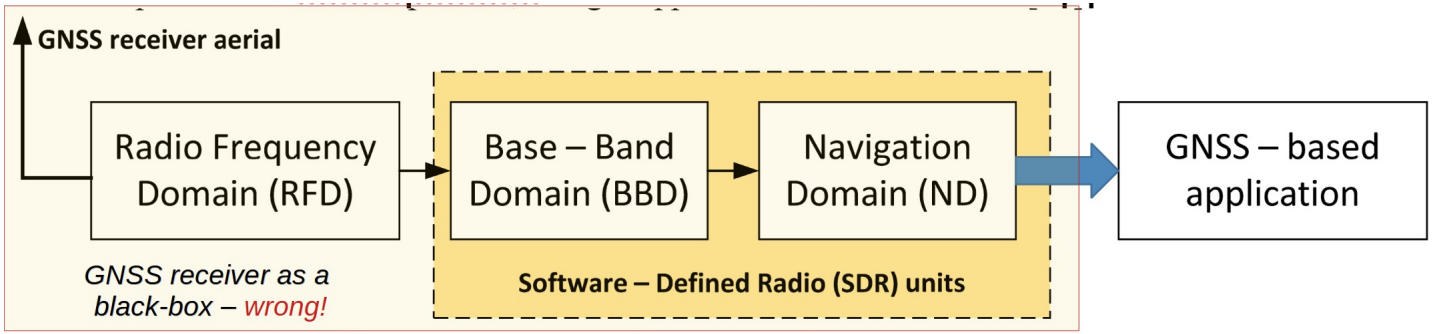




Statistical learning TEC predictive model for GNSS ionospheric delay mitigation in self-adaptive environment-aware SDR GNSS position estimation algorithm (R Filjar, *Croatia*)

State-of-the-art

- GNSS position estimation confined in non-transparent GNSS receiver black-box, detached from GNSS application

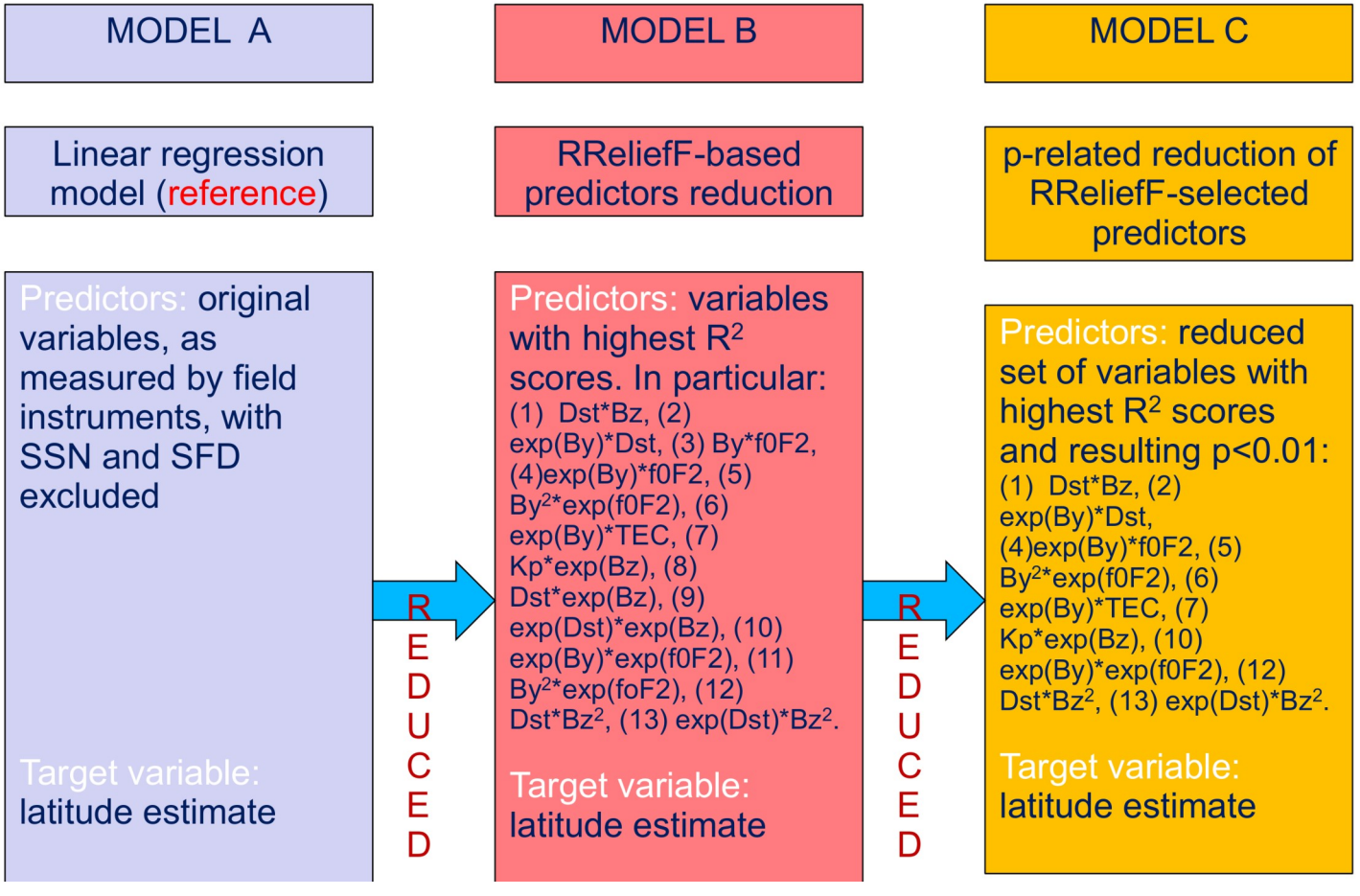


- Numerous advancements are not exploited in full: (i) **Software-Defined Radio (SDR)**, (ii) **statistical and machine learning**, (iii) **computational capacity of mobile devices**, (iv) **mobile platforms with** SDR GNSS receivers AND **embedded sensors** (smartphones, connected vehicles, IoT devices, etc.), (v) open access to **position environment data in near-real time** (space weather, geomagnetic, and ionospheric indices, spatial databases etc.), (vi) **mobile internet and Internet of Things (IoT)**

State-of-the-art

- Statistical learning multi-predictor models based on immediate SW/ionospheric conditions awareness improve GNSS ionospheric effects correction considerably

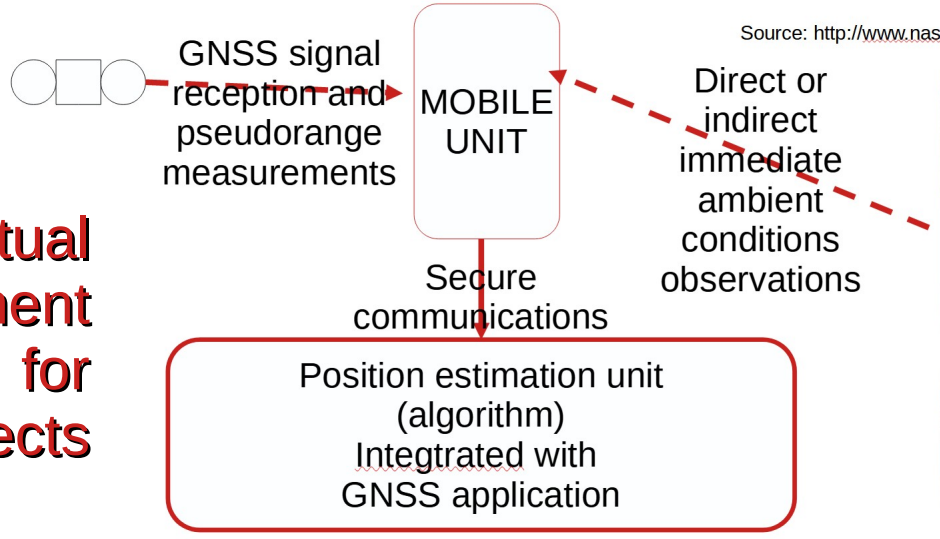
Source: doi:10.33012/2018.16016



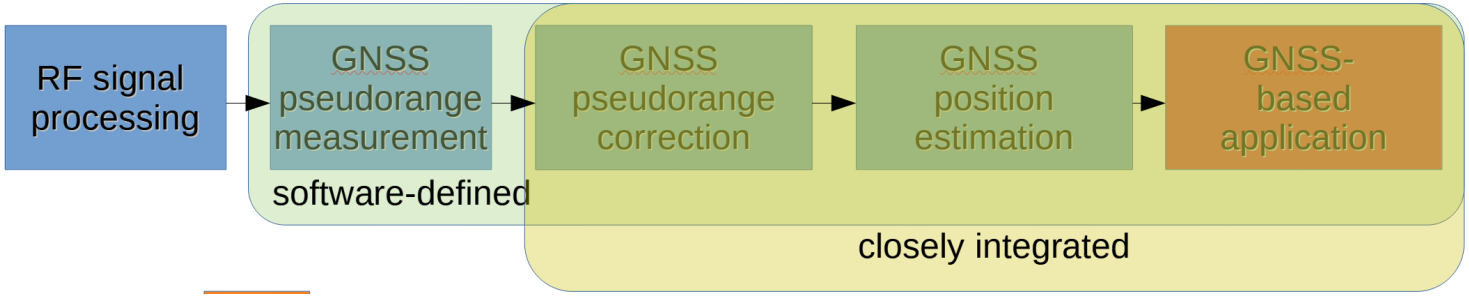
Statistical learning TEC predictive model for GNSS ionospheric delay mitigation - Concept

- Mobile unit → **observing immediate positioning environment conditions** (space weather, ionosphere) **itself**, and/or **utilising trusted third-party real-time observations or predictions for pseudorange cori**

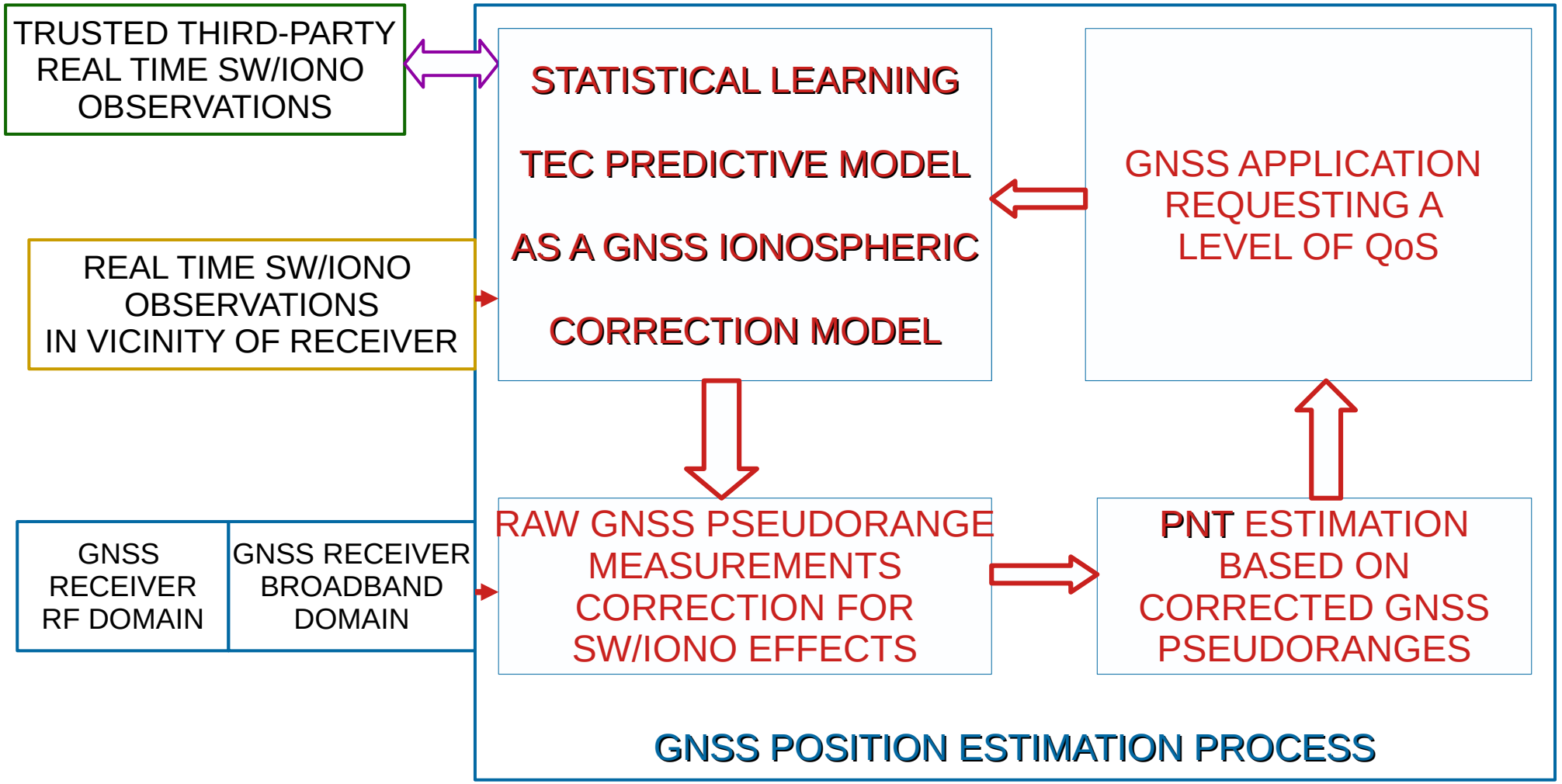
Recognition of the actual positoning environment conditions → a pre-requisite for improved adverse effects mitigation



Source: http://www.nasa.gov/mission_pages/sunearth/news/M11-125-swef.html

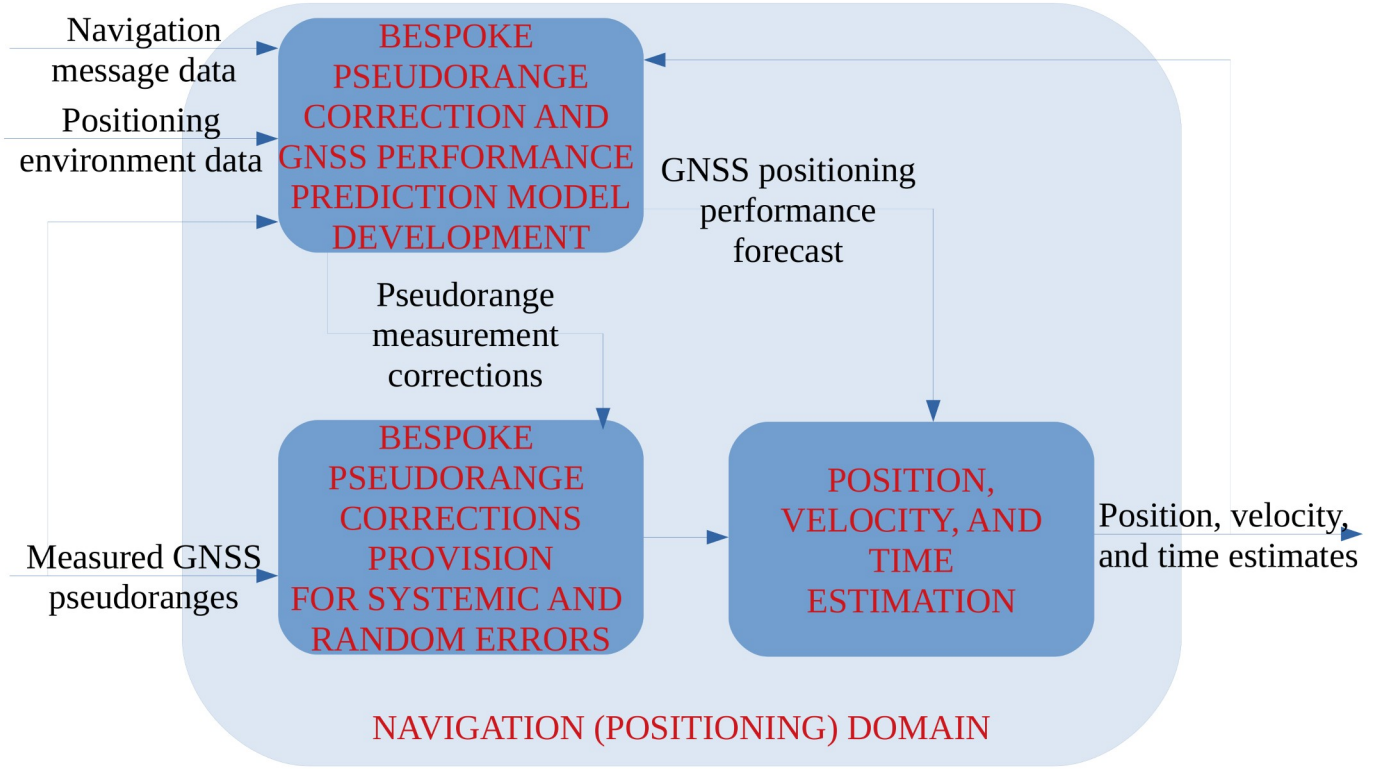


Statistical learning TEC predictive model for GNSS ionospheric delay mitigation - Concept



Statistical learning TEC predictive model for GNSS ionospheric delay mitigation – Realisation & demonstration

1. Mitigation of space weather/ionospheric effects on GNSS position estimation performance:
   - direct observations of immediate positioning environment
   - trusted third-party data (stream, server-application access), with optional processing (interpolation)
2. Tailored framework developed in the open source R environment for statistical computing

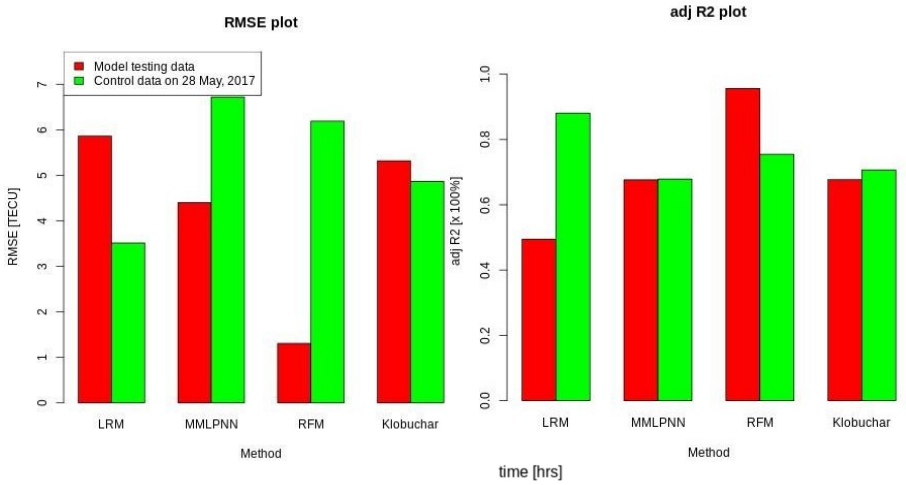


Statistical learning TEC predictive model for GNSS ionospheric delay mitigation in self-adaptive environment-aware SDR GNSS position estimation algorithm (R Filjar, *Croatia*)

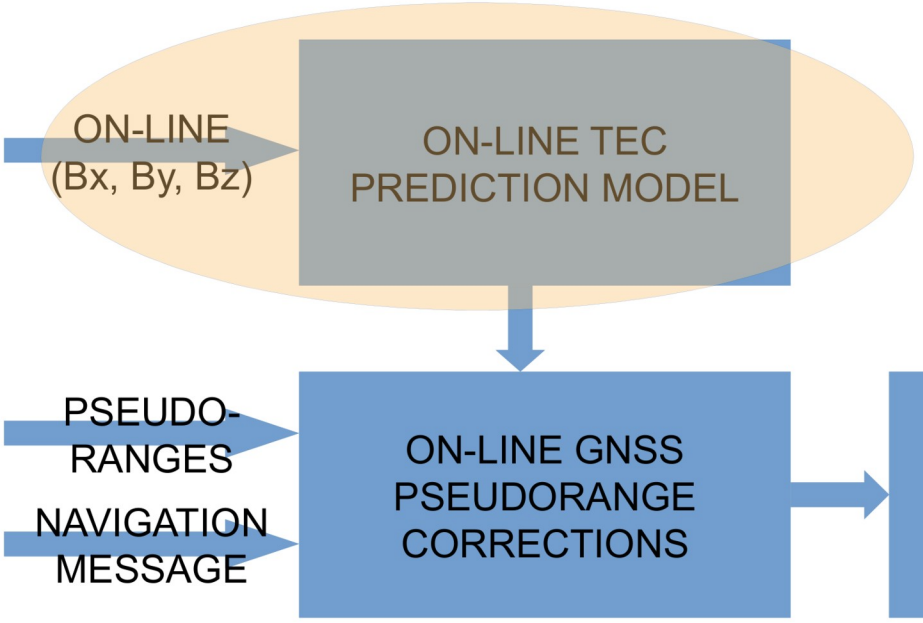
Demonstration

- Case-study of a short-term rapidly developing geomagnetic storm in sub-equatorial area (Darwin, NT, Australia)

LRM … Linear Regression Model, MMLPNN … Monotone Multi-layer Perceptron Neural Network Model, RFM … Random Forest Model, Klobuchar … standard Klobuchar Model



Reference model: global Klobuchar model



Klobuchar model considered as the benchmark / reference model.

Statistical learning TEC predictive model for GNSS ionospheric delay mitigation - Validation

- Case-study of short-term rapidly developing geomagnetic storm in sub-equatorial area (Darwin, NT)
- Single-frequency GPS-based position estimation, no additional infrastructure utilised → GPS position estimation process self-adapted to the immediate environment conditions
- Ionospheric corrections: (i) Klobuchar model, (ii) geomagnetic field density-based statistical learning Linear Regression Model (LRM), source: *doi: 10.33012/2022.18247*

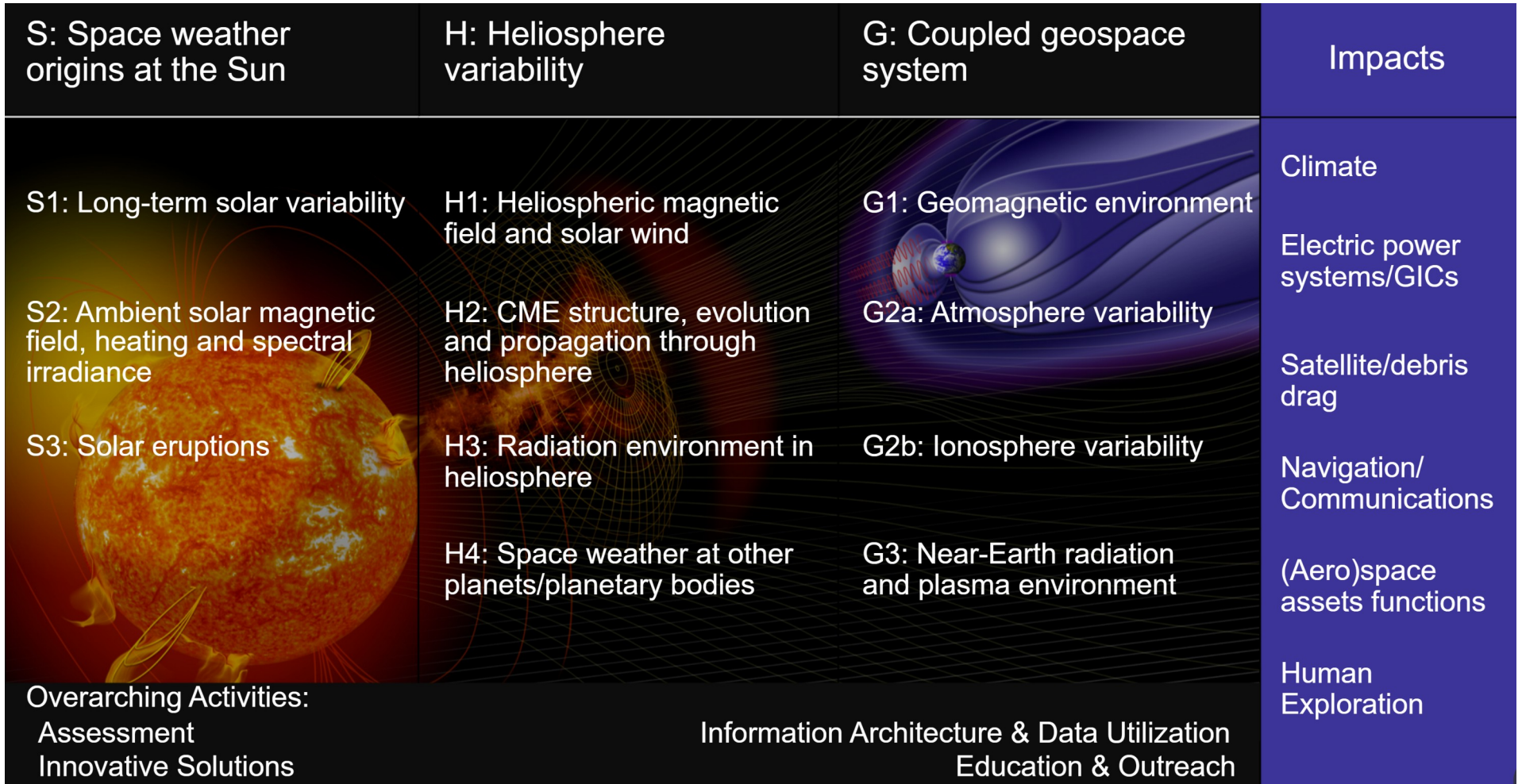
in [m]	mean		standard deviation	
	Klobuchar corrections	self-adaptive corrections	Klobuchar corrections	self-adaptive corrections
northing error	-1.5368	-0.1098	2.24106	1.088705
easting error	0.72717	-0.02663	1.878769	0.9983062
vertical error	0.2225	-0.09773	1.29891	0.510632

Discussion

- Proposed utilisation of situation awareness of immediate positioning environment conditions for self-adaptive SDR GNSS position estimation.
- GNSS positioning performance demonstrated in the case of short-term rapidly developing ionospheric disturbance.
- The need for space weather/geomagnetic/ionospheric observations and indices data standardisation (access, structure and format), access, and inter/multi-disciplinary competence development
- Activities, potentially through International Space Weather Action Teams (ISWAT, COSPAR)

Discussion

- Source: https://www.iswat-cospar.org/



Recommendations

- 1. Positioning environment (SW/iono) conditions awareness to improve GNSS positioning estimation algorithm, as well as GNSS PNT performance and resilience against adverse effects.
- 2. Self-adaptive statistical learning GNSS ionospheric effects model to be developed based on positioning environment awareness.
- 3. Positioning environment (SW/iono) conditions awareness to be obtained by: (i) direct SW/iono observations in the immediate vicinity of receiver, and/or (ii) link to trusted third-party sources.
- 4. International co-operation to be facilitated, established, and operated to:
  - 4.1 develop standards for SW/iono data structure, formats, and protocols for internet-based data exchange;
  - 4.2 collect, assemble, aggregate, collate, and allow access to location-based real-time and archived SW/iono observations;
  - 4.3 foster self-adaptive GNSS correction model development, validation, and standardisation;
  - 4.4 develop inter-/multi-disciplinary competence in support of transition to positioning environment-aware self-adaptive GNSS positioning.

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In appreciation of your attention, and
with invitation to
Baška SIF (Spatial Information Fusion) Meetings,
every October in Baška, Krk Island, Croatia

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