



International Space Weather Initiative Workshop ICTP, Trieste, Italy, 2019

```

1 % program   : RTKPOST-QT ver.2.4.3 Emlid b28
2 % inp file  : /media/renato/OPERATIONAL/m.19o
3 % inp file  : /media/renato/OPERATIONAL/brdc1240.19n
4 % obs start : 2019/05/04 14:19:50.9 GPST (week2051 569990.9s)
5 % obs end   : 2019/05/04 14:29:57.0 GPST (week2051 570597.0s)
6 %
7 % (lat/lon/height=WGS84/ellipsoidal,Q=1:fix,2:float,3:sbas,4:dgps,5:single,6:ppp,ns=# of satellites)
8 % GPST      latitude(deg) longitude(deg) height(m)  Q  ns  sdn(m)  sde(m)  sdu(m)  sdne(m)  sdeu(m)  sdun(m)  age(s)  ratio
9 2019/05/04 14:58:01.330 46.090330951 16.080107152 222.3947 5 6 4.1624 3.2423 7.1795 -1.7374 1.3117 3.3278 0.00 0.0
10 2019/05/04 14:58:02.331 46.090370194 16.080095625 235.1402 5 7 3.1084 3.1525 6.0997 -0.9591 2.1428 0.7698 0.00 0.0
11 2019/05/04 14:58:03.000 46.090385666 16.080085583 225.7448 5 7 3.1084 3.1526 6.0994 -0.9591 2.1431 0.7692 0.00 0.0
12 2019/05/04 14:19:58.000 46.090108097 16.080218217 216.2279 5 7 3.6115 2.6015 9.0128 0.9155 1.4743 3.9645 0.00 0.0
13 2019/05/04 14:19:59.000 46.090254083 16.080165517 231.6379 5 7 3.6111 2.6016 9.0119 0.9156 1.4755 3.9637 0.00 0.0
14 2019/05/04 14:20:00.000 46.090172663 16.080044227 194.6382 5 7 3.6108 2.6017 9.0111 0.9157 1.4766 3.9629 0.00 0.0
15 2019/05/04 14:20:01.000 46.090271173 16.080110759 233.6381 5 7 3.6104 2.6017 9.0103 0.9158 1.4778 3.9621 0.00 0.0
16 2019/05/04 14:20:04.000 46.090276858 16.080014978 245.2466 5 7 3.6093 2.6019 9.0079 0.9161 1.4812 3.9597 0.00 0.0
17 2019/05/04 14:20:05.000 46.090280686 16.080013005 235.6149 5 7 3.6089 2.6020 9.0071 0.9162 1.4824 3.9589 0.00 0.0
18 2019/05/04 14:20:06.000 46.090329158 16.080090291 239.5410 5 7 3.6085 2.6021 9.0063 0.9163 1.4835 3.9581 0.00 0.0
19 2019/05/04 14:20:08.000 46.090240211 16.080171843 201.7472 5 7 3.6078 2.6022 9.0047 0.9165 1.4858 3.9565 0.00 0.0

```

Challenges in space weather and GNSS data aggregation and consolidation for research

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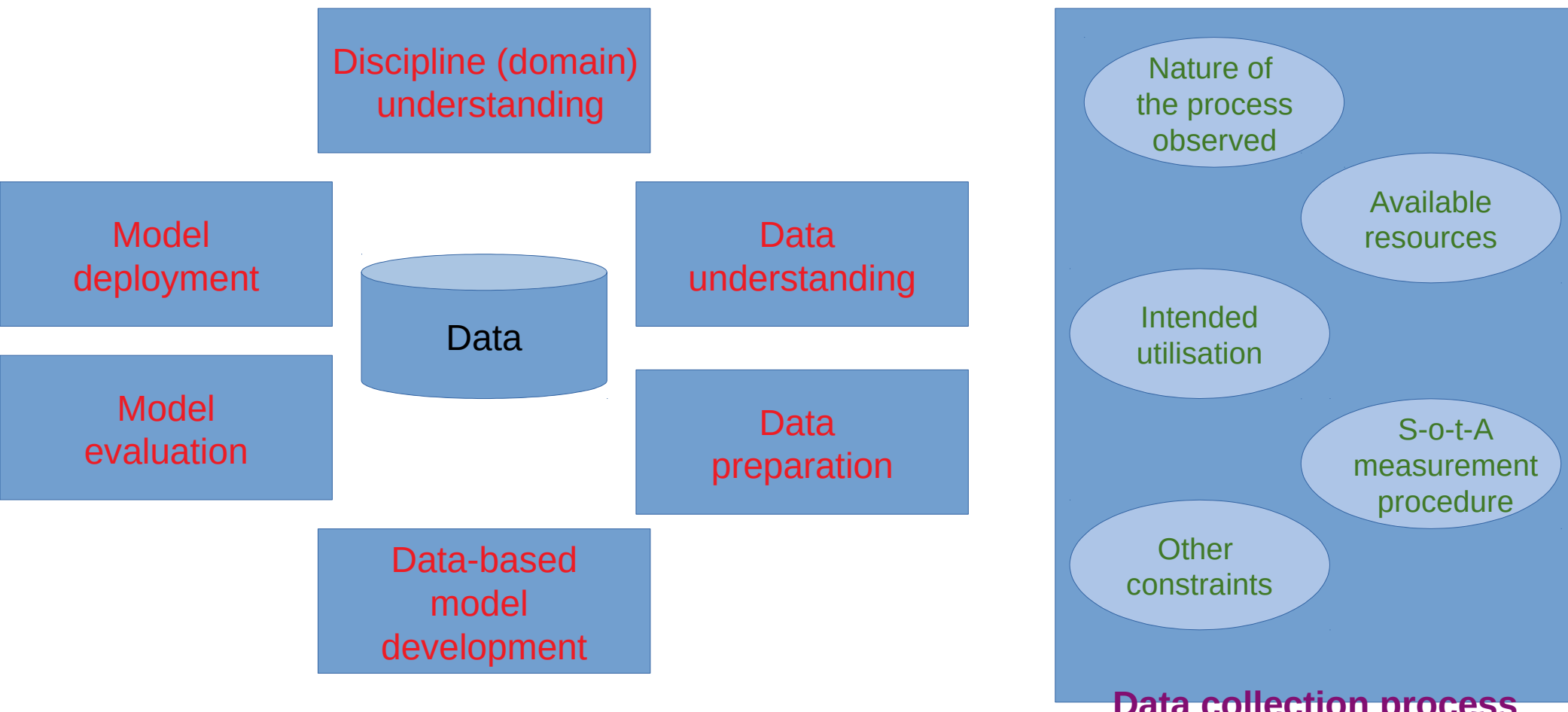
- Content
- Introduction and motivation
- Problem statement
- Overview of data sources
- Overview of data content and formats
- Methodology proposal
- Methodology demonstration
- Recommendations

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- Introduction and motivation
- *'Data is merely a raw material of knowledge.'*
- (New York Times)
- Science is hungry for data.
- Aggregation – a process for compilation of a data set from different trusted data sources
- Consolidation – a process for assemblage of a structured data set using the aggregated data
- Space weather (incl. ionospheric and geomagnetic) data aggregation and consolidation for multi-disciplinary research

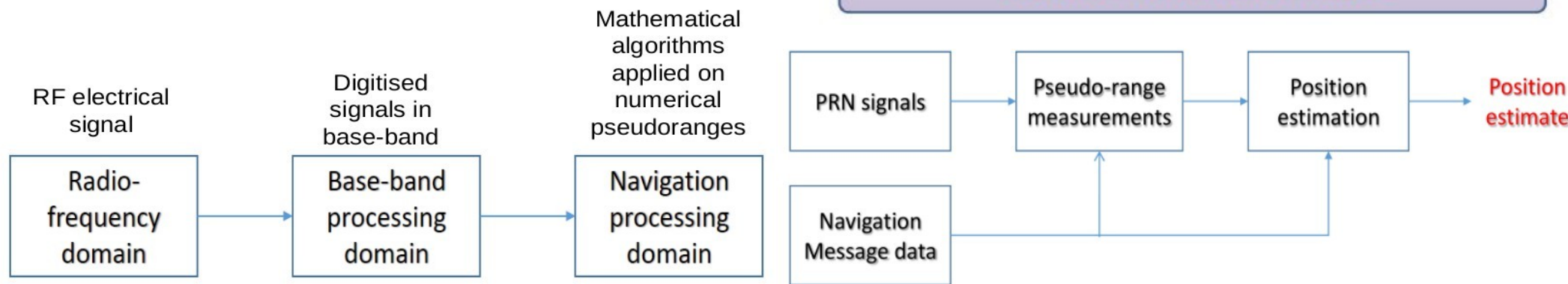
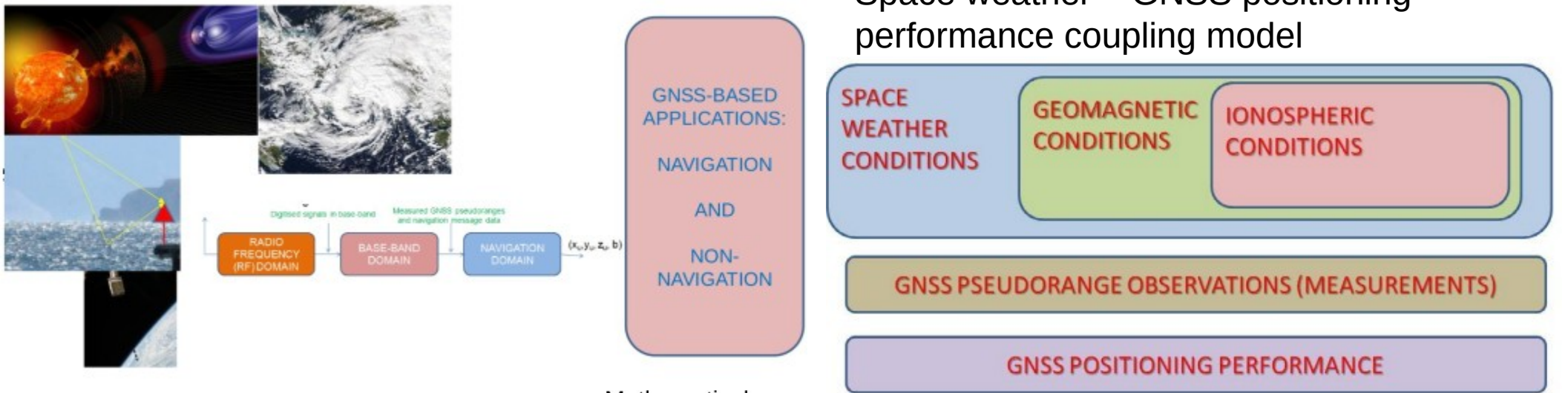
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- Problem statement
- Data sets are mostly collected with best intentions, resulting with unexpected consequences.



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- Problem statement: development of a forecasting model of GNSS positioning performance deterioration caused by space weather and ionospheric conditions



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- Overview of data sources
- Issues: (i) bespoke scenario-related data access, (ii) systematic provision of data

Data sub-set	Indices (originally measured variables)	Source(s)
Solar activity data	SSN, SFD	NOAA (https://www.ngdc.noaa.gov/stp/spaceweather.html)
Geomagnetic condition data	Bx, By, Bz Kp, Ap, Dst	INTERMAGNET (http://www.intermagnet.org/data-donnee/data-eng.php) NOAA (https://www.ngdc.noaa.gov/stp/spaceweather.html)
Ionospheric condition data	f0Es, f0F2 TEC, dTEC SID	NOAA (https://www.ngdc.noaa.gov/stp/spaceweather.html) derived from IGS RINEX observations (ftp://cddis.gsfc.nasa.gov/gnss/data/daily/) Stanford University SID database (http://sid.stanford.edu/database-browser/)
GNSS positioning performance indices	GNSS northing, easting, vertical positioning errors	Derived from stationary IGS RINEX observations (ftp://cddis.gsfc.nasa.gov/gnss/data/daily/) or our own observations taken at Baška, Krk Island, Croatia

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- Overview of data content and formats
- Issues: (iii) numerous formats, (iv) different sampling rates, (v) various expressions of a time-stamp as sample's ID

```
1 3.03 OBSERVATION DATA M: Mixed RINEX VERSION / TYPE
2 rinex ON NSL 20190511 201855 UTC PGM / RUN BY / DATE
3 MARKER NAME
4 MARKER TYPE
5 rinex ON User OBSERVER / AGENCY
6 4239788.0544 1305636.9814 4567459.9458 APPROX POSITION XYZ
7 XXXXXXXX HUawei VTR-L09 REC # / TYPE / VERS
8 XXXXXXXX VTR-L09
9 0.0000 0.0000 0.0000 ANT 1 DST0801Q01 000-012-011-008-007-005-003-005-006-005-005-007-007-006-007-006-008-008-007-006-004-005-003-003-003-006
10 0.0000 0.0000 0.0000 ANT 2 DST0801Q02 000-001 000-001 001 004 003 003 004 004 007 005 004 004 003 003 002 000 004 005 006 006 005 001-007 003
11 G 4 C1C L1C D1C S1C SYS 3 DST0801Q03 000-007-007-005-005-004-003-002-002 001 002 002 001 001-001 001 000 001 004 004 004 004 003 003-000
12 R 4 C1C L1C D1C S1C SYS 4 DST0801Q04 000 004 006 009 008 006 006 004 004 004 004 005 007 008 006 007 013 013 014 013 013 016 016 021 037 010
13 E 4 C1C L1C D1C S1C SYS 5 DST0801Q05 000 031 021 020 010 011 011 015 016 002-017-008-001-006-014-015-020-017-012-006-013-016-025-025-014-003
14 C 4 C1C L1C D1C S1C SYS 6 DST0801Q06 000-005-006-009-015-018-016-018-022-023-029-026-020-016-016-016-020-022-021-019-019-018-021-023-025-018
15 2019 05 11 18 19 13.9998285 GPS TIM 7 DST0801Q07 000-021-022-026-030-024-026-028-027-024-022-023-022-020-025-022-020-019-017-016-017-018-019-020-017-02259:55
16 END 8 DST0801Q08 000-015-015-016-015-016-014-015-013-017-022-025-020-017-018-024-025-026-025-025-026-026-020-021-022-020
17 > 2019 05 11 18 19 13.9998285 0 11 9 DST0801Q09 000-023-022-024-023-021-020-020-023-021-021-022-021-021-021-020-018-015-017-019-020-018-018-018-016-020
18 G01 24194485.606 -218815.425 3347.816 20.291
19 G08 20805905.371 -105873.542 1512.176 19.012
20 G10 20822259.650 75520.082 -1082.790 16.341
21 G11 23484184.637 -254866.483 3621.784 25.537
22 G14 24362694.358 -205027.042 2407.452 20.022
23 G16 24143319.1 1 1801012515213337232327101013177 18 22 9 9 12 4 4 5 100.63---066.80
24 G18 21885896.3 2 18010225152217 7 3 717102010 90 6 3 2 3 6 4 7 4 40.21---067.20
25 G22 24852718.3 3 180103251523 0 710 7 310 3 0 40 0 3 4 3 2 4 2 0 20.00---068.30
26 G27 20477078.6 4 180104251524 7 010 0 7 31310 50 3 0 4 0 3 2 5 4 30.00---067.20
27 G32 23301588.5 5 180105251525 71713 7 7131020 93 3 6 5 3 3 5 4 7 40.21---067.00
28 R15 22823772.1 6 18010625152613 0 7 0 3 0 3 3 30 5 0 3 0 2 0 2 2 20.00---067.10
7 18010725152710 0 0 0 3 7 7 3 30 4 0 0 0 2 3 3 2 20.00---067.60
8 1801082516 1 3 7231737302017153 2 3 9 6 22 15 7 6 90.52---068.00
9 1801092516 23723201320201717167 22 9 7 5 7 7 6 6 90.52---068.50
10 1801102516 313171010 310 3 0 67 5 6 4 4 2 4 2 0 30.10---068.10
11 1801112516 4 310 0 3 7 0 3 7 33 2 4 0 2 3 0 2 3 20.00---068.50
```

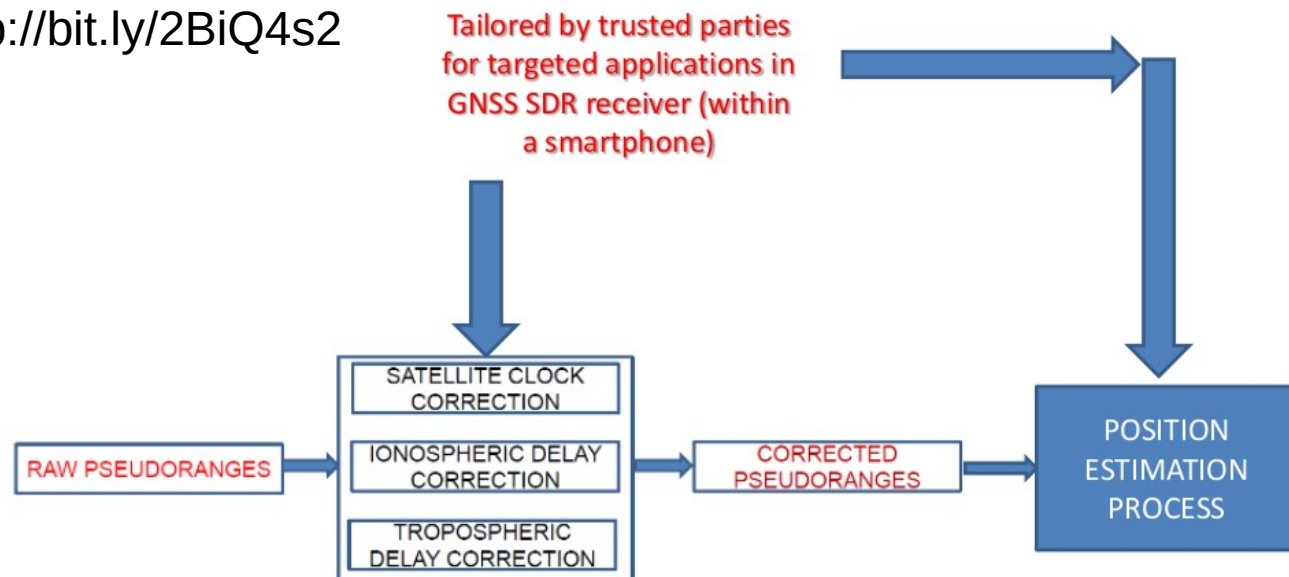
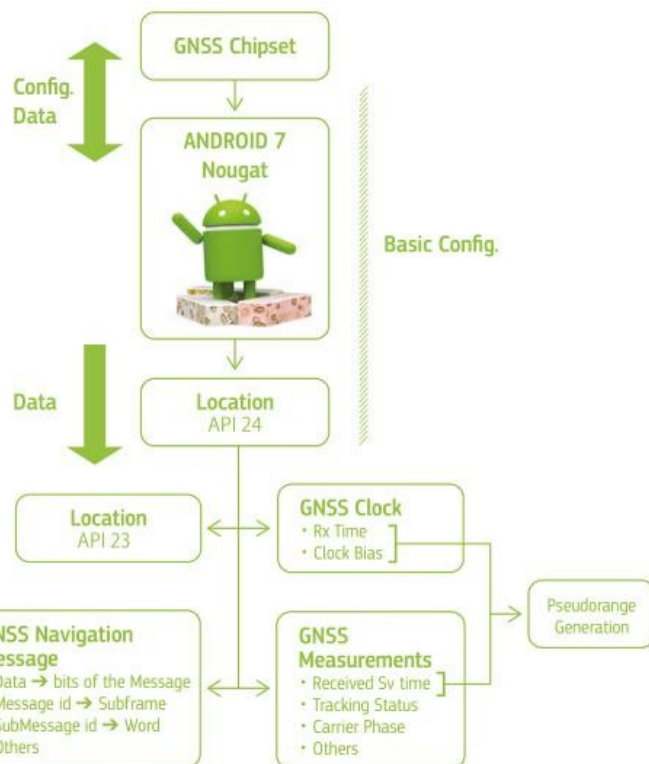
```
1 # Site = GIMPZ
2 # Longitude = 45.33
3 # Latitude = 17.68
4 #
5 # UTC_Offset = -23
6 # TimeZone = CET
7 #
8 # UTC_StartTime = 2015-03-17 00:00:00
```

```
15 #DataMax=15060452.119
16 #dataquality_average_v0.1=0.144428
17 #dataquality_max_v0.1=4.197576
18 2015-03-17 00:00:00 3556751.51528
19 2015-03-17 00:00:05 3572599.78873
20 2015-03-17 00:00:10 3588448.06218
21 2015-03-17 00:00:15 3604296.33563
22 2015-03-17 00:00:20 3620144.60908
23 2015-03-17 00:00:25 3635992.88253
24 2015-03-17 00:00:30 3651841.15598
25 2015-03-17 00:00:35 3667689.42943
26 2015-03-17 00:00:40 3683537.70287
27 2015-03-17 00:00:45 3699385.97632
28 2015-03-17 00:00:50 3746122.73534
29 2015-03-17 00:00:55 3792859.49435
```

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- Overview of data content and formats
- Utilisation of raw single- and dual-frequency GNSS pseudoranges provided through Android Location API (selected devices) – GSA Raw Measurement Task Force

Reference: GSA GNSS Raw Measurements Task Force. (2017). Using GNSS raw measurements on Android devices (white paper). European GNSS Agency. Prague, Czechia. Available at: <http://bit.ly/2BiQ4s2>



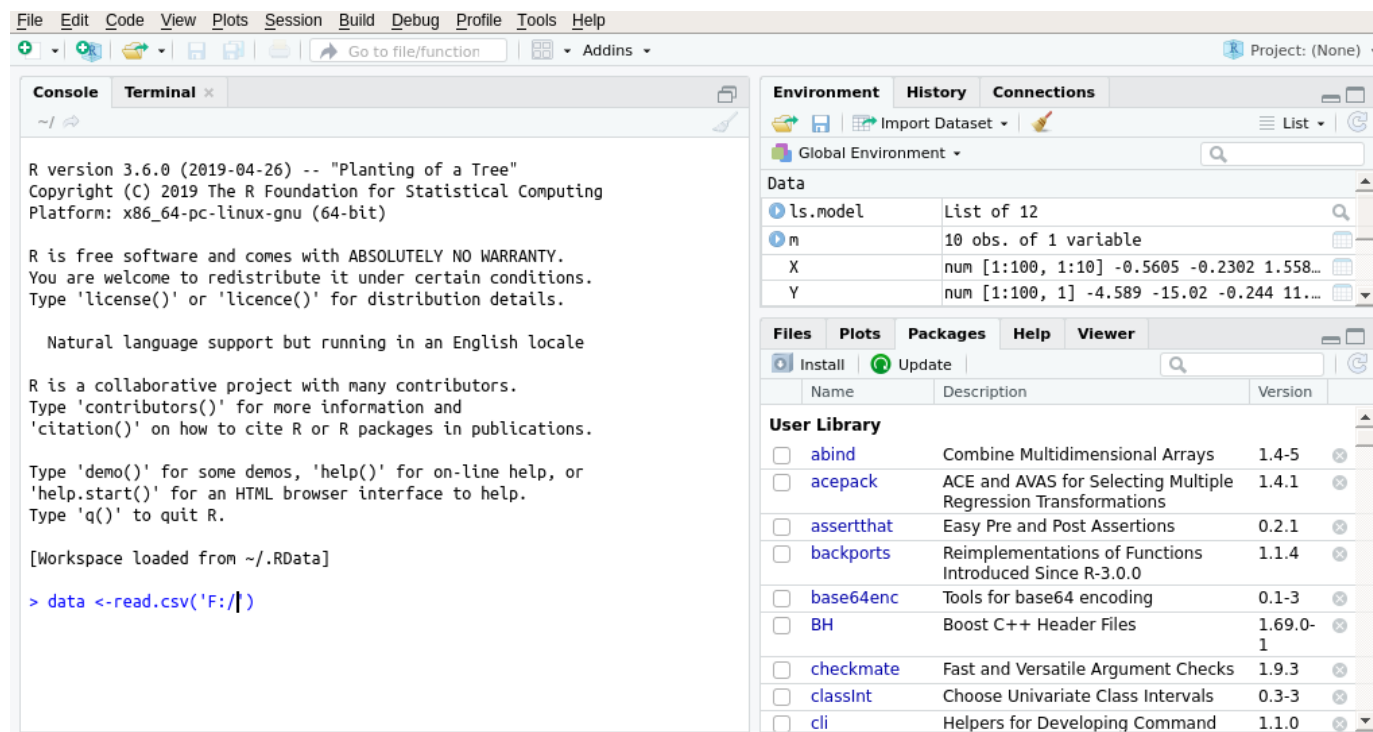
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- Methodology proposal
- (i-a) Structured description of space weather data applications to allow for systematic and seamless data utilisation
- (i-b) Categorisation of space weather data applications
- (i-c) Standardised terminology and ontology
- (ii) common agreement on data access procedure and methodology (incl. structures of web-addresses)

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- Methodology proposal
- (iii) Set of dedicated data parsers have to be developed
- **R environment for statistical computing**
- Selection of R libraries in support of data **wrangling** (tidyr, tidyverse, dplyr, lubridate)

R is available as an open source software at: <https://www.r-project.org/>

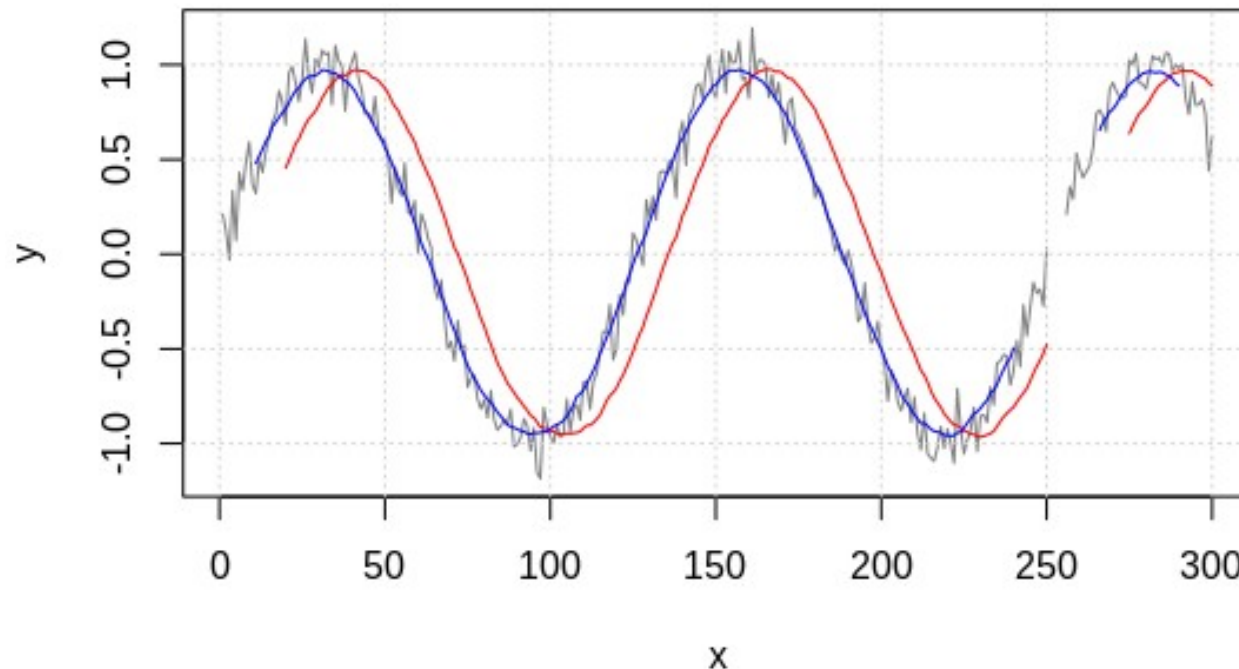


The screenshot displays the RStudio environment. The console window shows the R version 3.6.0 (2019-04-26) and the command `> data <- read.csv('F:/')`. The Environment pane on the right shows the Global Environment with a list of objects: `ls.model` (List of 12), `m` (10 obs. of 1 variable), `X` (num [1:100, 1:10] -0.5605 -0.2302 1.558...), and `Y` (num [1:100, 1] -4.589 -15.02 -0.244 11...).

Name	Description	Version
<input type="checkbox"/> abind	Combine Multidimensional Arrays	1.4-5
<input type="checkbox"/> acepack	ACE and AVAS for Selecting Multiple Regression Transformations	1.4.1
<input type="checkbox"/> assertthat	Easy Pre and Post Assertions	0.2.1
<input type="checkbox"/> backports	Reimplementations of Functions Introduced Since R-3.0.0	1.1.4
<input type="checkbox"/> base64enc	Tools for base64 encoding	0.1-3
<input type="checkbox"/> BH	Boost C++ Header Files	1.69.0-1
<input type="checkbox"/> checkmate	Fast and Versatile Argument Checks	1.9.3
<input type="checkbox"/> classInt	Choose Univariate Class Intervals	0.3-3
<input type="checkbox"/> cli	Helpers for Developing Command	1.1.0

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- Methodology proposal
- (iv) Varying sampling rates should be treated with statistical methods, such as *Moving Average* (smoothing, filtering) – R package *smooth*



- (v) cross-discipline agreement on datum expression

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- Methodology demonstration

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 Filic
Renato Filjar

Forecasting model of space weather-driven GNSS positioning performance

Forecasting model of space weather-driven GNSS positioning performance degradation

Mia Filic, 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.



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Filic, Filjar

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- Recommendations
- 1. International collaboration on cross-disciplinary data format standardisation, considering environments for data processing
- 2. Description and categorisation of scenarios of space weather data utilisation
- 3. Capacity development in widely embraced and utilised computational environments
- 4. Research facilitation in the segment of efficient data preparation and data quality assessment

In appreciation of your kind attention!



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