Real-Time Geophysical Applications with Android GNSS Raw Measurements

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open problems and Geoscience applications
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Outline

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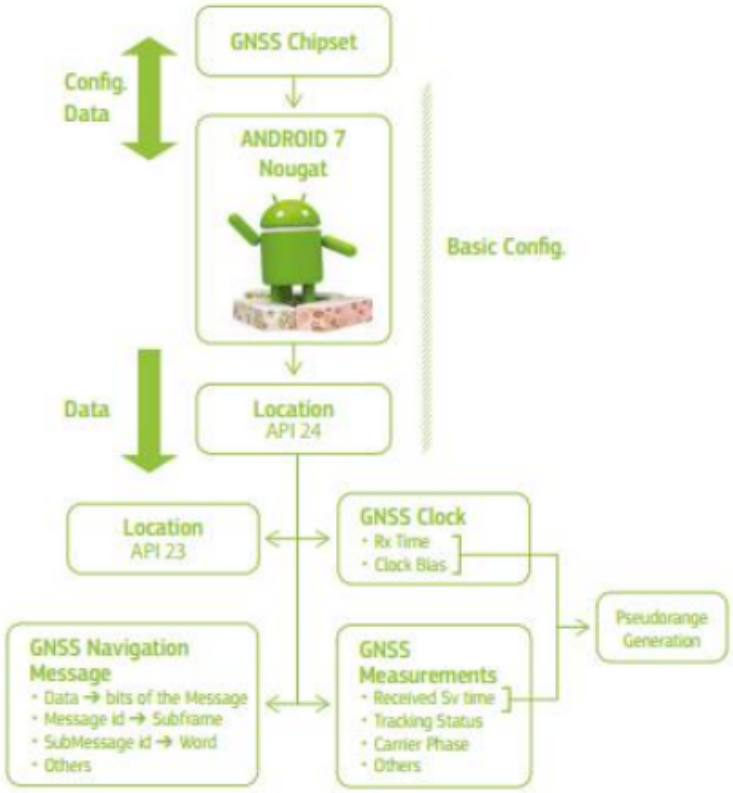
Android GNSS Raw Measurements API

Innovations

Running on Android 7.0 or higher, **Android GNSS Raw Measurements API** allows to access:

- **GNSS Clock**:
  - Receiver clock (pseudorange computation)
  - Clock bias
- **GNSS Navigation Message**:
  - Nav message bits
  - Nav message status
- **GNSS Measurements**:
  - Received satellite time (pseudorange computation)
  - Code
  - Phase



Navarro, M. et al. *Assessing Galileo Readiness in Android Devices Using Raw Measurements*. 30th International Technical meeting of the Satellite Division of ION, Portland, Oregon, September 2017. v, 18, 20

Benefits for GNSS Mass-Market Community

The availability of GNSS observables from Android smartphones enables:

- **improved location accuracy** with high-end positioning algorithm (RTK and PPP)
- **Geoscience applications** of such mass-market devices

Input from GNSS community

GSA Raw Measurements Task Force:

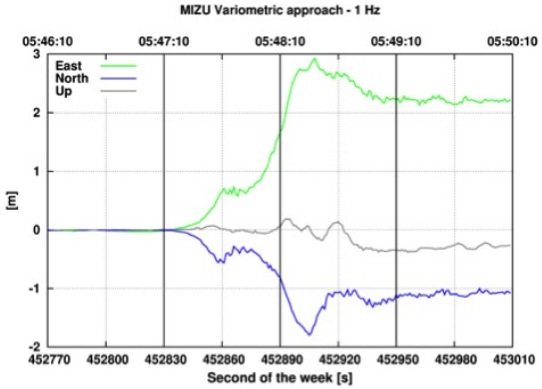
- aims to share knowledge on Android raw measurements (**Discussion forum** and **Measurements Database**)
- encourages researches and innovative application

Galluzzo, G; Navarro, M. and Sunkevic M. *Using Android Raw Measurements on Android Devices*. IPIN 2018, Nantes, France, 24-27 September 2018

How Can Smartphones Contribute to Geosciences ?

- Geosciences generally require **dense information**
- Smartphones are the **most common GNSS mass-market device**
- The release of **multi frequency and multi constellation** Android smartphones enhances GNSS solutions
- **Multi sensor devices**, as smartphones, increase the number of **independent measures** related to Geoscience applications

Earth's fast movement



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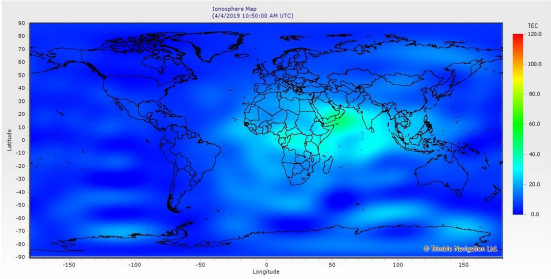
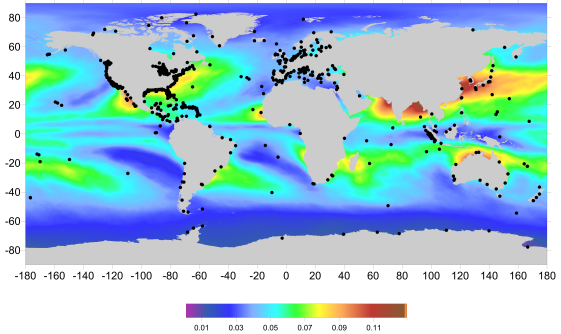
Ionospheric monitoring



www.trimbleionoinfo.com/Images.svc/TEC

Tropospheric monitoring



www.altimetry.info

Purpose of the work

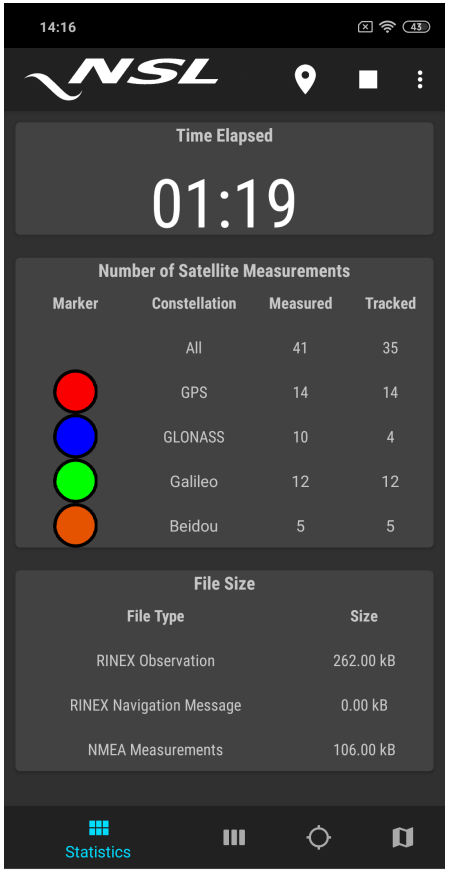
This work is a **feasibility study** aiming at evaluate the **real-time capabilities of Android smartphones**:

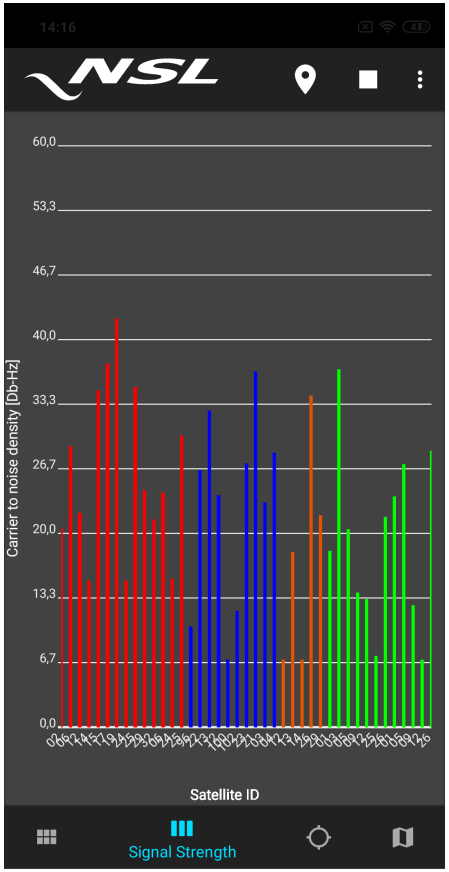
- to detect **fast movements**, with frequency shaking and oscillation amplitude comparable to **seismic waveforms**
- to monitor **ionospheric conditions**

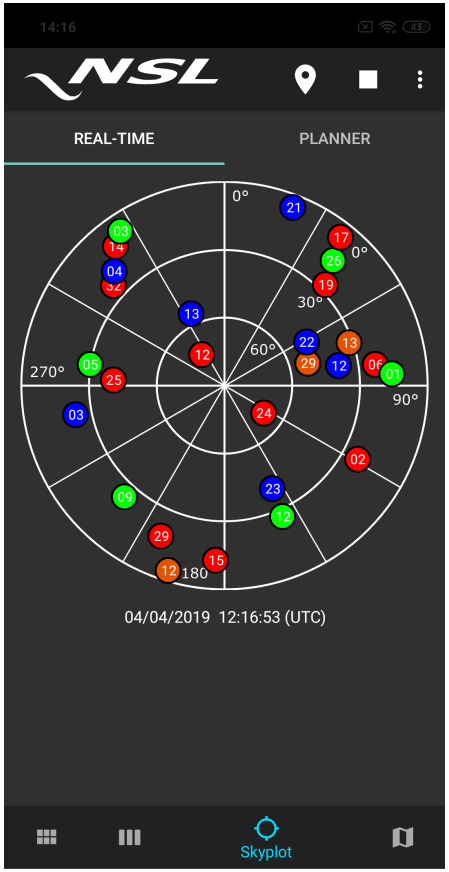
Outline

RINEX Logger and Monitoring App

- **Rinex ON** has been developed by NSL as part of **FLAMINGO** initiative (www.flamingognss.com) - an HORIZON 2020 project.







VADASE (Variometric Approach for Displacements Analysis Stand-Alone Engine)

How does VADASE work?

- **real-time estimation of epoch by epoch velocity**
- multi-constellation and multi-frequency compatibility
- **no ambiguity term** is contained in the observation equation

Observation equation *[Colosimo et al., 2011]*

$$\underbrace{L_R^S(t+1) - L_R^S(t)}_{\text{time difference of phase observations}} = \Delta L_R^S = \underbrace{\Delta\rho_R^S]_{OR} - c\Delta\delta t^S + \Delta T_R^S - \Delta I_R^S}_{\text{known terms}} + \underbrace{e_R^S \Delta\varepsilon_R + c\Delta\delta t_R}_{\text{unknowns}} + \underbrace{\epsilon_R^S}_{\text{noise}}$$

VADASE: a Consolidated Tool for GNSS Seismology

VADASE allows the estimation of:

- **real-time 3D velocities** with accuracy of **few mm/s** on high-end receivers
- **real-time 3D fast movements displacements** with accuracy of **1-2 cm** on high-end receivers

Real-time GPS seismology with a stand-alone receiver: A preliminary feasibility demonstration

G. Colosimo,[1] M. Crespi,[1] and A. Mazzoni[1]

Received 20 August 2010; revised 25 June 2011; accepted 19 August 2011; published 3 November 2011.

Global Navigation Satellite Systems Seismology for the 2012 M_w 6.1 Emilia Earthquake: Exploiting the VADASE Algorithm

by E. Benedetti, M. Branzanti, L. Biagi, G. Colosimo, A. Mazzoni, and M. Crespi

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS

GPS Near-Real-Time Coseismic Displacements for the Great Tohoku-oki Earthquake

Mara Branzanti, Gabriele Colosimo, Mattia Crespi, and Augusto Mazzoni

VADASE: state of the art and new developments of a third way to GNSS Seismology

E. Benedetti, M. Branzanti, G. Colosimo, A. Mazzoni and M. Crespi

Article

VADASE Reliability and Accuracy of Real-Time Displacement Estimation: Application to the Central Italy 2016 Earthquakes

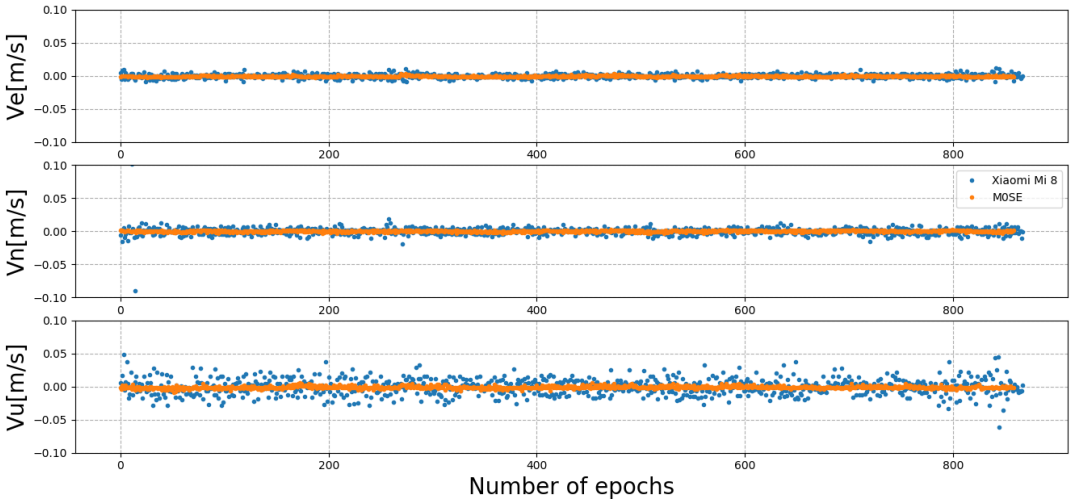
Francesca Fratarcangeli [1,*], Giorgio Savastano [1,2,†], Maria Chiara D'Achille [1], Augusto Mazzoni [1], Mattia Crespi [1], Federica Riguzzi [3], Roberto Devoti [3] and Grazia Pietrantonio [3]

Outline

Xiaomi Mi 8 vs M0SE (EUREF/IGS Station)

Test description

- Xiaomi Mi 8 in **open sky environment** near M0SE station
- **1Hz observations** collected for **15 minutes**
- **GPS and Galileo L1/E1** VADASE processing with **cycle slip detectors** and recursive **Leave-One-Out** (LOO) algorithm



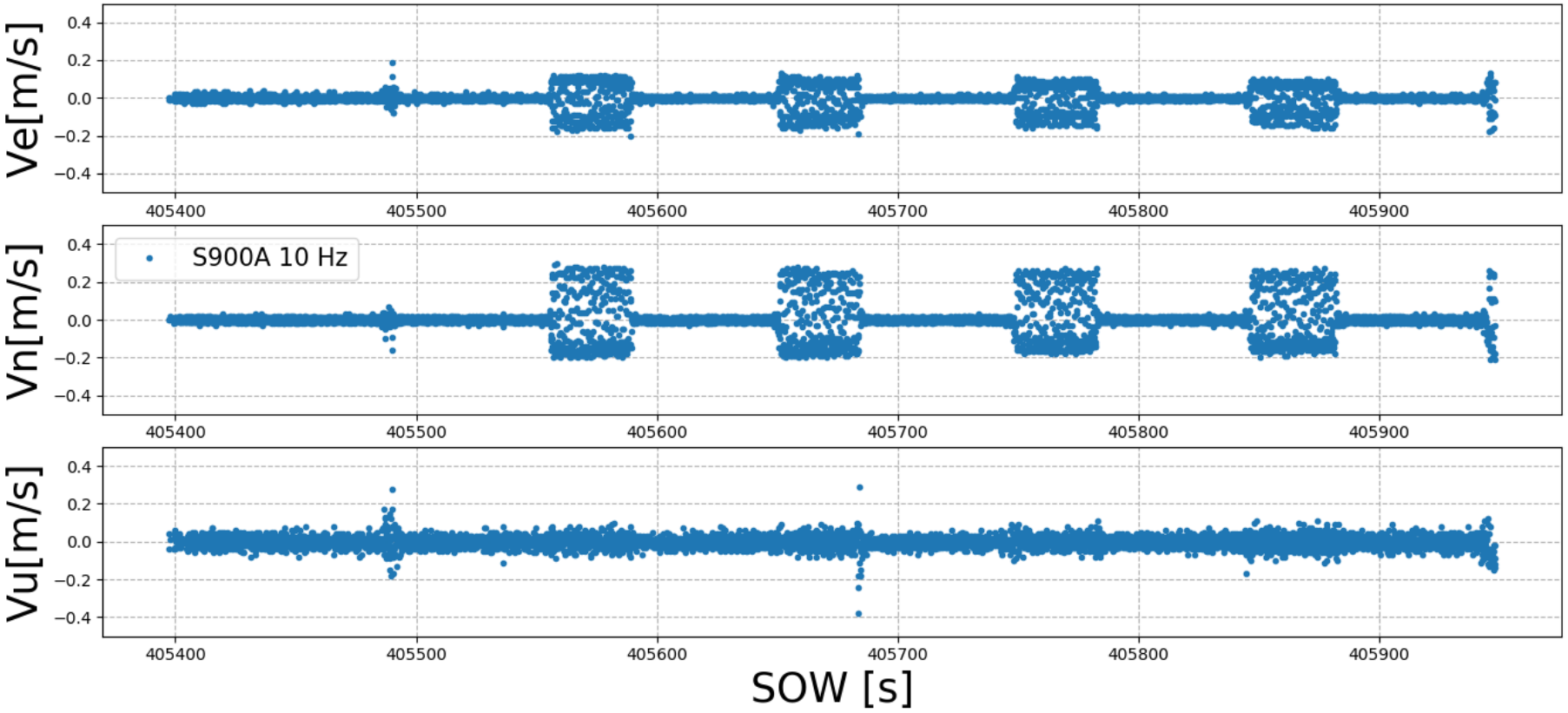
	RMSE [m/s]		
	East	North	Up
Mi 8	0.003	0.007	0.012
M0SE	0.001	0.001	0.002

Experiment with a Vibrating Table

Test description

- **Xiaomi Mi 8** and **STONEX S900A** in **open sky environment**
- Acquisition rate **1Hz** for the smartphone and **10 Hz** for the GNSS receiver
- 1D Oscillation **frequency** $\approx$ **1 Hz**
- 1D Oscillation **amplitude** $\approx$ **0.08 m**
- Two phases of the movement with **different velocities**
- Oscillatory and static periods
- **GPS and Galileo L1/E1** processing

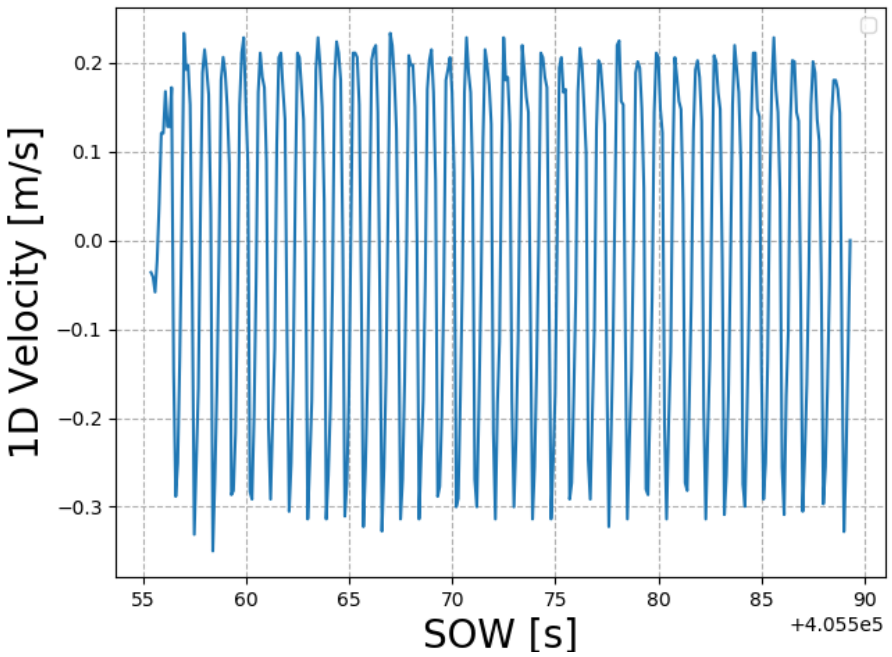
Velocity from STONEXS900A



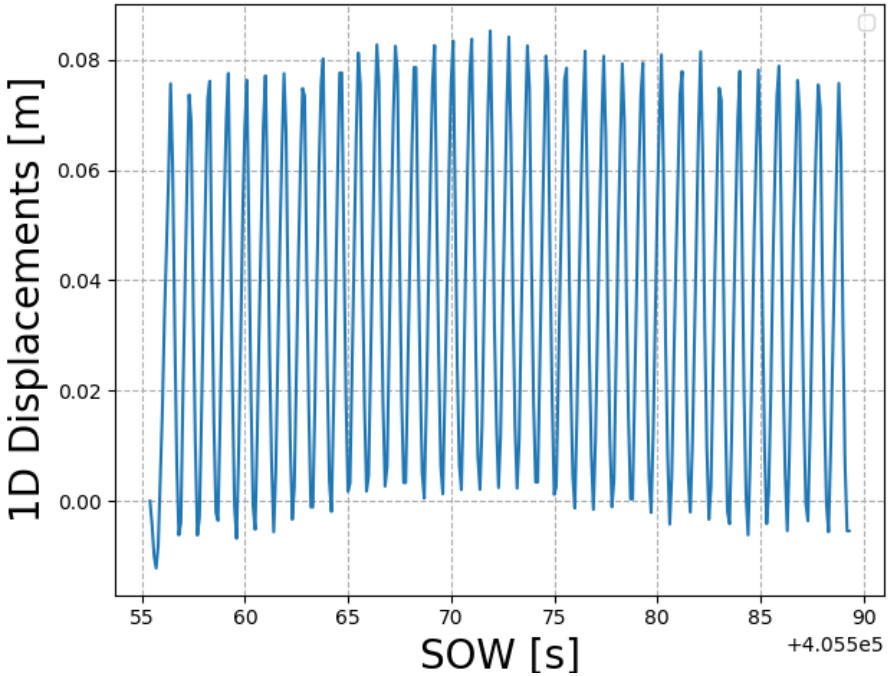
- VADASE allows to detect fast movements of the vibrating table

Characterisation of the Movement with STONEX S900A

1D Velocities

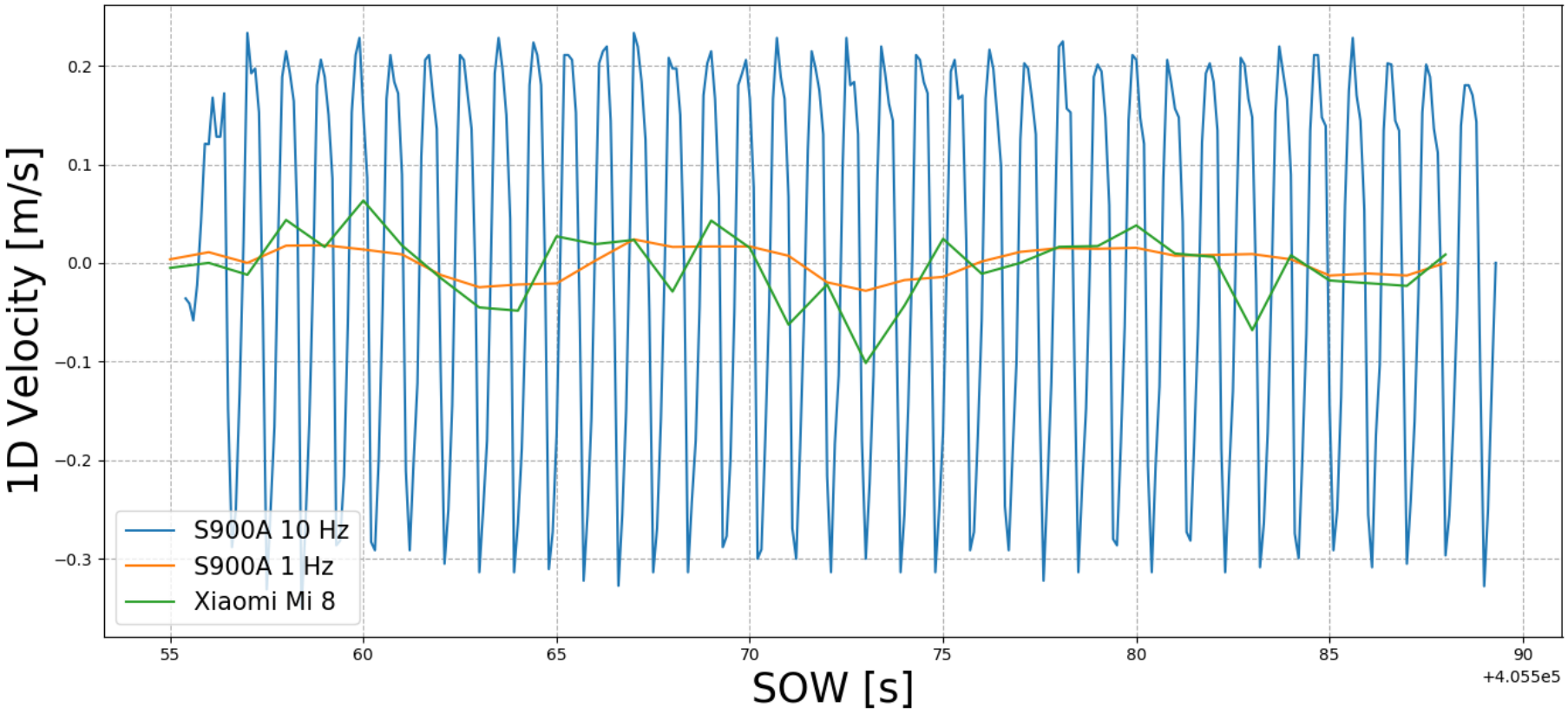


1D Displacements



- **Zero-crossing** method outcomes:
  - Displacement **Amplitude = 0.081 m ± 0.002 m**
  - Maximum **Velocity = 0.26 m/s ± 0.022 m/s**
- VADASE with 10 Hz observations is able to describe the oscillations

Aliased Solutions from 1Hz Observations

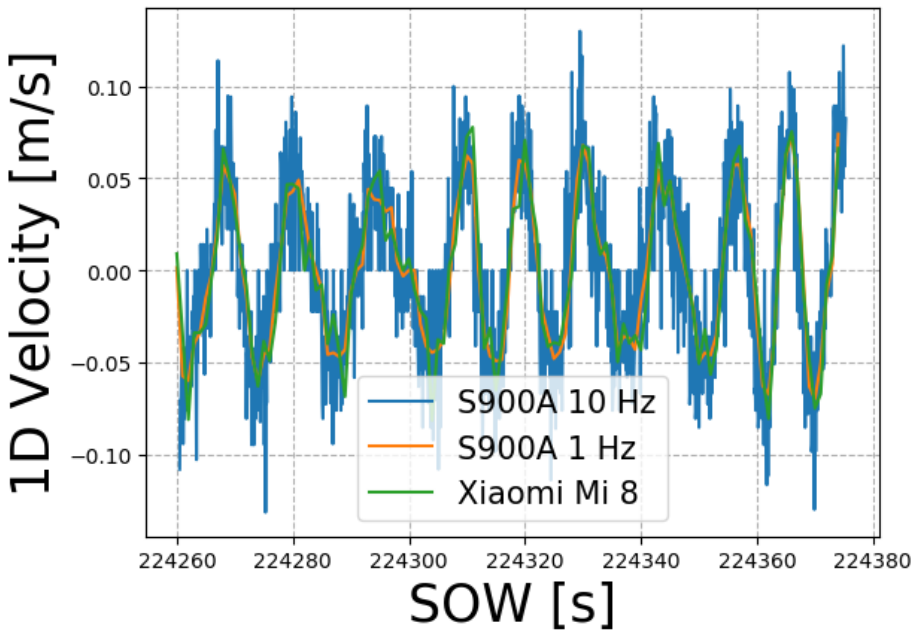


- **ALIASING**: acquisition rate (1Hz) prevents the possibility to reconstruct a phenomenon with similar frequency (slightly lower than 1Hz)

Modified Vibrating Table

Test description

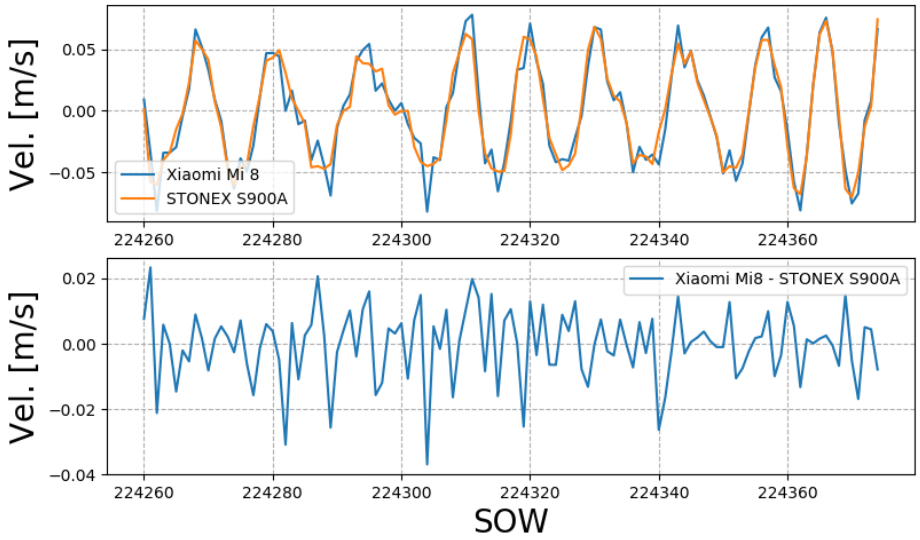
- **Xiaomi Mi 8** and **STONEX S900A** in **open sky environment**
- Acquisition rate **1Hz** for the smartphone and **10 Hz** for the GNSS receiver
- 1D Oscillation with fluctuating **frequency≈ 0.1 Hz**
- 1D Oscillation **amplitude ≈ 0.125 m**
- The movement improved is not regular
- **GPS and Galileo L1/E1** processing



Acquisition rate of 1 Hz allows to retrieve the vibrations induced by the table

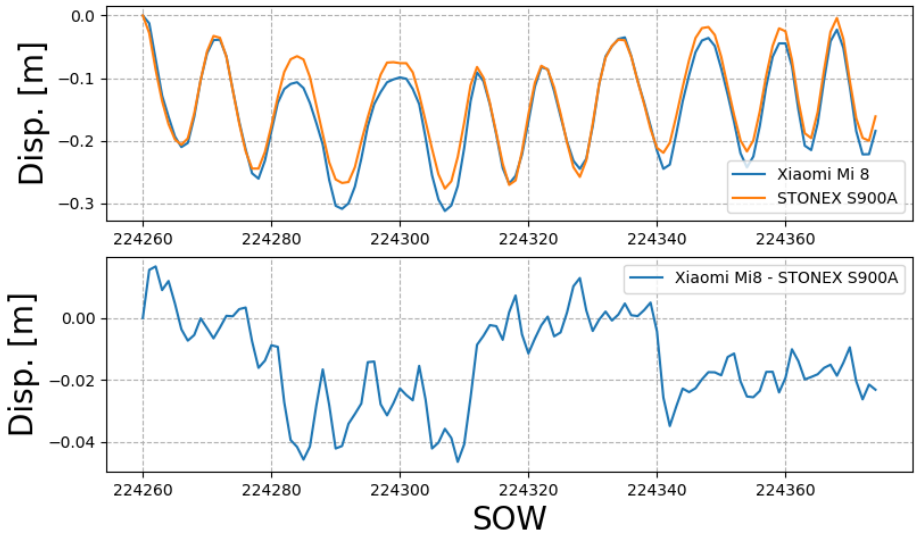
Comparison between Xiaomi Mi 8 and STONEX S900A

1D Velocities



- **RMSE = 0.011 m/s**
- Spikes are observed near the velocities peaks

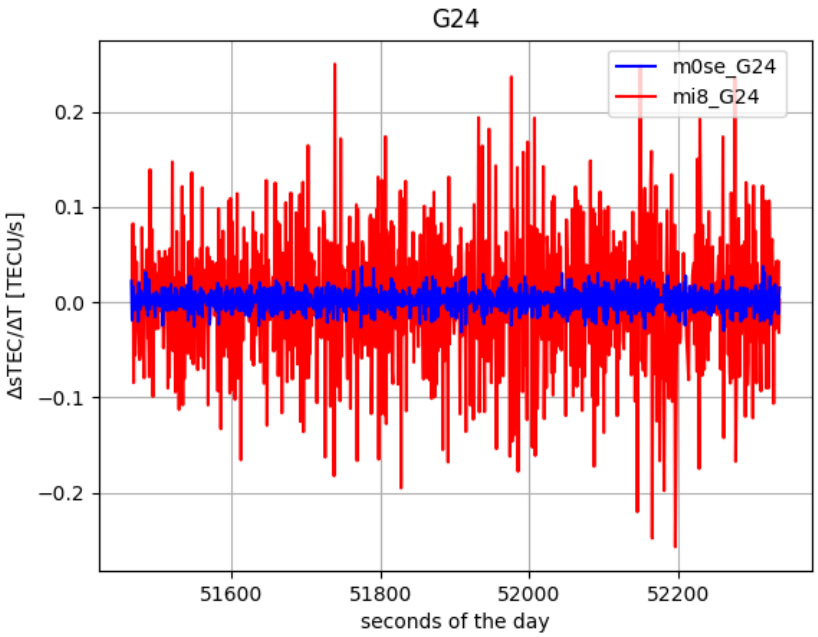
1D Displacements

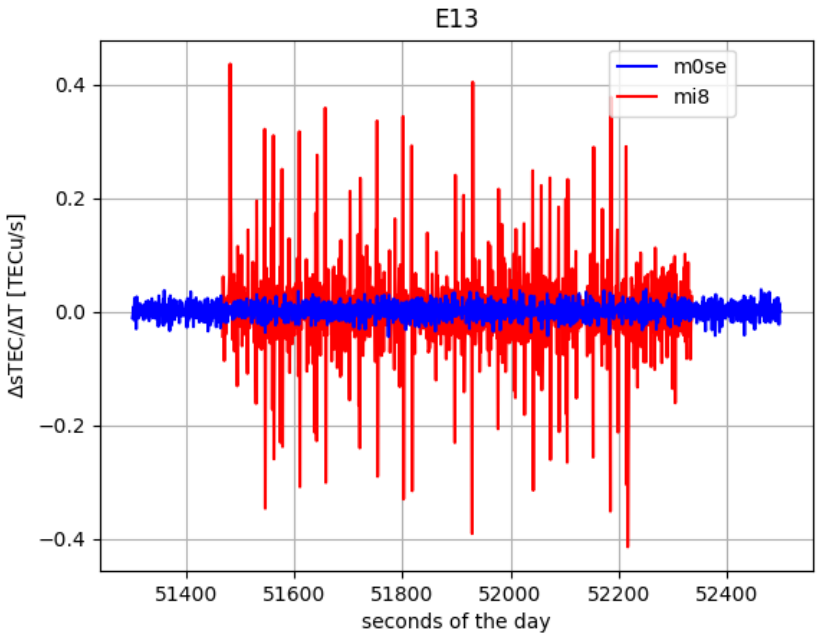


- **RMSE = 0.021 m**
- Spikes are observed near the velocities peaks

Results from VARION

- Originated from **VADASE**, **VARION** allows the real-time estimation of time variation of the **total electron content** (TEC)
- The computation starts from the time variation of **geometry free** combination on phase measurements.





- RMSE = **0.072 TECU/s**
- RMSE = **0.082 TECU/s**

Outline

Conclusions

- **Android GNSS raw measurements** analysed with VADASE are able to **retrieve real-time fast movement velocities and displacements**
- RMS of **1 cm/s for the velocity** and **2 cm for the displacements** with respect a geodetic class receiver were obtained in this work
- Acquisition rate of **1 Hz prevents** the detection of the **majority of fast movements** happening on the Earth (e.g. earthquakes)
- Among the noisier measurements, the possibility **to densify ionospheric information with Android smartphones** was proven

Future Developments

- Test the methodology with **high frequency GNSS raw measurements** (if provided by future Android versions)
- Test the methodology **without static-start conditions** to replicate the typical user behaviour
- Analysis of ionospheric conditions with Android measurements during **high ionospheric activity periods**

Thanks for your kind attention