GNSS Networks and Reference Stations

Innovative Solutions from Leica Geosystems

VADASE - Real-time motion estimation on-board a stand-alone GNSS receiver

Farouk KADDED (Leica Geosystems) / GeoPos 5/10/2017
Farouk.kadded@leica-geosystems.fr

PART OF HEXAGON

SAPIENZA UNIVERSITÀ DI ROMA

- when it has to be **right**

Leica Geosystems

Leica SPIDER

Leica Geosystems campus

VADASE – Velocity & Displacement Engine

Innovative solution for real-time motion estimation on-board a stand-alone GNSS receiver

Outline

- Motivation & Background
- Application examples
  - University of Rome
  - Leica external pre-evaluation
  - Leica internal application testing
- Use Cases & Conclusions

VADASE – Velocity & Displacement Engine
Motivation & Background

Using GPS for Seismology ...

- Historically mainly to study long-term deformation, daily solutions (plate tectonics, crustal deformation, post-glacial rebound, subsidence)
- More recently research using kinematic post-processed using
  - Instantaneous differential positioning
  - Precise Point Positioning

➔ Both methods not fully autonomous and not fully available in real-time

VADASE – Velocity & Displacement Engine
Motivation & Background

University of Rome “Sapienza” - Geodesy and Geomatics division :

- ***Idea*:**
  Real-time site displacement from a single stand-alone GNSS receiver

VADASE

Velocity Approach for Displacements Analysis Stand-Alone Engine

Aim to determine seismic displacements in real-time ...

- 1 cm accuracy / Global reference frame / within few minutes after event

VADASE – Velocity & Displacement Engine
Motivation & Background

Technology applied:

- **Velocity Estimation**
  - Epoch-by-Epoch LSQ estimation of site velocity using high-rate (i.e. 1 Hz or more) carrier phases observations and broadcast orbits
- **Waveform or Displacement determination**
  - Integration of estimated velocities leads to high-rate site motion waveform and displacement information

➔ No correction signals needed!

- **Patent applied by University of Rome**

VADASE – Velocity & Displacement Engine
Application Examples

University of Rome

- Japan: Tohoku-oki earthquake (post processed)

Leica external pre-evaluation

- Geospatial Information Authority of Japan (GSI)
- UNAVCO testing facilites – Waveform simulation

Leica internal application testing

- Kinematic „Train“ test
- Motion Test Plaform (video)

VADASE – Velocity & Displacement Engine

Application Examples: Earthquake

Studies performed by University of Rome - Earthquakes:

- Comparison of VADASE approach performed by post-processed data from various seismic events
- Example from Tohoku-oki earthquake / Mw 9.0, 11.03.2011 / 1 Hz data

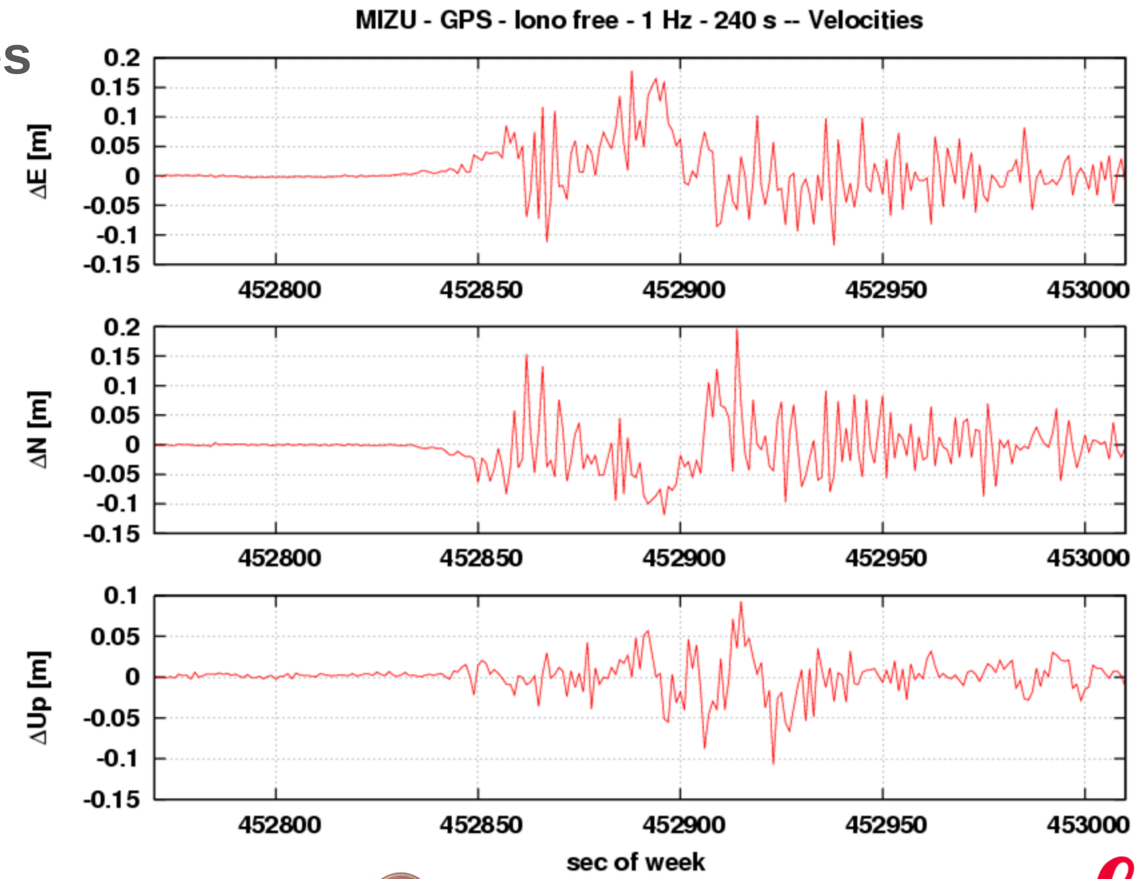
SAPIENZA
UNIVERSITÀ DI ROMA

- when it has to be **right**

VADASE – Velocity & Displacement Engine
Application Examples: Earthquake

Tohoku-oki earthquake / Mw 9.0, 11.03.2011

- Estimated velocities
- IGS Site "MIZU"
- 140 km from epicenter



SAPIENZA UNIVERSITÀ DI ROMA

- when it has to be **right**

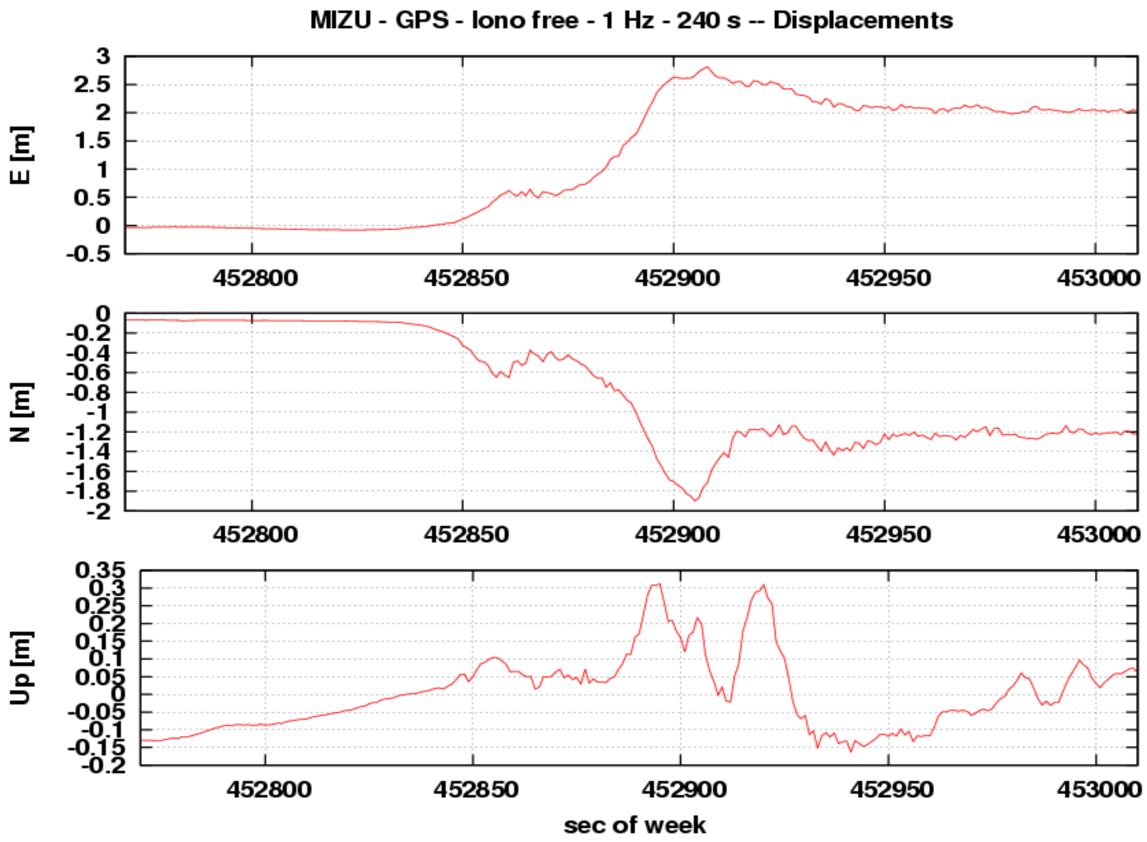
Leica Geosystems

VADASE – Velocity & Displacement Engine

Application Examples: Earthquake

Tohoku-oki earthquake / Mw 9.0, 11.03.2011

- Integrated velocities ➔ Displacements



2.4 m Total horiz. displacement

2.2 m – ΔE
2.9 m – MAX ΔE

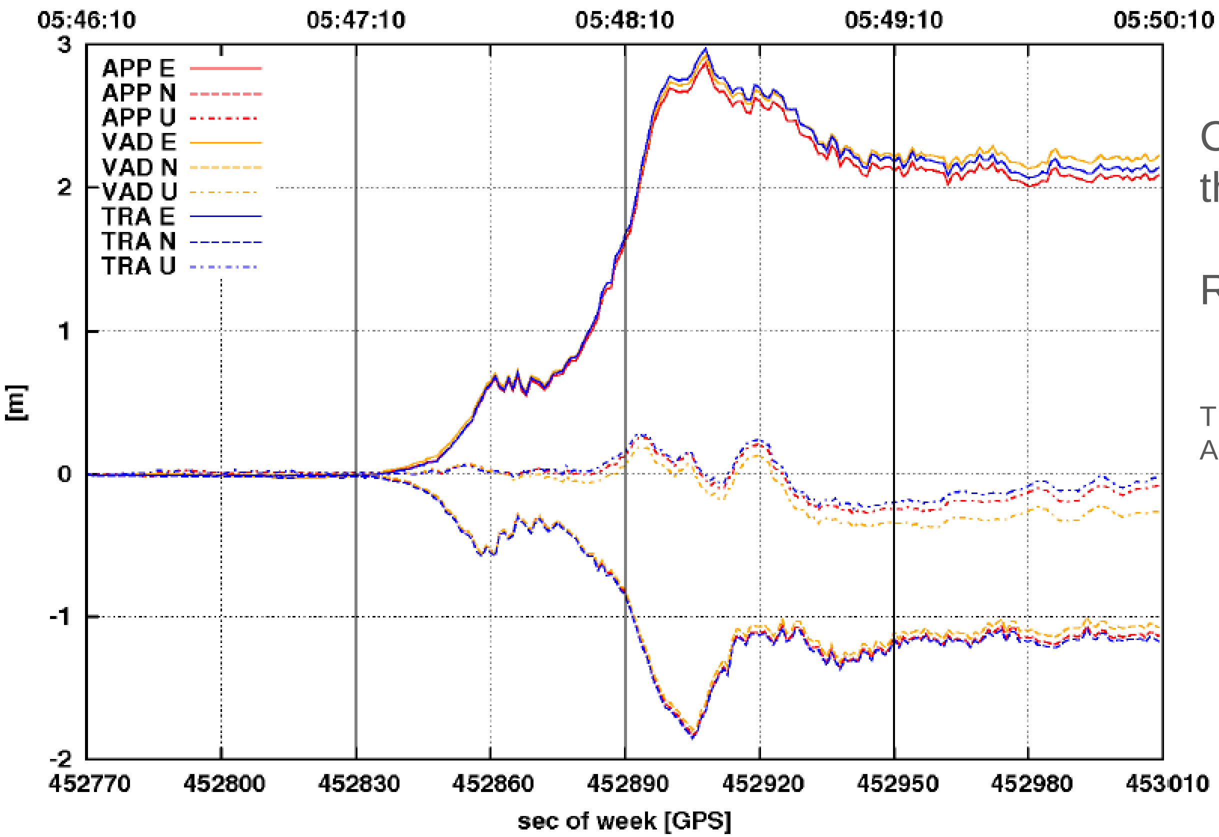
1.0 m – ΔN
1.8 m – MAX ΔN

0.1 m – ΔH
0.3 m – MAX ΔH

VADASE – Velocity & Displacement Engine
Application Examples: Earthquake

Tohoku-oki earthquake / Mw 9.0, 11.03.2011

- Comparison with TRACK and APP



Correlation coeff. higher than 0.90

RMSE within 5 cm (plane)

TRACK = Diff. Pos.
APP = PPP solution

VADASE – Velocity & Displacement Engine
Further Readings – University Rome

- G. Colosimo, M. Crespi and A. Mazzoni; ***Real-time GPS Seismology with a stand-alone receiver: A preliminary feasibility demonstration***; Journal of Geophysical Research, Vol 116, doi: 10.1029/2010JB007941

- G. Colosimo, M. Crespi, A. Mazzoni and T. Dautermann; ***Co-seismic Displacement Estimation, Improving Tsunami Early Warning Systems***; GIM 2011; http://www.gim-international.com/issues/articles/id1710-Coseismic_Displacement_Estimation.html

- M. Branzanti, G. Colosimo, M. Crespi and A. Mazzoni; ***GPS Near-Real-Time Coseismic Displacements for the Great Tohoku-oki Earthquake***; IEEE Geoscience and Remote Sensing Letters, Vol 99, doi: 10.1109/LGRS.2012.2207704

- E. Benedetti, M. Branzanti, L. Biagi, G. Colosimo, A. Mazzoni, and M. Crespi; ***Global Navigation Satellite Systems Seismology for the 2012 Mw 6.1 Emilia Earthquake: Exploiting the VADASE Algorithm***; Seismological Research Letters, Vol 85 ; doi: 10.1785/0220130094

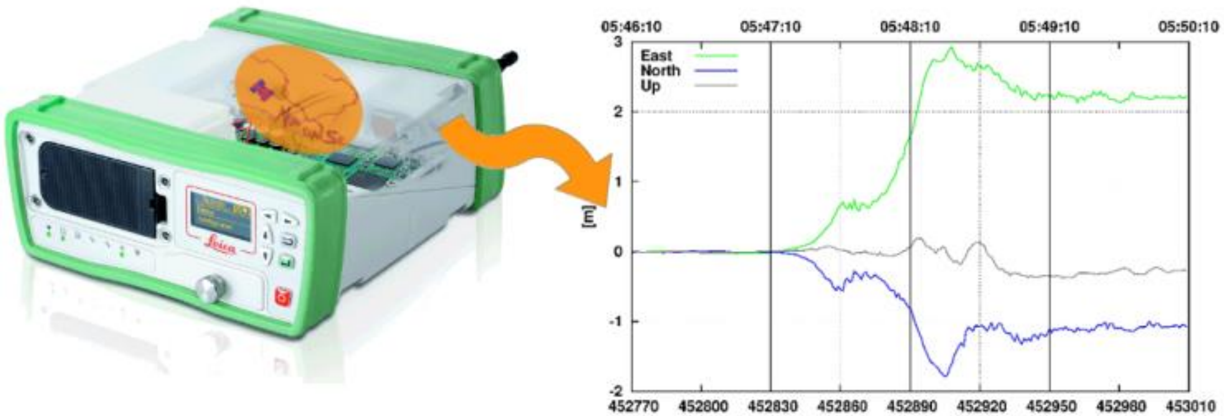
- ***European Satellite Navigation Competition***: http://www.esnc.eu/index.php?anzeige=dlr10.html

VADASE – Velocity & Displacement Engine

Leica GR10/GR25/GM10 - Integrated Solution

Leica Geosystems VADASE on-board GR/GM-Series receiver:

Velocity And Displacement Autonomous Solution Engine



- **Pu** ... al time
- **Se** ... change
- **Me** ... dcast orbits to obtain relative
- **Non-Purpose:** Detection of absolute position or slow movement
- **Benefits:** Fully autonomous & real time
  No reference data / corrections required

VADASE – Velocity & Displacement Engine
Application Examples

University of Rome

- Japan: Tohoku-oki earthquake (post processed)

Leica external pre-evaluation

- Geospatial Information Authority of Japan (GSI)
- UNAVCO testing facilites – Waveform simulation

Leica internal application testing

- Kinematic „Train“ test
- Motion Test Plaform (video)

VADASE – Velocity & Displacement Engine
Application Examples: GSI Evaluation

Geospatial Information Authority of Japan (GSI)

- March 2014 GSI made evaluation using GR10 with prototype on-board integration of original “Rome-VADASE” application
- Tests under static & various dynamic conditions and obstructed area
- Comparison made to RTK-Lib with double difference processing

VADASE – Velocity & Displacement Engine

Application Examples: GSI Evaluation

Japan GSI – Test Results: Motion 1 cm/s

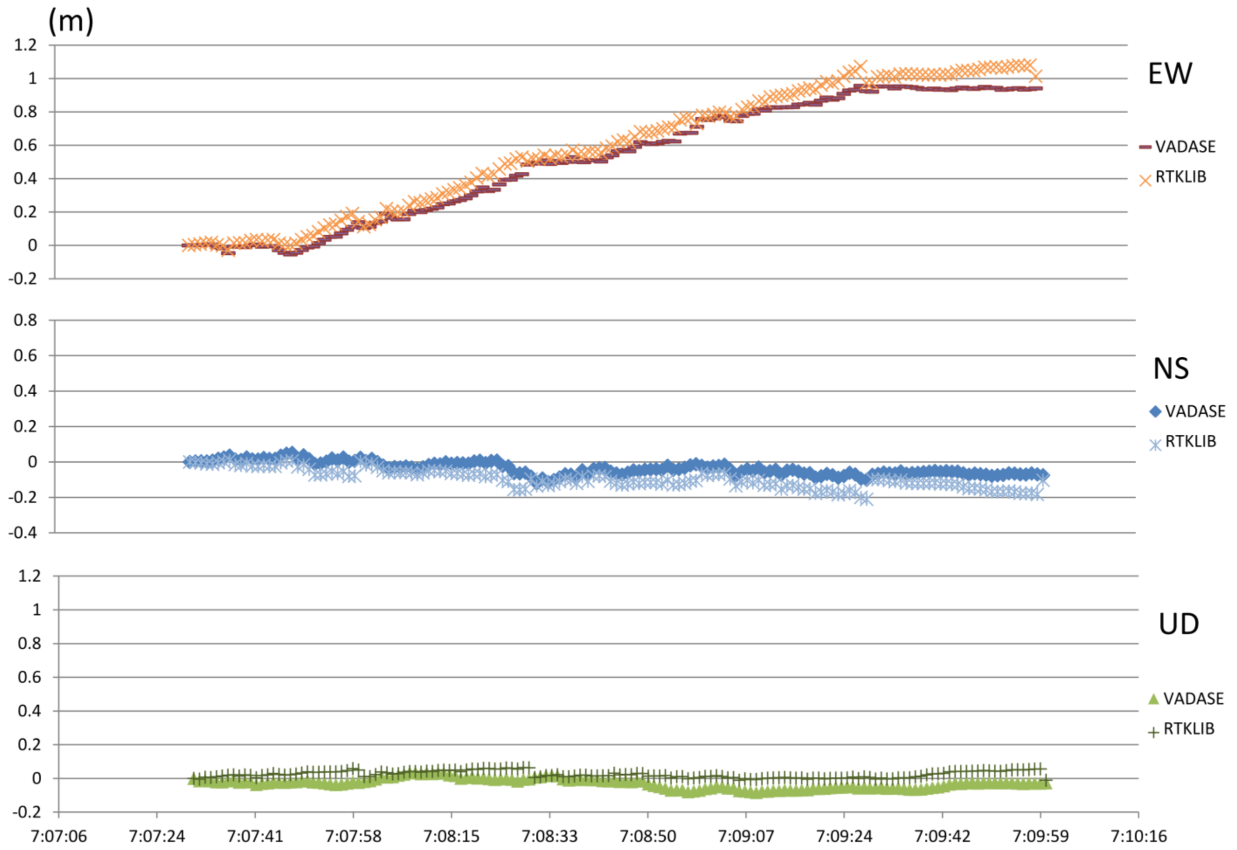


Fig. 1-3 Moving 1cm/s

VADASE – Velocity & Displacement Engine
Application Examples: GSI Evaluation

Japan GSI – Test Results: Motion 10 cm/s

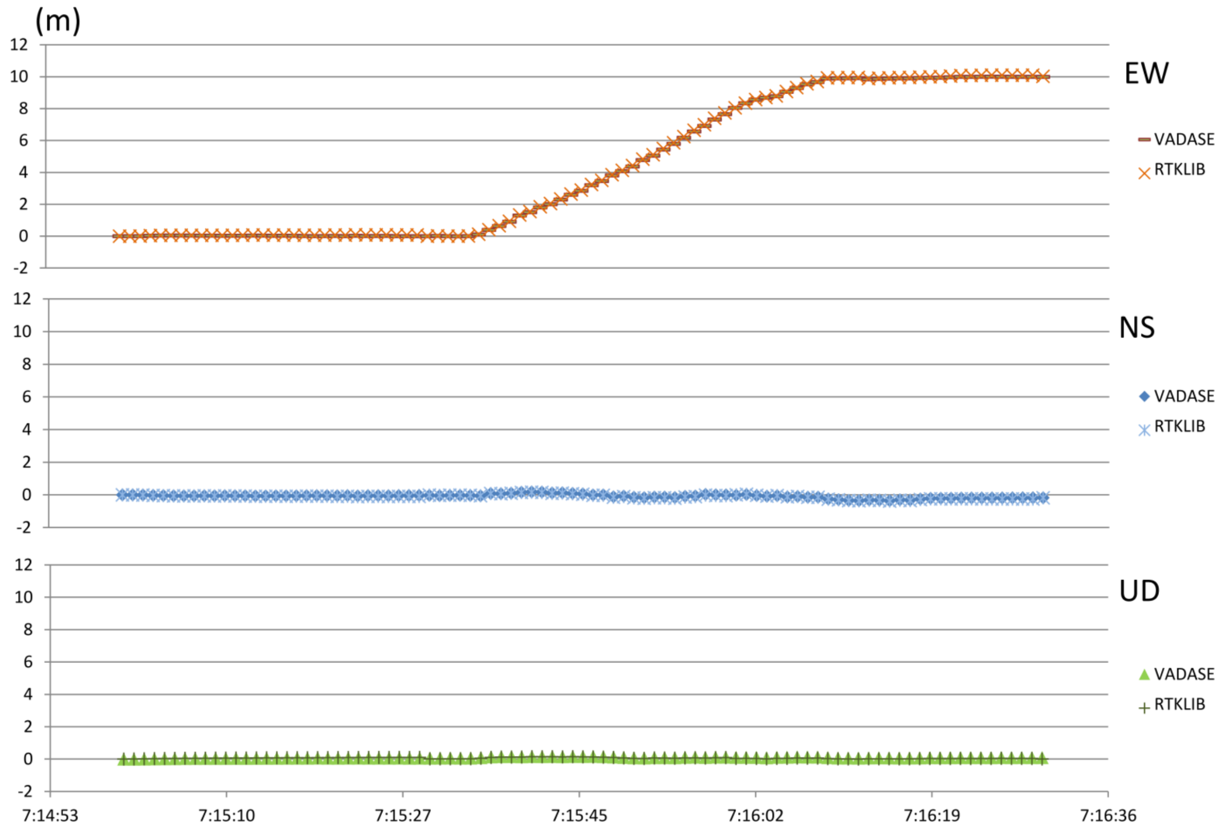


Fig 1-5 Moving 10cm/s

VADASE – Velocity & Displacement Engine
Application Examples: GSI Evaluation

Japan: GSI – Test Results with obstruction

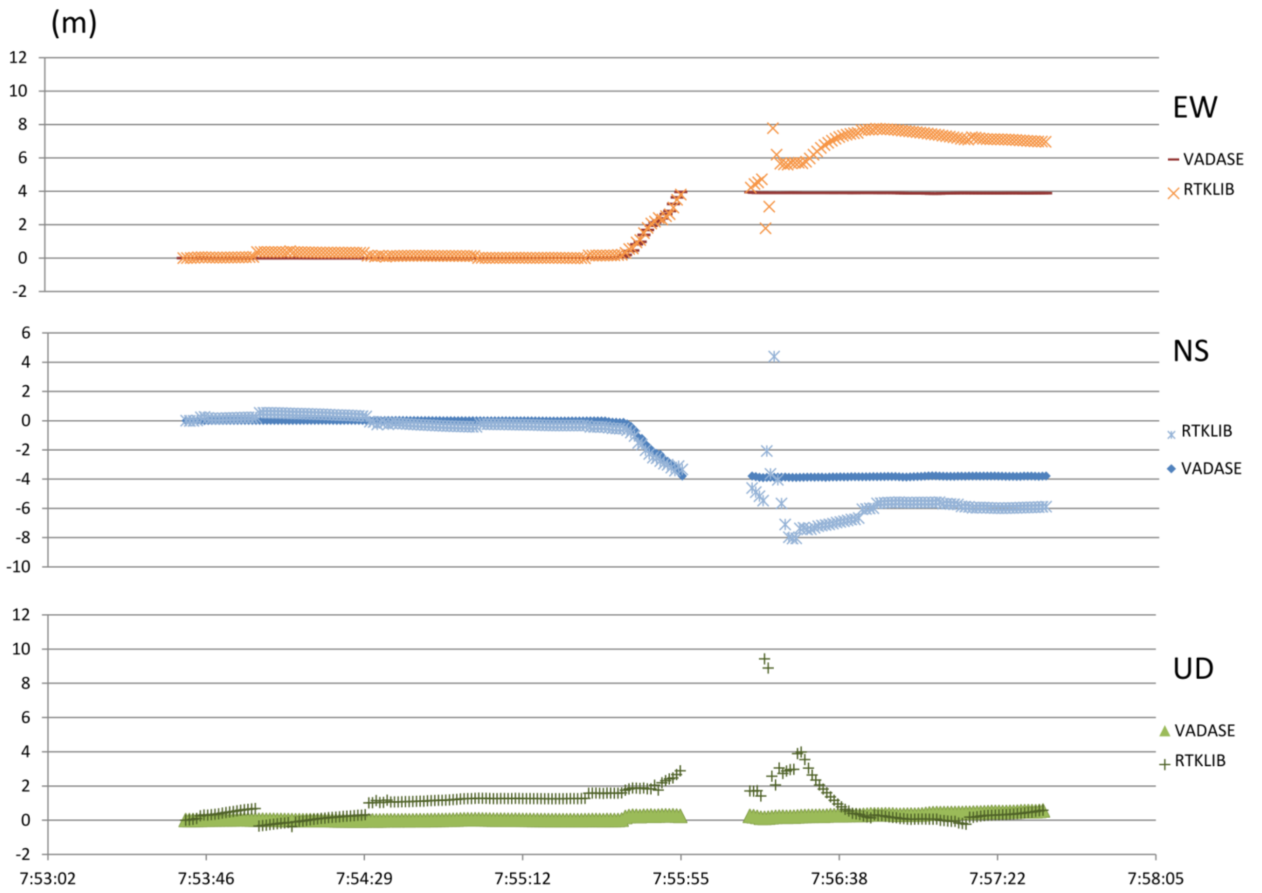


Fig. 2 Moving under the trees

VADASE – Velocity & Displacement Engine
Application Examples: GSI Evaluation

Japan: GSI – Test Results: Static

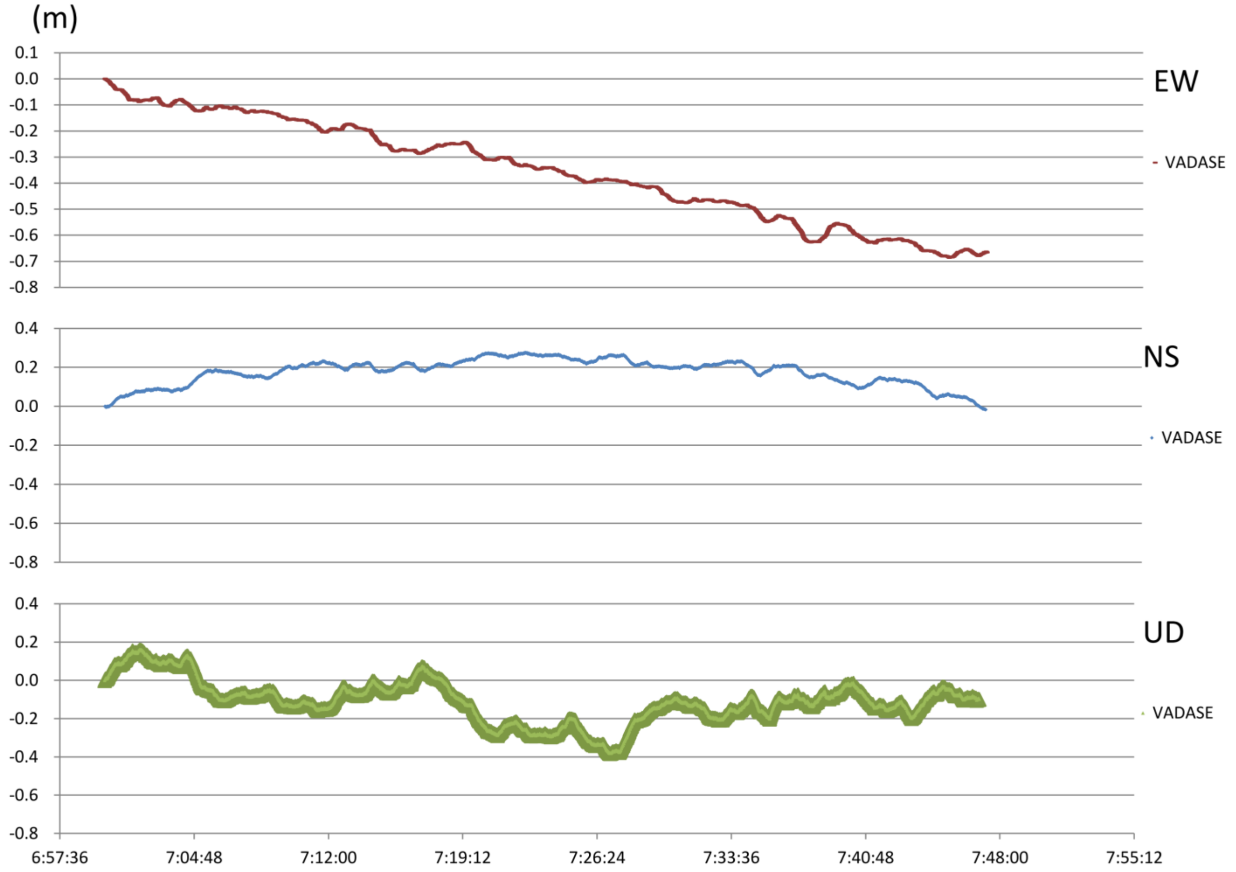


Fig. 3 Static

VADASE – Velocity & Displacement Engine
Application Examples: GSI Evaluation

Japan: GSI

- **Conclusion:**
  - VADASE produced appropriate position quality in same conditions
  - Advantage for Seismic and Tsunami observations through provision of almost instant displacement information
  - Possible future potential for very compact light-weight / low power measurement system solution

VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

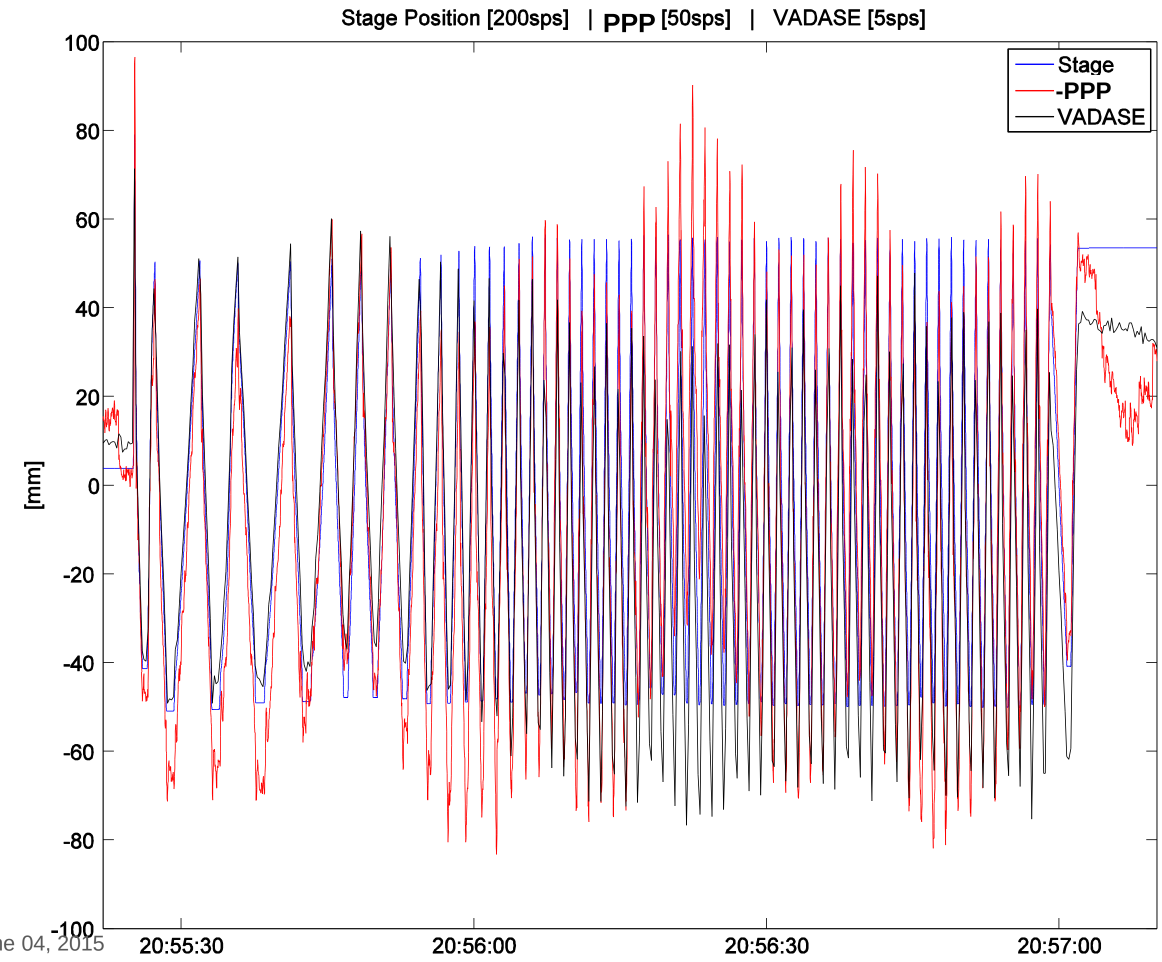
USA: UNAVCO Waveform Simulation (November 2014)

- Preliminary testing on pneumatic controlled test stage.
- Test stage still under development to obtain better ground truth reference data about movement.
- Reference data at up to 200 samples per sec. [sps]
- Allows sinusodial movement in approx.
  NW-direction no height shifts
- Comparison done between:
  RT-PPP (50Hz) vs. VADASE (5 Hz)
  [Note: VADASE evaluation version SW code is not performance optimised and therefore was limited to 5 Hz. At least up to 20Hz will be available in future.]

VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

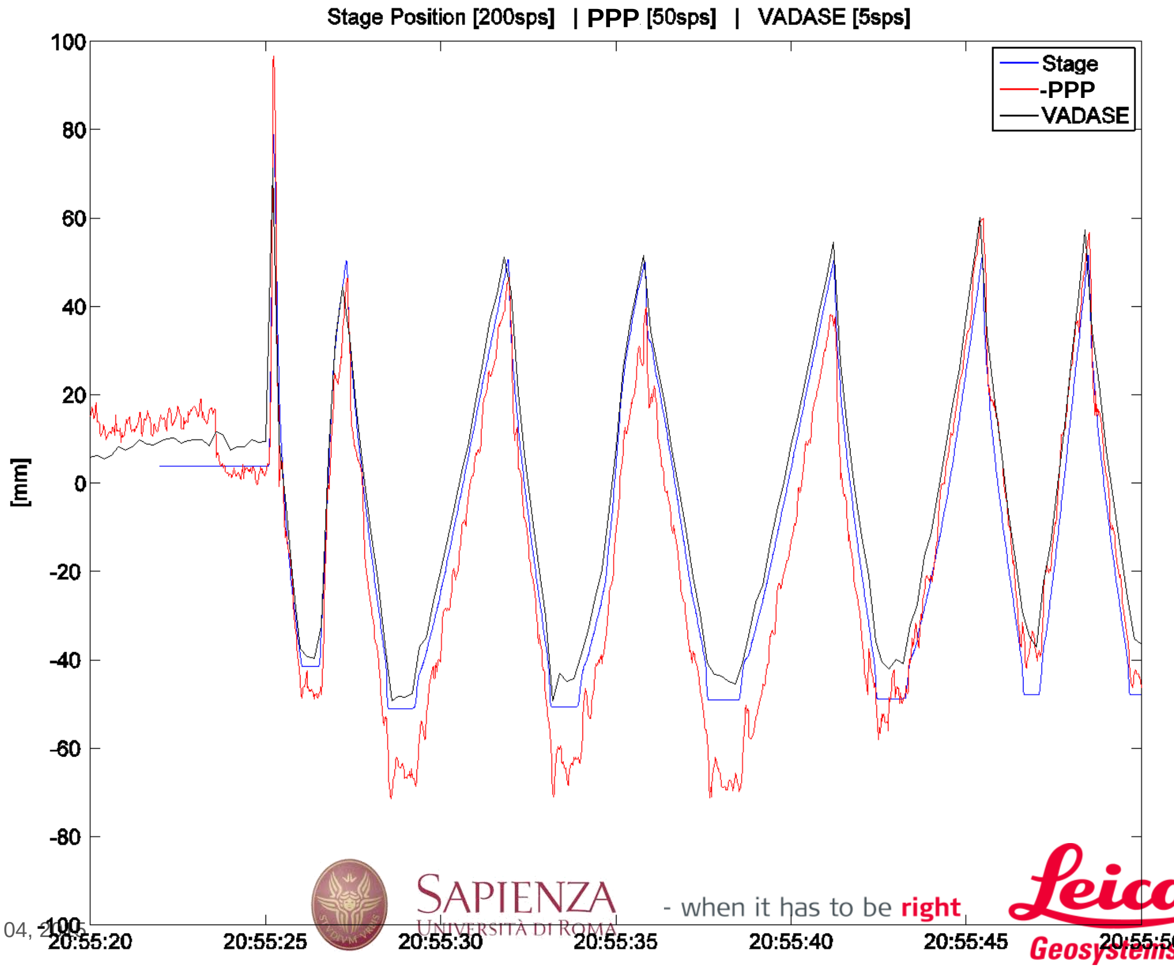
- Overview
- ~ 4 min
- „Stage“ = 200 Hz Reference position
- PPP @ 50Hz
- VADASE @ 5 Hz



VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

- Zoom –
  Start of Experiment



SAPIENZA
UNIVERSITÀ DI ROMA

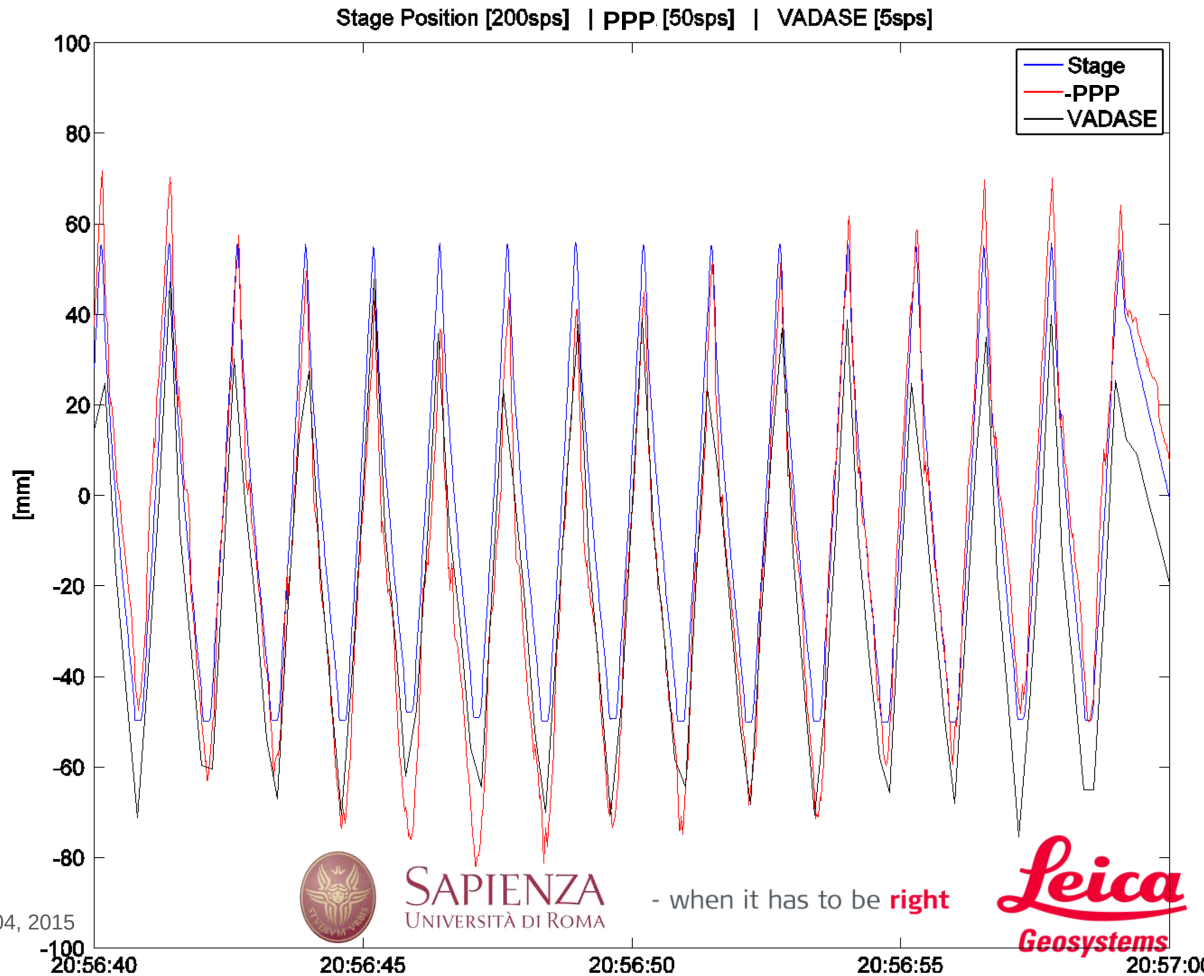
- when it has to be right

Leica Geosystems

VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

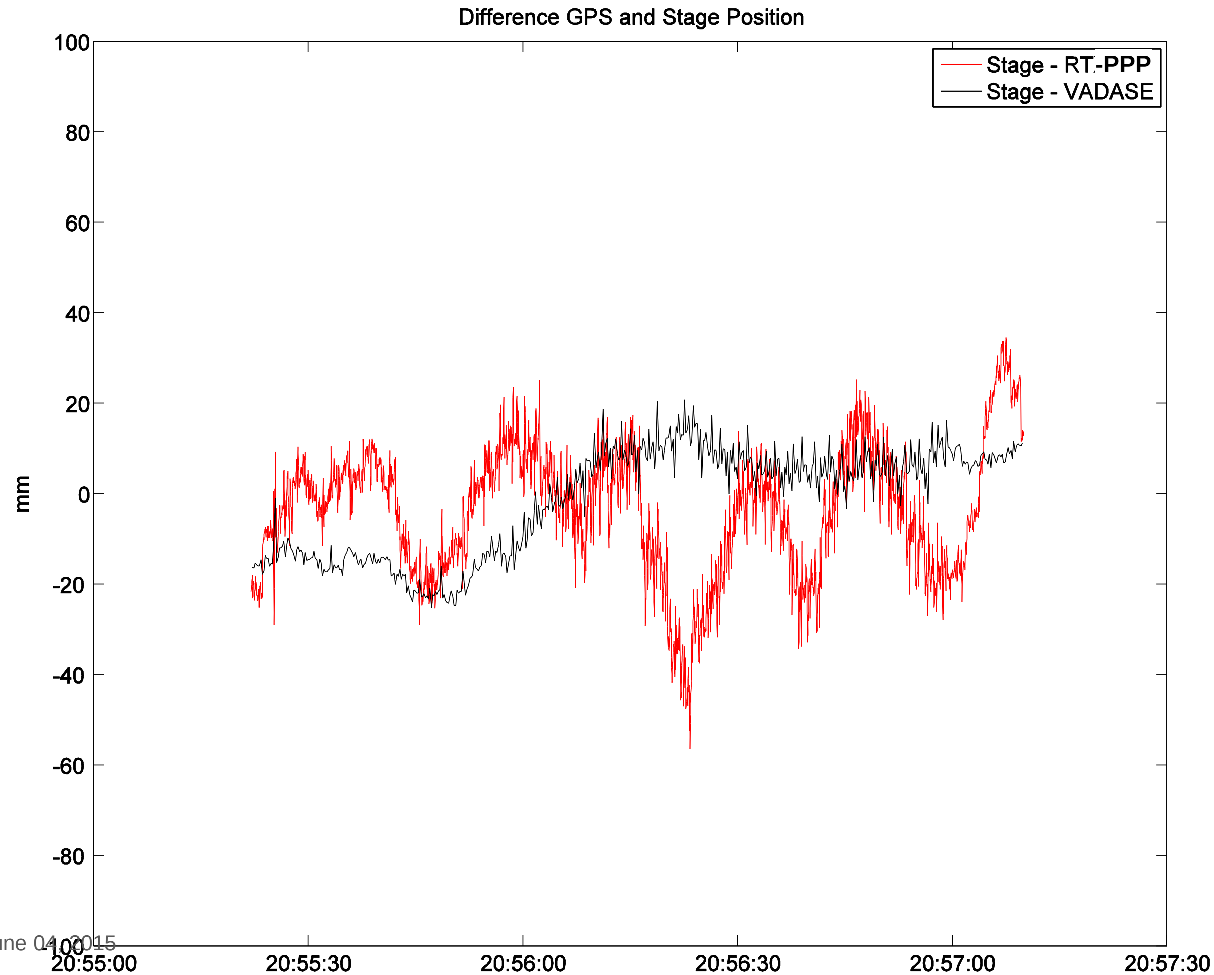
- **Zoom – End of Experiment**



VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

- Position difference between „Stage“ reference and GPS based results of RT-PPP and VADASE



VADASE – Velocity & Displacement Engine
Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

- **Summary:**
  - These preliminary results are rated promising
  - Amount of drift over 5 minutes period is reasonable
  - VADASE shows results following clearly more precisely the actual movement with less „overdrive“ on the amplitude.
  - VADASE shows results with less process noise

VADASE – Velocity & Displacement Engine
Application Examples: Leica „Train“-Test

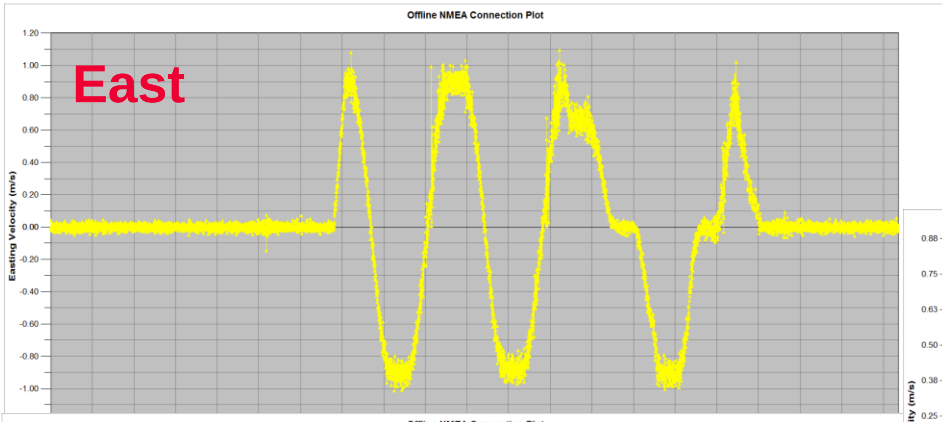
Leica “Train”- Testrail: Dynamic performance – 20 Hz

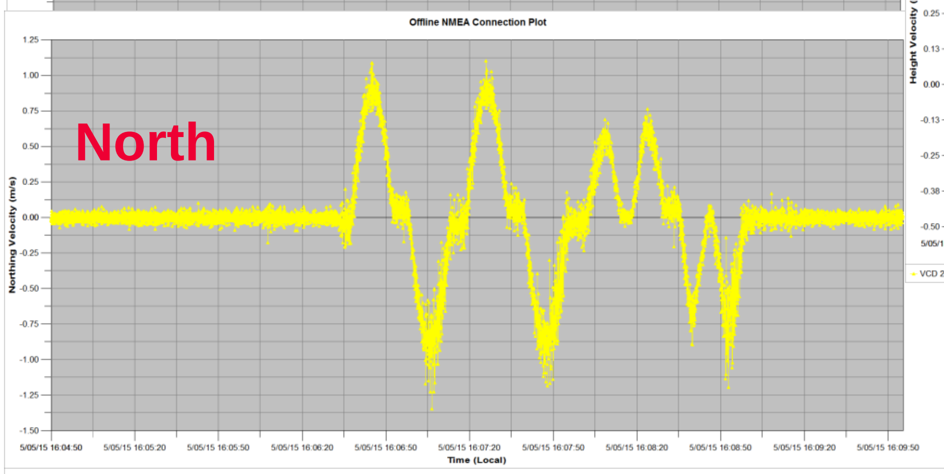
- **Goal:** Analyse dynamic behaviour
  - 2 runs continuous (max) speed
  - 3rd run varying speed accellerate / decellerate
  - Analysis done with Leica SpiderQC

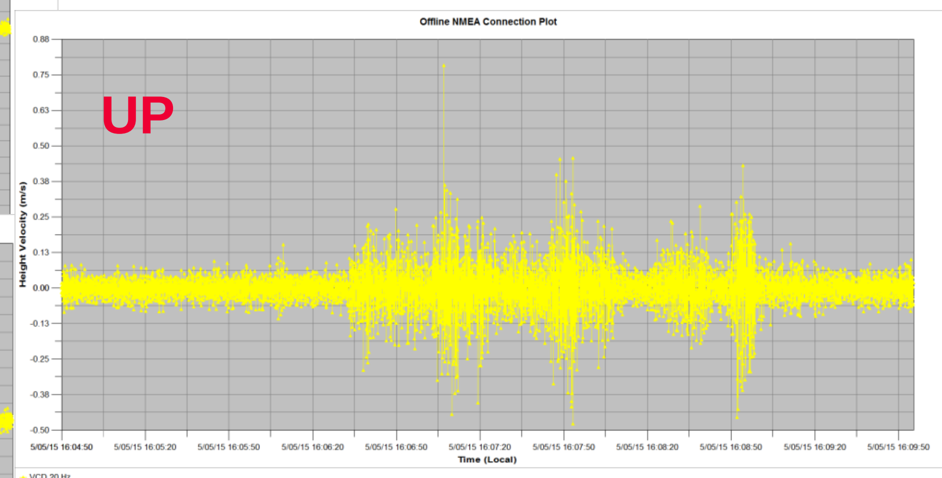
VADASE – Velocity & Displacement Engine

Application Examples: Leica „Train“-Test

Leica “Train”- Testrail: Dynamic performance – 20 Hz Velocities



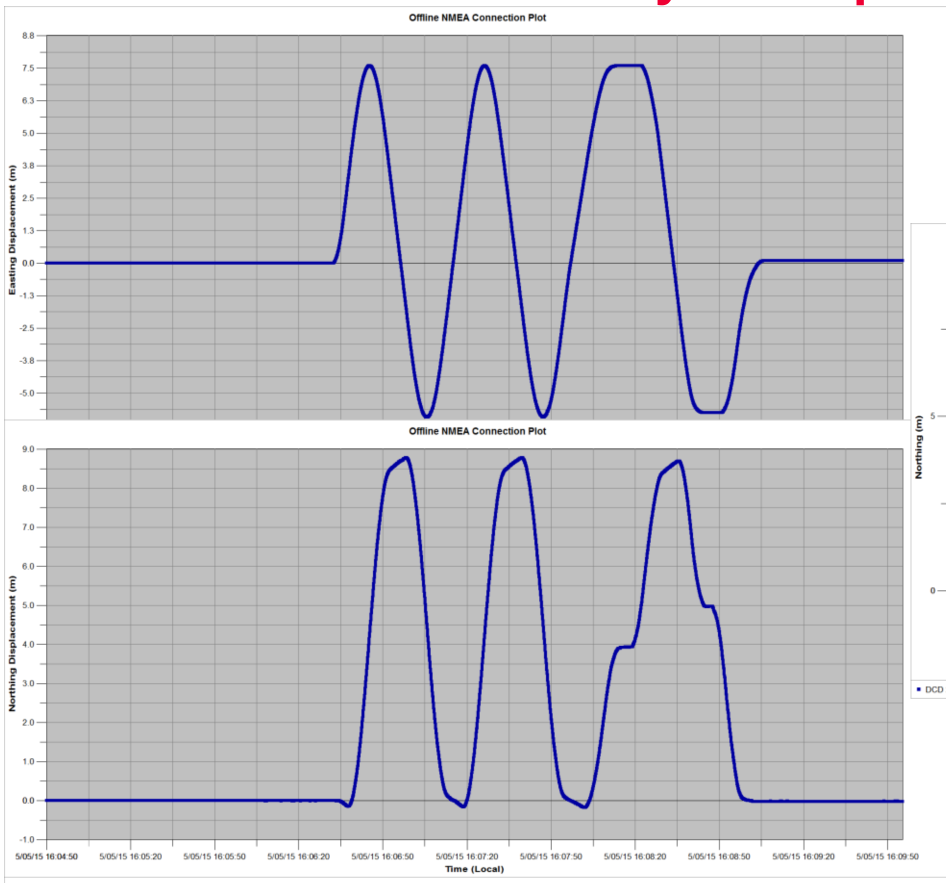


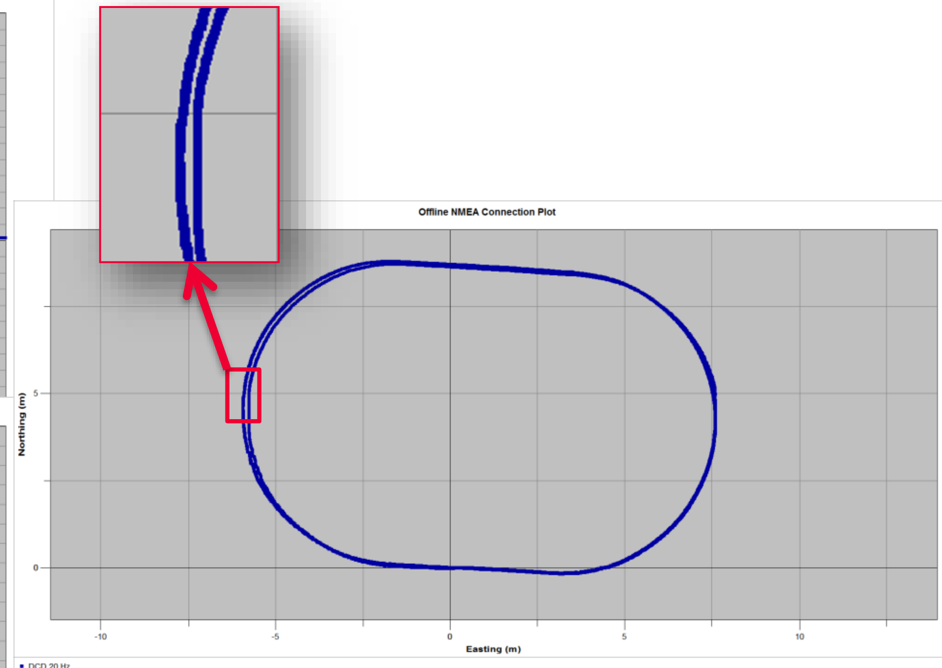


VADASE – Velocity & Displacement Engine

Application Examples: Leica „Train“-Test

Leica “Train”- Testrail: Dynamic performance – 20 Hz Velocities





SAPIENZA
UNIVERSITÀ DI ROMA

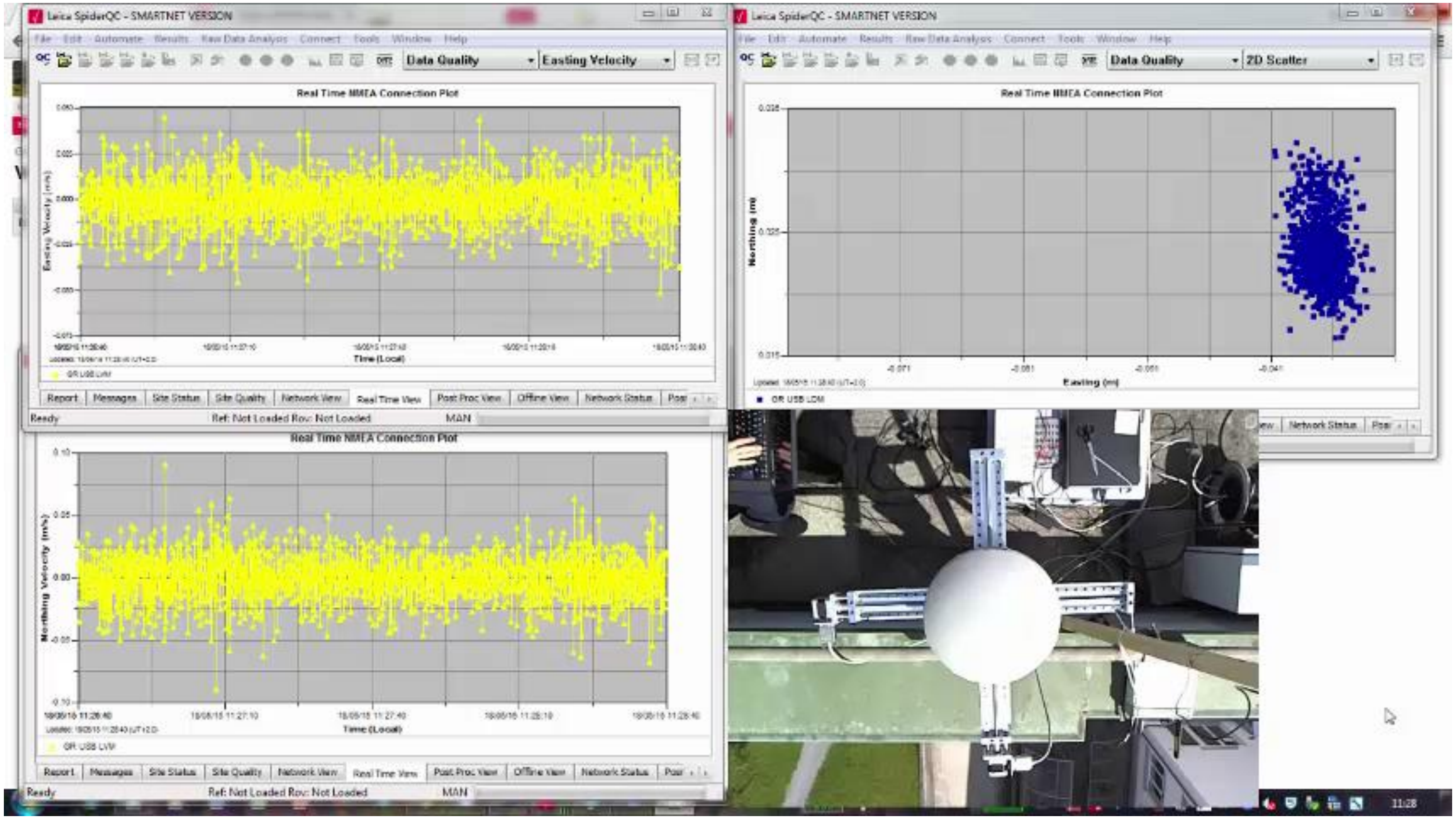
- when it has to be **right**

Leica Geosystems

VADASE – Velocity & Displacement Engine

Application Examples: Leica „Test Platform“-Test

Leica “Test platform”- Dynamic performance – 20 Hz Velocities



SAPIENZA UNIVERSITÀ DI ROMA

- when it has to be **right**

Leica Geosystems

VADASE – Velocity & Displacement Engine
Use Cases

- **Innovative real-time motion detection for various applications**
  - Seismology
    - co-seismic displacements and waveforms retrieval
  - Early warning systems
    - Natural or man-made hazards (volcanic, earth quake / tsunami, fracking, …)
    - Safety monitoring for infrastructure elements (railways, highways, etc.) close to potential hazard (landslides, etc.).
  - Monitoring
    - Structural and geotechnical engineering monitoring (buildings, skyscrapers, dams, oil platforms etc.);
    - Oscillations monitoring for different type of structures
    - Permanent GNSS network reference station “accident” monitoring
    - …

VADASE – Velocity & Displacement Engine

Innovative solution for real-time motion estimation on-board a stand-alone GNSS receiver

- **Benefits: Simple - Efficient – Reliable - Robust**
  - Fast, relative displacements at high data rates
  - Over short intervals of a few minutes, with high accuracy of ~2-4 cm
  - Fully autonomous - Stand alone receiver – No correction signal needed

- **Conclusion**
  - Complement to other GNSS solutions for real time displacement detection, when continuous correction stream cannot be guaranteed
  - Provides a first & fast displacement analysis, before post processing
  - Opens potentially new applications in GNSS structural monitoring
  - Provides alternate autonomous monitoring for reference stations

THANK YOU FOR YOUR ATTENTION!

Velocity And Displacement Autonomous Solution Engine

The best answers combine the smartest solutions

When you are interested in high rate and real time cm-level fast motion detection of an autonomous station, or be independent of any external reference, the **VADASE** provides the solution – when it has to be right.

Leica Spider
GNSS Networks and Reference Stations
Smart Solutions from Leica Geosystems

- when it has to be **right**

Leica Geosystems

PART OF HEXAGON