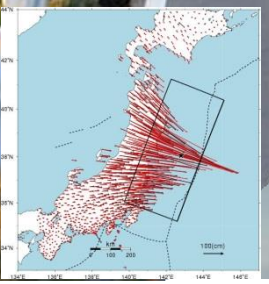
GNSS Networks and Reference Stations



Innovative Solutions from Leica Geosystems

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

PART OF HEXAGON

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- when it has to be **right**

Leica Geosystems

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

Variometric **A**pproach for **D**isplacements **A**nalysis **S**tand-Alone **E**ngine

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

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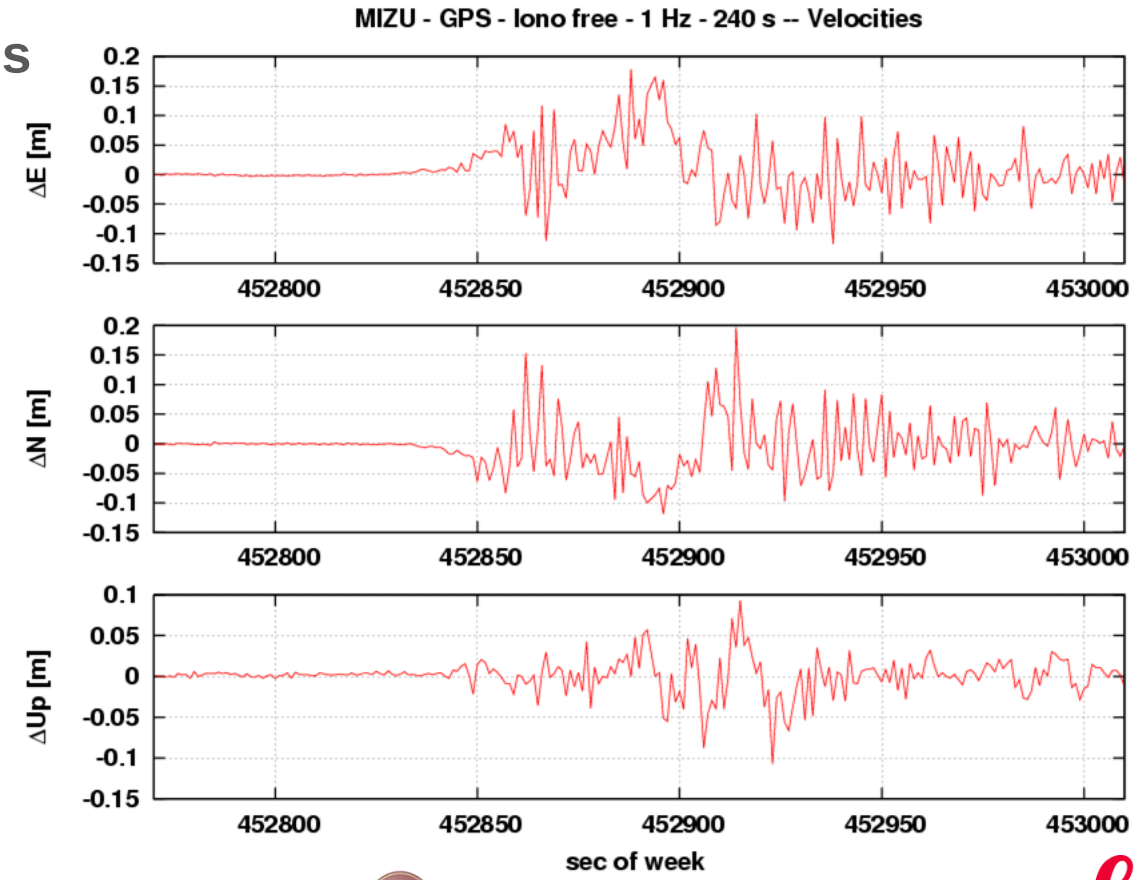
VADASE – Velocity & Displacement Engine

Application Examples: Earthquake

Tohoku-oki earthquake / Mw 9.0, 11.03.2011

- Estimated velocities
- IGS Site “MIZU”
- 140 km from epicenter



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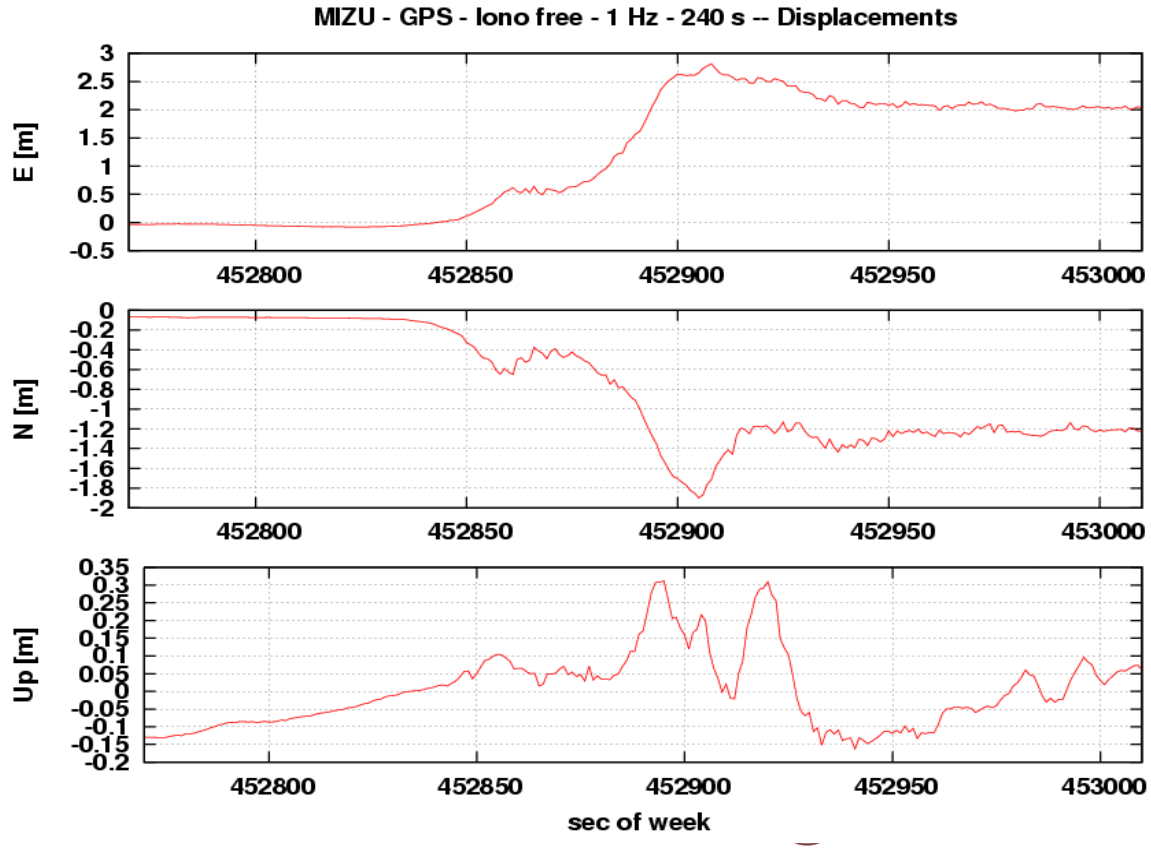
Application Examples: Earthquake

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

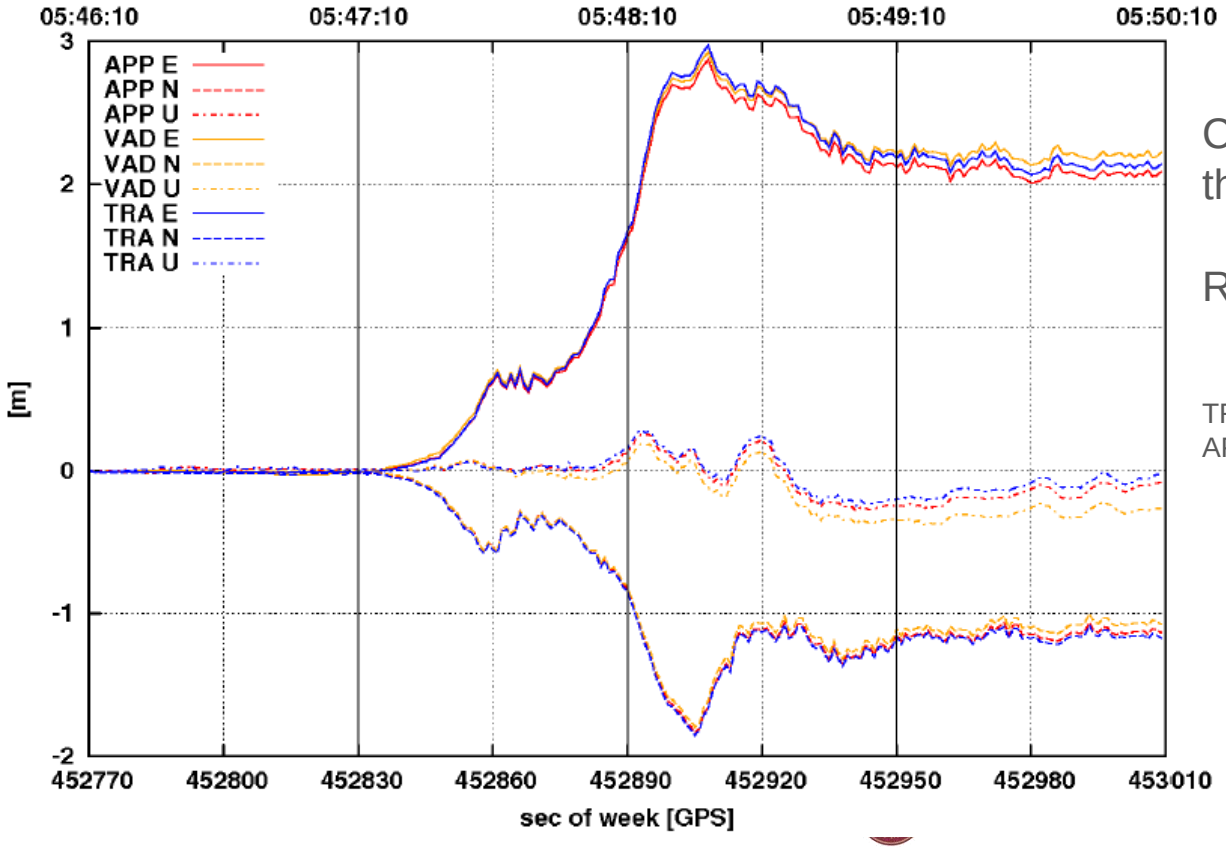
0.1 m – ΔH
0.3 m – MAX ΔH

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

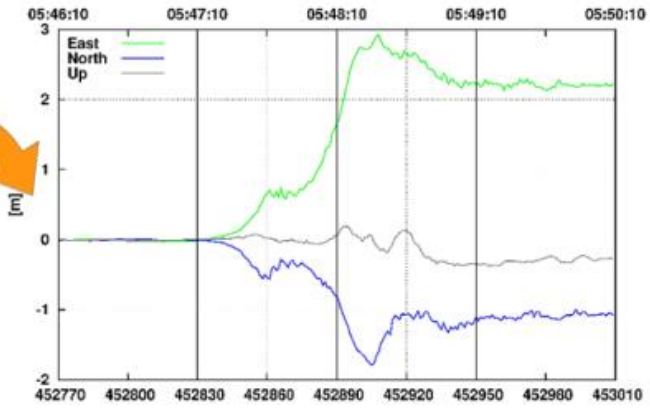
- G. Colosimo, M. Crespi and A. Mazzoni; ***Real-time GPS Seismology with a stand-alone receiver: A preliminary feasibility demonstration***; Journal of Geophysical Research, Vol 116, doi: 10.1029/2010JB007941
- G. Colosimo, M. Crespi, A. Mazzoni and T. Dautermann; ***Co-seismic Displacement Estimation, 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 **A**nd **D**isplacement **A**utonomous **S**olution **E**ngine



- **Pu** …l 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

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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

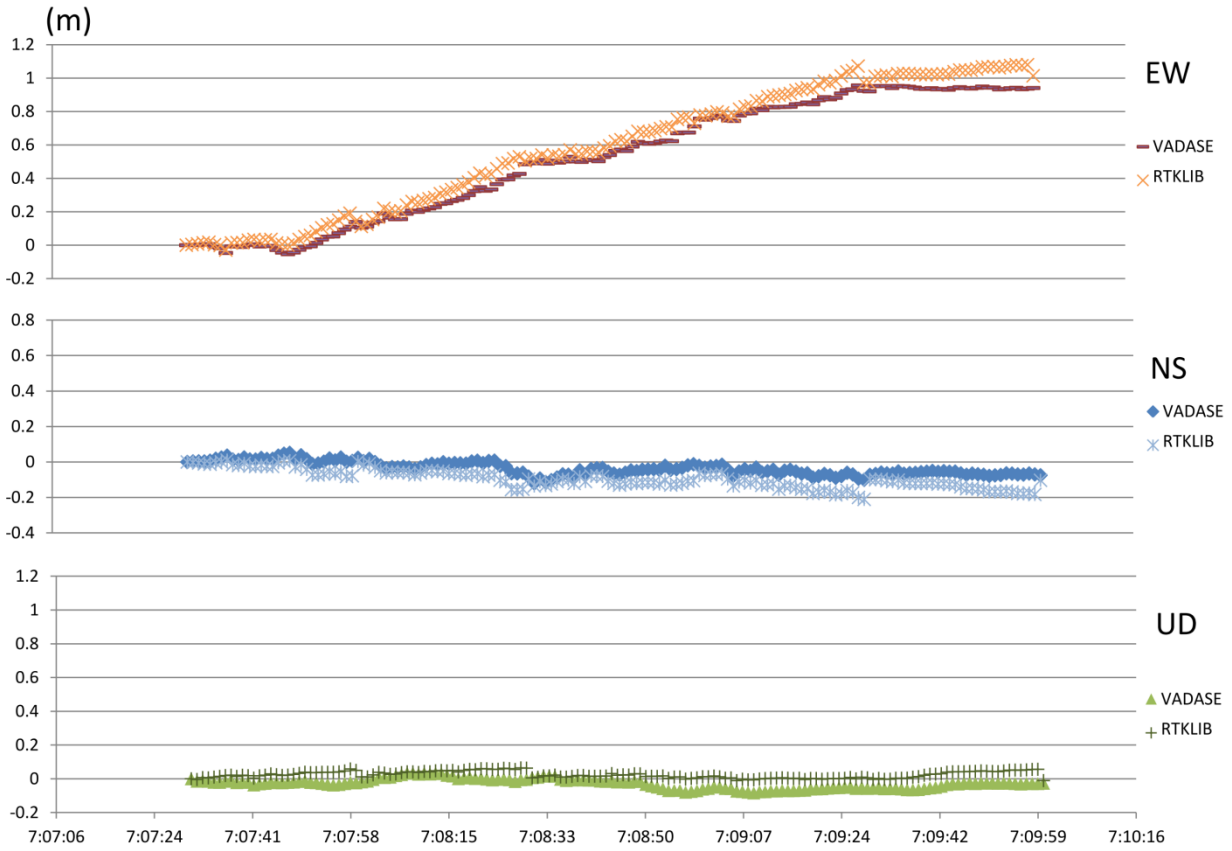


Fig. 1-3 Moving 1cm/s

VADASE – Velocity & Displacement Engine

Application Examples: GSI Evaluation

Japan GSI – Test Results: Motion 10 cm/s

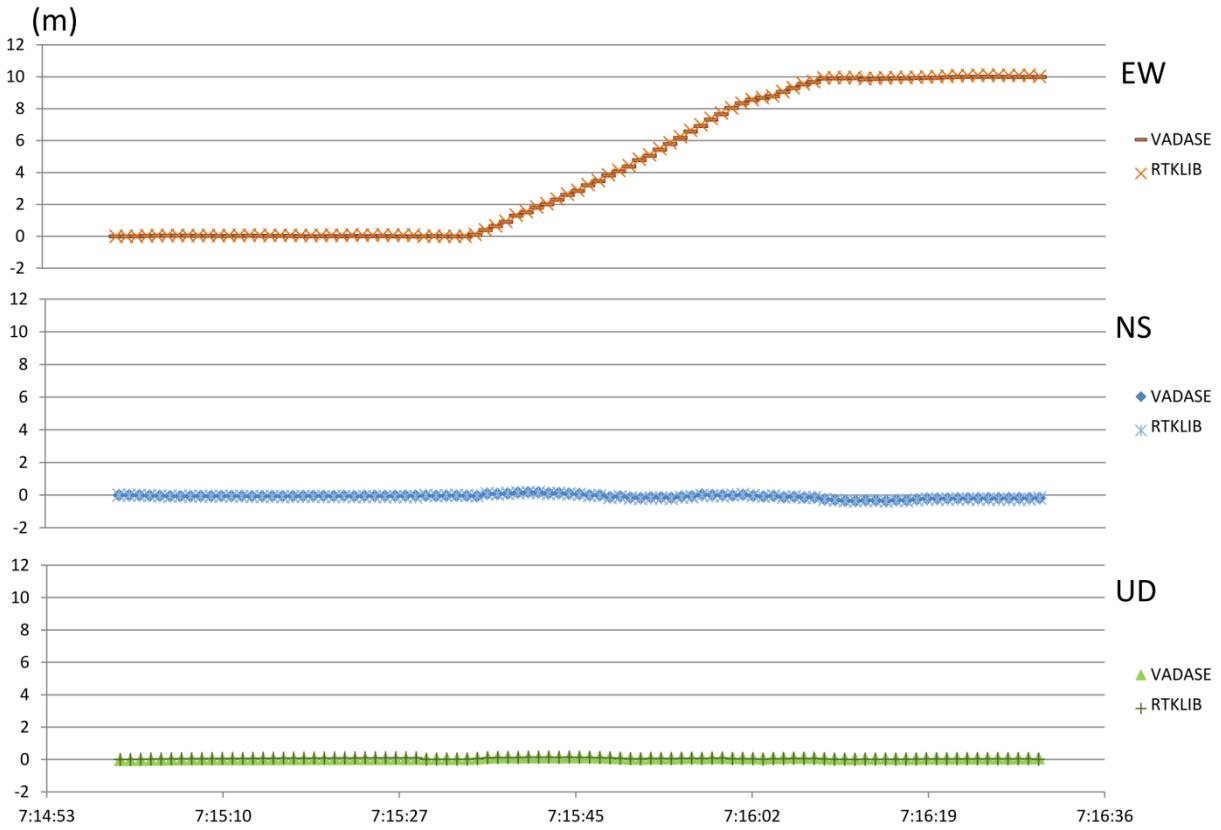


Fig 1-5 Moving 10cm/s

VADASE – Velocity & Displacement Engine

Application Examples: GSI Evaluation

Japan: GSI – Test Results with obstruction

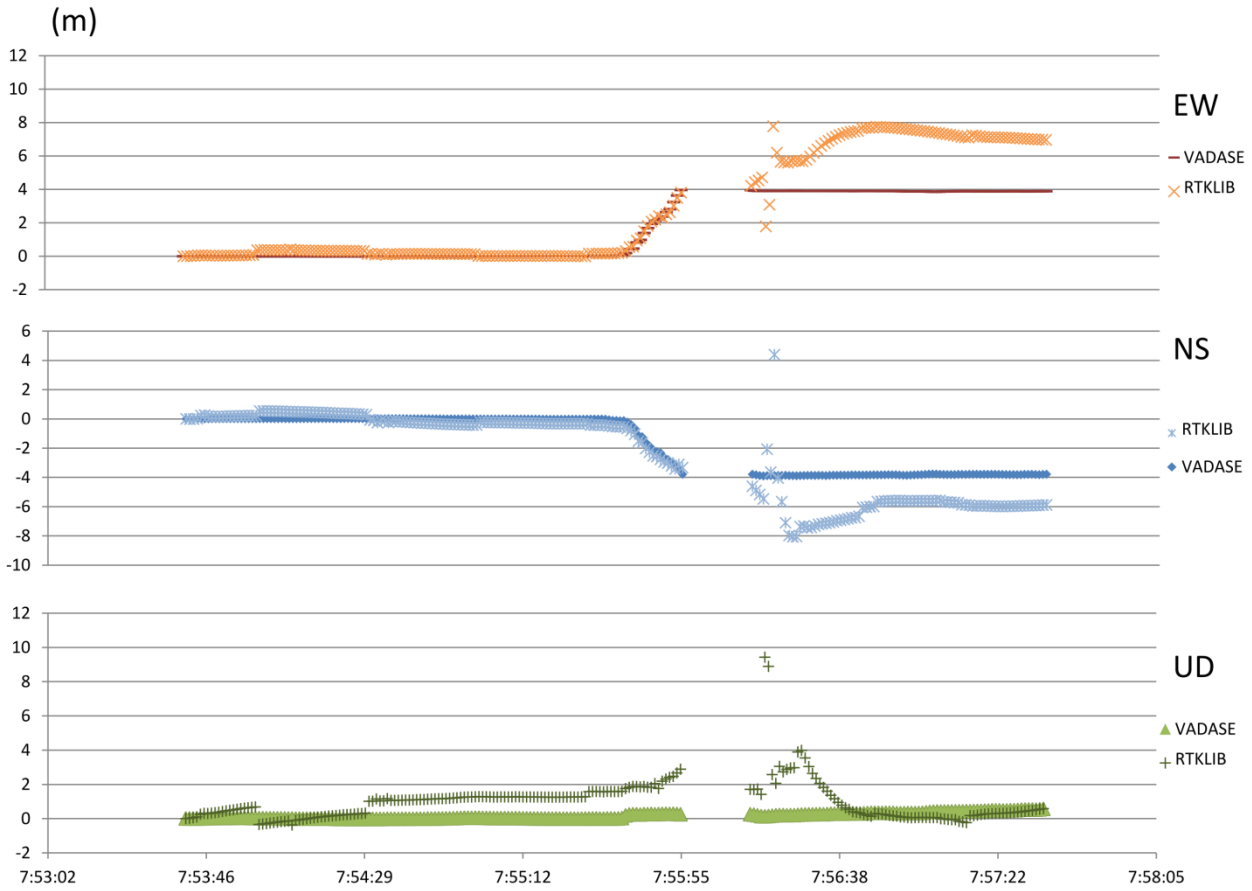


Fig. 2 Moving under the trees

VADASE – Velocity & Displacement Engine

Application Examples: GSI Evaluation

Japan: GSI – Test Results: Static

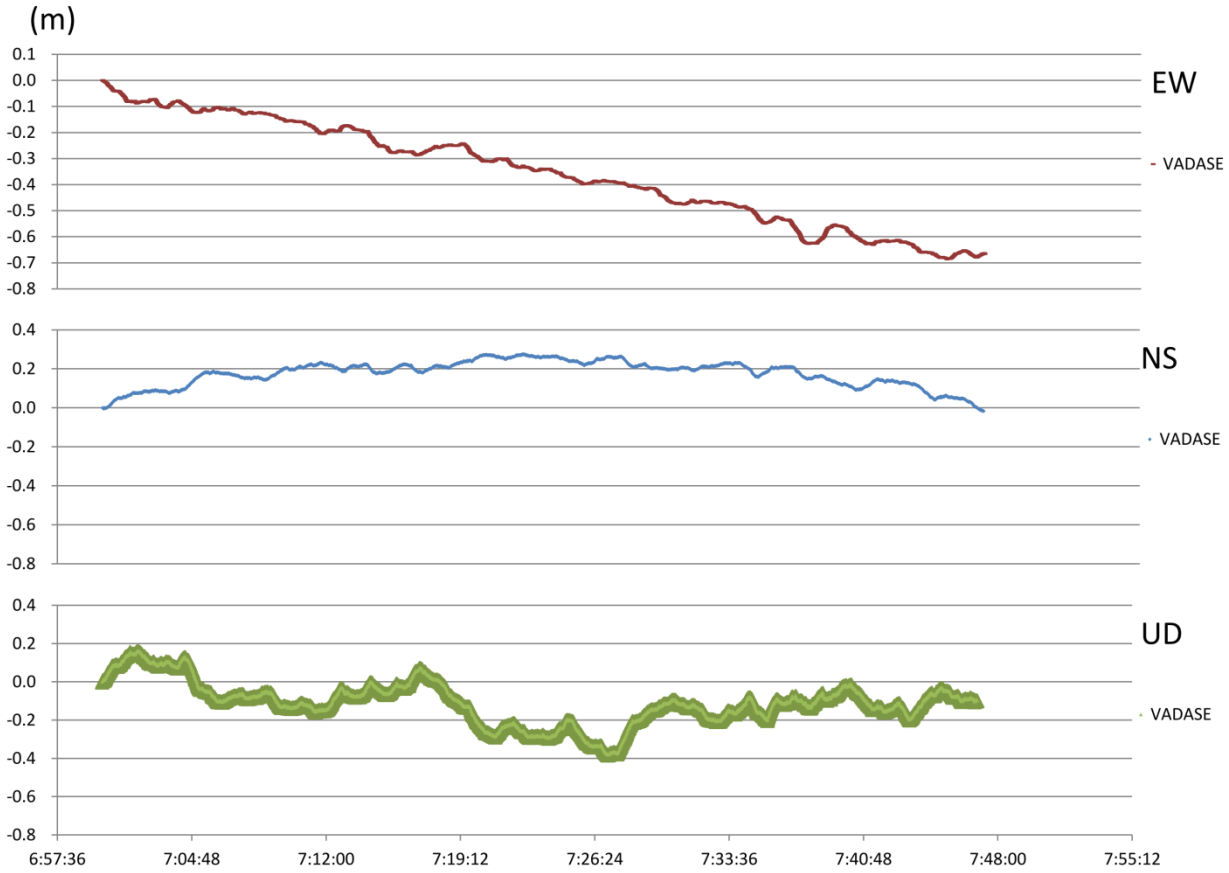


Fig. 3 Static

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)

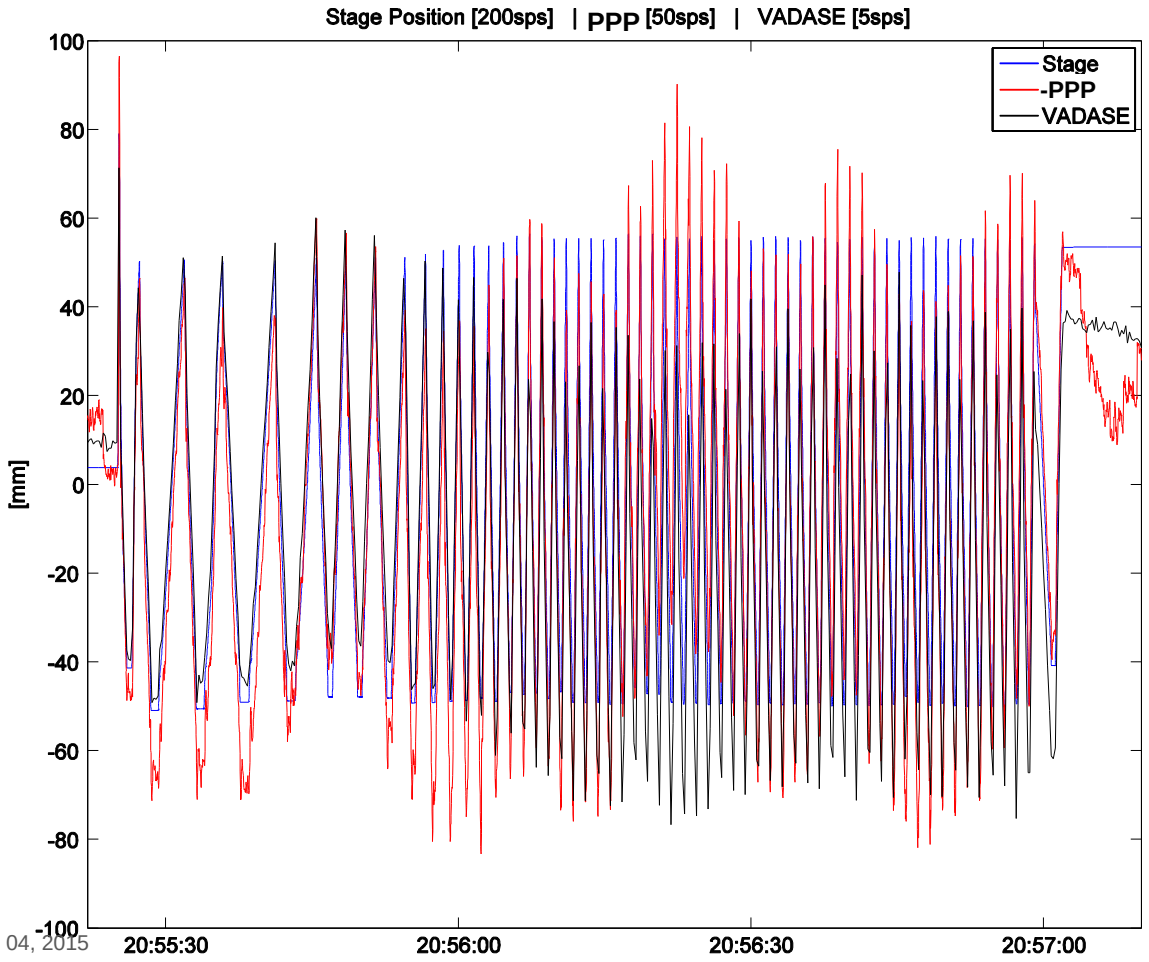
  [Note: VADASE evaluation version SW code is not performance optimised and therefore was limited to 5 Hz. At least up to 20Hz will be available in future.]

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

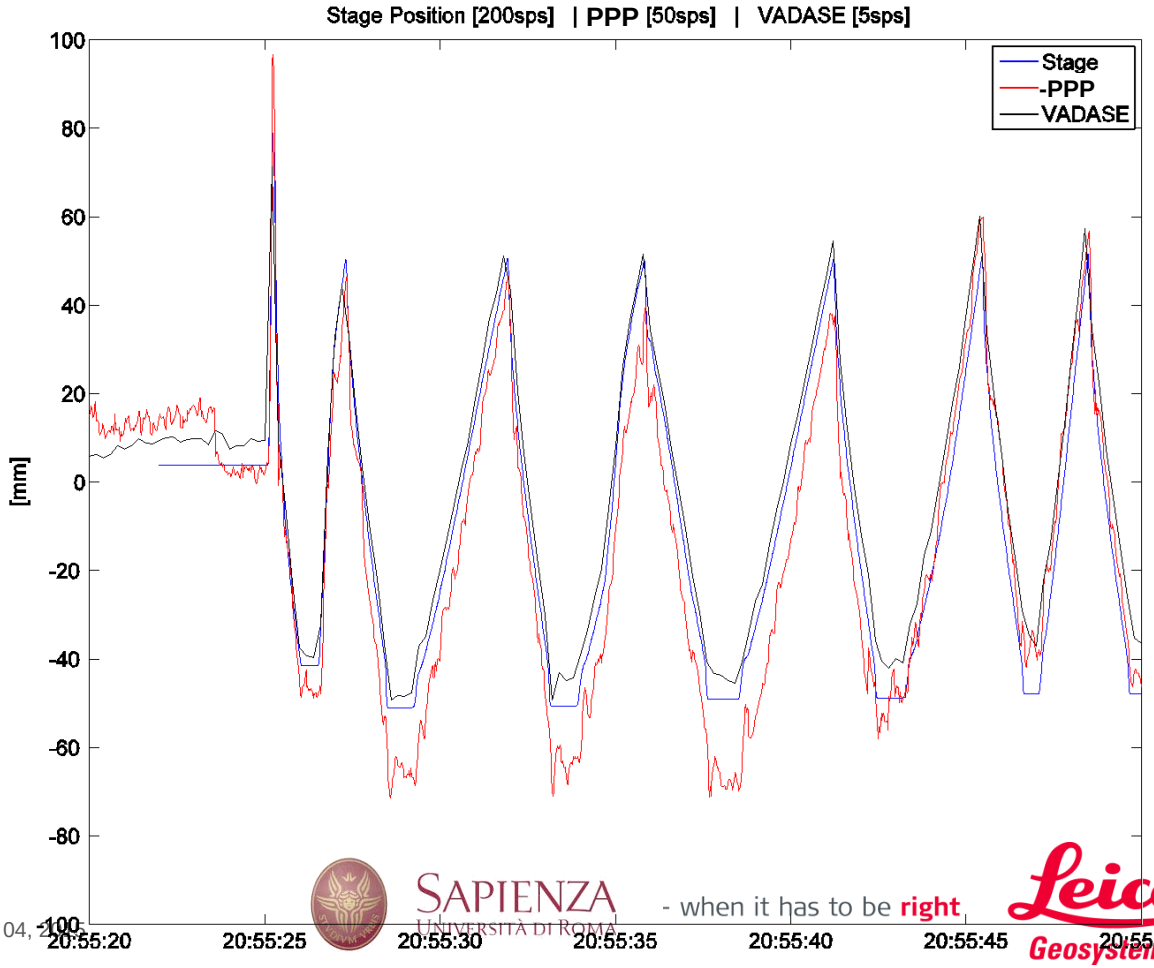


VADASE – Velocity & Displacement Engine

Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

- **Zoom –**
  Start of Experiment

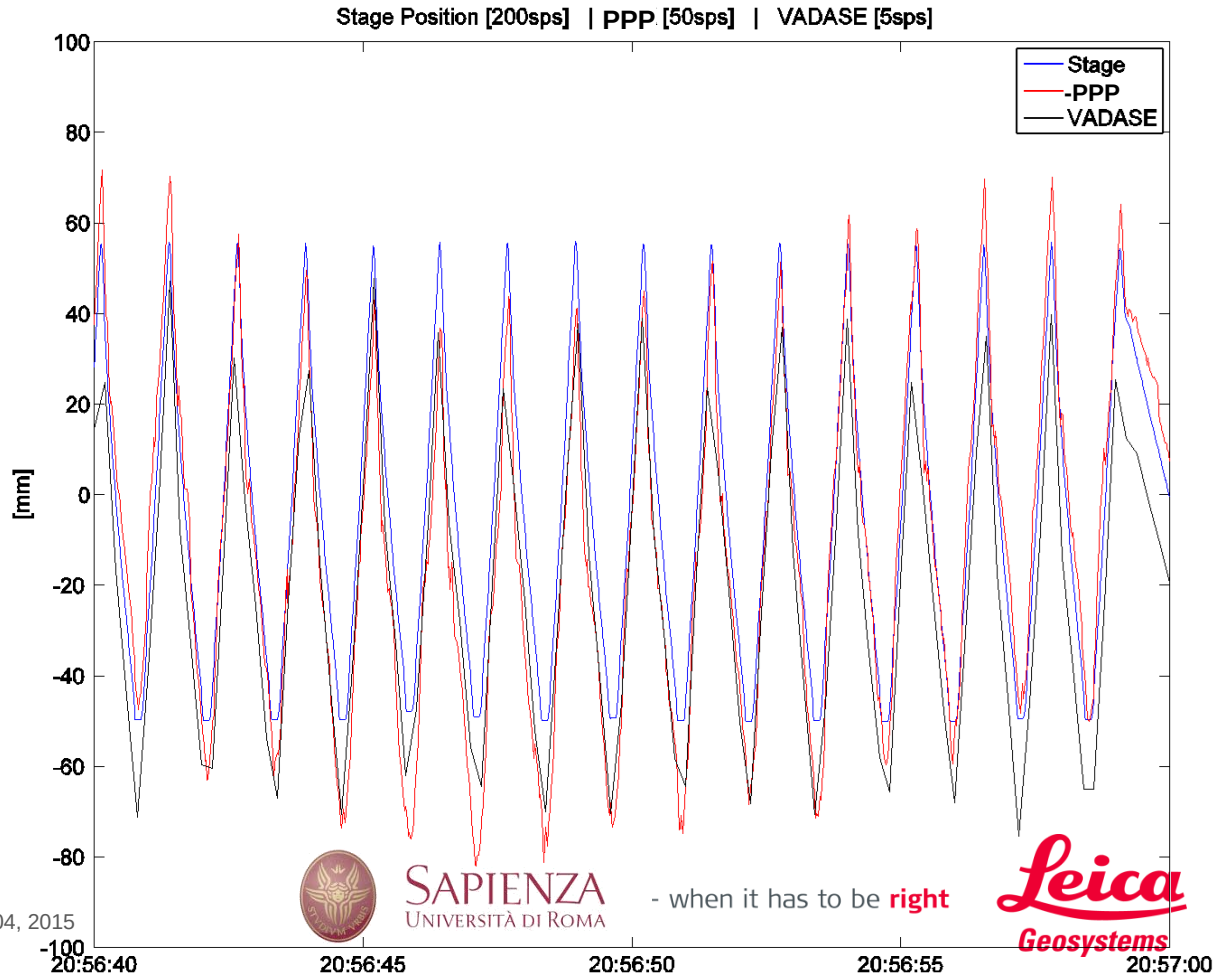


VADASE – Velocity & Displacement Engine

Application Examples: UNAVCO Evaluation

USA: UNAVCO Waveform Simulation (November 2014)

- Zoom –
  End of Experiment

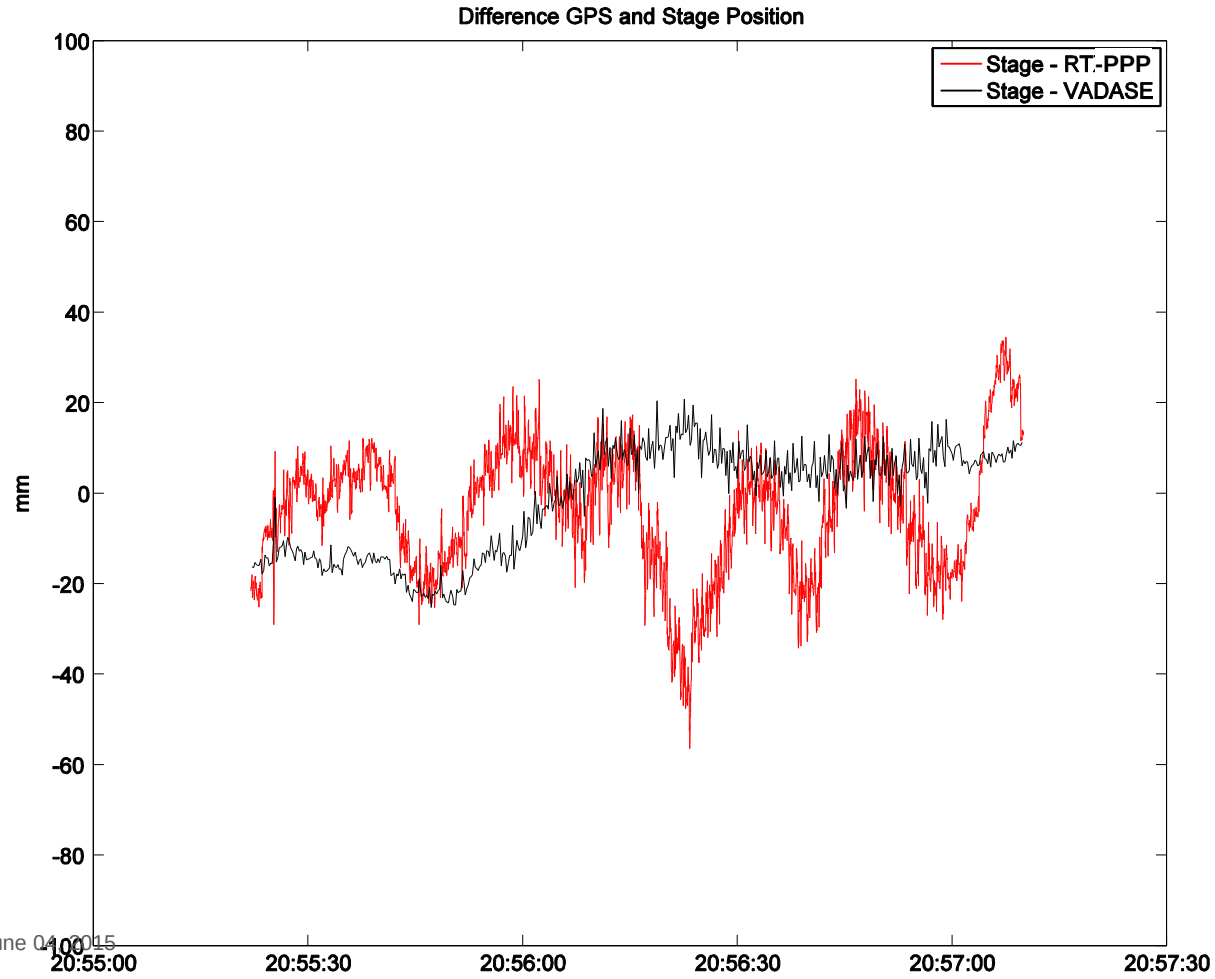


VADASE – Velocity & Displacement Engine

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 minute 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

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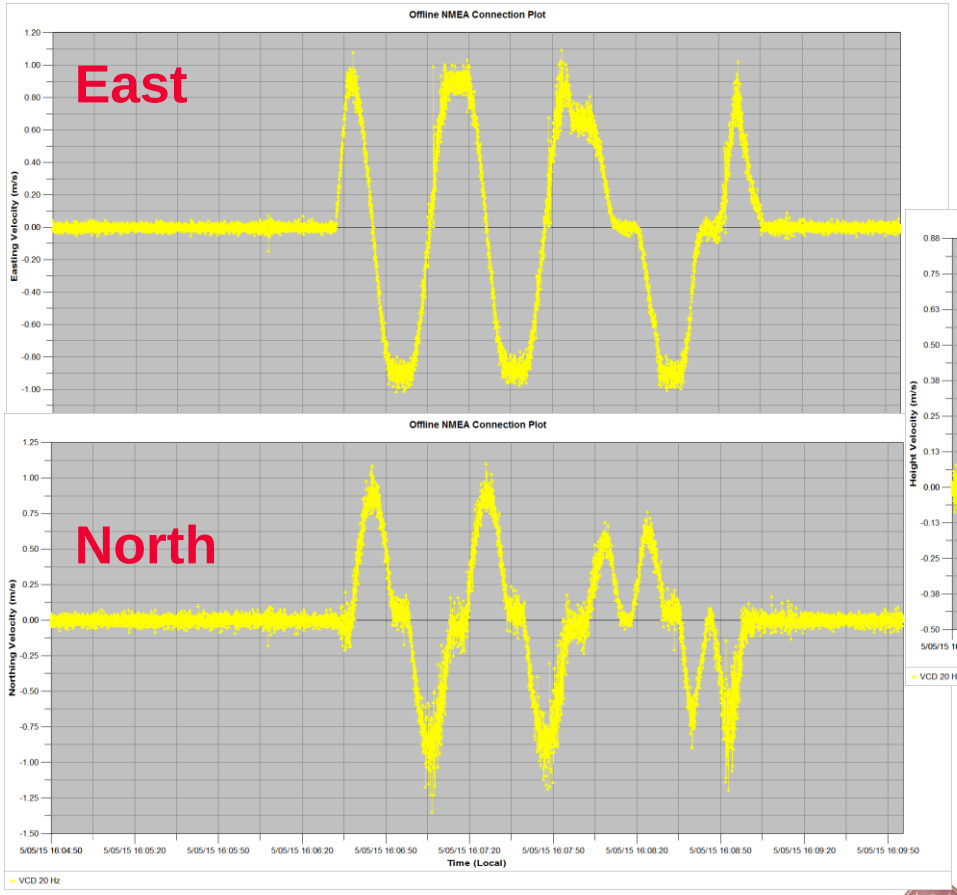
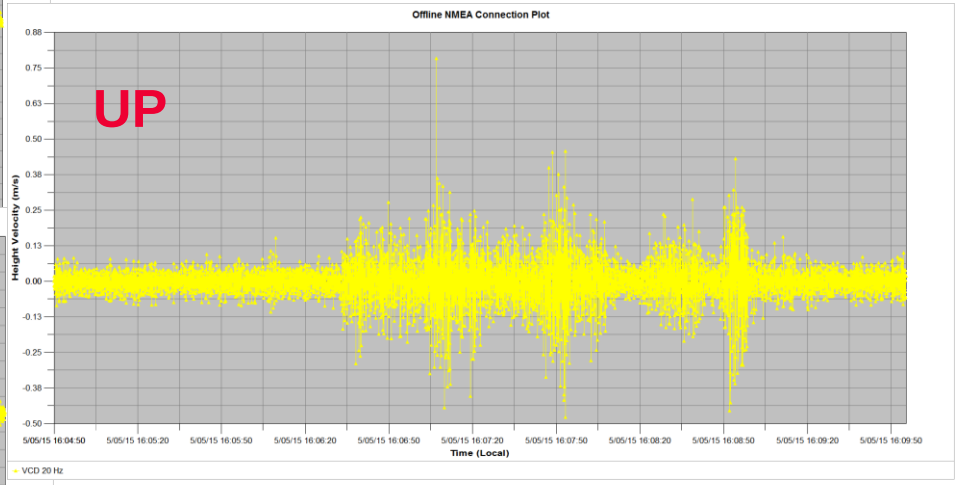
VADASE – Velocity & Displacement Engine

Application Examples: Leica „Train“-Test

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





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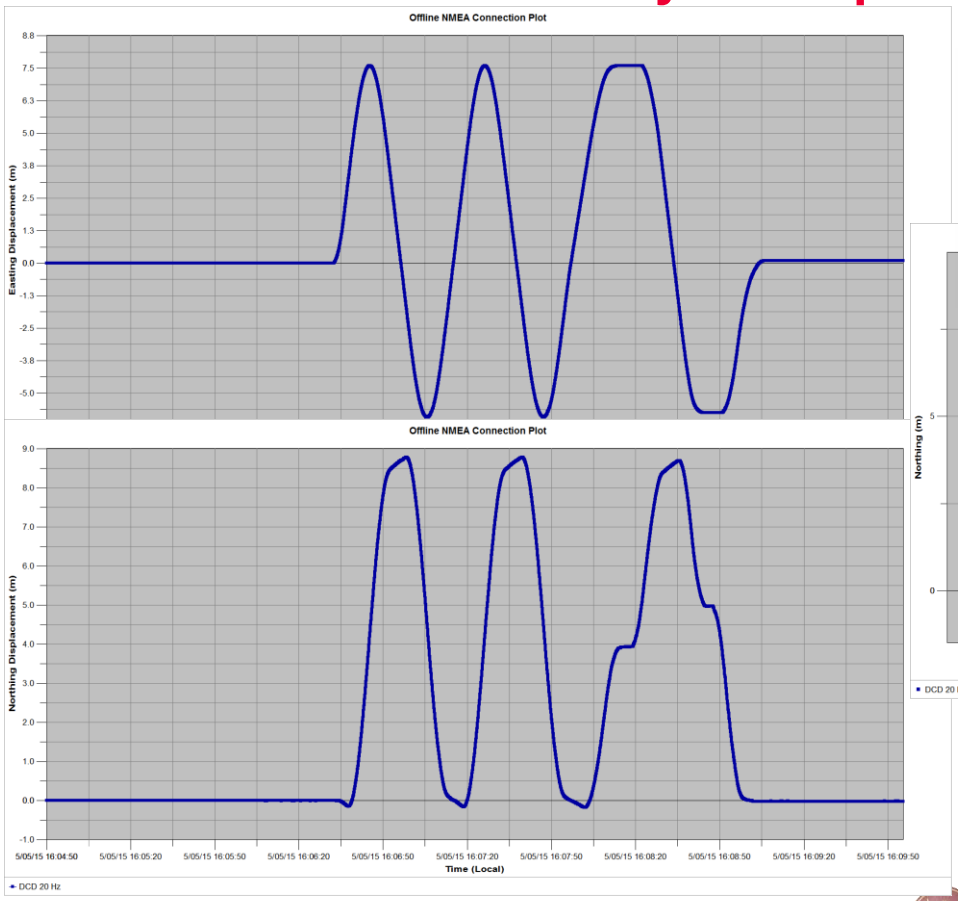
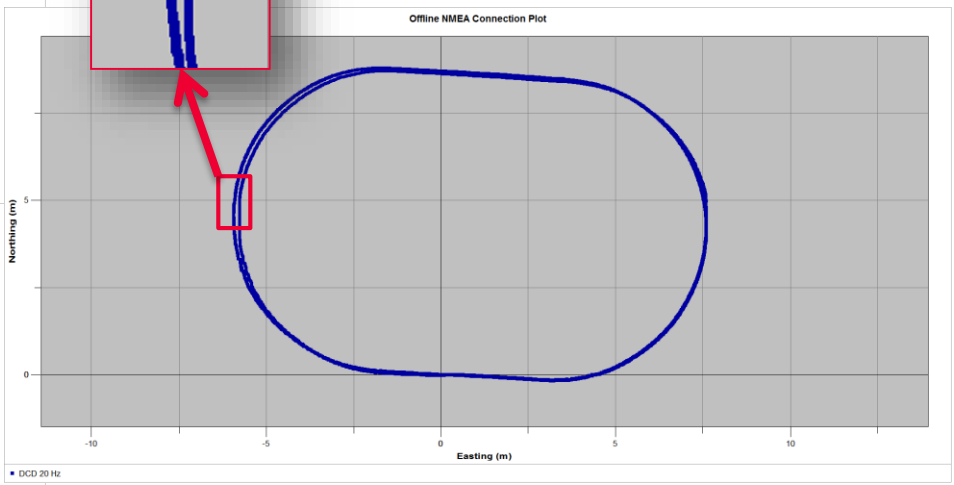
VADASE – Velocity & Displacement Engine

Application Examples: Leica „Train“-Test

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





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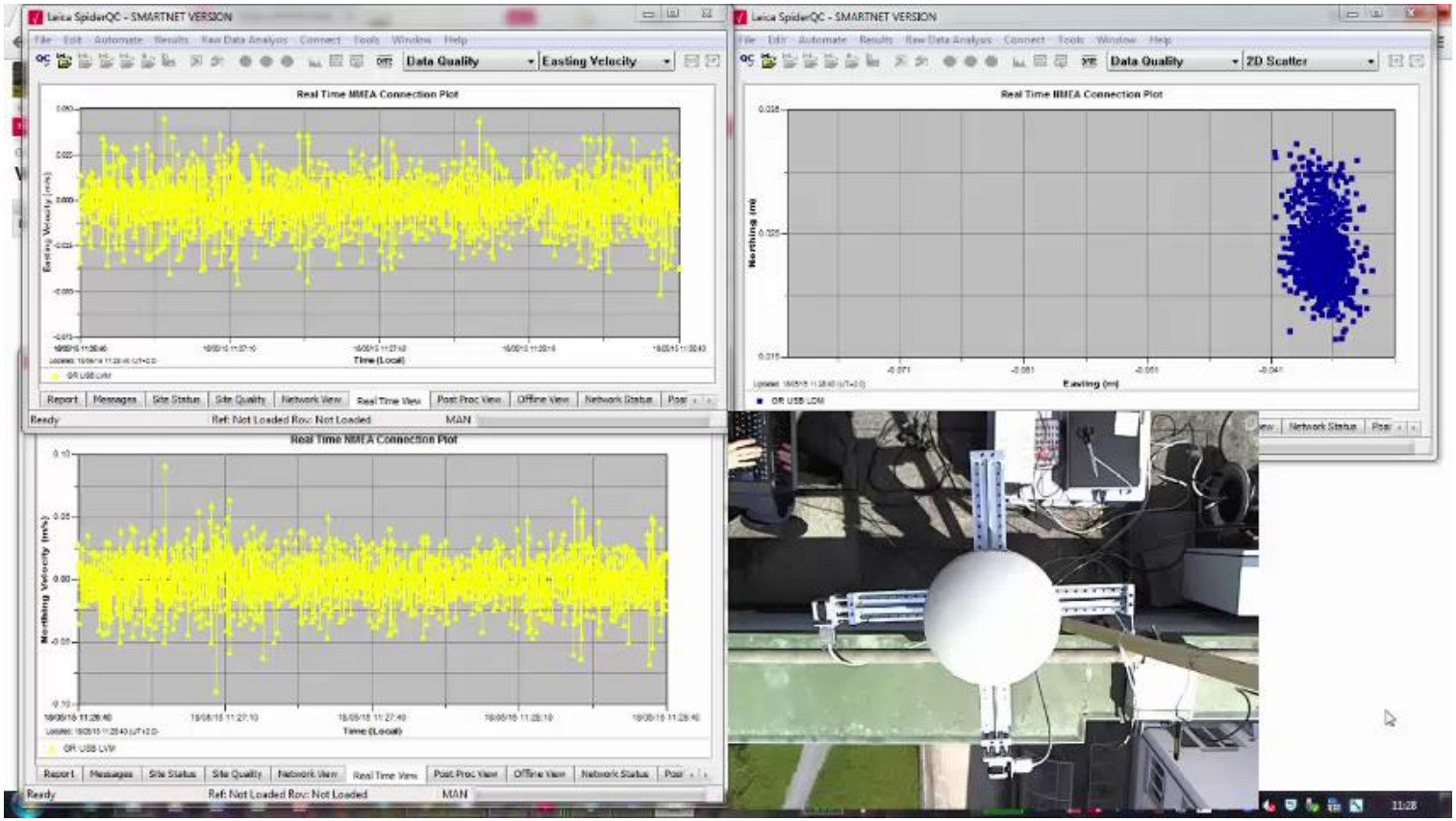
VADASE – Velocity & Displacement Engine

Application Examples: Leica „Test Platform“-Test

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



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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 **A**nd **D**isplacement **A**utonomous **S**olution **E**ngine

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

PART OF HEXAGON

- when it has to be **right**

Leica Geosystems