Recent advances of VADASE to enhance reliability and accuracy of real-time displacements estimation

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Introduction

VADASE (Variometric Approach for Displacements Analysis Stand-alone Engine) is a relatively new processing approach (2011), able to estimate in **rea*l*−time** velocities and displacements in a global reference frame (ITRF), using high−rate (1 Hz or more) carrier phase observations and broadcast products (orbits, clocks) collected by a **stand−alone** GNSS receiver, achieving an **accuracy within 1−2 centimetres** (usually better) over intervals up to few minutes. VADASE was originally developed within GNSS Seismology, but it was conveniently applied also to structural monitoring.[1]
It is well known from the very beginning that VADASE displacements might be impacted by two different effects: **spurious spikes** in the velocities due to **outliers** (in this case, displacements, obtained through velocities integration, are severely corrupted), and **trends** in the displacements (mainly due to broadcast orbit and clock errors).
Two strategies were introduced, respectively based on Leave−One−Out Cross Validation [2] (VADASE−LOO) for a **receiver autonomous outliers detection**, and on a network augmentation strategy to filter common trend out (A−VADASE)

VADASE−LOO

- n variometric equations, as standard but
- n different solutions with VADASE algorithm with $(n-1)$ equations, each solution leaving out a different common satellite
- staristical test on the observation equation residual of the excluded satellite (more powerful than standard test on least squares residuals)
- outlier(s) identification and rejection

DATASET: high−rate (1Hz) GPS observation from M0SE (Rome, Italy) 3 February 2016 − 9 April 2016 (67) days: **more than 6 millions solutions** (one each second) for each velocity component

A−VADASE

The hypotesis

- LOO−VADASE velocity and displacement solutions from all the stand-alone receivers are collected epoch−by−epoch at a common data center in real−time

The trends removal strategy

- trends are due to highly spatially correlated errors (satellite orbits and clocks), at least at local scale (about 100 kilometers)
- trends removal must preserve and not be impacted by peculiar solutions (e.g. earthquake waveforms) of single receivers

Trends can be filtered out removing the median of all the epoch−by−epoch displacement solutions

VADASE−LOO Stats

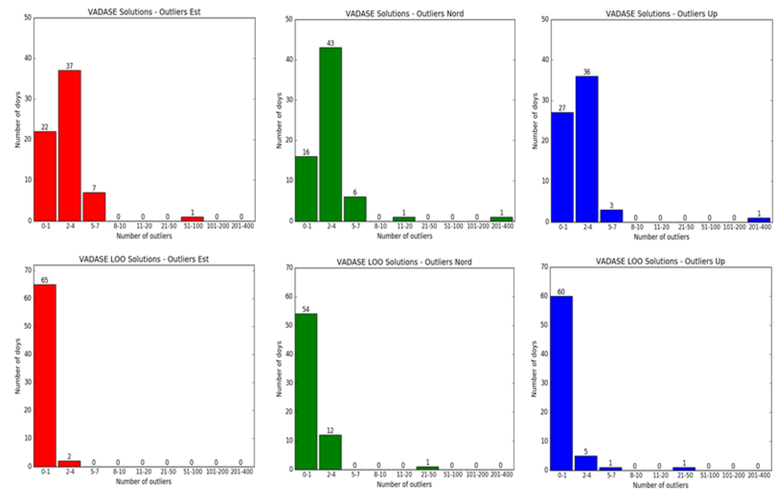

Figure 1: Outliers in more than 6 millions solutions Up Standard VADASE − Down VADASE LOO

Removed outliers by VADASE−LOO:
93% for East, **81%** for North and **82%** for Up

Aug. 24, 2016 Earthquake

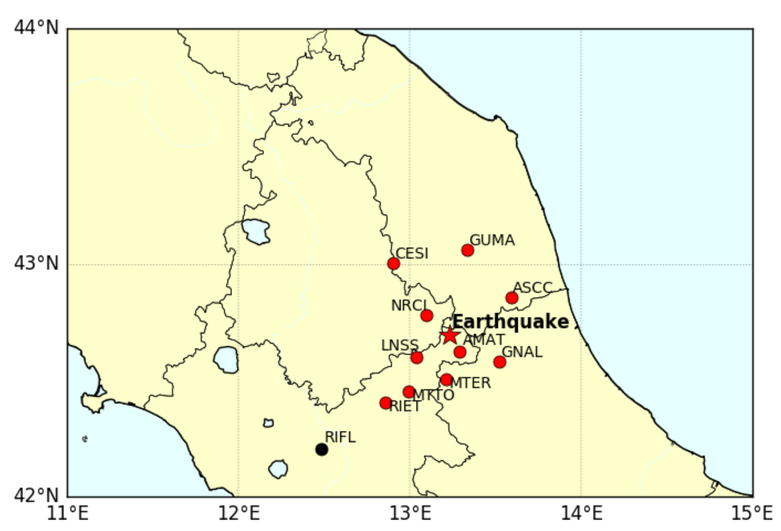

Figure 2: GNSS stations map

Application to Amatrice (Central Italy) $M = 6.0$ Aug. 24, 2016

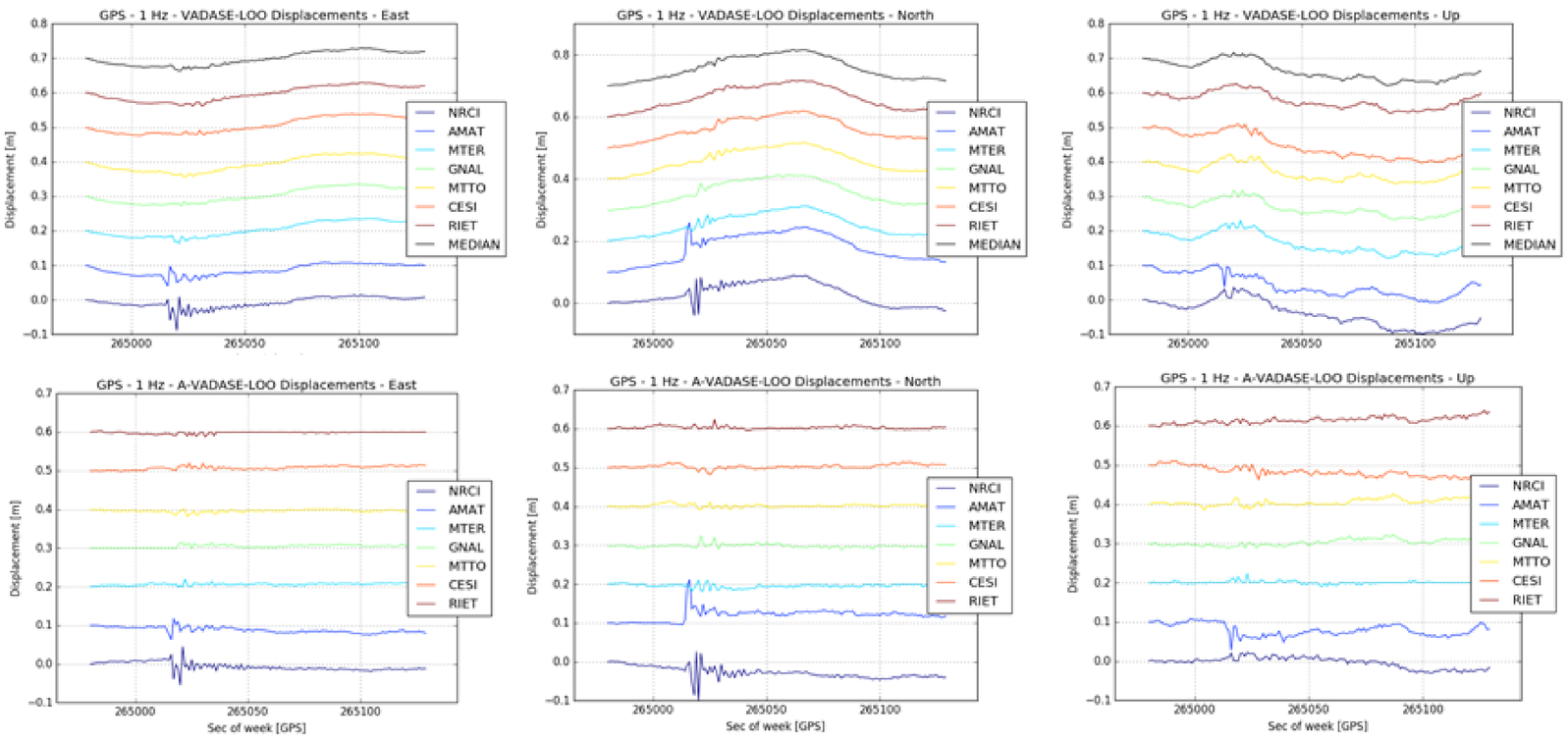

Figure 3: Estimated displacements fof GNSS stations: Up Vadase−LOO, Down A−VADASE solutions obtained removing the median

Conclusions

VADASE−LOO
receiver **autonomous rea*l*−time** strategy to **detect outliers** and to improve the variometric solution reliability
A−VADASE
network augmentation real−time strategy to **filter out common trends** and to guarantee waveform and coseismic displacement **accuracies within 1 cm in horizontal components and 2 cm in the height**

Prospects

VADASE−LOO requires n solutions each epoch: improvement of computational efficiency
A−VADASE requires median solution computation: improvement of the solutions set to be medianized and refinement of local detrending
Coseismic displacements estimation: assessment and improvement of the testing procedure for real-time

References

[1] Colosimo G., Crespi M., and Mazzoni A (2011) Real-time GPS seismology with a stand-alone receiver: A preliminary feasibility demonstration, *J. Geophys. Res.*

[2] M. A. Brovelli, M. Crespi, F. Fratarcangeli, F. Giannone, E. Realini (2008) Accuracy assessment of High Resolution Satellite Imagery orientation by leave-one-out method, *ISPRS Journal of Photogrammetry and Remote Sensing*