**Titolo della tesi:** VADASE real time GPS monitoring: reliability evaluation and improvement (Tesi sperimentale)

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VADASE (Variometric Approach for Displacement Analysis Stand-alone Engine) is a new approach to obtaining real-time the 3D displacements of a single GNSS receiver proposed by Geodesy and Geomatics division (AGG) of Sapienza University of Rome. This solution utilizes the broadcast orbits and the time differences of the high-rate (i.e. 1 Hz or more) carrier phases observations to ascertain the receiver movements over short intervals at centimeters accuracy level in real-time. Since September 2, 2015, it was embedded in a series of Leica Geosystems AG GNSS receivers, thanks to an agreement with Sapienza University.

Since the very first investigations, it was rather clear that the real-time variometric solutions can be impacted by two different effects, which can severely mask the actual phenomena: spurious oscillations in the velocity estimates due to outliers in GNSS observations, resulting in false displacements; overall, even time dependent, trends in the integrated displacements. The recent advances around VADASE just focused on these problems, trying to find reasonable solutions able to enhance reliability and accuracy of VADASE solutions, preserving as much as possible their main feature, that is to be available in real-time.

With regards to the first problem, a strategy to detect outliers in the observations during the real-time estimation was defined on the basis of the Leave-One-Out Cross Validation (LOOCV).

With regards to the second problem, at first it was clearly identified a strong spatial correlation of these trends among close GNSS stations (within 100 km), so that it was introduced an augmentation strategy (A-VADASE) to filter out these trends on the basis of a spatial median.

This work is intended to evaluate the effectiveness and reliability of VADASE-LOO and A-VADASE strategies. Trying to satisfy this goal, VADASE-LOO and A-VADASE were applied to real data.

After a theoretical overview on the variometric model and Leave-one-out strategy, VADASE and VADASE-LOO were applied to high-rate (1 Hz) observations of M0SE GPS permanent station obtaining a set of 67 daily solutions in terms of 3D velocities. The analysed solutions for each component were 5788733 (67days*86399). The number of outliers was evaluated comparing the value of 3D velocities with the default thresholds of LEICA GR25 receiver installed in M0SE GPS permanent station. The number of outliers of VADASE solutions were compared with the number of outliers of VADASE-LOO solutions. The effectiveness of VADASE-LOO to detect outliers was

proven: the number of outliers of VADASE solutions was 212 for East, 455 for North and 401 for Up, while the number of outliers of VADASE-LOO was 15 for East, 86 for North and 73 for Up. VADASE-LOO reduced noticeably the number of outliers: the percentage of removed outliers by VADASE-LOO was 93% for East, 81% for North and 82% for Up.

VADASE-LOO was a reliable strategy to remove outliers in estimated 3D velocities due to outliers in GNSS observations. It's very important to underline that the velocity noise level can vary significantly from one site to another. It is not recommended to have a unique default threshold for all sites. Consequently, velocity thresholds based on observations collected from a specific site should be taken over to replace the default thresholds if local conditions lead to a different noise level of the estimated velocities.

VADASE-LOO and A-VADASE were applied to real example concerning in Central Italy earthquake (Mw = 6.0) occurred on August 24, 2016. The earthquake was recorded by a number of GPS stations belonging to the Rete Integrata Nazionale GPS (RING), SmartNet ItalPoS and Rete

Regione Lazio. VADASE-LOO was applied to high-rate (1 Hz) observations of several GPS stations, which are located near the epicenter. Displacements, obtained by the integration of 3D velocities in 150s interval, presented trends due to the possible mismodeling of different intervening effects (such as multipath, residual clock errors, orbit errors, and atmospheric errors). A-VADASE was applied to the integrated displacements to filter out these trends on the basis of a spatial median. After the application of the augmentation strategy, the results obtained for GPS stations of AMAT, NRCI, MTER, MTTO, GNAL, CESI and RIET were compared with those stemming from the PPP approach implemented by APP and NRCan (only for RIET station). For each station, the two solutions (A-VADASE-LOO vs PPP) were aligned (i.e. their difference was set to zero) at a conventional initial epoch (starting epoch of AMAT) and compared within a time interval of 30s (i.e. this interval was chosen according to the earthquake duration). The retrieved positions were differenced at the corresponding epochs and the agreement between the solutions was evaluated by the RMSE of the differences.

The RMSE of the differences between A-VADASE-LOO (Median) and PPP ranged from 0.4 to 0.7 cm in East, from 0.7 cm to 2.6 cm in North and from 0.9 cm to 2.3 cm in Up in 30s interval.

Then, another augmentation strategy, based on the selection of one station (within 100 km from the epicenter) where the earthquake signature was not evident in the time series of 3D velocities and integrated displacements, was used. For Central Italy Earthquake Rignano Flamimio (RIFL) GPS station was selected. Also in this case, after the application of the augmentation strategy, the results obtained for GPS stations of AMAT, NRCI, MTER, MTTO, GNAL, CESI and RIET were compared with those stemming from the PPP approach implemented by APP and NRCan (only for RIET station). The RMSE of the differences between A-VADASE-LOO (Rignano) and PPP ranged from 0.3 to 0.6 cm in East, from 0.6 cm to 2.3 cm in North and from 0.9 cm to 1.9 cm in Up in 30s interval.

Overall, the agreement between A-VADASE LOO (Rignano) vs PPP and A-VADASE LOO (Median) vs PPP was generally within 0.1 cm for the East component, 0.3 cm for the North component and 0.4 cm for the Up component.

All this work demonstrated that VADASE-LOO is an effective reliable strategy to detect outliers in real-time in estimated 3D velocities due to outliers in GNSS observations. It's important to note that VADASE-LOO, in presence of movement, preserves the actual phenomenon.

Moreover, A-VADASE is a reliable accurate strategy to remove trends in the integrated displacements. The detrended displacements and waveforms displayed good agreement, at a level of a few centimeters, with the results carried out on the same data set using PPP strategy.

VADASE, with VADASE-LOO and A-VADASE strategies, has demonstrated effectiveness and reliability in retrieving real-time waveforms and coseismic displacements with an accuracy within a few centimeters. It can provide a significant contribution to tsunami warning systems and movements of man-made and natural structures monitoring.