

**INTERNATIONAL ASSOCIATION OF GEODESY
ITALIAN REPORT 2015-2019**

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WG 2.2.1: Integration and validation of local geoid estimates

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WG 4.3.7: Real-time Troposphere Monitoring

Rosa Pacione

JWG 4.3.8: GNSS tropospheric products for Climate

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Commission 1

Istituto Geografico Militare (IGM)

(Lucia Baroni, Marianna Carroccio, Federica Cauli, Renzo Maseroli)

Monitoring of the National Geodetic Reference Frame

A cumulative reprocessing of RDN2 was performed combining temporal series from January 2008 to December 2016. Updated positions, velocities and discontinuities of RDN2 permanent stations were defined, estimating:

- a Set of Coordinates valid for each interval between discontinuities
- velocities computed over the entire 9-years period

A new GNSS permanent station “IGM2” was installed as a twin station of “IGMI” (the two stations are 21 meters apart). IGM2 was installed in December 2017 and was included in EPN in November 2018, while IGMI has been part of EPN since January 2007.

A densification of GPS + levelling points (about 300 points) was carried out for the future improvement of the Italian geoid model.

Levelling network

The updated height differences and gravity values of the high precision levelling network were delivered to the UELN data center, in order to participate to the European adjustment for the estimation of normal heights within the new realization of EVRF2019.

Monitoring of seismic activity

Levelling and GPS field surveys were performed in the area of Central Italy after the 2016 earthquake sequence, in order to measure vertical and horizontal displacements. Points from both levelling network and GPS static network (IGM95) were re-surveyed, finding up to 50 cm horizontal shifts in the area of Norcia and up to 95 cm vertical shifts on the western flank of the Mount Vettore.

Italian Geomagnetic Field Map at 2015.0

The magnetic survey data over 123 stations belonging to the Italian Magnetic Network were updated and the Italian Geomagnetic Field Map at 2015.0 was published (in cooperation with INGV), including the following four maps: total field, horizontal and vertical components and declination.

Verto on Line software

“Verto on Line” software was published on the IGM internet website: it consists of a free service for coordinate transformation (only horizontal coordinates) among the reference frames currently in use in Italy (ROMA1940, ED1950, ETRF89, ETRF2000). The service is available at the following link: <https://www.igmi.org/it/verto-on-line>

Italian Space Agency/Space Geodesy Center “G. Colombo” (ASI/CGS)

(Giuseppe Bianco, Vincenza Luceri, Rosa Pacione)

The ASI Space Geodesy Center "G. Colombo" (CGS) has contributed to the IERS Technique Centers (ILRS, IVS, IGS/EUREF) since the beginning of the Service activities both in its role of fundamental station and analysis center.

The ILRS Governing Board recognized ASI/CGS' continuous and rigorous contribution and appointed it as one of the official ILRS Analysis Centers (ACs) when the ILRS AC structure was finalized (2004). In June 2004 the Center was selected by the International Laser Ranging Service (ILRS) as its primary Official Combination Center (CC) for station coordinates and Earth Orientation Parameters.

ASI/CGS is an official IVS Station, Data Center since the beginning of the service (1999) and Analysis Center since 2011.

ASI/CGS is operating as EUREF LAC since 1996, producing since then the requested solutions for the European reference frame densification and tropospheric applications. In 2009, ASI/CGS became also an EPN Regional Broadcaster for the dissemination of Real Time orbit and clock corrections as well as observation streams. Since 2012 ASI/CGS is participating to EUREF Technical Working Group and in 2014, at the EUREF Symposium, ASI/CGS was appointed as EPN Tropospheric coordinator.

ASI/CGS has been participating since 1999 to several GNSS Meteorological projects (COST 716, MAGIC, TOUGH, E-GVAP, COST Action ES1206) and is presently participating to E-GVAP, devoted to operational meteorology in Europe, as Analysis Center and Combination Center.

Information on the CGS and some of the analysis results are available at the CGS WWW server GeoDAF (Geodetic Data Archiving Facility, <http://geodaf.mt.asi.it>).

SLR Data Analysis

ILRS Activities

In the years 2015-2019, ASI/CGS has been deeply involved in the ILRS activities, mainly in support of the reference frame maintenance and under the coordination of the Analysis Working Group. Due to its double role of Analysis Center and Combination Center, ASI/CGS provides both its single AC solution and the combined product of the official ILRS ACs whenever requested. Main projects:

- Official ILRS Products: Weekly and Daily site position and Earth Orientation Parameters obtained using LAGEOS and ETALON data. The solutions provide the weekly coordinates of the worldwide SLR tracking network and the daily EOPs as ILRS contribution to the USNO Rapid Service
- ITRF maintenance: long term time series of site coordinates and EOPs computed according to the requirements of the IERS inter-technique Combination Centers. The ILRS contribution to the ITRF2014 has been delivered following the guidelines of the IERS Call for Participation and the ILRS contribution to the next ITRF (ITRF2020) has been planned
- ILRS Weekly orbits: ILRS official satellite ephemerides for LAGEOS and ETALON
- Bias monitoring: time series of estimated range biases for the worldwide network using LAGEOS and ETALON data in order to update the ILRS data handling file
- Station qualification: ASI/CGS is one of the ACs designated by the AWG to validate the data from new or upgraded sites or after an earthquake
- ILRS Analysis Standing Committee: co-chairing of the committee and participation to the activities and pilot projects

IERS contribution: production of EOP time series regularly performed as ASI/CGS operational EOP series:

ETRUSCO-2 Project: characterization and validation of the optical performance of satellite Laser Ranging Arrays under laboratory-simulated space conditions.

ASI/CGS internal projects:

The ASI/CGS SLR analysis activities extend beyond the accomplishment of its role within ILRS/IERS and were addressed in the following main application fields.

- Reference Frames: annual generation of multi-year solutions from Lageos I and II data, used as a benchmark for global network coordinates/velocities EOPs, satellite ephemerides and accelerations, site biases
- Gravity: long term time series of low degree Earth's geopotential coefficients and geocenter

VLBI Data Analysis

IVS Activities

In the years 2015-2019, ASI/CGS has been deeply involved in the IVS projects:

- Session Earth Orientation Parameter Series: Time series of X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dpsi, and deps
- Terrestrial Reference System (TRF): Set of station positions, velocities, and correlations
- Celestial Reference System (CRF) Set of right ascension and declination for sources
- Tropospheric Parameters: Regular submission of tropospheric parameters for all VLBI stations observing in the IVS R1 and R4 sessions the results are available on the IVS products ftp sites
- Daily Solution Files operational submission for each 24-hour session to provide earth orientation and site positions, the covariance matrix of the estimates and decomposed normal equations
- Contribution to IVS combination for ITRF2014

IERS Contribution Regular submission to the IERS EOP operational series of R1 and R4 session EOP estimates

ASI/CGS internal projects:

- Global VLBI Solutions: Every year, global VLBI solutions are produced, including all the observation sessions since 1979 onwards. The estimated parameters of the global solution are:
 - Celestial Frame: right ascension and declination as global parameters for 637 sources
 - Terrestrial Frame: Coordinates and velocities for 92 stations as global parameters
 - Earth Orientation: Unconstrained X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dpsi, and deps

GNSS Data Analysis

EUREF/IGS Activities

In the years 2015-2019, ASI/CGS has been deeply involved in the EUREF activities, mainly in support of the reference frame maintenance. Main projects:

- Official EUREF Products:
 - EPN Final weekly product: site coordinates and tropospheric parameters using IGS Final products, covering a European sub network of 65 sites, 2-week latency
 - EPN Rapid daily product: site coordinates using IGS Rapid products, now covering a European sub network of 65 sites, 1-day latency
 - EPN NRT hourly product: site coordinates using IGS Ultra- Rapid products, now covering a European subnetwork of 65 sites, 1-hour latency
- EPN Reprocessing: Reprocessing the EPN Network from 1996 onwards

IERS contribution: operational submission to the IERS EOP operational series of GPS daily EOP estimates.

ASI/CGS internal projects:

ASI/CGS GPS analysis activities extend beyond the accomplishment of its role within EUREF and E-GVAP and were addressed in the following main application fields.

- Reference Frames: annual generation of multi-year solutions of site coordinate and velocity of a GNSS network covering the central Mediterranean area.

Multi-technique Data Analysis

ASI/CGS internal projects:

- Gravity: long term time series of degree 2 Earth's geopotential coefficients variations obtained from SLR and VLBI EOP estimates, through excitation functions and time/frequency comparison with Angular Atmospheric and Oceanic Momenta components (from IERS dedicated sub-bureaus).
- EOP excitation functions. Regular production of the daily geodetic excitation functions from the ASI/CGS estimated EOP values for IERS (SLR, VLBI), since 2006.

- Geodetic solution combination realization, implementation and testing of combination algorithms for the optimal merging of global inter- and intra-technique solutions and of regional (e.g. Mediterranean) solutions to densify tectonic information in crucial areas.

Politecnico di Milano

(Ludovico Biagi, Vincenza Tornatore)

Crustal deformation in the Italian region and its relationship with the national reference frame

(Ludovico Biagi)

The Italian reference frame is materialized by a network of 100 GNSS stations that were adjusted in ETRF2000 at epoch 2008.0: the purpose of this study was to estimate and discuss the deformation field in Italy from that epoch until 2018, focusing on geodetic and cadastral applications. Istituto Nazionale di Geofisica e Vulcanologia has been continuously monitoring a network of permanent GNSS stations for several years: our study was based on a specific INGV solution that was estimated in 2013. In this solution, the ITRF2008 coordinates and velocities of 741 stations were published: 653 of them were in Italy and provided a quite dense set for our study. Firstly, the velocities were transformed from ITRF2008 to ETRF2000. Then, the ETRF2000 horizontal velocities were spatially analyzed. Actually, Italy seems clearly divided in different sub-regions that move in different directions but have quite homogeneous internal behaviours. A Bayesian clustering on the horizontal velocities was implemented to group the stations in five final sub-regions. The rotation of each sub-region with respect to the mean European motion was estimated: in each sub-region the spatial covariances of the residual velocities were analyzed, so to investigate the residual deformation. In a time span of 10 years, the deformation field induced by the slow geodynamics is significant but can be easily modeled by rigid motions of the five sub-regions; indeed the values and the spatial correlation of the residual velocities are negligible. Moreover, the estimated displacements induced by three earthquakes that occurred in August and October of 2016 in central Italy were analyzed. The effects are significant at the local scale and cannot be easily modeled: a new estimation of the national reference frame in that area is needed.

Database of IVS data input to ITRF2014

(Vincenza Tornatore)

Contribution to the realization and publication of Database of IVS data input to ITRF2014 as Responsible of the Associate International VLBI Service (IVS) and NASA's Goddard Space Flight Center (GSFC) Analysis Center PMD (Politecnico di Milano DICA)

VLBI Global Observation System (VGOS)

(Vincenza Tornatore)

Studies and simulations on running or in preparation VGOS stations have been developed. In particular the Radio Frequencies Interferences (RFI) threatening the new broadband systems (2GHz-14GHz), due to several new commercial services arising (see 5G and internet satellites as Spacelink, OneWeb) that operate in bands of VGOS has been carried out. This work has been developed also under the framework of the Committee on Radio Astronomy Frequencies (CRAF).

Comparison of space geodetic techniques contributing to ITRF2014

(Vincenza Tornatore)

Coordinate time series from three space geodesy techniques that have contributed to the realization of the ITRF2014 were compared. In particular the height component time series extracted from official combined intra-technique solutions submitted for ITRF2014 by DORIS, VLBI and GNSS have been investigated. The main goal of this study is to assess the level of agreement among these three space geodetic techniques. Our comparison shows that two of the estimated signals, having one-year and 14 days periods, are common to all the techniques. An open problem is the identification of the nature of the signal with 14 days period.

University of Bologna

(Sara Bruni, Susanna Zerbini)

Space ties for an improved ITRF

The DIFA group has developed a study concerning the potential contribution of space ties to the realization of global terrestrial reference frames. The study accounted for both simulated and real GNSS and SLR data. This work is a contribution to the activities of IAG SC1.2 (Global reference Frame).

University of Padua

(Mauro Bertocco, Alessandro Caporali, Joaquin Zurutuza)

Regional and Local Reference Frames realization

As Honorary Member of EUREF IAG Reference Frame Sub-Commission for Europe, integrated in the Sub-Commission 1.3, Regional Reference Frames, under Commission 1 – Reference Frames: Maintenance of the European Reference System and its realizations. Processing standards for GNSS data. Relation to IGS, EuroGeographics and National Mapping and Cartographic Authorities in Europe. As member of the Processing Group of the Rete Dinamica Nazionale (RDN) of IGMI (Istituto Geografico Militare Italiano): maintenance of the RDN at regular intervals.

As responsible of the GPS network of the Regione Veneto: maintenance of the 40 GNSS permanent network, alignment to RDN/ETRS89, weekly network adjustment with Bernese 5.2 and IGS/EPN processing standards, analysis of Time Series

Support to IAG SC1.3 - WG1 Integration of dense velocity fields into the ITRF by sending SINEX files of the Italian network to EUREF for combination and stacking with the EPN.

As Local Analysis Center of the European Permanent Network (EPN): weekly analysis of a European subnetwork of 58 stations, and of 650 stations for the EPN_D (Densification) Project.

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University of Padua

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Commission 2

Istituto Nazionale di Geofisica e Vulcanologia

(Filippo Greco, Antonio Pistorio)

Istituto Nazionale di Ricerca Metrologica

(Emanuele Biolcati, Alessandro Germak, Claudio Origlia)

Italian Space Agency/Space Geodesy Center “G. Colombo” (ASI/CGS)

(Francesco Baccaro, Domenico Iacovone)

Regional comparison of absolute gravimeters - EURAMET.M.G-K2 Key Comparison

The Regional Key Comparison of Absolute Gravimeters, EURAMET.M.G-K2 and Pilot Study, was held at the new campus of the University of Luxembourg in Belval during the first two weeks of November 2015. All the measurements have been collected during 11 days from the 3rd to the 13th November 2015.

Before the comparison, the Technical Protocol (TP) was approved by participants and CCM-WGG. The TP includes the list of the registered participants, a description of the comparison site, the timetable of the measurements and standardized table to express the uncertainty of the gravimeters. It also specifies the data processing as well as the reporting of the results.

The schedule of absolute measurements has followed the TP. Nevertheless, due to the fact that one registered absolute gravimeter was not able to participate, three absolute gravimeters (FG5-215, FG5X-220, FG5X-302) measured more sites (4-5) to obtain an optimal distribution of measurements at 9 stations used for the comparison.

VÚGTK/RIGTC (Research Institute of Geodesy, Topography and Cartography) was the Pilot Laboratory under the leadership of Dr. Vojtech Pálinkáš. Prof. Dr. Olivier Francis and Ir. Gilbert Klein of the University of Luxembourg were in charge of the local organization of the comparison. The EURAMET.M.G-K2 and Pilot Study is registered as EURAMET project 1368. The comparison was organized in accordance with the CIPM MRA-D-05 of the Consultative Committee on Mass and Related Quantities (CCM). It is linked to the results of the CCM.G-K2 comparison (Francis et al. 2015) by means of four absolute gravimeters that have participated to both comparisons.

Istituto Nazionale di Geofisica e Vulcanologia

Establishment of new gravimetric stations in Central Italy

(Giovanna Berrino, Filippo Greco, Federica Riguzzi)

INGV has recently funded a project to realize a network of GPS and gravimetric stations in Central Italy, in the area affected by the recent seismic activity of 2009 and 2016. The aim is to detect, through the occupation of sites already existing on the territory and measured in the past, possible variations in the gravity and deformations occurred over a long period.

Two gravimetric campaigns were carried out on a subset of fundamental sites with absolute gravimeters (FG5#238 and A10#39). These first order sites were also inter-connected with relative gravimetric surveys and to some auxiliary sites established to estimate their accurate positions with GPS.

One of the absolute sites is L'Aquila, which has been realized in the underground laboratory of the Science Faculty of L'Aquila University (Coppito), just below the GPS permanent station AQUI, which is located on the roof of the same building. The height difference between AQUI GPS and the gravimetric point has been measured by classical topographic survey in co-operation with the research unit of DICEA (Sapienza University), to achieve the height of the gravimetric site with centimetre accuracy.

The vertical gradient of gravity was also measured in the absolute vertices. The A10#39 gravimeter has been inter-compared with the Italian reference absolute gravimeter, the IMG-02 (realized by INRiM, Torino), whereas the FG5#238 gravimeter has already been several times inter-compared with it.

Gravimetric monitoring of highest risk Italian active volcanoes (Campi Flegrei, Ischia and Vesuvio)

(Giovanna Berrino)

The INGV Osservatorio Vesuviano regularly carries out relative and absolute gravity surveys devoted to the monitoring of the highest risk Italian active volcanoes: Campi Flegrei, Ischia and Vesuvio.

Precise relative gravity measurements are routinely carried out since 1981 at Neapolitan volcanoes (Vesuvius, Campi Flegrei and Ischia) on networks covering the whole volcanoes. All the networks are referred to the absolute station in Napoli, located outside the volcanic areas, periodically measured to control its time stability, also belonging to the National Zero Order Gravity Network. Each network includes one or more absolute gravity stations, most of them established in middle '80 and periodically measured to check the long-term gravity changes and confirm those obtained by relative measurements. Since 2015 several absolute field surveys are also routinely carried out at Campi Flegrei at all the benchmark of the relative network. The micro-g A10#39 absolute gravimeter, specific for field surveys and acquired by INGV Napoli at the end of 2014, is used to collect data.

Gravimetric monitoring of highest risk Italian active volcanoes (Etna)

(Filippo Greco, Daniele Carbone)

The INGV Osservatorio Etneo has been operating a relative gravity network for the monitoring of Etna volcano (Italy) since '80. The network has been developed and has evolved over the years and currently it consists of:

- (a) 71 benchmarks covering the whole volcano area, for relative gravity campaigns; LaCoste& Romberg model D and Scintrex CG-3M, CG-5 and CG-6 gravimeters were used over time
- (b) 3 continuously running gravity stations equipped with iGravs superconductive gravimeters by GWR; the installation of iGrav SGs at Mt. Etna began in 2014, in the framework of an infrastructural project (VULCAMED) funded by the EC and by Italian national sources; this is the first network of SGs ever installed on an active volcano
- (c) 14 stations for absolute gravity (AG) measurements; repeated AG measurements have been performed at Mt. Etna using the IMG-C-02 gravimeter in the period 2007-2009 and the MicrogLaCoste FG5#238 gravimeters from 2009 till now

Gravimetric estimation of the Moho depth in Antarctica

(Alessandra Borghi, Rosaria Tondi)

In the framework of the Italian PNRA Project (2014-2016 PNRA 2013/B2.06, National Programme of Research in Antarctica - Lithospheric response of the mantle dynamic and of time-varying cryosphere – project coordinator A. Morelli, INGV-BO) the terrestrial and satellite gravity data in the Antarctica region have been studied and a pure gravimetric estimation of the Moho depth has been computed.

Istituto Nazionale di Geofisica e Vulcanologia

(Alessandra Borghi)

University of Bologna

(Luca Vittuari)

Gravimetric estimation of the deflection of the vertical at VLBI sites in Italy

(Alessandra Borghi, Luca Vittuari)

Gravimetric estimation of the Deflection of the Vertical in two Italian area surrounding the VLBI antennas and comparison with the method based on the joint use of high precision spirit leveling and GNSS observations and the astro-geodetic measurements.

Politecnico di Milano

(Alberta Albertella, Riccardo Barzaghi, Barbara Betti, Daniela Carrion, Carlo De Gaetani, Maddalena Gilardoni, Ahmed Mansi, Federica Migliaccio, Mirko Reguzzoni, Lorenzo Rossi, Fernando Sansò, Giovanna Sona, Giovanna Venuti)

Global gravity field estimation using satellite data

Global gravity field estimation with GOCE data applying the space-wise approach, producing the 5th and 6th release of global grids of gravity gradients at mean satellite altitude and the corresponding spherical harmonic coefficient solutions. The estimated GOCE-only models have been used for geophysical applications (e.g. global and local Moho estimation) and oceanographic applications (e.g. global and local MDT estimation).

Study of new concepts for future gradiometric missions based on cold atom interferometry technology.

Regional gravity field estimation

At regional scale, geoid estimation has been carried out in the framework of the GEOMED2 project, aiming at the determination of a high-accuracy and high-resolution geoid model for the Mediterranean Sea. This estimate has been obtained using land and marine gravity data and GOCE/GRACE based Global Geopotential Models. The adopted methodology has been the well-known remove-compute-restore procedure in combination with stochastic and spectral methods for the determination of the residual geoid component. The obtained geoid model will form the basis for height-system unification in the Mediterranean area and will allow deriving high-resolution models of the Mean Dynamic Topography (MDT) to be used in estimating the circulation in the Mediterranean Sea.

Height datum problem

Combining satellite-only global gravity models and GNSS/leveling data, an approach has been devised for the solution of the height datum problem. Studies on the indirect effect of biases into gravity anomalies have been performed as well. The approach has been applied to real datasets, such as the Italian and the Spanish ones.

In the framework of JWG 2.2.1, a procedure to merge local and regional geoids has been studied and tested on some European models.

Inverse gravimetric problems

Study and implementation of a gravimetric inversion algorithm based on the Bayesian approach in order to introduce a priori geological information. The estimated model is subdivided into voxels, each characterized by two random variables, i.e. a label identifying the material and the mass density. The use of discrete labels allows us to preserve the material discontinuities in the mass distribution. The algorithm has been applied to the estimation of a crustal model below a neutrino detector in southern China.

Gravimetric correction for the Italian leveling network

A new approach for the gravity corrections to leveling data in the framework of Molodensky's theory has been developed and applied to the official Italian leveling network. Gravity data needed for the corrections have been predicted from the Italian gravity dataset used for the local geoid estimate. The corrected leveling observations have been used for the European height datum definition.

Funded projects

GOCE-HPF (High-level Processing Facilities): funded by the European Space Agency (ESA), it involves European university and research centers with the final aim of producing Level 2 GOCE data and estimating a global model of the Earth gravitational field. Politecnico di Milano is responsible for the model by the space-wise approach and it is now computing global grids of gravity gradients at mean satellite altitude that should have a higher local content than the one of the spherical harmonic coefficients.

MOCASS (Mass Observation with Cold Atom Sensors from Space): funded by the Italian Space Agency

(ASI), it involves Politecnico di Milano, University of Trieste and the AtomSensors company. The project goal is to study an innovative satellite gravity mission based on advanced cold-atom interferometry in response to an ASI call for new concepts of mission and payload for Earth Observation. Simulations confirm that MOCASS can have better performances than GOCE in estimating the static gravity field.

CAI (Cold Atom Interferometry): funded by Thales Alenia Space Italia in response to an ESA tender. It involves Politecnico di Milano, Delft University of Technology and the MARWAN company. The project goal is to investigate the performances of a new gradiometric mission based on cold atom interferometry.

MEGG-C (Mediterranean GOCE Geoid and geostrophic Circulation): funded by ESA in the framework of the STSE programme. The goal of the project is the estimation of a gravimetric geoid, the MDT and corresponding geostrophic currents in the Mediterranean Sea using GOCE models.

eCRUST with activities called “Very Improved KINematic Gravimetry (Viking)”, “Innovative Tools for Gravity data processing” and “Bayesian Inversion - Proof of Concept”. These activities were performed in the framework of the contract between ENI SpA and Politecnico di Milano.

‘Modeling the Earth’s Crust: from outer space to deep under’: funded by Netherlands Organization for Scientific Research (NOW), led by the University of Twente and involving also Politecnico di Milano among other research centers. Currently, the project is devoted to the computation of an updated version of the GEMMA global crustal model.

University of Bologna

(Sara Bruni, Susanna Zerbinì)

Continuous gravity measurements with superconducting gravimeter

The DIFA group, in collaboration with the BKG (Frankfurt), manages a superconducting gravimeter (SG023) at Medicina since 1996. This dataset is compared and combined with the co-located GPS height time series to assess the consistency between the two independent techniques and to model the local geophysical and geotechnical processes. Recently, instrumentation such as rain gauges and soil moisture probes was installed in addition to the available water table sensors, to better develop the data interpretation. Absolute gravity measurements are also regularly performed at Bologna, Medicina and Loiano. This work contributes to the activities of IAG JSG 3.1 (Intercomparison of Gravity and Height Changes)

University of Trieste

(Carla Braitenberg)

Earth tectonic gravity changes observed with present and future satellites

Mountain building is an ongoing process on Earth, measured by tectonic uplift through GNSS at orogens. We investigate what the mass changes are that accompany mountain building, and predict the associated gravity changes. We find that the signal cannot be neglected, because it interferes with the glacial and hydrologic signal. We have simulated the expected tectonic, glacial and hydrologic signal for Alps and High Mountains of Asia area and analyzed the amplitudes in function of spectral content, in order to compare this signals with the spectral error curves of GRACE, GOCE and future satellites with an atom interferometry gravity detector. The spectral characteristics of the atom sensor allows an increased sensitivity in detecting small glaciers and hydrologic basins. It is also superior in detecting the tectonic gravity signal due to mountain building or seamounts eruptions.

Organizational activity

2017- present Alps-Array-Gravity Research Group

2015-2019 Carla Braitenberg (Chair): International Association of Geodesy, Commission 2 Gravity Field, WG 2.6.1: Potential field modeling with petrophysical support

2013-2016 Carla Braitenberg responsible with and I. Panet (IPG, Paris) of Solid Earth section for the Future Gravity Mission Science Requirement Consolidation Working group: directed by Prof. R. Pail, TU Munich.

Publications

Istituto Nazionale di Geofisica e Vulcanologia

Istituto Nazionale di Ricerca Metrologica

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Commission 3

Istituto Nazionale di Geofisica e Vulcanologia

GPS data processing

(Antonio Avallone, Nicola D'Agostino, Roberto Devoti, Grazia Pietrantonio, Federica Riguzzi, Enrico Serpelloni)

INGV is hosting a nation-wide GPS network (RING) dedicated specifically to the monitoring of current crustal deformation in Italy. The data are on public domain and available on-line at ring.gm.ingv.it. All permanent GPS stations in Italy and Europe are routinely processed, using three different software: Gamit, Bernese and Gipsy. Time series and combined secular drifts of the stations are also available on-line.

Geodetic observations at fault scale or local scale

(Antonio Avallone, Nicola D'Agostino, Roberto Devoti, Grazia Pietrantonio, Federica Riguzzi, Enrico Serpelloni)

The analysis of the co-, post- and inter-seismic deformation is useful to study the seismic cycle of seismically active faults. INGV is managing numerous campaign networks and small permanent networks dedicated to study local tectonic and/or volcanic processes (e.g. OMBRA, SAGEONET, CAGEONET projects). The episodic campaigns and continuous monitoring through permanent GPS stations allowed the detection and estimation of coseismic deformations due to the recent seismic sequence occurred in central Italy in 2016-2017. The source models of the mainshocks were estimated both through the inversion of coseismic offsets detected by GPS and also after the joint inversion of InSAR and GPS observations.

Early seismic source location using GPS data

(Roberto Devoti, Grazia Pietrantonio)

Seismic source location using only GPS data has been experimented during a shallow earthquake in the island of Ischia (Italy) on the 21st of August 2017. The simulation suggested that real-time GNSS data can support the seismic location system in the early stage of the emergency phase and demonstrate that a early location of the local hypocenter is possible in less than half an hour (Devoti et al, 2018). This fact inspired the proposal of a prototype system, connected to the national RING infrastructure, capable to provide real time displacements and source parameters, in occasion of seismic events.

EPOS

(Antonio Avallone, Nicola D'Agostino, Enrico Serpelloni)

INGV is one of the two data processing center and data provider for the EPOS platform (European Plate Observing System, www.epos-ip.org). Regular updated GNSS time series for the official GNSS network of permanent stations in Europe are processed at the INGV analysis center using PPP processing scheme (Gipsy-Oasis) and delivered regularly to the database of the GNSS Thematic Core Service (TCS).

GPS time-series

(Alessandra Borghi)

Three main researches were developed:

- study of the temporal correlation in the GPS time-series and implementation of an analysis methodology based on the Second Order Stationary Random Processes to assess the stochastic properties of the GPS coordinate time series.
- analysis of the GPS time-series of the continuous GPS stations in the Central Italy area, struck by Mw 6.3 L'Aquila earthquake (2009 April 6), in search of any transient deformation during the long and important foreshock sequence.

- analysis of the GPS time observations and time-series of the continuous GPS stations in the Garhwal-Kumaun, Himalayan region, collected from 2007 and to 2011, for seismic hazard investigations.

Sapienza University of Rome

GNSS Seismology: real-time variometric approach (VADASE)

(Elisa Benedetti, Mara Branzanti, Gabriele Colosimo, Mattia Crespi, Francesca Fratarcangeli, Augusto Mazzoni)

In recent years, extensive work has been done to effectively exploit Global Navigation Satellite Systems (GNSS) for estimating important earthquake parameters such as the seismic moment and magnitude (i.e. GNSS Seismology). The rapid and accurate assessment of these parameters is of crucial importance to achieve reliable tsunami generation scenarios and eventually dispatch an early warning. In this framework, since 2010, Geodesy and Geomatics division (AGG) of Sapienza University of Rome developed a new approach to obtain in real-time the 3D displacements of a single GNSS receiver. This solution, called VADASE (Variometric Approach for Displacement Analysis Standalone Engine), is able to estimate in real time the 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 (even single frequency only) GNSS receiver, achieving a stable velocity accuracy of few mm/s, and a displacements accuracy within 1-2 cm (usually better) over intervals up to a few minutes. VADASE has been tested as tool to evaluate in real time the noise level of wide GNSS permanent arrays (including the atomic clock performances), necessary to set up proper thresholds to highlight significant velocity anomalies (caused, for example, by an earthquake) and to raise due alarms. The last refinements of VADASE include real-time strategies to remove possible outliers, to filter trends common to different GNSS permanent stations, and to estimate the coseismic displacements occurring at each GNSS permanent station.

Integration of geodetic and seismological information for understanding and prediction of earthquakes

(Mattia Crespi, Augusto Mazzoni, Andrea Nascetti)

Earthquakes cannot be predicted with ultimate precision, so that the progressive reduction of the prediction uncertainty in space and time is an evergreen and challenging task. To this aim, algorithms (like CN, M8 and M8S) based on objective recognition of seismicity patterns exist for some decades for intermediate-term middle-range prediction of earthquakes above a pre-assigned magnitude threshold.

A new integrated approach to earthquake prediction is proposed, based on the synergy of geodetic and seismological information, defining a new paradigm for time dependent hazard assessment scenarios. Through a retrospective analysis of the 2016-2017 seismic crisis in Central Italy and the 2012 Emilia sequence it is demonstrated that the proper integration of seismological and geodetic information can achieve what here is called intermediate-term narrow-range earthquake prediction. The extent of the alarmed areas identified for the strong earthquakes, above a given magnitude threshold, by earthquake prediction algorithms based on seismicity patterns can be significantly reduced from linear dimensions of a few hundred to a few tens of kilometers, leading to an improved more specific implementation of low-key preventive actions, like those recommended by UNESCO as early as in 1991.

Sessions organization at international congresses/symposia/workshops

Organization of the session *Theory of multi-GNSS parameter estimation* (A. Khodabandeh, M. Crespi) at the IX Hotine-Marussi Symposium (Rome, Italy) in 2018

Co-organization of the sessions *High-precision GNSS: methods, open problems and Geoscience applications* at the European Geoscience Union General Assembly (Vienna, Austria) in 2017, 2018 and 2019

Editorial activity

Special Feature of Measurement Science and Technology on *High-Precision Multi-Constellation GNSS: Methods, Selected Applications and Challenges* (Editors: Jacek Paziewski, Mattia Crespi) (<https://iopscience.iop.org/journal/0957-0233/page/High-Precision-Multi-Constellation-GNSS>)

Special Issue of Remote Sensing on *High-precision GNSS: Methods, Open Problems and Geoscience Applications* (Editors: Xingxing Li, Jacek Paziewski, Mattia Crespi) (https://www.mdpi.com/journal/remotesensing/special_issues/GNSS_rs)

Technology transfer

VADASE algorithm implemented by Leica in the firmware of GR series GNSS receiver since 2 September 2015 (<http://blog.leica-geosystems.com/leica-vadase-is-worlds-first-autonomous-gnss-monitoring-solution-onboard-a-stand-alone-receiver>)

University of Bologna

(Sara Bruni, Susanna Zerbini)

GNSS Permanent Network in Northern Italy

The DIFA Geodesy group has developed since 1996 and maintains a permanent network of five GNSS stations located at Bologna, Medicina, Marina di Ravenna, Trieste and Loiano. Bologna (BOLG) and Medicina (MSEL) are part of the EUREF EPN network. The Marina di Ravenna GNSS station is co-located with the tide gauge of the ISPRA Italian national network, while the GNSS station at Trieste is co-located with the tide gauge of the ISMAR-CNR. The Group is involved in the scientific analysis and interpretation of GNSS data focusing on crustal deformation and the estimation of atmospheric parameters. In the framework of these activities, a study concerning the GPS data of the ENI network is carried out. Within the activities of the EU OPERANDUM project, an additional permanent GNSS station is being installed at Goro, co-located with a tide gauge of the ARPAE, in the regional park of the Po River Delta. This work contributes to the activities of IAG SC 1.3 (Regional Reference Frame) and SC 3.5 (Tectonics and Earthquake Geodesy).

Sea level and vertical land motion

The DIFA team has been a leading group in the field of sea-level studies since many years. During the last four years, the group has estimated long-period sea-level trends in the Mediterranean using centennial tide gauge records. Common patterns of variability have been assessed by means of the EOF approach. Moreover, the initial 50 years (1873-1922) of high and low waters of the Marina di Ravenna tide gauge have been rescued and quality assessed. The relevant monthly means were made available to the PSMSL. This work has allowed to reconstruct the entire centennial history of this tide gauge. These studies contributed to the activities of the IAG JWG 3.2 (Constraining Vertical Land Motion of Tide Gauges) and of GGOS.

Organizational activity

The DIFA group has contributed to the scientific realization of the:

2016 18th General Assembly of the WEGENER project (SC 3.5), Ponta Delgada, Azores, Portugal

2018 19th General Assembly of the WEGENER project (SC 3.5), Grenoble, France

2016-2018 WEGENER (SC 3.5) sessions at EGU General Assemblies

University of Padua

(Mauro Bertocco, Alessandro Caporali, Joaquin Zurutuza)

Geodynamic in Europe from GNSS time-series

As Chairman of the CEGRN Consortium (Central European Geodynamics Research Network): Geokinematic investigations in Central Europe using long term data (1994-2019) from 1226 permanent GNSS stations.

Geophysical modelling of the inferred velocities, correlation of the areas of high strain with structural geology, historical seismicity. Focus on Central Apennines in Italy, on the Trans European Suture Zone (Central Europe), Eastern Alps, Carpathians and Balkans.

University of Trieste

(Carla Braitenberg)

Geodetic measurements in Karst areas to characterize the hydrology

We have analyzed crustal deformation observed with tiltmeters and space geodetic methods (GPS) in Karst areas. The hydrology in Karst is particular, because water flows in channels and fractures, rather than being a diffuse aquifer. The hydrology of the classical Karst straddling Italy and Slovenia is well studied, and showed that the hydrologic flows achieve high pressure, with values up to 10 atmospheres. The overpressure produces an uplift of the terrain, which is observable with GPS and tiltmeters. We intend to enlarge this study to investigate if the deformation can be observed with further techniques.

Sessions organization at international congresses/symposia/workshops

2016 Carla Braitenberg (General Chair): 18th Geodynamics and Earth Tides Symposium (Trieste)

Publications

Istituto Nazionale di Geofisica e Vulcanologia

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Commission 4

Italian Space Agency/Space Geodesy Center “G. Colombo” (ASI/CGS)

(Giuseppe Bianco, Vincenza Luceri, Rosa Pacione)

Since 2012 ASI/CGS is participating to EUREF Technical Working Group and in 2014, at the EUREF Symposium, ASI/CGS was appointed as EPN Tropospheric coordinator.

ASI/CGS has been participating since 1999 to several GNSS Meteorological projects (COST 716, MAGIC, TOUGH, E-GVAP, COST Action ES1206) and is presently participating to E-GVAP, devoted to operational meteorology in Europe, as Analysis Center and Combination Center.

Information on the CGS and some of the analysis results are available at the CGS WWW server GeoDAF (Geodetic Data Archiving Facility, <http://geodaf.mt.asi.it>).

EUREF/IGS Activities

In the years 2015-2019, ASI/CGS has been deeply involved in the EUREF activities, mainly in support of the reference frame maintenance. Main projects:

- Official EUREF Products:

EPN Final weekly product: site coordinates and tropospheric parameters using IGS Final products, covering a European sub network of 65 sites, 2-week latency

- EPN Tropospheric Product: Combination of the tropospheric products of the different EPN analysis centres for the generation of the combined EPN station zenith path delay solutions

GNSS Meteorology Activities

In the years 2015-2019, ASI/CGS has been deeply involved in the GNSS-Met activities as E-GVAP Analysis Center and Combination Center.

- Official E-GVAP Products:

NRT ZTD estimates: every hour, 15' ZTD estimates with a 1h45' latency for a European network of more than 350 sites are produced

NRT ZTD combined estimates: every hour, the 15' ZTD estimates from the contributing E-GVAP Analysis Centers are combined and made available to the project, using a combination SW developed at ASI-CGS

Quality Control: on hourly basis AC bias w.r.t. the combined solutions are computed providing a quality indicator for each solution

ASI/CGS GNSS-Met activities in support of NWP applications, nowcasting and forecasting of severe weather events, and climate research have been carried out in the framework of E-GVAP and of the EU COST Action “Advanced Global Navigation Satellite Systems tropospheric products for monitoring Severe Weather Events and Climate” (GNSS4SWEC). ASI/GCS in collaboration with IGN has co-chaired GNSS4SWEC Working Group 3 ‘Use of GNSS Tropospheric Products for Climate Monitoring’. Moreover within the IAG Sub-Commission 4.3 ‘Atmosphere Remote Sensing’, ASI/CGS chaired the Working Group ‘GNSS tropospheric products for Climate’ with the main objectives to assess existing reprocessed GNSS tropospheric products, foster the development of forthcoming reprocessing activities, review and update GNSS-based product requirements and exchange format for climate and promote their use for climate research, including a possible data assimilation of GNSS troposphere products in climate models.

ASI/CGS internal projects

ASI/CGS GPS analysis activities extend beyond the accomplishment of its role within EUREF and E-GVAP and were addressed in the following main application fields.

- Zenith Tropospheric Delays (ZTD) Residual Fields: hourly generation of ZTD residuals fields covering the central Mediterranean area.
- Integrated Water Vapour Fields: hourly generation, 15 min resolution, of Integrated Water Vapour fields covering the central Mediterranean area.

Multi-technique Data Analysis

EPN Tropospheric Product Evaluation: Inter-technique evaluation of EPN tropospheric products versus radiosonde data and VLBI estimates.

Politecnico di Milano

(Riccardo Barzaghi, Barbara Betti, Ludovico Biagi, Noemi Cazzaniga, Alessandro Fermi, Carlo De Gaetani, Diana Pagliari, Livio Pinto, Mirko Reguzzoni, Lorenzo Rossi, Fernando Sansò, Giovanna Venuti)

Geodetic monitoring with low-cost GNSS receivers

The accuracy and the reliability of low-cost u-blox GNSS receivers were experimentally investigated for local monitoring. Two experiments were analyzed. In the first, a baseline (65 m long) between one geodetic reference receiver and one u-blox was continuously observed for one week: the data were processed by hourly sessions and the results provided comparisons between two processing packages and a preliminary accuracy assessment. Then, a network composed of one geodetic and two u-blox receivers was set up. One u-blox was installed on a device (slide) that allowed to apply controlled displacements. The geodetic and the other u-blox (at about 130 m) acted as fixed references. The experiment lasted about two weeks.

The data were processed again by hourly sessions. The estimated displacements of the u-blox on the slide were analyzed and compared with the imposed displacements. All of the results were encouraging: in the first experiment the standard deviations of the residuals were smaller than 5 mm both in the horizontal and vertical; in the second, they were slightly worse but still satisfactory (5 mm in the horizontal and 13 mm in vertical) and the imposed displacements were almost correctly identified.

Also, low-cost GNSS receivers have been used for a diffuse structural monitoring of dams and historical buildings. The results show that millimeter accuracy can be reached despite using low-cost instrumentation.

GNSS navigation in multi-sensor systems

The integration of GNSS receivers (geodetic and low-cost grade) with RGB and/or RGB-D cameras has been investigated and tested in a urban environment at an experimental level. This has been done by designing an ad hoc extended Kalman filter integrating GNSS estimated coordinates with acquired images, also taking into account the relative positions of the instruments on the rover.

GNSS meteorology

GNSS estimated tropospheric zenith delays have been used to monitor atmospheric water vapor at local scale, by using ad hoc experimental networks of both geodetic and low-cost receivers. Assimilation of the retrieved delays into high-resolution numerical weather prediction models has been performed resulting in a better localization and quantification of predicted local heavy rain phenomena. Empirical prediction models based on GNSS delays and standard meteorological variables are under study. Integration of GNSS and Interferometric Synthetic Aperture Radar derived atmospheric phase screens has been performed and assimilation tests of the resulting maps have been done obtaining promising results.

Funded projects

SINERGY (Synthetic aperture Instrument for Novel Earth Remote-sensed Meteorology and Hydrology) funded by the Italian Space Agency (ASI) - call for new concepts of mission and payload for Earth Observation. The project, involving Italian Universities and research Institutes, aims at investigating and demonstrating the scientific readiness of methods for applying geosynchronous SAR data in the field of meteorology and hydrology. Politecnico di Milano contribution consisted in the calibration/validation of SAR products with GNSS.

STEAM (SaTellite Earth observation for Atmospheric Modelling) funded by the European Space Agency (ESA). Within the project, involving Italian Universities research Institutes and companies, Politecnico

di Milano contribution consisted in the calibration/validation of SAR products with GNSS and water vapor delay models, then used in Numerical Weather Prediction model assimilation experiments. LAMPO (Lombardy-based Meteorological Predictions and Observations) funded by Cariplo foundation. It is a pilot project aiming at improving the nowcasting of convective storms, by exploiting an ad hoc dense network of low-cost GNSS receivers and meteorological observations. TWIGA (Transforming Weather Water data into value-added Information services for sustainable Growth in Africa) funded by the European Commission under the H2020 program. Politecnico di Milano is leading the work package on Atmosphere including experimental activities in the field of GNSS and SAR meteorology.

Politecnico di Torino (Fabio Dovis)

Robust Positioning for Urban Traffic

The research has been focused on the integration with GNSS of measurements coming from other sensors (inertial sensors, barometers, magnetometers, cameras) that can be used for positioning, in order to enhance robustness and performance of navigation solutions, and on the definition of quality metrics and the assessment of positioning performances in strongly constrained environments such as city centers.

Sapienza University of Rome

Real-time variometric approach for navigation (KIN-VADASE) and application to low-cost receivers and smartphones

(Mara Branzanti, Gabriele Colosimo, Mattia Crespi, Marco Fortunato, Augusto Mazzoni, Gabriele Pirazzi)

Kinematic implementation of the Variometric Approach for Displacement Analysis Standalone Engine (Kin-VADASE) was proposed and tested as an alternative technique to estimate in real time kinematic parameters of stand-alone receivers, also at high rate, with both dual-frequency geodetic class receivers and single frequency low-cost receivers. Kin-VADASE was tested and assessed in controlled lab experiments, then Kin-VADASE was applied to real cases: trans-oceanic boat equipped with dual-frequency geodetic class receivers for trajectory and attitude estimation and waves characterization; trajectory estimation through low-cost dual-frequency prototypal receivers; mass-market GNSS chip embedded in android smartphones for gesture tracking and pedestrian, car and airplane navigation. The research activity related to navigation with android smartphones has been developed under the umbrella of the GSA *GNSS Raw Measurements Task Force* (<https://www.gsa.europa.eu/gnss-applications/gnss-raw-measurements/gnss-raw-measurements-task-force>).

Integration of GNSS with other sensors

(Elisa Benedetti, Mattia Crespi, Francesca Fratarcangeli, Andrea Nascetti, Roberta Ravanelli)

The research was developed both to assess, with real experiments, the possibility to integrate low-cost GNSS and MEMS accelerometers and to propose a model for their integration, to merge their different benefits and promote the diffusion of low-cost monitoring solutions. A merging approach was set up at the level of the combination of kinematic results (velocities and displacements) coming from the two kinds of sensors, whose observations were separately processed, following to the so called loose integration, which sounds much more simple and flexible thinking about the possibility of an easy change of the combined sensors.

Real-time variometric approach for ionosphere GNSS sounding (VARION) and tsunamis early warning (Mattia Crespi, Augusto Mazzoni, Michela Ravanelli, Giorgio Savastano)

A new variometric approach, named VARION (Variometric Approach for Real-Time Ionosphere Observation) was defined and implemented to estimate slant TEC (sTEC) variations in real-time on the basis of GNSS observations. VARION was thoroughly tested in a real-time scenario, computing TEC variations at 56 GPS permanent stations in Hawaii as induced by the 2012 Haida Gwaii tsunami event. We observed TEC perturbations with amplitudes of up to 0.25 TEC units and traveling ionospheric perturbations (TIDs) moving away from the earthquake epicenter at an approximate speed of 316 m/s. The same sTEC perturbations were estimated using the standard software for post-processing available at JPL, obtaining a very consistent comparison. Also, the comparison with the real-time tsunami MOST (Method of Splitting Tsunami) model, produced by the NOAA Center for Tsunami Research, was consistent, observing variations in TEC that correlate in time and space with the tsunami waves. VARION was then used in a retrospective analysis to detect sTEC perturbations induced by a significant number of tsunamis and earthquakes. Finally, VARION was also applied in a real-time scenario to the signals coming from geostationary GNSS satellites (GEO satellites) included in the U.S. Wide Area Augmentation System (WAAS), to characterize the ionospheric response to the 24 August 2017 Falcon 9 rocket launch from Vandenberg Air Force Base in California. This application, named VARION-GEO approach, was proven able to provide ionospheric sTEC real-time measurements not affected by the motion of the ionospheric pierce points (IPPs). Furthermore, the VARION-GEO sTEC determinations experienced a steady noise level throughout the entire observation period, making this technique particularly useful to augment and enhance the capabilities of well-established GNSS-based ionosphere remote sensing techniques and future ionospheric-based early warning systems.

GNSS meteorology

(Mattia Crespi, Augusto Mazzoni, Alessandra Mascitelli)

The research was devoted to assess the possibility to densify GNSS permanent networks with low-cost single-frequency receivers to enhance the resolution of ZTD (Zenith Total Delay) estimations, to prove the benefit of the assimilation of these ZTDs within meteorological models to improve the meteorological forecasting at regional scale, and to use GNSS derived ZTDs to calibrate other sensors, as sun-sky radiometers.

Positioning and monitoring with SAR

(Mattia Crespi, Paola Capaldo, Augusto Mazzoni, Francesca Fratarcangeli, Andrea Nascetti)

The goal of this research was to assess the potential for positioning and monitoring offered by the Synthetic Aperture Radar (SAR) slant-range measurements made available by high resolution SAR satellite sensors as TerraSAR-X and COSMO-SkyMed. Thanks to this higher amplitude resolution (up to 0.20 m pixel resolution in the Staring SpotLight mode for TerraSAR-X) and to the use of on board dual-frequency GPS receivers for precise orbit determination at few centimetres level, it was proven on selected study cases that the SAR images offer the capability to achieve, in a global reference frame, positioning accuracies in the decimeter range, and monitoring accuracies at local level at 1-2 centimeters accuracy.

Sessions organization at international congresses/symposia/workshops

Organization of the session *Theory of multi-GNSS parameter estimation* (A. Khodabandeh, M. Crespi) at the IX Hotine-Marussi Symposium (Rome, Italy) in 2018

Co-organization of the sessions *High-precision GNSS: methods, open problems and Geoscience applications* at the European Geoscience Union General Assembly (Vienna, Austria) in 2017, 2018 and 2019

Editorial activity

Special Feature of Measurement Science and Technology on *High-Precision Multi-Constellation GNSS: Methods, Selected Applications and Challenges* (Editors: Jacek Paziewski, Mattia Crespi) (<https://iopscience.iop.org/journal/0957-0233/page/High-Precision-Multi-Constellation-GNSS>)

Special Issue of Remote Sensing on *High-precision GNSS: Methods, Open Problems and Geoscience Applications*
(Editors: Xingxing Li, Jacek Paziewski, Mattia Crespi)
(https://www.mdpi.com/journal/remotesensing/special_issues/GNSS_rs)

Technology transfer and relevant applications in science and engineering

VARION algorithm is under incorporation into JPL's Global Differential GPS System as a novel contribution to future integrated operational tsunami early warning systems
(<https://www.nasa.gov/feature/jpl/scientists-look-to-skies-to-improve-tsunami-detection>)

University of Genoa

(Bianca Federici, Ilaria Ferrando, Domenico Sguerso)

GNSS for Meteorology (G4M)

The GNSS monitoring of atmosphere can deepen the knowledge of meteorological phenomena, primarily the severe ones, with detailed time and space scales and it improves the existing observational networks (e.g. rain gauges, meteorological radars, satellite images). In this context, we have conceived an automatic procedure, named G4M (GNSS for Meteorology) in order to produce 2D Precipitable Water Vapor (PWV) maps and analyze its evolution in time with high spatial and temporal resolution. The input data are GNSS, pressure and temperature observations, not necessarily co-located and spread over the considered domain, coming from existing infrastructures. The procedure is capable to detect meteorological events with reliable results, thanks to a Heterogeneity Index, based on PWV spatial variability. As a matter of facts, a strong correlation between high variability of PWV and intense rain has been noticed, and it could be used as promising indicator to locate severe meteorological events in time and space. The procedure will be applied as a contribute to the Alcotra Project Concert-Eaux, using an ad-hoc network of low-cost GNSS and environmental sensors in the Bendola sub-basin.

Impact of tropospheric delay on GNSS positioning during severe events

In high-accuracy surveys, the tropospheric delay induces a not negligible effect on the GNSS positioning, in case the meteorological conditions are not homogeneous and/or the height variations are significant. In the positioning solution it is possible to consider the tropospheric effect through the ZTD estimation, but in the not-scientific approach many times the tropospheric effects are modelled only with the dry component, i.e. ZHD. In fact ZWD is difficult to model, due to its strong dependence on the spatial and temporal variability of the water vapor content.

The procedure, named G4M (GNSS for Meteorology) in order to reproduce the 2D distribution of PWV for its monitoring in space and time, have the possibility to evaluate the ZWD amount with high spatial and temporal resolution on the study area. Particular attention was paid on the year 2011, because on 4 November a stationary and self-healing storm occurred over Genoa (Italy). During this event, ZWD variations have been observed up to 100 mm in 3 days and up to 300 mm per 2011. At the same time, the ZWD may show a spatial variability up to 100 mm in 15 km and 50 mm in 5 km. These effects may probably be smoothed and reduced thanks to long temporal observations sessions, but surely are not negligible and should be considered. Starting from such results, an evolution of the ZWD effect on Up component has been observed in the positioning estimation of the Permanent Stations in Genoa and in Turin, the last one not involved in the highly localized evolution of the event. The first results encourage deepening the knowledge of the tropospheric effects on the GNSS positioning, particularly significant in orographically complex area.

University of Padua

(Alessandro Caporali, Mauro Bertocco, Joaquin Zurutuza)

GNSS multi-constellation solution

As member of the Galileo Reference Center – Member States EU Project: Evaluation of Key Performance Indicators (KPI) of the Galileo GNSS for positioning, navigation and timing, and its interoperability with GPS, Glonass, BeiDou.

University of Trento

(Battista Benciolini, Francesca Tesolin, Alfonso Vitti, Paolo Zatelli)

Metrology and point clouds co-registration

Some works exploited expertise and knowledge typical of the geodetic disciplines in different fields of application from mechanical metrology to point clouds co-registration:

- quaternion algebra for dealing with rotations sequences was the key point in the development of an original model for the calibration of articulated arms measuring machines with an arbitrary number of junctions
- a synthetic quality index for the applied Helmert transformation was derived and applied to describe the quality of co-registered point clouds

GNSS multi-constellation variometric solution

The impact of Galileo code and phase observations on the solutions of the variometric approach for the determination of displacements and velocities was investigated and assessed against multi-constellation solutions. The study was carried out considering high rate acquisition epochs. Results support the sounding of the variometric approach for seismological applications and its application in other engineering fields that would benefit from higher rate sampling too.

Publications

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