Co-Located GNSS Stations Within the Italian National Tide Gauge Network

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***Abstract* - The purpose of this work is to introduce the ISPRA project aiming to realize a permanent GNSS coastal network collocated with the tide gauges of the ISPRA national network. The objective of integrating the two networks is to link the reference points of the tide gauge to an absolute ITRS reference system (International Terrestrial Reference System). In particular, the GNSS network allows the continuous monitoring of vertical movements; the medium-long term series analysis will allow discriminating between the effect of vertical movements possibly present in the areas where the tide gauges are installed from the sea level variation due as an effect of the climate change. At the same time, this network can contribute to the study of the Italian geodynamic evolution, the subsidence phenomena, the evolution of the Italian coasts, and the risk scenarios preparation especially in densely populated coastal areas.**

Keywords - GNSS, reference system, tide gauges, climate change, coastal areas

I. INTRODUCTION

For decades, tide gauge networks have been the most used tool for studying sea-level variations. Usually, the sensors record the variation concerning a local geodetic datum (e.g. the Genoa 1942 mean sea level) in particular locations along the coast where the tide gauges are located. The relative variability of the sea level is determined by the sea level height and the vertical movements of the surface of the solid earth, both on a global and local scale. Consequently, the extent of natural or anthropogenic ground movements can hide the signal of long-term sea-level variation, increasing, for example, the risk of flooding on large coastal areas especially where subsidence phenomena are present [1].

Therefore, the importance of measuring vertical land motion (VLM - vertical land motion) is essential, in correspondence with tide gauge stations, both for estimating long-term variations in mean sea level and for defining the flooding risk in coastal areas, also related to climate change [2], [3]. Traditionally, the determination of the soil vertical movements in correspondence with the site where the tide gauges are installed is carried out by referring the sea level data to geodetic reference stations using high-precision geometric leveling measurements, repeated after a few years.

This methodology can require significant time and costs. In recent years, the use of satellite measurements has increased through the installation of permanent GPS / GNSS stations integrated with the tide gauges stations, only available in the world observing systems in a limited number of stations (25% of tide gauges have a GNSS station at less than 10 km) [4], [5], [6]. The installation of a permanent GNSS station in correspondence with a tidal gauge, or in its proximity, allows for the continuous recording of ground movements in that area, as well as sea-level variations are continuously recorded by the tide gauges. Furthermore, the use of GNSS measurements allows us to refer the data recorded by the tide gauge to an absolute reference system [7], [8].

II. RMN STATIONS

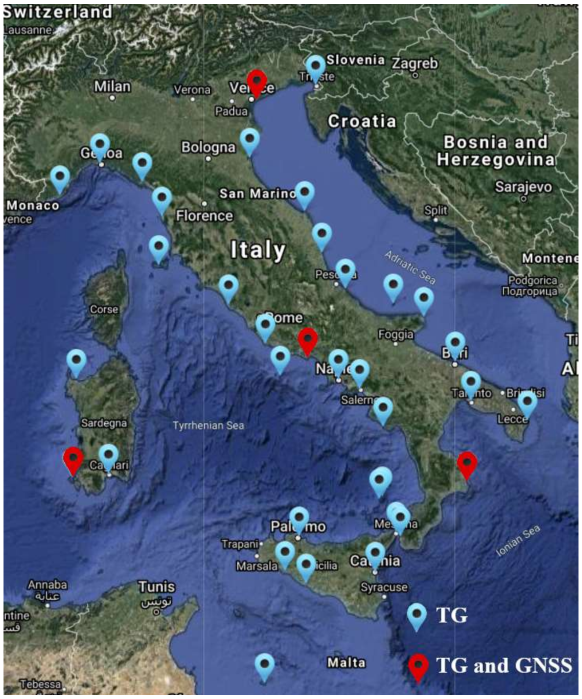

Fig. 1. RMN and GNSS stations

The ISPRA National tide gauge network (RMN) currently consists of 36 meteo-tidal stations for the automatic real-time acquisition of sea level height and some meteorological parameters such as wind speed and direction, pressure, and air temperature. The stations are uniformly distributed along the Italian coasts and located mainly within the port facilities (Figure 1). The tide gauge data are also provided to the Permanent Service for Mean Sea Level (PSMSL) a repository used in the measurement of long-term sea-level change [9].

For all the RMN stations (except Aeolian islands Ginostra and Strombolicchio stations that, due to the particular location of their level sensors directly at sea, are equipped with piezometric sensors and stilling pipes open), the sea level parameter is monitored with a microwave sensor (i.e. the radar level transducer) able of accuracy of ±1 mm and a sensitivity of 0.5 mm and long-term stability. The transducer produces a series of microwave impulses that are sent from the radar emitter to the measuring level. The reflected microwaves are noticed by spar and sent to electronic devices where a microprocessor appraises the signal and identifies the reflected echo coming from the measured surface calculating the distance from the transducer. The operational range of the sensor is 0.6-15 m, the analog output range is 4-20 mA, and the working temperature is comprised into the range from -30 °C to +80 °C.

The radar level transducer is installed in tandem with a second float level sensor based on “shaft-encoder” technology (now with the backup function). The float level sensor operational since 1998, is able of an accuracy of ±1 cm and a sensitivity of 1 mm with a response time of less than 20 s and working temperature from -30 °C to +80 °C.

The conventional float system drives an absolute shaft encoder with digital output in a Gray code encoder at 25 bits. The microprocessor-based electronic module provides different outputs proportional to the hydrometric level. The transducer also allows the correct control functioning, data pre-processing, and electrical signal analog to digital conversion. These characteristics warrant excellent accuracy, long-term stability, and high data reliability.

By comparing the measurements of the two sensors it is possible to obtain a precise calibration of the radar sensor such as to guarantee perfect continuity of the level data series.

Each level sensor refers to a tide gauge benchmark (TG bracket) whose altitude is determined by referring to the Italian high-precision leveling network of the IGM (Istituto Geografico Militare) and for accuracy by connecting to the nearest IGM benchmark.

All the RMN stations are also equipped with meteorological sensors such as an anemometric sensor to retrieve wind speed and direction 10 meters above the ground data, a barometric sensor, an air temperature sensor, and a water temperature sensor, as well as a sensor for relative humidity. The ultrasonic anemometric sensor is able of accuracy of ±0.2 m/s and sensitivity of 0.01 m/s for intensity and accuracy of ±2° and sensitivity of 0.1° for direction. The digital barometer is the Vaisala model PTB220B with measurement range 500-1100 hPa, based on a silicon capacitor with a very low thermal expansion coefficient and a negligible mechanical hysteresis, able of accuracy of ±0.3 hPa at +20°C. The air temperature and water temperature sensors are based on a platinum thermo-resistance Pt100 with a response curve agree the Class 1/3 DIN 43760 standard, capable of an accuracy of ±0.1°C and sensitivity of 0.03°C in the range from -30 °C to +60 °C. The sensing element of the sensor for relative humidity is a laser-trimmed thermostat polymer capacitive sensing element with on-chip integrated signal conditioning able of accuracy of ± 2 % and sensitivity of ± 0.5 %.

All the stations are equipped with a local data management and storage system, moreover, the transmission (based on industrial UMTS/4G routers) is operated in real-time. The monitoring stations result fundamental for the characterization and protection of the coastal area since, besides the reconstruction of the tide signal, the RMN represents the national reference for the forecast models of tides and storm surges, for the geophysical models able to detect, continuously, soil deformations with considerable reliability, for the meteorological models due to the collection of meteorological data along the coastal zone, as well as, constitutes important environmental protection inside the ports of the main Italian cities.

The sea level and meteorological data are published in real-time through the RMN’s portal (available at www.mareografico.it).

III. GNSS STATIONS

The ISPRA Project for equipping the RMN with co-located GNSS stations has been developed, over the last few years, in collaboration by the Application of Geophysical Methods Unit (GEO-GFI) with the Physical sea state monitoring and Marine Climatology Unit (COS-CLM), to update the methods to determine the vertical soil movements just in correspondence with the tide gauge sensors using modern geodetic technologies [10]. Since 2009, the Venice tide station has been integrated with a permanent dual-frequency GPS station equipped with a Choke Ring antenna [11]. Starting from summer 2020, three new GNSS stations co-located at the RMN stations of Carloforte (CARF-Figure 2), Crotone (KRRM) and Gaeta (GAEA-Figure 3) have been installed, while a fourth station will be installed in a few months in the south of the Sicily Island. The first three stations are equipped with multiple frequency geodetic instruments, currently recording the satellite data sent by the

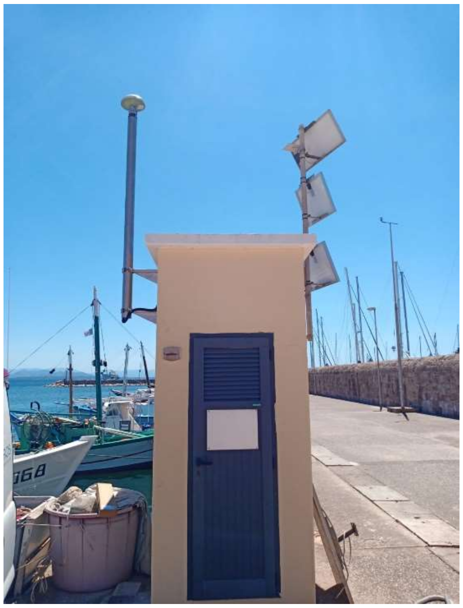

Fig. 2. Carloforte GNSS station

Fig.3. Gaeta GNSS station

GPS and GLONASS constellations and acquiring continuously data with 1Hz frequency. Crotone and Carloforte stations were equipped with Leica GR30 reference station receivers with 555 channels (Figure 4). Gaeta station was equipped with a Leica GX1220GG receiver. Wherever possible, High-precision geodetic GNSS antennas were installed directly on the tidal cabin (Figure 2). In the case of Gaeta, the GNSS instrumentation has been installed on a terrace of the building close to the tide gauge and equipped with a Choke Ring antenna (Figure 3).

After the request made to the IGN (Institut Géographique National, Paris) the stations obtained a unique 4-character identifier and an IERS DOMES number, as required by the IGS Guidelines:

- CARF 14664M001;
- GAEA 14665M001;
- KRRM 14666M001.

Remote management of the equipment is conducted through the Leica GNSS Spider software and a unique infrastructure dedicated to the GNSS data analysis and storage has been created.

IV. GNSS DATA ANALYSIS

The GNSS data of the three stations were analyzed using the Teqc (Teqc-Translation, Editing, and Quality Checking) analysis software provided by the University Navstar Consortium (UNAVCO), to verify the data quality and the integrity of the RINEX files [12]. The analysis of the first-period data reveals a strong percentage of the ratio between the total amount of expected observations and the number of files acquired (R1>90%). Moreover, the multipath values, for MP1 and MP2, are included within the range 0.15-0.30 m for the Carloforte station, 0.25-0.50 m for the Crotone station, and 0.20-0.40 m for the Gaeta station, these values are in agreement with literature.

The RINEX data available were processed to obtain three-component daily positions. We process all the RINEX data available from GNSS stations in 24-hr batches to obtain daily three-component positions. GPS data were reduced using the Jet Propulsion Laboratory (JPL) GIPSY-OASIS II software (version 6.3) in a precise point positioning mode applied to ionospheric-free carrier phase and pseudo-range data [13] and using JPL's final fiducial-free GPS orbit products (available at https://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products). Precise point positioning mode was applied to the ionospheric-free carrier phase and pseudo-range data using JPLs final fiducial-free GPS orbit products. Ambiguity resolution was applied using the wide lane and phase bias (WLPB) method, which phase-connects individual stations to IGS stations in common view. Resolving ambiguities significantly reduces the scatter mostly in the east component time series. The ocean loading was computed from the FES2004 tidal model coefficients provided by the Ocean Tide Loading Provider and applied as a station motion model. Satellite orbit and clock parameters were provided by JPL,

Fig. 4. Crotone GNSS receiver

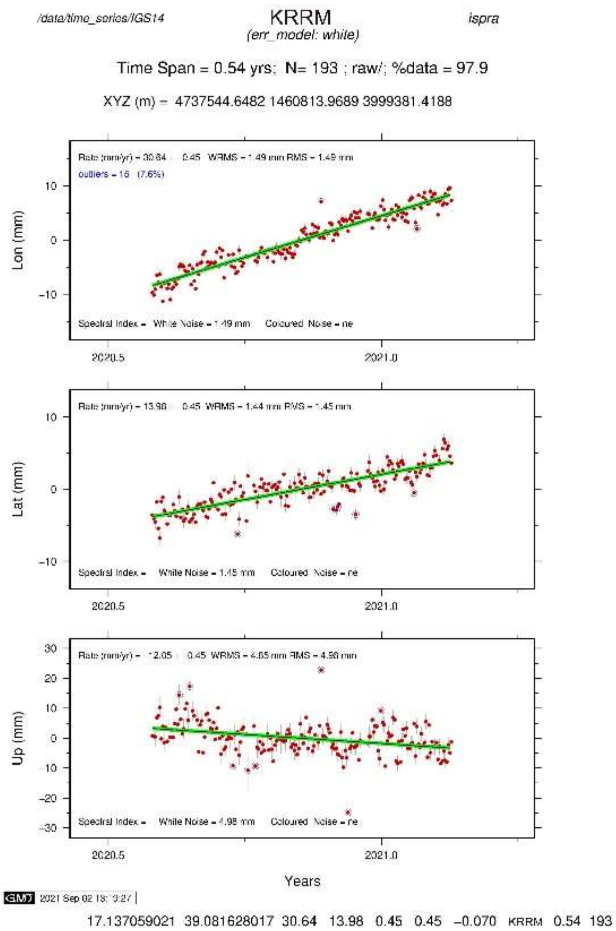

Fig. 5. GPS time series of Crotone station in the period May 2020-Jan 2021: Red dots: daily mean measures; Blue circles: outliers; Green line: linear interpolation.

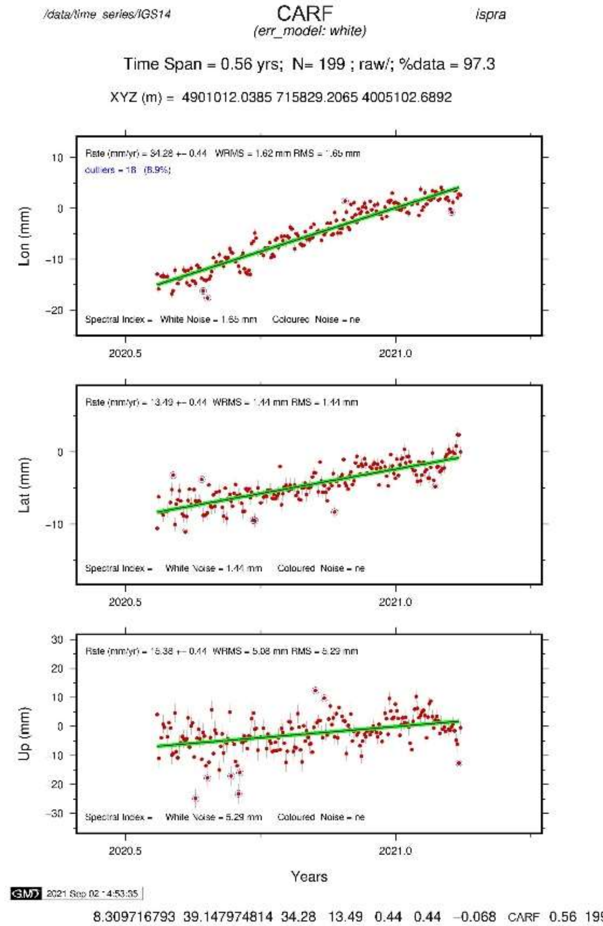

Fig.6. GPS time series of Carloforte station in the period May 2020-Jan 2021: Red dots: daily mean measures; Blue circles: outliers; Green line: linear interpolation.

which determined them using a subset of the available IGS core stations as tracking sites.

The fiducial-free daily GPS solutions were aligned to IGS14 by applying a daily seven-parameter Helmert transformation (three rotations, three translations, and a scale component) obtained from JPL (Figure 5 and 6).

The preliminary analysis of the dataset available for the two stations installed in 2020 highlights that the trend of the time series is almost linear during the analyzed period, with a low number of outliers, about 10%. The RMS error is about 1 mm for the horizontal components and 5 mm for the vertical components.

V. Conclusions

Although the period of operation of co-located GNSS stations is still short for calculating station displacement rates, it can be said that the data acquired in the first period are in agreement with the literature indications for permanent GNSS stations. Even if the estimated vertical velocity of the stations varies according to multiple parameters, it has been demonstrated that it can reach an accuracy of about 1 mm/year after a few years of operation [3].

The GNSS data will be made available according to the specific international data dissemination standards. A special The website is being created where the RINEX files of the stations will be available. In the future will be stored the acquisitions of the new stations of the tide gauge network that are being implemented.

The project is in progress and previews the installation of four additional GNSS systems in correspondence with Trieste, Ortona, Bari e Otranto RMN tidal stations on the Adriatic Sea, as part of the AdriaClim Project This last project, funded by the Interreg Italy-Croatia cooperation program, is dedicated to supporting the development of science-based regional and local climate change adaptation plans. AdriaClim will address climate change threats by developing regional and local adaptation plans based on up-to-date meteorological and oceanographical information acquired through newly implemented observing and modeling systems for the Adriatic Sea. The results are still preliminary; more reliable estimates of vertical land movements will be obtained after an extended monitoring period. However, by 2022 the network of RMN tide-gauge co-located GNSS stations will be 8 and will help improve the quality of sea level data recording.

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