# Environmental Loadings: Effects on Height and Gravity

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## Introduction

The Department of Physics of the University of Bologna has started to install during mid 1996 a permanent GPS network in order to study vertical crustal motions in the southeastern Po Plain and along the northern border of the Adriatic plate. At present, four permanent GPS stations (CGPS) are operational at Medicina, Bologna, Porto Corsini and Trieste. Time series of daily solutions are analyzed to provide significant information on both long and short-period height variations. Seasonal fluctuations were identified and interpreted. The removal of the seasonal oscillations allows the reliable estimate of long-term linear trends.

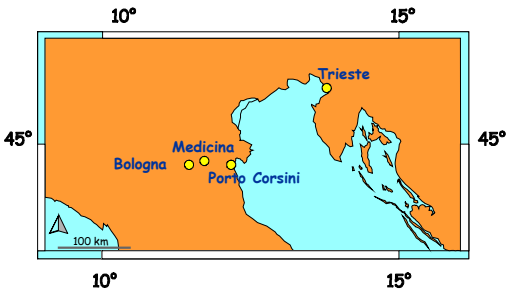


Fig. 1 Location of the CGPS and gravity stations

Independently from space geodetic techniques, another way to constrain vertical deformation is to use precise gravity measurements with cryogenic relative gravimeters and ballistic absolute gravimeters. The presently available accuracy enables to determine vertical changes in the sub-centimetric range corresponding to what can be achieved nowadays with precise vertical positioning. At Medicina, in addition to the GPS receiver, a superconducting gravimeter belonging to the Bundesamt für Kartographie und Geodäsie (Frankfurt am Main, Germany) is also operational since mid 1996. The continuous gravity series allows the study of ground deformation and signals related to global/regional processes and local environmental effects. A marked seasonal oscillation, becoming quite recognizable towards the end of 1997, is present both in the GPS and gravity data series. The observed oscillations have been interpreted and modeled as the sum of various environmental loadings for the height and gravity series and the Newtonian attraction components for gravity alone. In particular, atmospheric, hydrological and oceanic effects have been estimated. Thermal expansion of the structures supporting the GPS antennas has been also modeled. In the case of the Medicina station, also the settlement due to soil consolidation has been modeled.

## CGPS data

Daily ellipsoidal coordinates of the reference benchmarks are derived by means of the Bernese software package version 4.2 with the adoption of IGS orbits, coordinates and velocities of five fiducial IGS stations in the region. The station coordinates are computed in the ITRF2000. A detailed description of the analysis procedure is given by Zerbini et al. (2001, 2002).

The series are characterized by a clear seasonal signal, which has been interpreted as the sum of different loading effects. The loadings induced by atmospheric pressure variations, local hydrology and non-tidal oceanic effects have been estimated and modeled (Zerbini et al., 2001, 2002). Thermal expansion of the structures supporting the GPS antennas has been also estimated. Additionally, for Medicina, the soil consolidation effect has been computed as well (Romagnoli et al., 2002). The model provides a quite satisfactory representation of the observed seasonal signal by reproducing up to about 70% of the oscillation (Fig. 2).

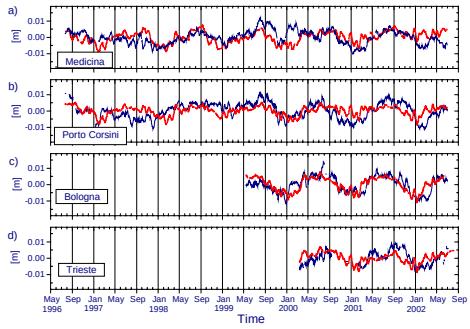


Fig. 2 Observed seasonal fluctuations in the CGPS height series (solid line) and relevant models (dotted line)

After removing the modeled seasonal oscillation, the linear trends were estimated. All the series are characterized by negative linear trends of different magnitude: Porto Corsini (–10.73±0.09 mm/yr) and Bologna (–18.44±0.23 mm/yr), in particular, exhibit considerable subsidence rates mainly of anthropogenic origin. Medicina (–1.56±0.08 mm/yr) and Trieste (–4.77±0.46 mm/yr) show moderate subsidence rates.

## Gravity data

At Medicina, the superconducting gravimeter is installed in a temperature-controlled laboratory on a concrete pier, founded 1 meter deep into the ground. The 10-second sampled gravity data, filtered to 1-minute data are analyzed by means of the ETERNA, version 3.30, software package. After subtracting the Earth's and ocean tides and polar motion, the long-term stability of the absolute gravity measurements performed with AXIS FG5 absolute gravimeters is the basis to estimate the superconducting gravimeter drift and to remove the offsets between data blocks. Details on the data analysis procedure can be found in Zerbini et al. (2001, 2002).

The series of gravity values is characterized, as well as the CGPS heights, by a marked seasonal signal, which becomes quite clear after mid 1997. The gravity variations induced by loading and mass effects due to temporal changes in the geographical redistribution of atmospheric and hydrologic masses have been estimated and modeled (Zerbini et al., 2002). The seasonal settlement due to soil consolidation has been also estimated.

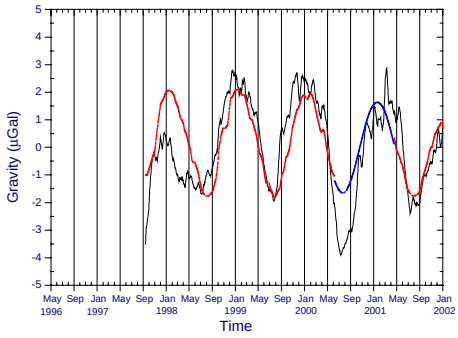


Fig. 3 Observed seasonal fluctuations in the gravity series (solid line) at Medicina and relevant model (dotted line)

The modeled seasonal variations reproduce quite well the observed seasonal signal in the gravity residuals. There are two periods during which the model fits the observed data less satisfactorily, namely the period end of 1997-mid 1998 and in mid 2000. In the first case, part of the difference is attributable to the magnitude of the long-term trend subtracted from the data, which in the initial period is considerably higher. An additional source of difference comes, most likely, from the non-tidal ocean modeling adopted. A preliminary analysis of bottom pressure data in the Northern Adriatic suggests that this model should be improved by accounting for a higher temporal variability of the ocean. After removing the modeled seasonal oscillation, a linear trend of +1.12±0.02 μGal/yr has been estimated.

## References

Romagnoli C., S. Zerbini, L. Lago, B. Richter, D. Simon, F. Domenichini, C. Elmi, M. Ghirotti, 2002, Influence of soil consolidation and thermal expansion effects on height and gravity variations, Journal of Geodynamics, in press.

Zerbini S., B. Richter, M. Negusini, C. Romagnoli, D. Simon, F. Domenichini, W. Schwahn, 2001, Height and gravity variations by continuous GPS, gravity and environmental parameter observations in the southern Po Plain, near Bologna, Italy, Earth and Planet. Science Lett., Vol. 192, 3, 267–279.

Zerbini S., M. Negusini, C. Romagnoli, F. Domenichini, B. Richter, D. Simon, 2002, Multi-parameter continuous observations to detect ground deformation and to study environmental variability impacts, Global and Planetary Change, 34, Nos. 1–2, 37–58.