GPS Activities at ASI/CGS as Data Provider and Data Processing in the field of atmospheric and landslide monitoring.

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Abstract

The Italian Space Agency (ASI) is a partner of the EC Projects TOUGH (Targeting Optimal Use of GPS Humidity measurements in Meteorology) and CERGOP2. In the framework of the TOUGH Project GPS data of an European network, having Italy as primary region, are analyzed for meteorological applications. ASI manages the Italian GPS fiducial network and delivers GPS data to the users through the EUREF local data center GeoDAF. This network belongs to the EUREF permanent network and ASI, as EUREF local analysis centre, contributes to the European terrestrial reference frame realization (http://epncb.oma.be/dataproducts/analysiscentres/index.html).
Moreover in the framework of the CERGOP2 Project local GPS networks have been established in Basilicata region (South Italy) and epoch GPS campaigns are performed for landslide monitoring.
An overview of ASI activities in the field of meteorological application and hazard monitoring will be given.

1. The Italian GPS Network

The Italian Space Agency (ASI) manages a GPS network of about 40 stations *(Fig. 1)* and among them 33 stations provide hourly data with 5 minute latency. GPS raw data collected at the remote sites are sent to Matera/Centro di Geodesia Spaziale (CGS) through INTERNET or ISDN line, they are converted into RINEX format and then transferred to ASI web and ftp site as well as EUREF local data center GeoDAF (http://geodaf.mt.asi.it, ftp://geodaf.mt.asi.it).

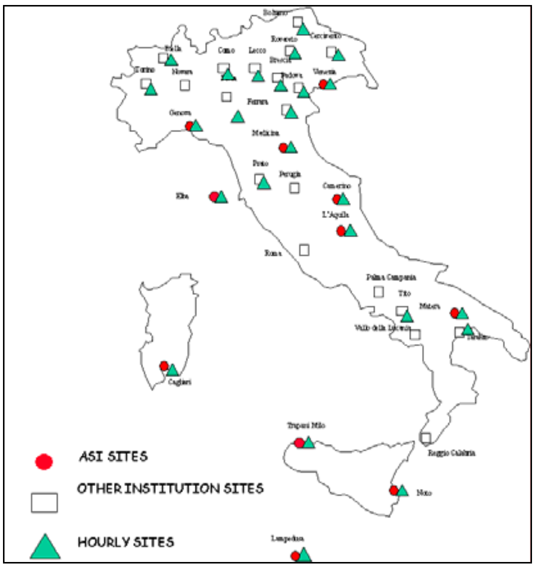

Fig. 1 Italian GPS Network managed by ASI.

2. Ground-based GPS meteorological activities

An overview of ASI ground-based GPS-Met activities is given in Fig. 2.

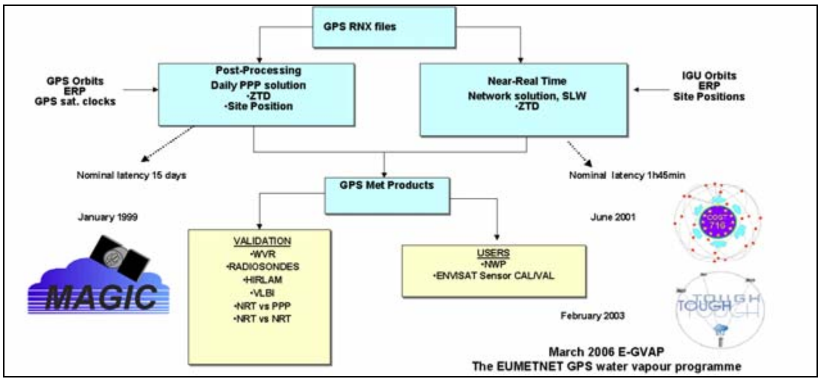

Fig. 2 ASI ground-based GPS-Met activities: an overview.

In the framework of the EC TOUGH Project (http://tough.dmi.dk), ASI continuously provides Zenith Total Delay in Near Real Time to meteorological agencies. The analyzed ground-based network (*Fig. 3*) is made by 57 stations on March 2006 covering the Central Mediterranean area with Italy as primary region.

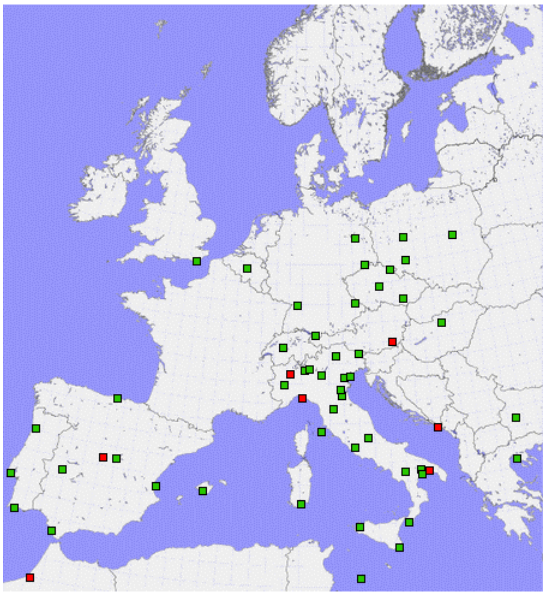

Fig. 3 ASI NRT ground - based network, March 2006. http://www.knmi.nl/samenw/egvap/validation/ztd_iwv.html.

On hourly basis an automatic processing collects all the hourly GPS data files available at the IGS/EUREF data centres. The GIPSY-OASIS II software is used for data reduction with the standard technique of network adjustment (COST-716, 2004). The IGS Ultra Rapid orbits are kept fixed but checked and "bad" satellites/stations are automatically excluded based on the analysis of post fit phase observation residuals, as suggested in Springer et al. (2001). A 24-hour sliding window for data handling is applied together with 5 minutes sampling rate and a cut-off angle of 10^0. The ZWD is estimated every 5 minutes with a stochastic model (random walk) and a constraint of 20 mm/sqrt(h) while the horizontal gradient is not estimated.
The station coordinates are kept fixed to values provided by combining 1 month of daily post-processed solutions, whose repeatability is at the centimeter level or better. They are updated every 30 days in order to take into account the tectonic (secular) movements of the area. The phase ambiguities are estimated as float and the satellite and stations clocks are estimated with respect to one reference clock (usually Wettzell till June 2005 and Brussell later). The Niell (1996) dry and wet mapping functions and the ocean loading corrections by Scherneck (1991) are applied. The information on the "relative" antenna phase center variation (PCV) provided by the IGS are applied as well.
The ZTD estimation is very sensitive to elevation dependent effects (e.g. PCV). Errors in the calibration of satellite and receiver elevation dependent phase delays, or errors in the mapping functions, may result in small systematic effects of a few mm in the estimated ZTD. However, using the wrong antenna type in the GPS processing, or fixing the coordinates to the wrong values (e.g. after an earthquake), may result in gross-errors of occasionally up to 1–2 cm in ZTD.

The ZTD estimates of the last hour are derived from the 24 hours batch; they are averaged to 15 minutes sampling rate, put into COST format (COST-716, 2003) and sent to the U.K. Met.Office where they are available to the meteorological users to be assimilated into numerical weather prediction model. NRT solutions are delivered to UK Met.Office database and can be seen at http://www.knmi.nl/samenw/egvap/validation/ztd_iwv.html

On a daily basis an European network of about 100 stations is analyzed in post-processed mode (PP). The Precise Point Positioning approach (Zumberge et al. (1997)) is applied, fixing JPL fiducial-free satellite orbits, clocks and earth orientation parameters. The main goal of the PP solutions is to provide both ZTD estimates for climate applications and station coordinates, which will be fixed in the NRT data processing when enough accuracy (height coordinates repeatability less than 10 mm) is reached (Pacione and Vespe, 2003) as for meteorological applications we need to monitor the terrestrial reference frame. An accuracy check for the station coordinated is performed regularly. The site coordinates repeatability is monitored as an indicator of ZTD quality. In *Fig. 4* the rms of the day to day scatter after removing the linear trend from the coordinates time series is plotted for each stations in the up, north and east component. As a rule of thumb, 9 mm in the height component turns into 3 mm ZTD and 0.45 kg/m^2 Integrated Water Vapour (IWV).

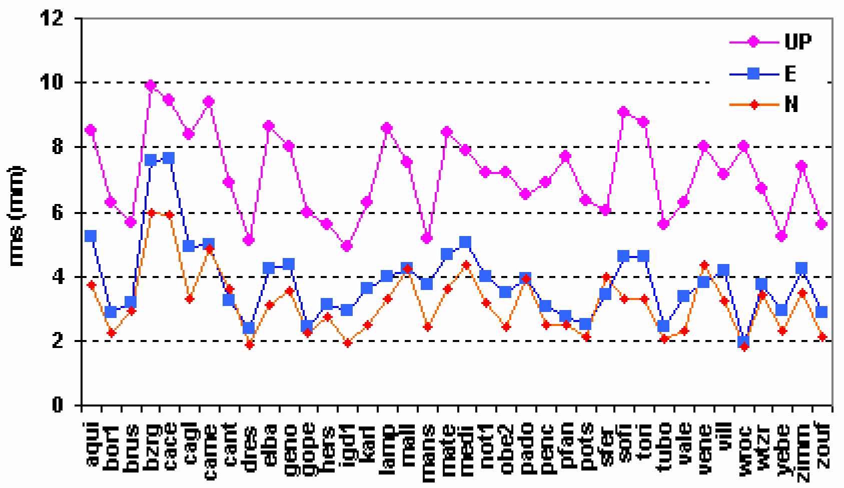

Fig. 4 rms of the day to day scatter in the coordinate time series, linear trend removed.

We evaluate ZTD NRT estimates w.r.t radiosonde profiles and HIRLAM (High Resolution Limited Area Model) numerical weather prediction model considering all the solutions delivered from April 2003 to December 2005. While radiosonde report are real measurements, that do not depend on a meteorological model, HIRLAM ZTD and IWV data are numerical weather prediction model estimates at the site location and thus are subjected to the constraints set by the finite resolution and by the quality of the HIRLAM model itself.
We select 13 sites having a latitude ranging from 38^0 to 50^0 and a longitude from –4^0 to 17^0 and covering almost all Europe and with a separation less than 60 km between the GPS and the Radiosonde launch site. Radiosonde profiles come from the World Meteorological Organization (WMO) Global Telecommunication Service (GTS) and are provided by the Danish Meteorological Institute in the framework of the TOUGH project as independent data set to validate GPS ZTD data. The radiosonde profiles are passed through a program developed during the MAGIC Project (Haase et al. 2003) that first checks the quality of the profiles and then determines ZTD, ZWD and IWV based on radiosonde reports. All of the considered radiosonde are Vaisala except those at the Zimmerwald site where Meteolabor radiosondes are launched.
We computed bias and standard deviation for each station and each month. Results (*Fig. 5*) show that GPS ZTD is greater than radiosonde ZTD with a bias of about 7 mm indicating that Radiosonde is drier than GPS. Vaisala dry bias is well known in literature and has has been discussed by Turner et al., (2003) and Vomel et al., (2006). The standard deviations has a seasonal dependence which seems to fit the atmospheric thermal cycle, being about 10 mm in summer and 7 mm in winter *(Fig. 5)*.
In the comparison statistics between the ZTD values extracted from HIRLAM and those derived from GPS NRT processing we have a bias ranging from –5 to 10 mm (left side up of *Fig. 6*) which approximately turns into –1 to 2 kg/m^2 IWV as can be seen in the right side of *Fig. 6*. LEC1 larger bias (about -6 kg/m^2) is caused by an altitude difference between LEC1 site and the closest synoptic station used to calculate the

pressure at the GPS antenna height, de Haan (2005). Also in this comparison mean and standard deviation of the residuals between GPS and HIRLAM ZTD and IWV are computed for each station and each month. There is a seasonal signal in the residuals time series with a standard deviation higher in summer than in winter. The monthly ZTD standard deviation increases from about 5 mm in winter to about 15 mm in summer for the ZTD and from 1 kg/m^2 kg to 5 kg/m^2 for the IWV.

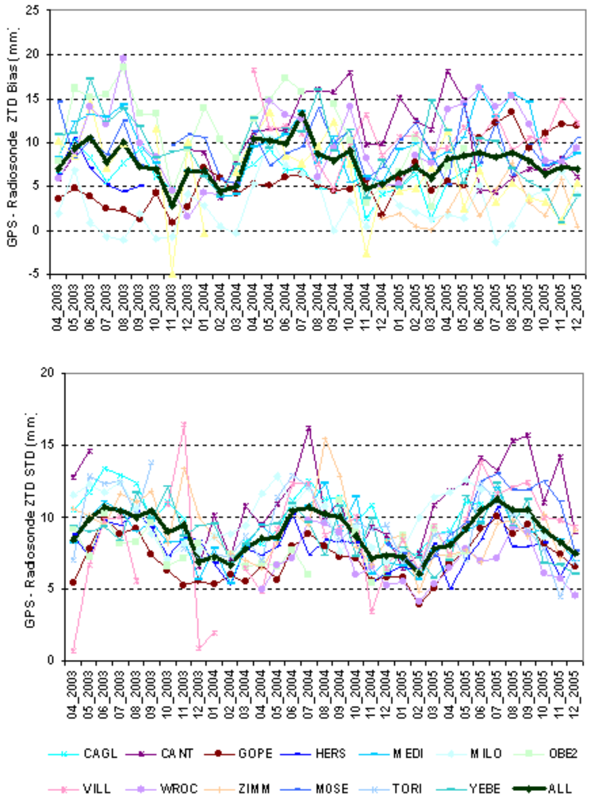

Fig. 5 Monthly variation in ZTD bias (up) and std (down) of GPS versus Radiosonde.

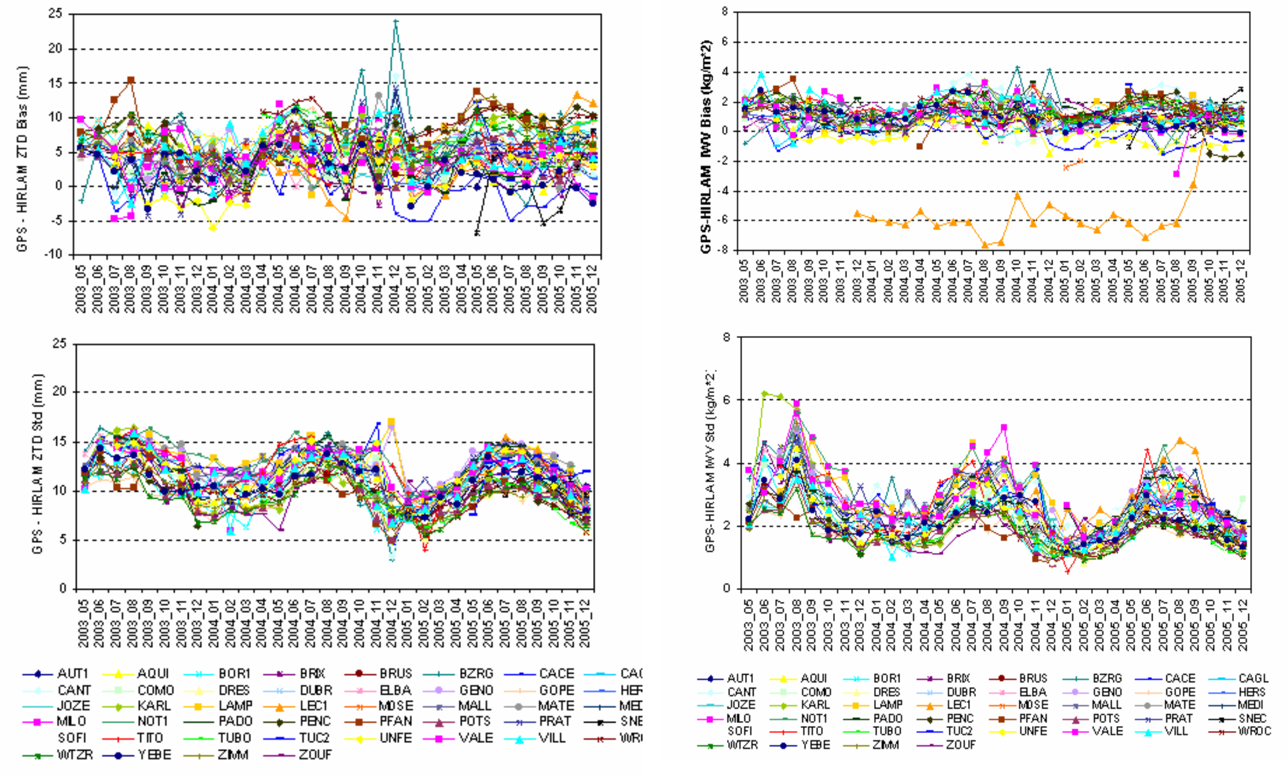

Fig. 6 Monthly bias (up) and std (down) of GPS versus HIRLAM ZTD (left) and IWV (right).

3. Landslide Monitoring

In the framework of the EC CERGOP2 Project, we monitor two sites located in Basilicata region (South Italy) and affected by landslide phenomena. These sites named Aliano and Avigliano (Rutigliano et al., 2004), (Sdao et al., 2005) are interested by large and active landslides subjected to frequent reactivation which causes severe damages to the urban structures. In order to monitor the evolution of the phenomena, epoch campaign are performed every month. The GPS results are cross-checked with the information obtained from careful geo-morphological surveys carried out in the area of interest.
Evidences of the landslide displacements for the Aliano site are reported in
Fig. 7. In
Fig. 8 the Delta North, Delta East and Delta Up component of motion. The values Delta North, Delta East and Delta Up are the vector components of the baseline calculated between each station of measurement and the reference point located on a stable area. The stability of the reference point is verified at each epoch campaign computing its coordinates considering a wider network of GPS stations belonging to the Italian GPS Network. The directions of motion (North, East, Up) are referred to a local reference system. The values shown in
Fig. 7 are residuals calculated for each point as the difference between the coordinates estimated with the data from the first measurement campaign and each other subsequent campaign.
Some GPS points of measurement (points ALI1,ALI2 in
Fig. 8 and
Fig. 7 *c, e*) have been placed on structures built up to stop the landslide evolution and as expected, show no evidence of displacement. On the other hand the results obtained on the data collected at point ALI3 (
Fig. 7 *e*) show a continuous motion of this part of the landslide.

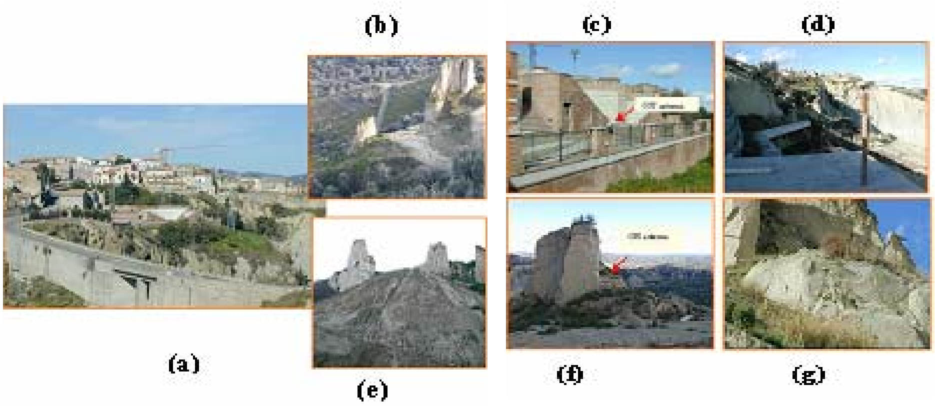

Fig. 7 Aliano landslide: evidence of the landslide displacements and arrangement of the GPS local network.

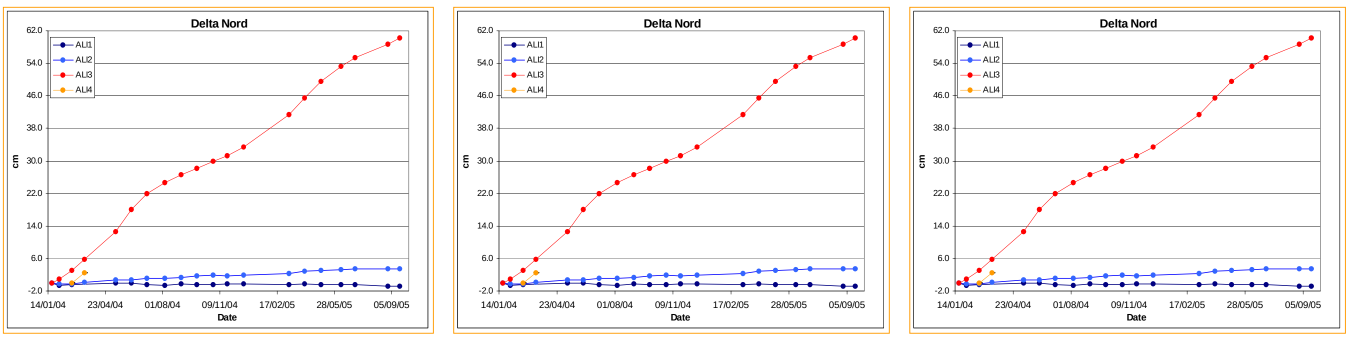

Fig. 8 Results in Delta North, East and Up component for Aliano test site.

As far as the Avigliano landslide is concerned, it is classifiable as a multiple and complex rototranslational landslide, which somewhere evolves into earth-flow. In the last years this landslide has been affected by frequent reactivations that have been the cause of large damages to the urban structures present in the area. Careful geo-morphological survey has been carried out and integrated with the interpretation of aerial photos taken at different scales. The results of these investigations gave us an indication where to install the six markers of a local GPS network. This network is periodically surveyed to investigate the landslide displacements referring all the measurements to a reference point located in a stable area.

4. Summary

We describe a systems for zenith total delay estimation , processing data from a ground-based GPS network located in the Mediterranean area. We validate Near-Real Time ZTD estimates with respect to radiosonde profiles and HIRLAM numerical weather prediction model. A mean bias of about 7 mm is detected between GPS and radiosonde which will be compensated by applying absolute antenna phase center corrections in the GPS data processing (Gendt et al. (2006)).
Results of GPS landslide monitoring using local GPS network are presented as well. The whole area of Basilicata region is affected by extensive landslide phenomena strictly related to climatic, geological and geomorphological factors. Often the landslides phenomena are reactivated after the rainfall periods, causing severe damages to the urban structures.
These activities are carried out in the framework of the EC Projects TOUGH and CERGOP2.

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