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A Complementary GPS Survey Mode for Precise Crustal Deformation Monitoring: the Conegliano-Montello Active Thrust Semicontinuous GPS Network

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A COMPLEMENTARY GPS SURVEY MODE FOR PRECISE CRUSTAL DEFORMATION MONITORING: THE CONEGLIANO-MONTELLO ACTIVE THRUST SEMICONTINUOUS GPS NETWORK

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Introduction

In the last few years Italy has been interested by an unprecedented rapid growing in the number of Continuous GPS (CGPS) networks installed both for scientific goals and other topographical purposes, and made available, through the web, to the scientific community. The INGV Rete Integrata Nazionale GPS (RING) network certainly represents the major and most important backbone of a "virtual" nationally distributed combined CGPS network. The combination of both types of CGPS networks, in fact, is allowing for a significant improvement in the tectonic details of the complex kinematic setting of the central Mediterranean plate boundary system in our country and in the surrounding regions. However, if from one side to study the kinematics of plates and micro-plates the average stations inter-distance required can be of the order of few tens to a hundred km, the study of the interseismic elastic strain accumulation processes across active faults, which is actually the most exciting and promising application of tectonic geodesy in Italy, requires inter-station distances of the order of the fault segments length, that is in the order of few km. For this reason, the integration of continuous and survey-mode GPS networks is still very important in several sectors of the Alpine-Apennines tectonic belt, due to lack, or a sparser distribution, of CGPS stations. However, if from one side survey-mode GPS networks, can still be considered a fundamental tool for studying the co-seismic deformation pattern, in order to reach the accuracies required to precisely measure the long-term interseismic velocities, and the velocity gradients expected for faults characterized by slip-rates of the order of few mm/yr, would need very long (~10 yrs) observation time windows. Moreover, an additional limit of campaign GPS measurements is the limited temporal resolution of the derived position time-series, which prevents any more detailed analysis of realistic velocity uncertainties and analysis of seasonal and potential transient deformation. In order to overcome the spatial resolution of CGPS networks and the temporal resolution of survey-mode GPS networks, a new class of GPS experiment has been implemented and tested in Italy in the framework of the REtreating TRench Extension and Accretion Tectonics (RETREAT) GPS experiment, resulting in a very interesting and promising technique. In this technical report we describe the scientific motivations, the methodology and the procedures adopted to realize the first integrated semicontinous GPS network for monitoring fault-scale interseismic deformation in Italy. In the second and third sections we review some of the principals of GPS measurements, and describe the advantage and disadvantage of semicontinuous GPS style of deployment with respect to classical permanent and survey-mode experiments. Following sections describe the characteristics of our new network across the Montello thrust. It is worth remembering that a semicontinous GPS station cannot replace a continuous GPS site, but, in many cases, we believe that this new mode of GPS data collection may represent an important tool to help improving the details of the velocity gradients measurable across known, or unknown, active fault systems, and will certainly help in developing and testing of models of the seismic cycle in the very next future in Italy.

1. Scientific Goals

The Montello–Conegliano thrust is the most remarkable active tectonic structure of the Southern Alpine fault belt in the Veneto-Friuli plain (Figure 1), as a result of the conspicuous morphological evidence of the Montello anticline, which is associated to uplifted and deformed river terraces and diversion of the course of the Piave River. The presence of several orders of Middle and Upper Pleistocene warped river terraces [e.g. Benedetti *et al.*, 2000] in the western sector strongly suggests that the Montello-Conegliano anticline is active and driven by the underlying thrust. However, in spite of the spectacular geomorphic and geologic evidence of activity of the Montello-Conegliano thrust, there is only little evidence on how much contractional strain is released through earthquakes and how much goes aseismic [Galadini *et al.*, 2005]. The Italian seismic catalogues have very poor-quality and incomplete data for the events associated with the Montello thrust, leaving room for different interpretations, as for example the possibility that these earthquakes were generated by nearby structures. In this latter case, the whole Montello–Conegliano thrust would represent a major "silent", and locked, structure, because none of the historical earthquakes reported in the Italian Catalogues of seismicity for the past seven centuries can be convincingly referred to the Montello source. Alternatively, the Montello-Conegliano thrust may represent a creeping, or partially creeping, fault segment of the seismogenic Southern Alpine thrust front.

Geodetically derived kinematic models of the Adriatic microplate [Battaglia *et al.*, 2004; D'Agostino *et al.*, 2005; Serpelloni *et al.*, 2005] predict that about 2 to 3 mm/yr of the Adria-Eurasia plate convergence should be accommodated across this sector of the Southern Alps (Figure 2), suggesting that a substantial elastic strain accumulation, and velocity gradient, should be present and detectable by precise GPS measurements. However the Venetian side of the Southern Alpine chain is poorly covered by GPS stations (Figure 3), and the number of sites available do not allow for any detailed analysis of the pattern and shape of the velocity gradient across it, preventing any modeling of the current state of crustal deformation. For this reason, we designed and realized a new kind of GPS experiment across the Montello-Conegliano fault system, with the goal of measuring the rate and pattern of active deformation, and developing models of the interseismic strain accumulation (i.e., geometry, kinematics and coupling of the seismogenic fault/s).

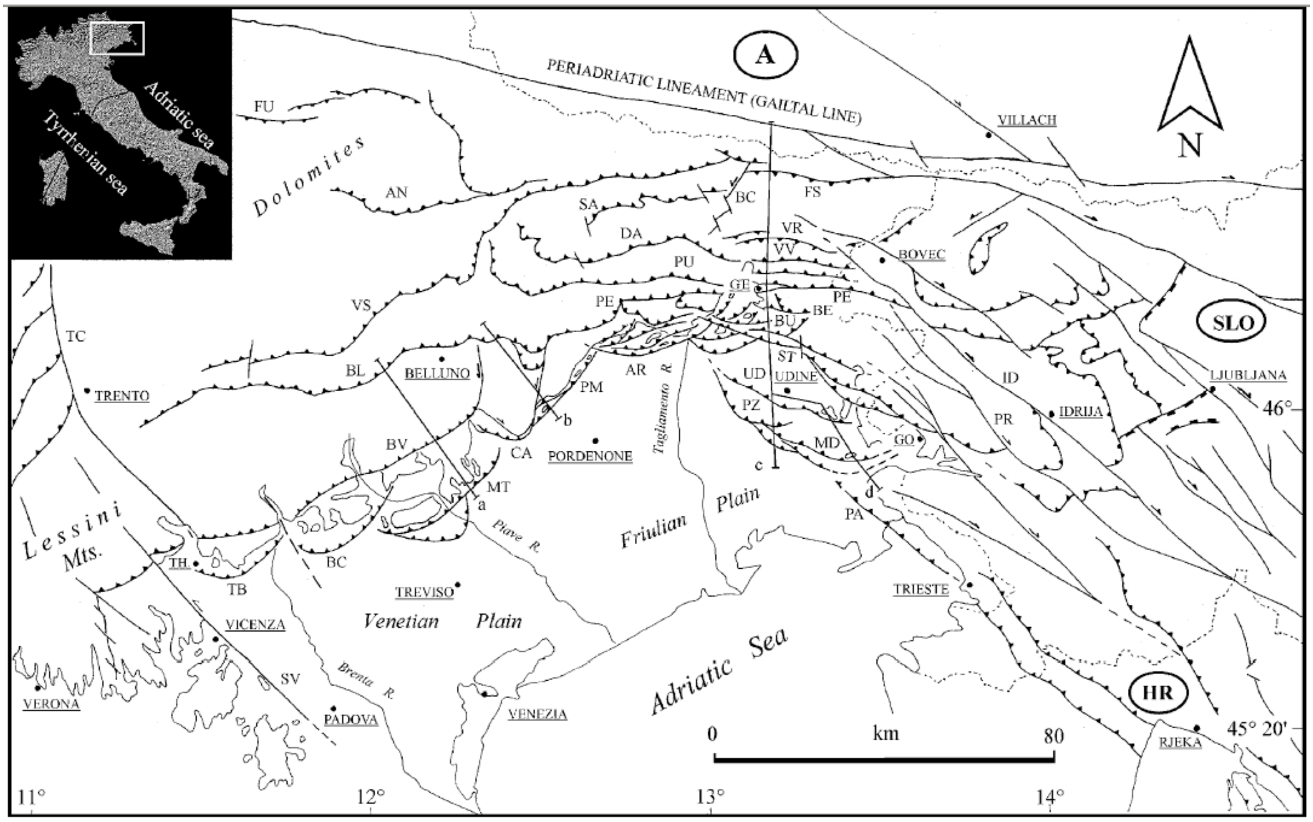


Figure 1. Structural model of northeastern Italy and western Slovenia showing the main thrust fronts of the Eastern Southalpine Chain [from Galadini *et al.*, 2005].

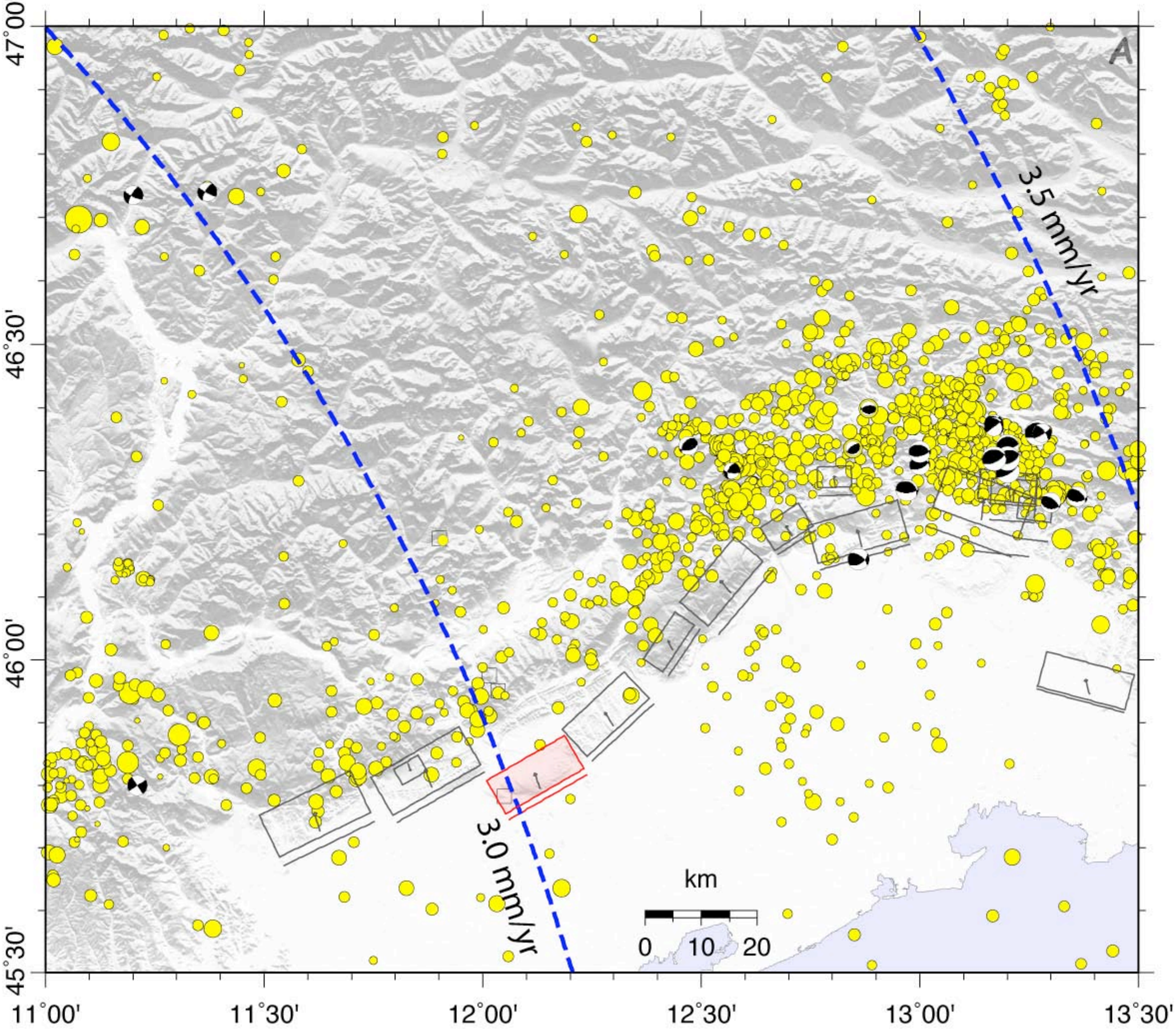


Figure 2. Seismotectonic map of the Southern Alps thrust front. Yellow circles show instrumental seismicity from the CSI 1.1 [Chiarabba *et al.*, 2003], and black beach-balls show focal mechanisms from the INGV RCMT and Harvard CMT catalogues. Grey boxes show fault from the DISS database [http://www.ingv.it/DISS]. The red box shows the Montello source. Blue dotted circles show the Adria-Eurasia great circles at 3 mm/yr and 3.5 mm/yr respectively, as obtained using the relative pole of rotation from Serpelloni *et al.* [2005].

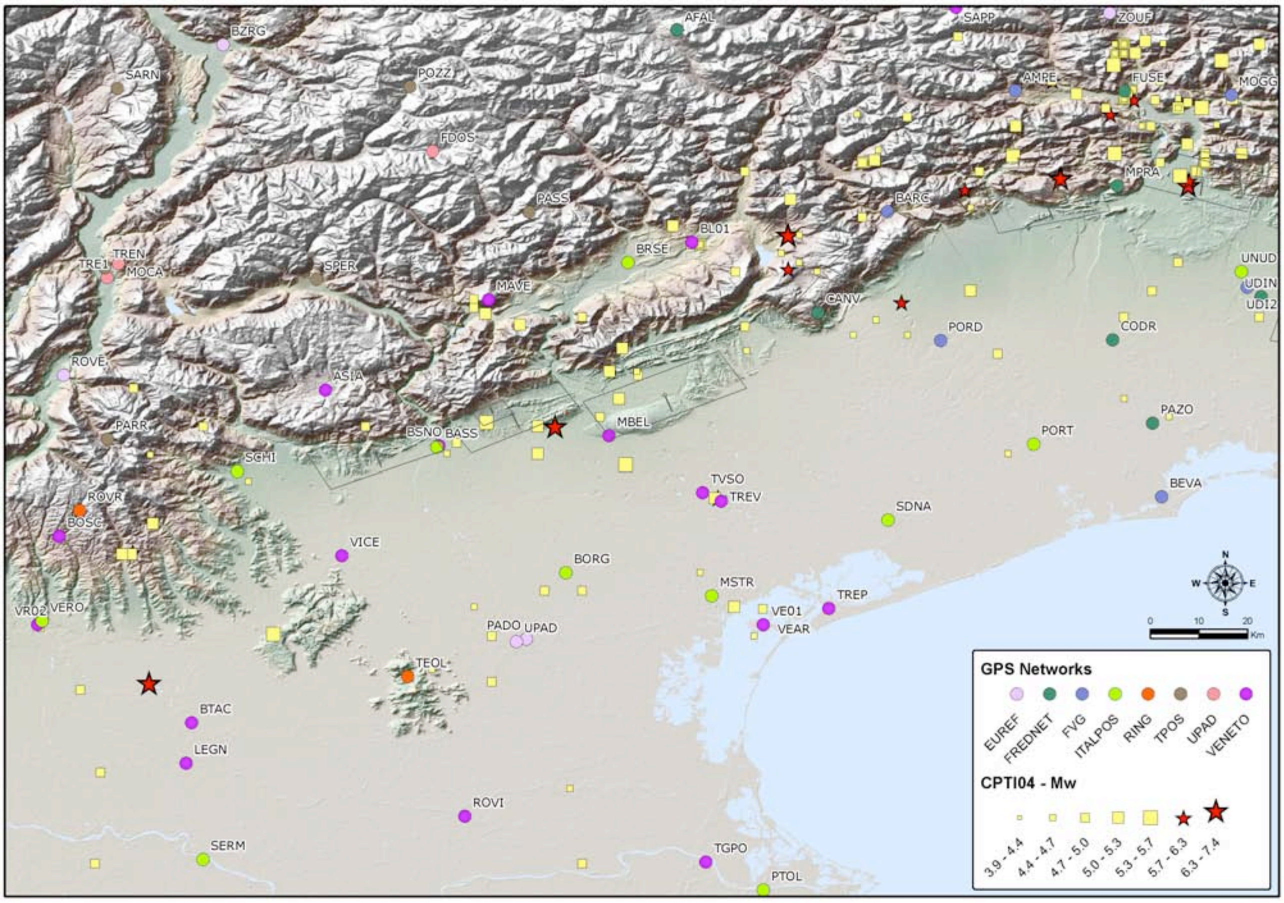


Figure 3. Map of the Southern Alpine region showing active faults from DISS3.0 and historical seismicity, together with existing Continuous GPS networks.

Modern GPS networks devoted to measure the local velocity gradients across active faults must be properly designed in order to fully capture the expected fault-scale tectonic signal, which can be later used to infer the geometric and kinematic properties of the fault. A possible, and relatively simple, approach, assumes that the measured velocity gradient results from the elastic deformation of the brittle crust in response to plate displacement away from the fault zone and ductile shear at depth. This conceptual model can be solved adopting the elastic dislocation theory [Okada, 1985] and it has been used successfully in several areas of the World [e.g., Vergne *et al.*, 2001; D'Agostino *et al.*, 2005].

The open issues regarding the Montello fault, in terms of seismogenic source properties, include:

1) the segmentation scheme applied to the Montello-Conegliano thrust, and to its seismic history;

2) the role of the "advanced" Montello thrust with respect to the northernmost fault related fold corresponding to the Pedemontana flexure, running from Veneto to Friuli region [Castellarin and Cantelli, 2006];

3) the way the Adria-Eurasia plate convergence is accommodated across this segment of the Southern Alpine thrust front;

4) the geometry and kinematics of the fault plane beneath and above the locking depth;

4) the fault coupling (i.e., the relationship between creeping and locking along the shallow and deeper fault plane).

While point 1) requires a denser network also along strike, including the detailed monitoring of the confining fault segments, the remaining points may be addressed by the use of a dense linearly developed (i.e., profile) array of station across the active fault segment. In this project, given its experimental and testing nature, and given that the GPS equipment available is quite limited, the new network has been developed as a dense GPS profile across the Montello fault, taking into account the available CGPS stations and the spatial resolution of the investigated tectonic signal.

Given the relatively small deformation rates (i.e. the velocity gradient between the Po Plain and the Alpine domain) expected across the area, and the importance of measuring vertical land movements in studying dip-slip faults, survey-mode GPS measurements would not guarantee the required accuracies and precisions. However, a very dense CGPS networks across all, or most of, active faults of the Alpine-Apennines belt is not practicable at present. The mode of GPS experiment proposed in this technical report, the so called semicontinuous GPS, may be a powerful tool to overcome the scarce accuracies of campaign GPS experiments, by providing an efficient tool to improve the spatial resolution of a continuous GPS network.

2. Comparison of GPS Geodetic Survey Methods

Geodetic GPS experiments are mainly conducted in two different modes: 1) permanent GPS (or continuous) and campaign GPS. Here we briefly describe and compare these methods in terms of advantages and limitations that might relate to specific requirements of a project specifically devoted to crustal deformation monitoring, and introduce a complementary class of GPS experiment, called semicontinuous.

1) In survey-mode GPS, campaigns are typically conducted every year or two over a period at least > 5 yrs. GPS antennas are typically mounted on tripods, centered over a permanent geodetic marker in the ground, with all the problems related to such kind of installations, and mainly the fact that the height of the antenna above the monument varies with each setup of the tripod and the ability to center the antenna and measure its height accurately depends on: a) the skill of the surveyor, b) the calibration of the tribrach, and c) the stability of the tripod. The fact that the antenna is physically located at a different point every campaign introduces another type of error. The phenomenon known as “multipath” occurs from the interference of phase arrivals from different paths that the satellite signal can take before reaching the antenna, for example, through ground reflections. This interference pattern can be very sensitive to the height of the antenna above the ground. In general, the outcome of multipath error is a systematic bias in the estimated coordinates of the station. Having the antenna set up at different heights during different surveys thus introduces a different bias each time the antenna is set up. A further possible problem at some GPS campaign sites is monument stability. Ultimately, epoch GPS must rely on long time periods (~10 yr) to produce accurate station velocities, in order to reduce the effect of setup errors, variable multipath errors, and other systematic and random errors in the epoch coordinate estimates. More recently, different types of self-centering geodetic markers and monuments have been tested and introduced in survey-mode GPS experiments (e.g., Anzidei and Esposito, 2003; http://www.unavco.org). However, if from one side the use of this kind of device reduce, or solve, the problem of variable antenna heights at different surveys, the temporal resolution of survey-mode experiments is still very limited, preventing any more detailed analysis of the time-varying position signal.

2) Permanent GPS is the ultimate method in terms of accuracy, and it mitigates many of the previously mentioned problems with survey-mode GPS experiments. The key advantages of permanent GPS are: a) the stability of the antenna, often mounted directly onto a very stable monument that is anchored deeply in bedrock, and b) the product that is a continuous time series of station position, which is important to characterize, and possibly mitigate, transient signals that may or may not be of tectonic origin. The two main disadvantages of permanent GPS are: a) for a fixed amount of funding, fewer stations can be installed, and b) siting and installation of a CGPS station can be difficult and time-consuming, requiring, for example, a permit to develop a permanent structure on the site, which may take a significant amount of time. Moreover, given other logistical issues (station accessibility, power or data transmission problems, etc) the location of a CGPS station can in some cases be a compromise, from a purely scientific point of view. These siting difficulties also add to the total cost, which may vary, depending on the monument used, but is now typically in the range of €5,000–€15,000 per station, excluding the GPS equipment. For a relatively small, set amount of funding, permanent GPS may not be an option to meet the goals of a geodetic project, particularly if relatively high spatial sampling is required to map the variations in the strain-rate tensor across a region.

3) Semicontinuous GPS (SGPS) is a recent concept. As the name suggests, the method involves a set of GPS receivers and antennas that are moved around a permanently installed network of “good quality” geodetic monuments, in a way that each station is observed some fraction of the time, with respect to a CGPS site, but with a higher temporal resolution than classic survey-mode GPS experiments. This survey-mode type of experiments has been successfully tested in several projects (http://wegener.unice.fr/data/PROJETS/SEMI/index.html; http://geodesy.unr.edu/networks/index.html; https://geodesy.geo.arizona.edu/pages/tectonic-geodesy-projects/joign-california.php). In practice, a set of GPS receivers can literally remain in the field for their entire life span, thus maximizing their usage, and

typically remain active at the same sites for several months during the year. The monuments, for this kind of experiment, must be designed with special antenna mounts so that the GPS antenna is forced to the same physical location at each site, and, in order to reduce the multipath error, positioned at the same height and correctly aligned to the north, above the permanently fixed geodetic marker. Self-centering devices allow to avoid errors in measuring the antenna height and in centering the antenna horizontally. The period of each yearly "session" depends on the design of the operations, and other climatic or logistical issues. Semicontinuous GPS, if well planned, allows to sample seasonal or transient tectonic signals. For example, if the number of sites is twice the number of receivers, then each station can be occupied on average 50% of the time, and therefore sessions of anywhere in the region of 1–3 months would be sufficient to sample the seasonal signal.

The semicontinuous GPS keywords are: low cost, rapid installation, and minimal permitting. In principle, we can think of SGPS as trading off temporal resolution for spatial resolution. The major advantages of semicontinuous GPS include:

a) SGPS stations are easy to realize and install (i.e., the geodetic marker is the only permanent object in the field), and do not require time-consuming, and experiment delaying, permitting;

b) enhanced spatial coverage as compared to continuous GPS (the cost savings over building permanent stations might be used to purchase more receivers);

c) enhanced temporal resolution than survey-mode GPS (being potentially able to capture seasonal signals);

d) velocity accuracies closer to continuous GPS than classic survey-mode GPS;

e) provide a way to optimally use the available campaign GPS equipment;

f) time to achieve specified velocity accuracy also closer to continuous GPS, as often the seasonal signal is a fundamentally limiting factor [Blewitt and Lavallée, 2002];

The major disadvantages of semicontinous GPS are:

a) the position time series is not continuous, but rather it is "intermittent", so a transient geophysical signal might not be resolved very well, or perhaps missed entirely if it occurred between occupations, the same problem can be encountered in case of measuring the co-seismic displacements, in case the receiver is not operating (even if, in this case, the better temporal resolution allow for a better computation of the co-seismic jump parameters);

b) the mobile equipment may be more susceptible to damage and power failure due to transportation, wind, variable whether conditions, which translates into a larger percentage of data lost, with respect to CGPS;

c) a disadvantage of semipermanent GPS is that telemetering, or remote control of the network, may not be available;

d) a major advantage of permanent GPS, as compared to semicontinuous GPS, is that a more robust monument can be constructed, significantly minimizing monument instabilities;

e) the height of a semicontinuous GPS monument can be another limiting factor, given is shallower installation, with respect to CGPS stations. This may cause problems in case of snow cover during the winter, or in selecting the correct position of the monument in case of obstacles.

3. Geodetic Requirements

For a scientific project that aims at mapping crustal deformation rates, a primary requirement is to sample sufficient stations spanning the region of interest with an appropriate spacing in order to be able to catch the expected tectonic signal. Furthermore, the station velocities must be determined to within errors that are significant smaller than the true (or expected) spatial variability in the velocity signal (i.e., the velocity gradient) in the area of interest. It might also be important to monitor possible time variation in the station position through time that might be of geophysical origin, or possibly due to some systematic error (such as seasonal variation in environmental conditions) that must be monitored and mitigated. Another important issue may also be a requirement on how quickly the velocity accuracy can be achieved to meet the goals of a specific project deadline. These considerations summarize the driving factors behind geodetic requirements. In turn, they can lead to very specific requirements for particular projects, which translate into details of experiment design. We now briefly consider each of these main general areas that drive the geodetic requirements and relate them to the GPS survey methods discussed previously.

3.1 Spatial Resolution

In general, the spatial resolution of a GPS network should be compatible with the characteristic distance scale over which the geophysical signal varies. A key feature of crustal strain associated with the earthquake cycle is that, typically, the characteristic distance scale corresponds to the thickness of the seismogenic zone within which faults are typically locked between earthquakes (see Figure 4). Therefore, in the interseismic period, assuming a locking depth of 10-15 km, the surface strain rate tends to be smoothed and cannot change very much over distances <15 km. Maximum variation in strain rate is typically found adjacent to active faults that have a large slip rate at depth, or with shallow locking-depths. A reasonable nominal spacing for most geodetic networks measuring fault-related strain rates is therefore in the range of ~10–20 km across the fault trace (along strike the spacing depends on the fault system segmentation). However, when very large uncertainties on the fault geometry exist, or when competing models of potential, but rather unknown, seismogenic active faults need to be tested, some more details of the velocity gradient may be required, and a smaller spacing in the GPS stations may be necessary (see Figure 4).

Spacing larger than the depth of the seismogenic layer (i.e., the locking-depth) would only serve to constrain the level and style of tectonic activity within a region, but would be less capable of identifying the currently active faults. It is worth noting that a broadly spaced network, such as the INGV-RING CGPS network, with typical spacing > 50 km, serve a fundamental role in providing a regional reference frame and a regional-scale tectonic context to more focused investigations, and it can help to identify regions that deserve more focus in future projects.

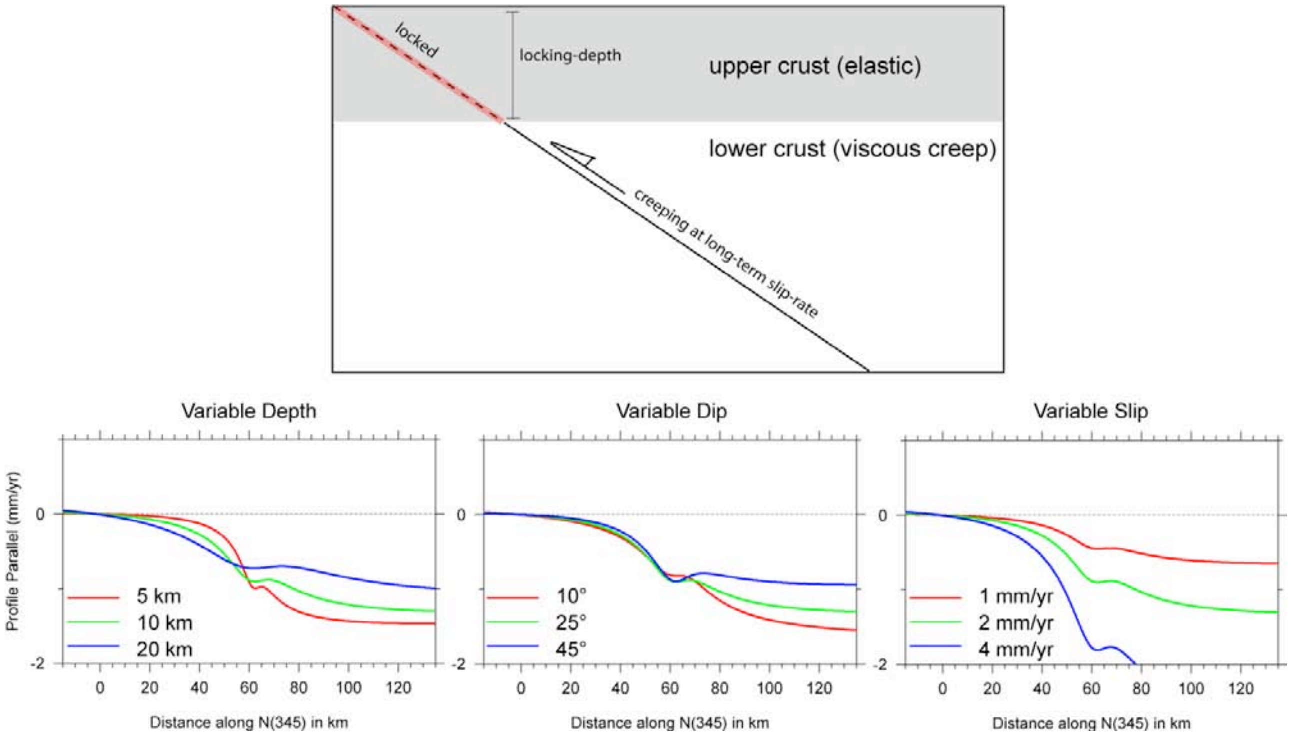


Figure 4. Conceptual model of interseismic deformation and model velocity gradients at varying fault plane parameters. Dislocation model of interseismic deformation assumes that the brittle crust is deformed by continuous aseismic creep, presumably occurring at rates comparable to the long term geologic slip-rates, of the fault plane in the lower crust. Velocity gradients are obtained by varying each parameter while keeping fixed the others.

3.2 Velocity Accuracy

The simplest and common goal of a GPS geodetic network is to resolve, with the adequate accuracy, the velocities of all stations. This raises two major problems: 1) how long will it take to achieve the required velocity accuracy? and 2) how often must the time series of stations positions be sampled in order to reduce both random and systematic errors? Both points assume that the unknown tectonic motion of a site is linear in time (i.e., assuming a constant velocity), and that any non-linear motions can be either modeled (such as solid Earth tides) or a posteriori characterized (such as seasonal coordinate variation).

In case of survey-mode GPS experiments, typically ~10 yr are required to achieve an accuracy of <<1 mm/yr in station velocity [Williams *et al.* 2004]. On the contrary, continuous GPS stations can achieve this accuracy within 1.5–2.5 yr, when it becomes possible to characterize the seasonal signal [Blewitt and Lavallée, 2002]. After 5 yr, permanent station velocity accuracy in a regional reference frame is typically ~0.1 mm [Davis *et al.*, 2003].

Stochastic models of permanent GPS time series show that monument stability can be a real issue with regard to how often it makes sense to sample the site position in order to properly resolve the station velocity [Langbein and Johnson, 1997; Williams, 2003]. Most GPS time series, like most natural processes, are characterized by a power-law noise, implying that frequent sampling will improve the velocity estimation, but only to a limit, beyond which higher frequency sampling does not help [Agnew, 1992]. This suggests that a semicontinuous observational strategy might be close to optimal in terms of resolving station velocity, with respect to a CGPS station, assuming an adequate sampling of the seasonal cycle and the diurnal cycle. For this reason, the fundamental epoch estimate should be based on a full 24 hours session, and the station should be visited several times per year.

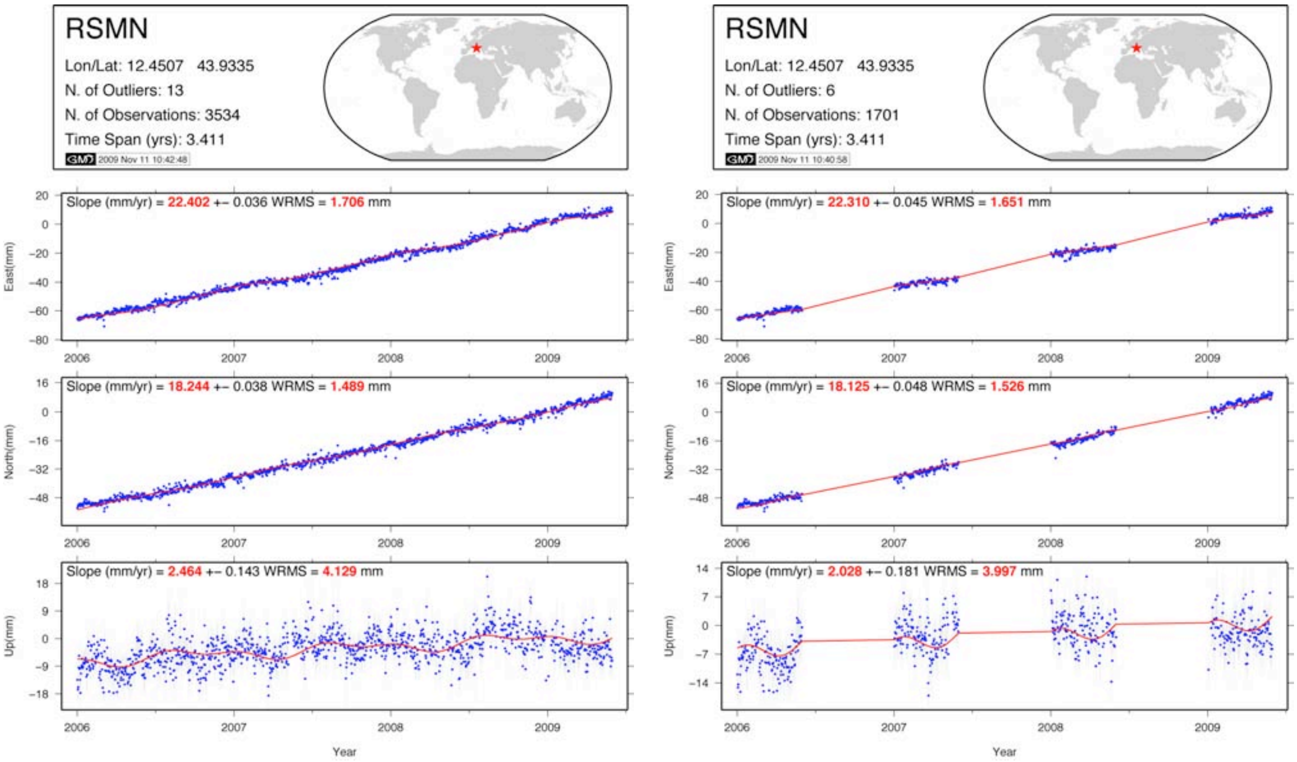
Assuming as error model the one described in Mao *et al.* [1999]:

$$\sigma_r^2 \cong \frac{12\sigma_w^2}{gT^3} + \frac{a\sigma_f^2}{g^b T^2} + \frac{a\sigma_{rw}^2}{gT}$$

where g is the number of measurements per year, T is the total observation time span of observations, a and b are empiric constants, given in Mao *et al.* [1999] ($a = 1.78$; $b = 0.22$), it is clear that for velocity accuracy, the most important factor is the time span elapsed between the first and last sessions/campaigns, and, secondly, the percentage of time occupied (or the number of measurements per year).

From a general point of view, a semicontinuous GPS experiment may be conducted following different strategies in planning the yearly sessions, but the key rule is that sites must be visited several times per year in order to sample through the seasonal cycle. Typical sessions may be in the range of 2 to 12 weeks. However, from a practical point of view, a regular schedule may not be possible to keep anyway, especially in case of changes in the weather and climate conditions that make one site, or part of the network, impossible to be visited or occupied during the whole year. For example, monuments at top of mountains, or at higher latitudes, may be covered by snow a significant fraction of time during the year. Moreover, during winter time, due to low temperatures and limited insolation, power failure (if solar panels are used) and consequent data loss, is most frequent. This implies that the observation strategy of a semicontinuous GPS network can vary depending on the climate and weather conditions of the area during the year.

In Italy, particularly in the Apennine and Alpine domains of northern Italy, this seasonal variability in the weather conditions may be a limit in managing semicontinuous GPS experiments. However, by planning "spring-summer" and "autumn-winter" sessions, depending on site location within the network, instead of weekly or monthly sessions during the year, still allow the achievement of the required accuracies. It is however worth remembering that this may cause the loss in the capabilities of detecting transients or seasonal features in the position time series, if occur during the winter time.



A **B**

Figure 5. Position time-series (IGS05) and linear velocity estimates. A: continuous GPS time-series, where annual and semi-annual seasonal terms are solved together with the linear velocity term; B: sub-sampled GPS time-series, where only the first 6 months of each year are used, while estimating both seasonal and linear terms.

In Figure 5 we show how velocity estimates performed using the whole 3.4 yrs time-series (A) and the 6 months sub-sampled time-series (B) of the same GPS station match quite well. Figure 5-A shows the IGS05 position time-series of the RING station RSMN (San Marino), which is installed following the same procedures that will be later described, and adopted for our new semicontinuous network. Although this test does not exactly reproduce the same conditions of semicontinuous experiments, since in Figure 5-B the antenna is not physically removed and replaced at each session, the estimated velocities agrees at < 0.5 mm/yr level for both horizontal and vertical components.

3.3 Temporal Resolution

In the previous section we discussed about how often GPS measurements should be made and for how long in order to resolve station velocities with the accuracies required for measuring tectonic strains, assuming that measuring the constant velocity term is the goal of our project. However, if temporal variation in station velocity is expected, or if transient phenomena are important scientific objectives (i.e., slow earthquake detection, post-seismic deformation monitoring), then permanent GPS networks are still mandatory, and semicontinuous GPS would not be temporally optimal in this scenario. However, with semicontinuous GPS the chances of discovery a tectonic transient would have actually been enhanced due to the higher spatial resolutions provided, with respect to CGPS networks.

Probably, the most obvious transient deformation that might be observed by a GPS network is a large earthquake. In this case, given that semicontinuous GPS stations can be quickly redeployed to a more optimal configuration, in order to better detect the coseismic displacement, because all sites would have been pre-surveyed, and to monitor postseismic deformation. After an earthquake occur, SGPS stations can be set, like permanent stations, in continuous operation for as long as the investigation requires. Moreover, additional instruments can be rapidly deployed to unoccupied monuments, and new SGPS sites, if allowed by the lithological or substrate conditions, can be quickly installed and integrated into the existing network.

As already mentioned, in terms of temporal resolution, a disadvantage of SGPS, with respect to CGPS, is that if telemetering may not be available for all sites, at least, and the knowledge of a transient or co-seismic deformation may be delayed by data acquisition latency.

4. The Conegliano-Montello Semicontinuous GPS Network

From this section, we start discussing the specific details of our GPS experiment. Given the small number of GPS receivers available (i.e., 5), and given the already mentioned scientific goals, our network has been developed as a linear SSE-NNW oriented array, constructed about parallel to the Adria-Eurasia convergence direction predicted by plate kinematic models. It is worth noting that, with respect to the previously mentioned key-rules of semicontinuous GPS, our equipment is not moved only over sites belonging to the same network, but when not observing the new Montello network, GPS receivers are moved to the Northern Apennines semicontinuous sites belonging to the former RETREAT GPS network [Cavaliere *et al.*, “La Rete GPS del Progetto RETREAT”, submitted to Rapporti Tecnici INGV].

Our new experimental network is designed with the goal of measuring tectonic strain rates spanning the region bounded by the Northern Adriatic block and the Alpine domain, and to develop models of how the deformation is accommodated across the the Conegliano-Montello segment of the Southern Alpine thrust. Geodetically derived kinematic models of the Adriatic microplate (see Figure 2) predict that about 2 to 3 mm/yr of the Adria-Eurasia plate convergence are likely to be accommodated across this sector of the Southern Alps, suggesting that a substantial elastic strain accumulation, and velocity gradient, should be present and detectable by precise GPS measurements. The Southern Alps show that the mountain front in the Veneto Region is active in the Plio-Pleistocene time only east of the Schio-Vicenza line, and for this area, the Montello hill is considered as the most external seismogenic source. However, as already mentioned, despite the spectacular geomorphic evidence of the Montello anticline, no historical earthquakes can be clearly associated to the Montello thrust. Debate exists regarding the real seismogenic nature of the Montello thrust, and the state of coupling of the thrust fault, in terms of ratio between locking and shallow creeping. Moreover, the seismogenic role of the more internal “Flessura Pedemontana” is still unknown and should be taken into consideration.

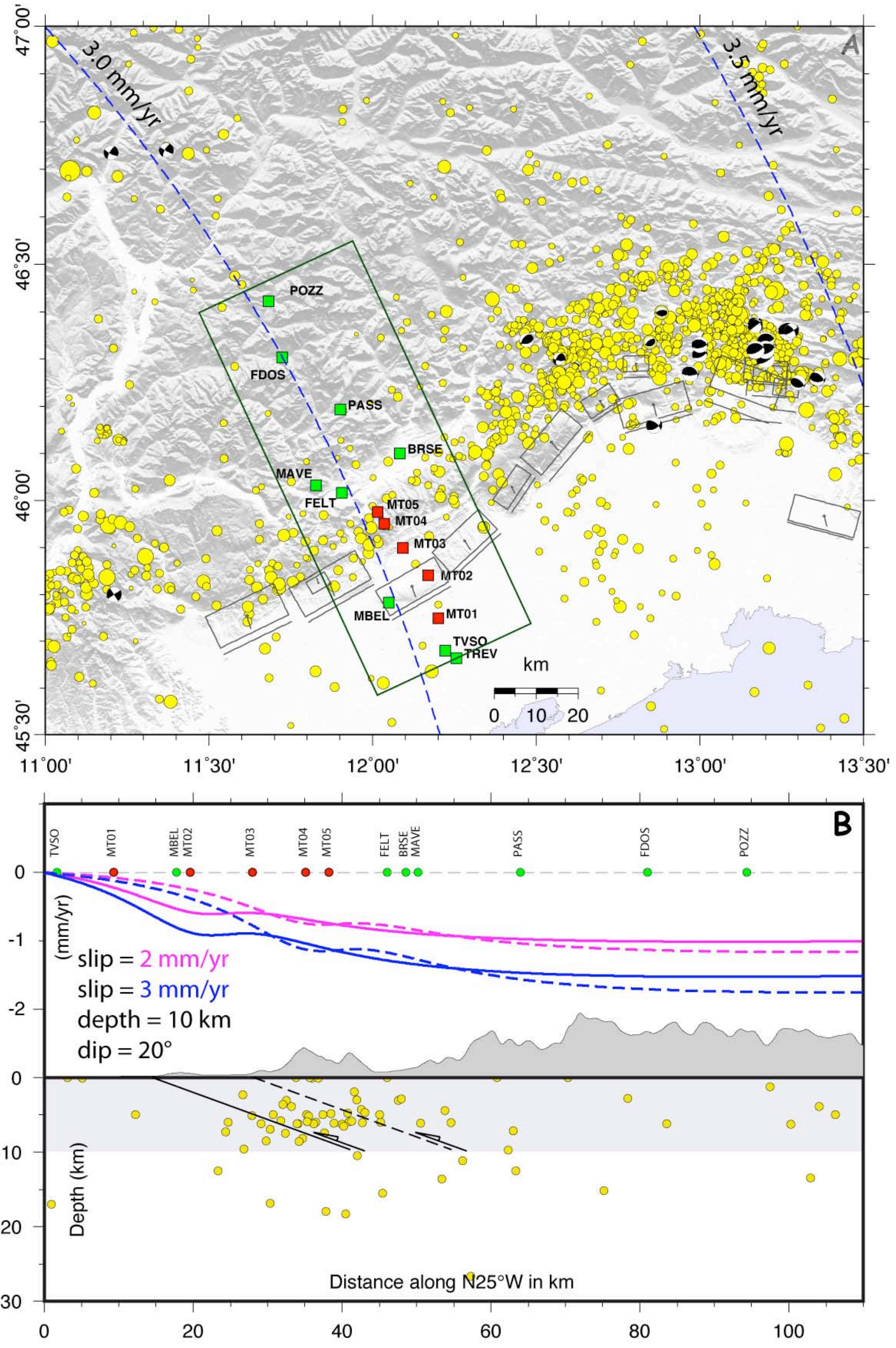


Figure 6. A: summer 2009 configuration of the Conegliano-Montello GPS network where green and red points show the position of already existing CGPS stations and of the new semicontinuous GPS sites, respectively. B: N25°W cross section showing topography, crustal seismicity and position of GPS stations along the profile. Pink and blue lines show the velocity gradients (w.r.t. Treviso station) predicted by dislocation models of alternative thrust faults.

Given the large uncertainties regarding both geometric and kinematic characteristics of the potentially seismogenic fault in this sector the Southern Alpine thrust front, our network should be able to capture the fault-related elastic strain signal, in the framework of the regional kinematics, and allow the developing of more detailed models of the local deformation. For this reason we develop simple forward elastic dislocation models of competing thrust faults (see Figure 6) and use the modeled velocity gradients to drive the choice of stations spacing. Figure 6 shows that our scientific goals require the development of a new GPS network able to measure differences in the stations velocities ≤ 2 mm/yr, with velocity accuracies ≤ 0.5 mm/yr and a spatial resolution of 5-10 km.

Few CGPS sites, belonging to commercial or public networks, mainly realized for topographical purposes, are operating in the study region, but mostly have poor monument quality. In any case, given the few GPS receivers available for this project, we use the available CGPS sites to design our semicontinuous network. In one case, MBEL, preliminary analyses of data show some clear inconsistencies in the velocity trend, and given that its key-location, we built an additional sites on the Montello hill. Moreover, one of the new sites, MT05, is going to be re-designed and become part of the INGV RING continuous GPS network.

4.1 The Network Geometry (and Future Development?)

Figure 7 shows the present-day distribution of GPS sites available along the Southern Alpine thrust front. Clearly, given the actual spacing, only the regional, and first-order, features of the deformation can be detected by using only the CGPS stations. Our new semicontinuous network will allow, in ~3 years, to measure the local strain signal along the Montello thrust fault.

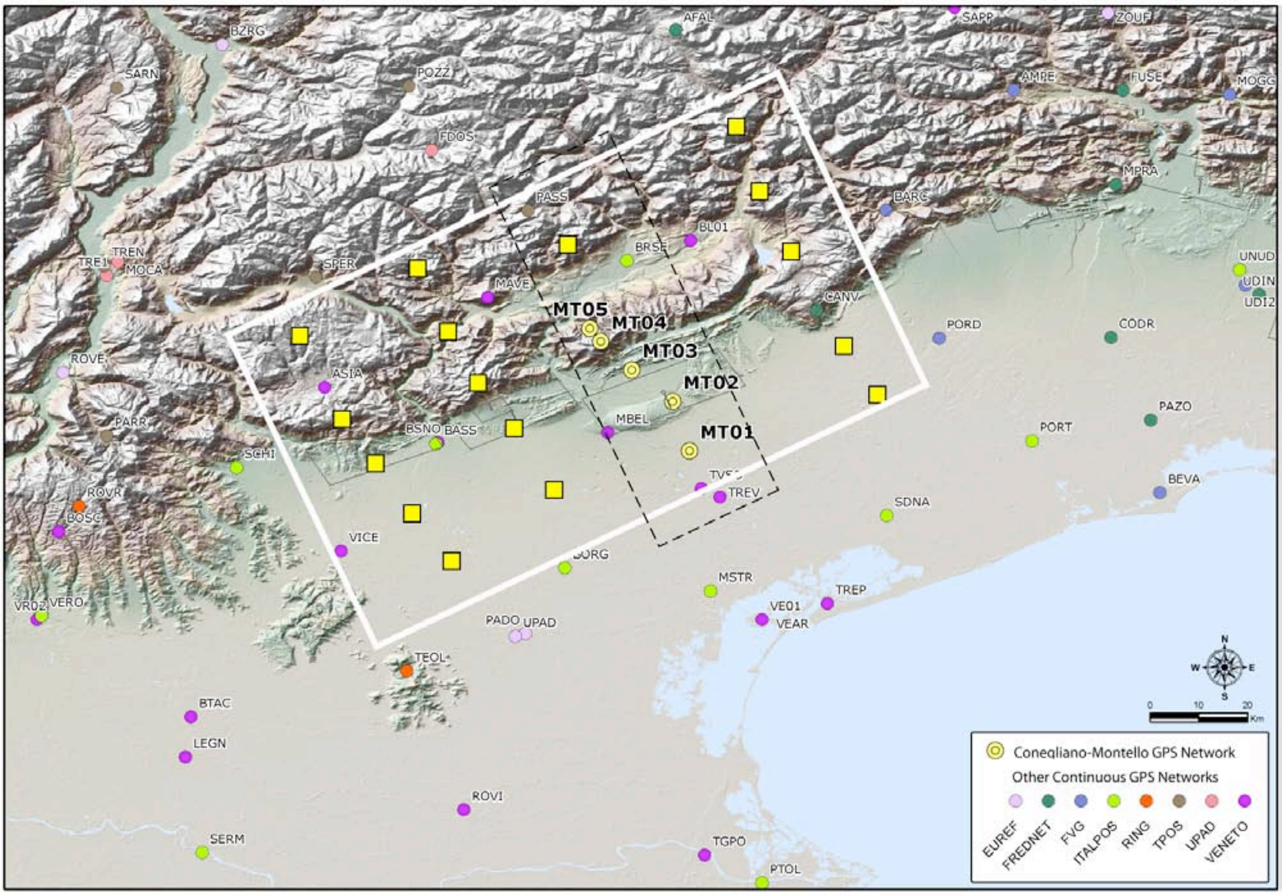


Figure 7. The configuration of the Conegliano-Montello semicontinuous GPS network (yellow circles within the dotted black box) with respect to existing continuous GPS stations belonging to several regional and national networks as at the end of summer 2009. Yellow squares show an hypothetical configuration of a wider semicontinuous GPS network for monitoring fault-related crustal strains across the Southern Alpine active thrust front in the Veneto region.

Potentially, a denser semicontinuous GPS network devoted to monitoring fault scale crustal strains can be imaged (Figure 7). With 10 receivers available, it would be possible to occupy 6 months per year 20 sites, with spring-summer sessions for the sites at higher elevations, and autumn-winter sessions for stations at lower altitudes and in the Po Plain. It is worth noting that a certain number of continuous GPS sites should be preferably included in a more regionally developed network, in order to guarantee the presence of a back-bone infrastructure that can precisely provide a regional kinemamic framework.

5. Station Design

In this Section we describe the criteria used for choosing and realizing the semicontinuous GPS stations, and describe the characteristics of the GPS instruments and site installation used for the Conegliano-Montello prototype SGPS network. Our experience will certainly help in testing, and eventually, improving standard installations for future deployments.

5.1 Semicontinuous Site Requirements and Design

Other than the criteria discussed in Section 3, about the general network design needed to meet the required scientific goals, there are several practical factors considered in realizing a semicontinuous GPS network. The principle is to maximize the quantity, quality, and usefulness of the resulting geodetic data set. It is worth noting that stringent requirements cannot generally be imposed if an adequate spatial resolution (in our case, ~10 km) must be maintained. This usually requires a site to be selected within a radius of ~1-2 km of a target candidate site. The following points consider each important aspect of semicontinuous GPS siting, in an approximate order of priority:

1) Accessibility. It is worth noting that the realization of a semicontinuous GPS site requires the use of electrical devices (e.g., drills, vacuum, etc….), which would ask for the use of portable power generators, and other heavy staff. For this reason, a semicontinuous GPS site must be easily accessible with 4x4 cars. Moreover, other than the realization phase, good and easy accessibility of a site means that more sites can be visited the same day. The network has been designed in a way that routinely operations can be sustained by a 2-3 days trip from INGV in Bologna, considering that up to 3-4 stations can be visited in one day. Weather conditions can vary greatly between the Po Plain and the Alpine sectors during the seasonal cycle, so it is crucial to choose sites that do not require long off-road driving. Navigation to the sites must be made facilitated by a GPS-enabled field computer with digital, or handheld GPS, and a detailed station book.

2) Monument Stability. In the case of a GPS station for crustal deformation monitoring, the biggest issue is whether the monument drilled into the rock, or the concrete (in case of building), can accurately represents the motion of Earth’s crust. Within the concept of semipermanent GPS networks, monument installation must be inexpensive and quick, so the monument stability issue, in this case, is particularly important (for CGPS installations, in fact, the money invested and the permissions obtained usually allow for deeply anchored monuments). Obviously, one wants to avoid anomalous motions, also because, at best, the problem will be detected after years of fieldwork. However, depending on the geology of the investigated area, realizing a shallow geodetic monument may be a big issue and a limiting factor. In many cases, particularly with soft rocks or unconsolidated sediments, a low stable building can be a good choice for realizing a semicontinuous GPS site. Given the short scale variability of geological outcrops, the geological record and vegetation distribution in many mountains areas of Northern Italy, the choice of the substrate is a critical point, which must be carefully evaluated.

3) Security. Given that semicontinuous sites are supposed to be left in the field for several weeks to several months each year, and given that fences or other fixed security infrastructures are not feasible for semicontinuous GPS, particular attention must be considered when selecting points for building new sites. When possible, a private or a public/State area, where free access to the land is already prohibited or at least limited, should be given priority. Most of times, other government lands are good for access and easy permitting, but they can be poor for security. Moreover, stations must be selected, when possible, so that they cannot be easily seen from the road. In any case, the impact of a stolen receiver is immense. From one side, the loss of solar panels and batteries is minor, from the other side loss of the receiver can make future measurements a problem, while considering that the site will have to be abandoned, and so all previous data collected there may be wasted. Nevertheless, security cannot become a sort of obsession, otherwise no data would be collected at all. Although a 100% secure semicontinuous site may be impossible to built, one can develop some tools and minimally impacting infrastructures to be used at least as deterrents, such as fixing the receiver and the solar panels to the rock outcrop using epoxied steel rods and padlocks, in a way to minimize any potential damage or theft.

4) Sky Visibility. Sites with the best sky visibility above 15° elevation are preferred. The tops of hills are preferred. Poor sky visibility to the north is acceptable, due to the fact that GPS satellites do not track within a ~35° cone around the north celestial pole. South-facing slopes can be selected, for example, also because of optimal orientation for powering solar panels on the ground. However, again, monument stability and accessibility issues may took priority with respect to sub-optimal sky visibility problems.

5) Multipath Environment. It is worth noting that good sky visibility also tends to mitigate multipath, because there will generally always be a direct GPS signal that is stronger than any reflected signal. Any significant (large, smooth) reflective surfaces that might create significant multipath should be avoided. Metallic structures such as fences and radio should also be avoided if possible. However, even relatively poor multipath environments can ultimately be acceptable, since modern GPS receivers can already apply some signal-processing technique to correct, or mitigate, the problem. Also in this case, spatial sampling, accessibility, security, and rock condition took usually the priority.

6) Data transmission. Although adding a telemetry system to a semicontinuous GPS station significantly enlarge the costs for each site, the use of GSM or GPRS/UMTS modems, when the signal is obviously present at the site, allows for remote monitoring of the state of functionality of the network, at least in terms of data recorded, external power level of charge, etc, if not for remote data downloading. In case of optimal exposure for insulation, and appropriate security of the site, spatial sampling and monument stability took the priority with respect to availability of GSM signals. However, if the session plan is to leave the equipment at the same site for several months during the year, having a means to remotely check the status of the stations is a very important feature, which can help in saving time (and money) and minimize data loss. Hopefully, future improvements and cost reduction of telemetry system will certainly allow for the realization of less expensive telemetry semicontinuous GPS stations.

The design of a semicontinuous GPS station, in order to fulfill the requirements described in the previous sections, should follow some key-rules and principles that can be summarized as following:

a) it has to be “mobile”, because in order to minimize the costs and permitting issues it has to be designed to leave as little a permanent footprint as possible when the station is not occupied by a GPS receiver;

b) is has to be “stable”, and the monument must be designed in order to guarantee the antenna to be attached to the rock outcrop, or building concrete, and maximize the stability, using the same method at each site to guarantee an homogeneous network;

c) it has to be “easy” to set-up, in order to monument the site as quick as possible, so that GPS data acquisition can begin immediately and more sites can be installed in one day, and, possibly, in order to allow an easy and accurate quick set-up by non expert operators (i.e., students);

d) the set-up has to be “repeatable”, in order to ensure the antenna is mounted precisely in the same position (horizontally and vertically) at each station every session, in order to eliminate eccentricity and mitigate multipath errors in the determination of stations velocity;

e) it has to be “modular”, in order to have interchangeable components among stations and to facilitate operations of on-site testing and repair, and, eventually, swapping of parts;

f) it has to be instrumentally “uniform”, in order to have functionally identical stations, so that the equipment available is not specific to certain stations, and thus logistical efficiency is improved;

g) it has to be “invisible”, in order to be difficult to discover accidentally, minimizing security issues;

h) is has to be “secure”, in order to minimize vandalism or theft, if accidentally discovered;

i) it has be “independent”, in order to adequate power and reliability while unattended for up to several months and maximize data collection;

l) it has to be “robust”, in order to minimize damages due to animals, weather and transportation.

5.2 Monumentation

In order to pursue points a), b), c) and d) described in the previous section, we choose a monument design developed by Mr. Massimo Bacchetti, at the Department of Physics (Sector of Geophysics) of the University of Bologna, and tested in the framework of the RETREAT GPS project [Cavaliere *et al.*, “La Rete GPS del Progetto RETREAT”, submitted]. The GPS antenna is mounted on a steel mast, screwed on a steel marker, fixed with epoxy resins into the substrate (Figure 8), as described in more details in the RETREAT network INGV Technical Report. The MAX-MOUNT is a relatively cheap and easy to install geodetic monument, which guarantees an easy and very precise re-positioning of the GPS antenna at each survey.

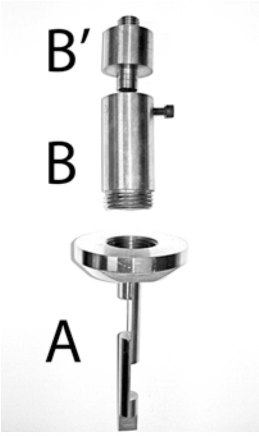
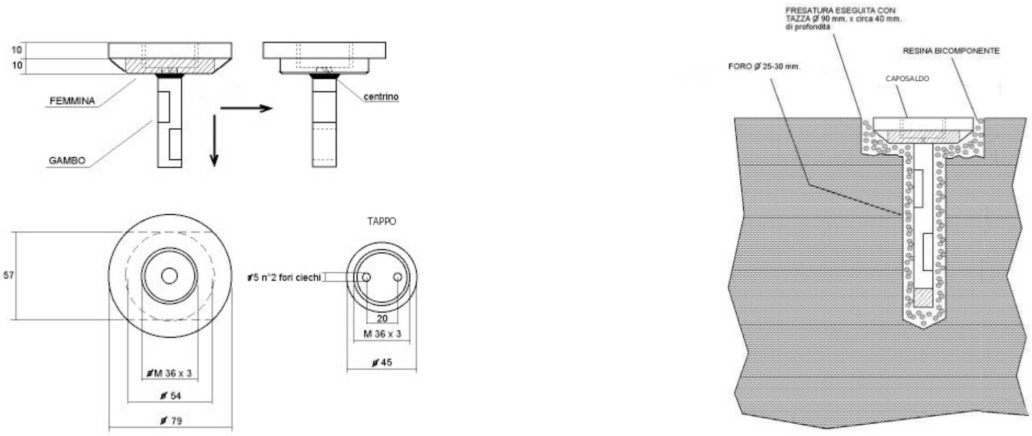


Figure 8. MAX-MOUNT type of GPS monument. A: geodetic marker; B: antenna mount, composed by a steel mast (B), which is screwed on the marker (A), and B', which is a horizontally 360° adjustable part, fixed on B.

5.2.1 The Geodetic Marker

The marker is a machine-controlled made stainless steel rod, with a M36 thread (mm 36 x 3) that allows the antenna mount to be perfectly screwed on, and leveled with a specifically designed tool (patent N. BO2004A000404) that allows an easy installation and a very precise leveling of the steel rod into the substrate (rock or concrete), guaranteeing that at each survey the antenna is correctly leveled without need to re-leveling. The steel rod, whose length can vary depending on the mechanical characteristics of the substrate (from 50 to 300 mm), after precise leveling is fixed with epoxy. The leveling device maintains the marker leveled into the substrate resisting the forces developed during the epoxy hardening phase, which can vary depending on the temperature and humidity conditions (0.5 to 6 hours, with values of 2 hours for temperatures between 10°-20°).



A **B**

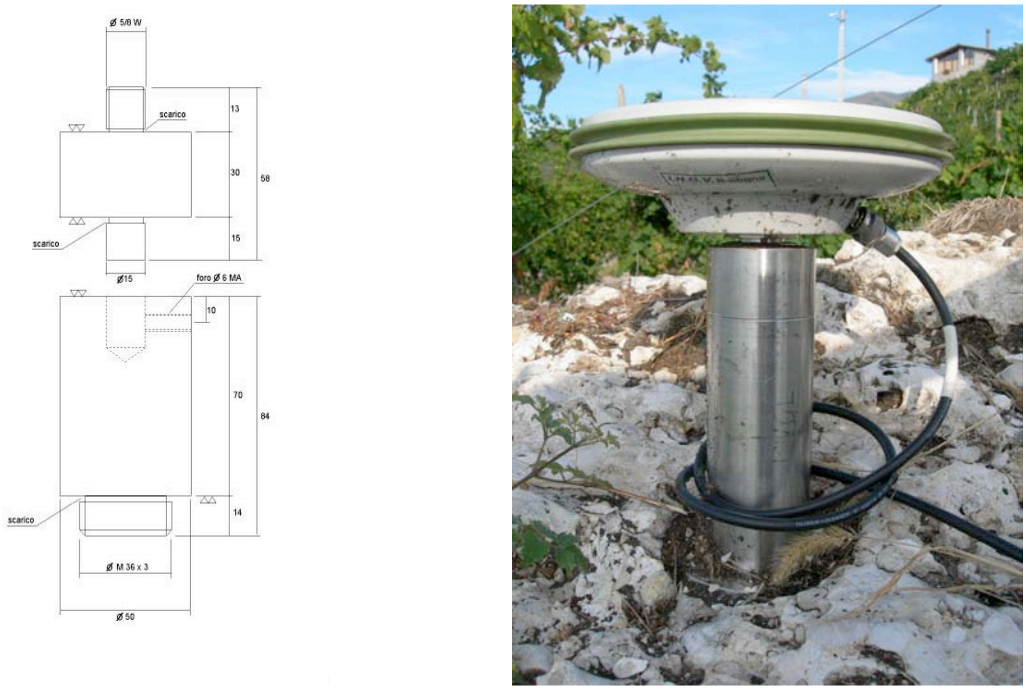
Figure 9. MAX-MOUNT GPS marker, technical design (A) and 2D section (B).

Figure 10 shows the different phases of a typical installation of the MAX-MOUNT geodetic marker on a concrete platform, but the same procedure is followed for rock outcrops. At the end of the installation, the only footprint left in the field, as requested by point a) in the previous section, is the marker surface, where the thread is protected by a steel or plastic cap screwed on it (Figure 10-I).

Figure 10. Realization phases of a MAX-MOUNT geodetic marker at site MT02.

5.2.2 The Antenna Mount

The antenna mount is a machine-controlled made stainless steel mast composed by two distinct elements (Figure 11). The first, whose length can vary depending on the site visibility conditions from 10 cm to 20 cm, is screwed on the leveled geodetic marker, the second element can rotate by 360° in order to accurately orient the GPS antenna to the North, and than is fixed at the correct orientation by a grain steel.

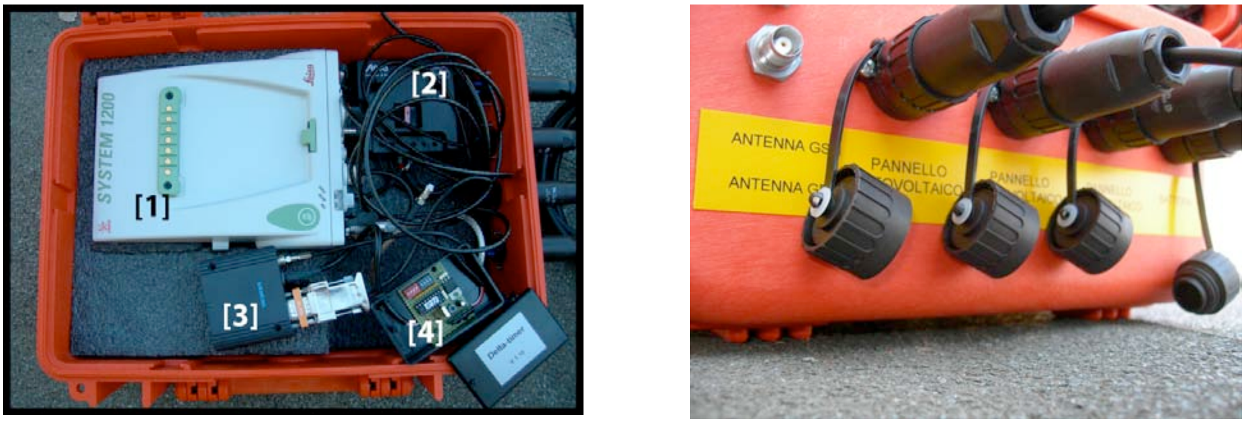


A B

Figure 11. The MAX-MOUNT antenna mount. Technical design (A) and installed on a MAX-MOUNT geodetic marker (B).

5.3 GPS Equipment and Receiver Enclosure

As described at points c) and f), uniformity in the GPS equipment allows to have functionally identical stations, so that the equipment available is not specific to certain stations, and thus logistical efficiency, interchangeability among components of stations facilitates operations of on-site testing and repair. In order to maintain homogeneity with the GPS equipment installed on the INGV-RING CGPS networks, we use Leica instruments, and in particular we use LEICA GRX1200GGPRO receivers and LEIAX1202GG antennas. This AX1202 geodetic antenna (see Figure 11-B) is lighter and smaller than choke-ring antennas, being more suitable for semicontinuos experiments. The receiver, with other electronic components, is housed in a plastic waterproof case (Figure 12), properly designed and built in the INGV-Bologna geodetic laboratory for this experiment.



A B

Figure 12. A: the plastic case containing the receiver [1], the power regulator [2], the GSM modem [3] and the delta-timer [b]. B: lateral panel of the case with the waterproof connections for the GPS antenna, the solar panels and the external batteries.

The receivers are all equipped with 4GB compact flash memory cards, and set for dual acquisition sampling rates, allowed by the receiver firmware. The standard 30 seconds data are stored in 24 hours daily raw data files, and the 10 Hz data are temporally stored in a ring-buffer, erased every 30 days. This set up allows, in case of significant earthquakes, to measure the full spectra of ground shacking and co-seismic rupture.

5.4 Power and Reliability

Semicontinuous GPS stations, if power connection is not available, must be powered by means of photovoltaic panels in order to guarantee reliability of the data acquisition during the monthly long sessions. Photovoltaic panels are used to power an external 12V (40A, or larger amperage) sealed battery, housed in a smaller plastic box, and charging is controlled by a power regulator, inside the receiver case, to which more batteries and solar panels can be connected. It is worth noting that semicontinuous GPS stations must be mobile and should left minimum fingerprints on the site during station inactivity, so big or fixed infrastructures for handling the photovoltaic panels must be avoided as much as possible. For this reason, the use of solar panels may be critical both in terms of security issues (i.e., visibility of the station) and for the installation of the panels themselves. In order to minimize as much as possible logistical problems and station visibility, we use flexible photovoltaic panels, specifically designed for extreme weather and outdoor conditions (Figure 13).


A B

Figure 13. A: FlexCell (27Wp) photovoltaic panel; B: Enecom (70 Wp) photovoltaic panel.

	Enecom	FlexCell
Power (P)	70 Wp	27 Wp
Operating voltage (Vmpp)	16,16 V	15 V
Operating current (Imp)	4,6 A	2,4 A
Open circuit voltage (Voc)	19,52 V	23 V
Short circuit current (Isc)	5,1 A	1,8 A
Dimensions	1110 x 536 x 1,5 mm	1305 x 642 x 2 mm
Weight	1300 gr	2900 gr
Cost	513 € (+tax)	600 € (+tax)

Table 1. Technical data of the photovoltaic panels used in the experiment.

We tested to different manufactured panels (Table 1 and Figure 13), both assembled using polycrystalline solar cells, embedded in a special type of plastic. The constructive processes of both types of panels guarantee a high level of efficiency, equal to that of the rigid panels commonly in use at remote INGV monitoring stations. This class of photovoltaic panels is extremely flexible, very light, waterproof, resistant and completely recyclable. The technical characteristics of this product enable it to be used on curved surfaces (e.g., rock outcrops) and on any item that needs to be flexible and hard wearing. Clearly, our choice of using polycrystalline-based photovoltaic panels is driven by the necessity of balancing the ratio between efficiency of the solar cells and the ability of using diffuse solar light on non-optimally oriented panels, the letter being a characteristic of polycrystalline solar cells with respect to monocrystalline solar cells that, instead, provide a higher efficiency. In our installations, the flexible panel is fixed on the ground following the outcrop shape while trying to have the panels as much as possible oriented to the south and to have half of the panels flat and half inclined at 30°.

In the end, given its constructive and technical characteristics, other than its significantly lower cost x Watt, the Enecom® photovoltaic panels resulted to be more appropriate for semicontinuous GPS with respect to the FlexCell® panels.

5.5 Security

Security, as previously mentioned, is a big issue in semicontinuous GPS experiments. Semicontinuous stations are vulnerable because usually are left in the field for a significant longer time span than classic survey-mode GPS (so the exposure is higher) and the realization of fences or other additional infrastructure to ensure a higher security level, such as for continuous GPS stations, is not possible. It is worth noting that there is almost nothing we can really do to preserve a remote GPS station from vandalism and theft, if this is the real goal of a vandal. However, we can try to mitigate the risk by choosing the appropriate location and use some, simple, security systems during the installation, with the goal of, at least, discourage malicious.


A B

Figure 14. A: the plastic case containing the receiver secured with steel cables and steel padlocks to a metal ring fixed with epoxy in the rock outcrop (or in the concrete); B: solar panels secured by preventing the bolt steel with eyelet that to be unscrewed.

In our experiment, the plastic bag housing the receiver (Figure 14-A) is secured by means of a steel cable, with loops welded to the extremities, assured on a pin with ring, fixed with epoxy in the substrate, by means of steel padlocks. The solar panels, with 6 eyelets for fastening the edges, are anchored to the substrate by means of threaded steel rods, embedded with epoxy into the substrate (rock outcrop or concrete), which are screwed with a steel bolt with eyelet. Bolts are then connected by a bar punched through L-profile, locked with padlocks so as to prevent its to be unscrewed.

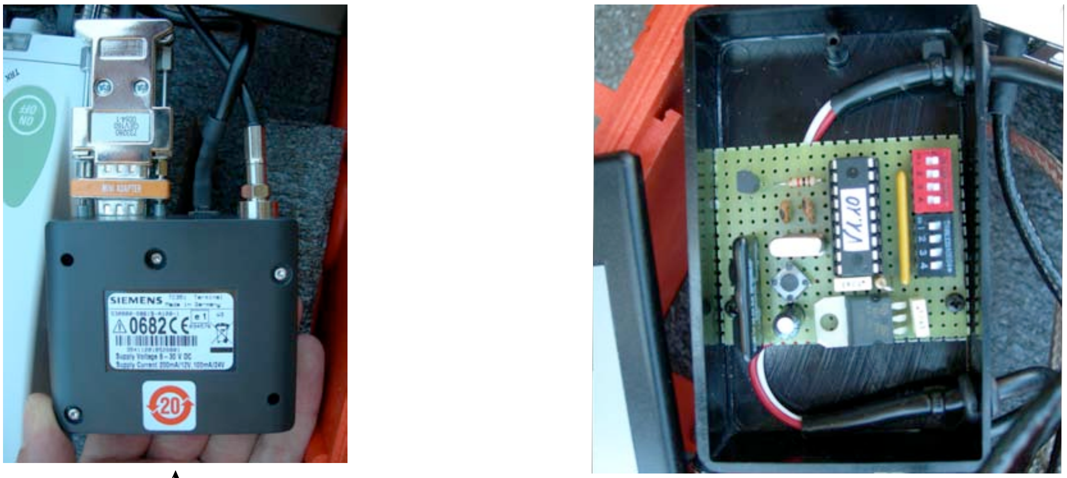
In areas prone to summer grazing, stations may be fenced in with wooden poles and steel cables (Figure 15). The wooden poles are strung in metal bases, attached to the substrate through threaded steel rods anchored by epoxy resin. In this way, after removing the station at the end of the session, only the steel rods top, protected by plastic caps, are left in the field.

A B

Figure 15. A: a wooden mobile pole stuck in the metal base and B: example of a light mobile fence, made by connecting wooden poles by means of steel cables.

5.6 Remote Control

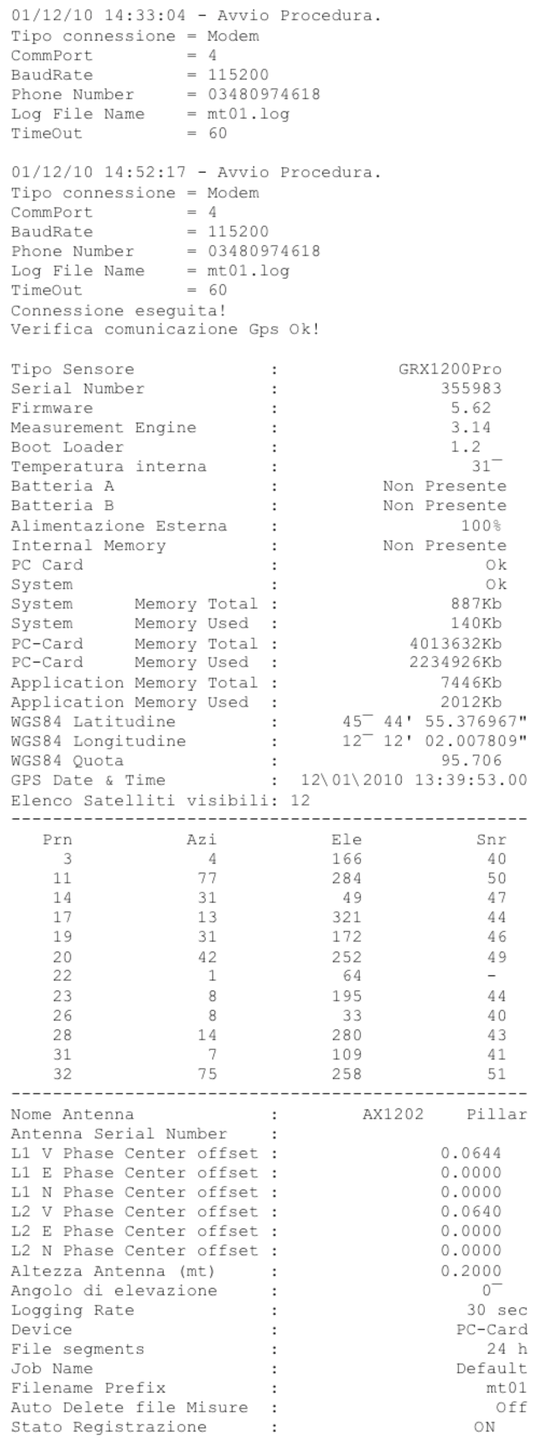
Remote control and data telemetry systems significantly increase the budget of semicontinuous GPS experiments. However, as already mentioned in Section 5.1, if the GSM signal is present at a site, the use of a telemetry system would allow for remote monitor of the state of functionality of the network, at least in terms of data recorded, external power charging level, etc. If the session plan is to leave the GPS equipment at operating for several months during the year, having a mean to remotely check the status of the stations is a very important feature that would help in saving time and money, and minimize data loss, alerting the operator in case of failures of GPS stations. For this reason, while taking into account that the GSM signal availability is not a priority with respect to security and stability of the site, we use GSM modems (Figure 16) to query the stations from remote.



A B

Figure 16. A: the GSM modem used, model Siemens TC35i connected to the RS-232 serial port of the receiver; B: the programmable delta-timer connected to the modem.

In order to query the stations from our laboratory we use a software developed by a collaboration between INGV and Leica Geosystem Italy, which consists on a series of executable commands working under MS-DOS operating systems (a Unix version is still under testing) that have been used in a batch script. The main commands of this suite allow to retrieve information about the state of functionality of the receiver (`inf_1200`), to configure the receiver (`cfg_1200`) and to download the data (`dwn_1200`). In particular, given that data downloading through GSM is both time consuming (i.e., expensive) and power consuming, we only routinely (one or two times a week) query the stations to obtain diagnostic information of each station (Figure 17).



```
01/12/10 14:33:04 - Avvio Procedura.
Tipo connessione = Modem
CommPort         = 4
BaudRate         = 115200
Phone Number     = 03480974618
Log File Name    = mt01.log
TimeOut          = 60

01/12/10 14:52:17 - Avvio Procedura.
Tipo connessione = Modem
CommPort         = 4
BaudRate         = 115200
Phone Number     = 03480974618
Log File Name    = mt01.log
TimeOut          = 60
Connessione eseguita!
Verifica comunicazione Gps Ok!

Tipo Sensore             :            GRX1200Pro
Serial Number            :                355983
Firmware                 :                 5.62
Measurement Engine       :                 3.14
Boot Loader              :                 1.2
Temperatura interna      :                   31¯
Batteria A               :          Non Presente
Batteria B               :          Non Presente
Alimentazione Esterna    :                  100%
Internal Memory          :          Non Presente
PC Card                  :                    Ok
System                   :                    Ok
System      Memory Total :                 887Kb
System      Memory Used  :                 140Kb
PC-Card     Memory Total :             4013632Kb
PC-Card     Memory Used  :             2234926Kb
Application Memory Total :                7446Kb
Application Memory Used  :                2012Kb
WGS84 Latitudine         :      45¯ 44' 55.376967"
WGS84 Longitudine        :      12¯ 12' 02.007809"
WGS84 Quota              :                95.706
GPS Date & Time          :  12\01\2010 13:39:53.00
Elenco Satelliti visibili: 12
--------------------------------------------------
   Prn           Azi           Ele           Snr
     3             4           166            40
    11            77           284            50
    14            31            49            47
    17            13           321            44
    19            31           172            46
    20            42           252            49
    22             1            64             -
    23             8           195            44
    26             8            33            40
    28            14           280            43
    31             7           109            41
    32            75           258            51
--------------------------------------------------
Nome Antenna             :        AX1202    Pillar
Antenna Serial Number    :
L1 V Phase Center offset :                0.0644
L1 E Phase Center offset :                0.0000
L1 N Phase Center offset :                0.0000
L2 V Phase Center offset :                0.0640
L2 E Phase Center offset :                0.0000
L2 N Phase Center offset :                0.0000
Altezza Antenna (mt)     :                0.2000
Angolo di elevazione     :                    0¯
Logging Rate             :                  30 sec
Device                   :                 PC-Card
File segments            :                    24 h
Job Name                 :                 Default
Filename Prefix          :                    mt01
Auto Delete file Misure  :                     Off
Stato Registrazione      :                   ON
```

Figure 17. Example of the `inf_1200` command output. The most important information regard the charging level of the external battery units, the GPS satellites visibility and the space available in the memory card.

The use of GSM modem increases energy consumption, and this aspect must be taken into account when configuring and sizing the solar panels and batteries installation. The GSM module is bypassed by a delta-timer, which is used both to turn off and on the modem at different times during the day, and to resent its configuration each day at least. This, from one side allows to reduce the power consumption and prevents the need to manually reset the modem.

5.7 Routine Installation and Measurement Strategy

Once a semicontinuous GPS station is realized, its installation is very rapid and easy and takes less than 1 hour each (Figure 18). The operations required are: a) mount and orient the geodetic antenna; b) install and lock the photovoltaic panels using the steel rods in the ground and plug the panels cables and battery cable into the dedicated connections; c) configure the receiver (if not already configured in the laboratory) and lock the bag with padlocks; d) if present, install the mobile fence using the steel rods present in the ground; e) say hello and good luck.

Figure 18. Typical installation and final configuration of a semicontinous GPS station belonging to our Conegliano-Montello network. The network station book is available in the Appendix A.

As regard the session planning, as already mentioned for this experiment we only planned a 3-6 months spring-summer session, only one site (MT01) where power connection is available worked continuously from 2008. Mid of October, the stations have been uninstalled and moved to occupy other semicontinuous sites in the Northern Apennines, belonging to the former RETREAT GPS network. However, in case of future development of the mobile semicontinuous GPS network in the Southern Alpine region (see Figure 7), the session plan would be that of measuring in a spring-summer session all the sites at higher altitudes and in a autumn-winter session the sites at lower altitudes and in the Po-Plain.

Acknowledgements

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Appendix A

The Conegliano-Montello semicontinuous GPS stations Books

STATION NAME *Centro Sociale di Santandrà*

REGION *Veneto* CITY *Povegliano (TV)*

ADDRESS *Via Borè n°10 , Santandrà*

M
T
0
1

LATITUDE 45.748706

LONGITUDE 12.200835

ELEVATION 112.02

SUBSTRATE *Concrete building*

MONUMENT *Max Mount 20 cm*

DIRECTIONS From Treviso to Santandrà. At the roundabout take the 1st exit and then turn left in via Borè. The station is on the top of building. You need a scale to reach.

NOTES Inside the right door of the building there is the switch to power the station.

GSM Signal: Strong

Land Property: Public

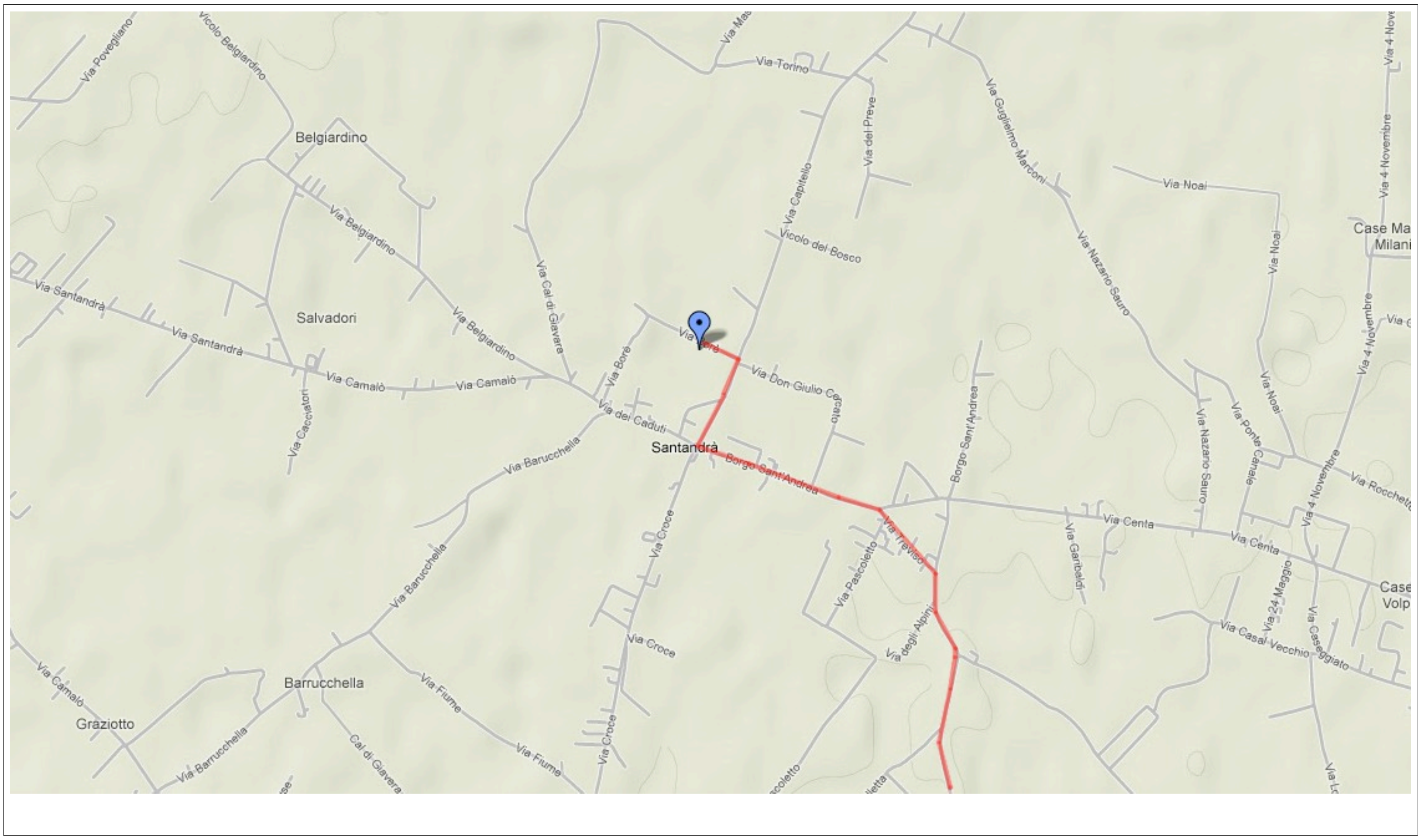
Access: Restricted

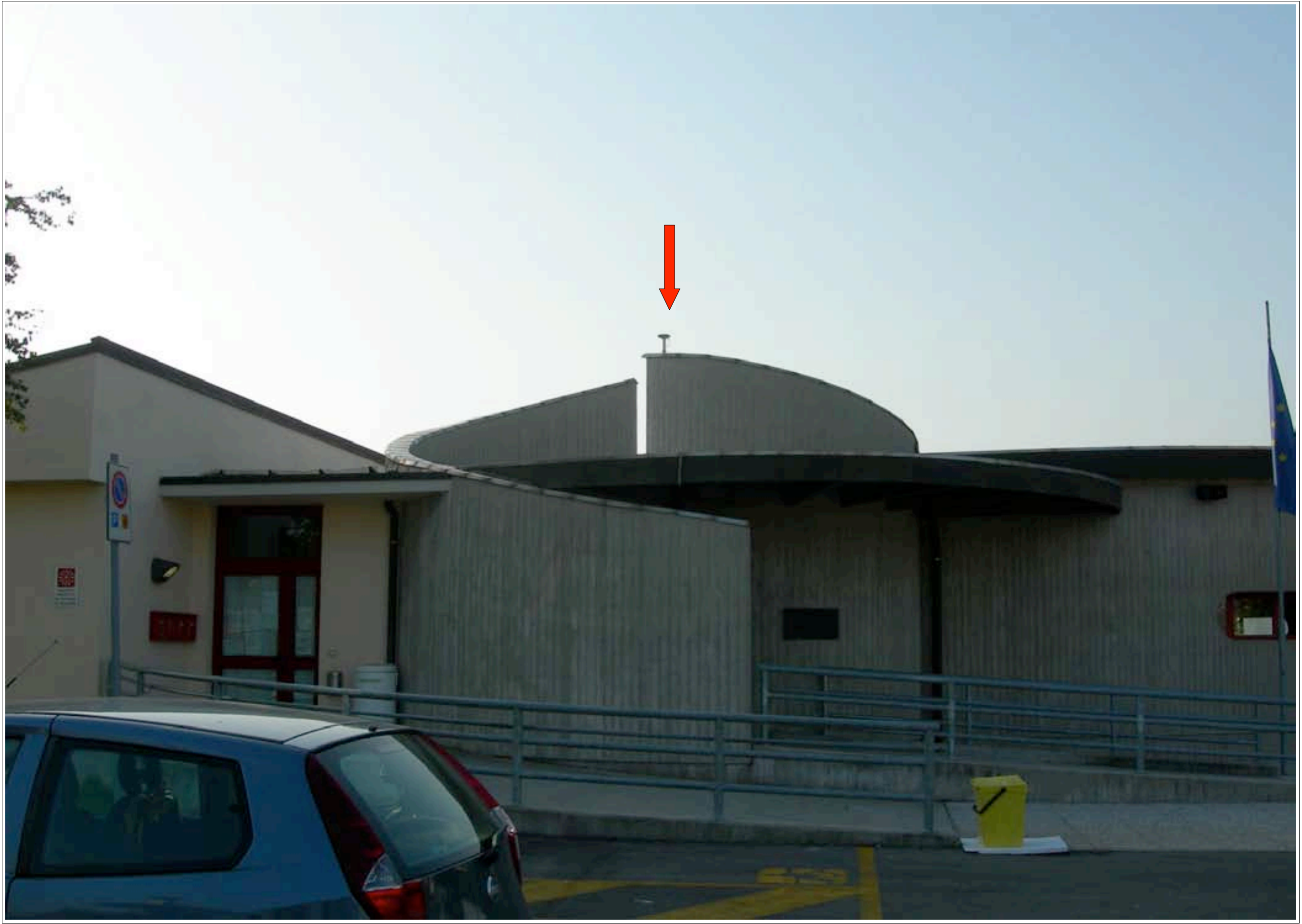
4x4 Car: No

Security Level: High

Security System: No

Mobile Fence: No





STATION NAME *Edison stoccaggio CN5*

REGION *Veneto*

CITY *Nervesa della Battaglia*

ADDRESS *Via Lauigi Lama, Santa Croce*

M T 0 2

LATITUDE 45.840319

LONGITUDE 12.170162

ELEVATION 219.16

SUBSTRATE *Concrete platform*

MONUMENT *Max Mount 15 cm*

DIRECTIONS From Treviso to Nervesa della Battaglia, follow the Montello direction, take Via Decima Armata. Arrived to Santa Croce turn left an continue along Via Lama for 2km. The station is on the left, inside a Edison S.P.A. protected area.

NOTES

GSM Signal: Weak

Land Property: Private

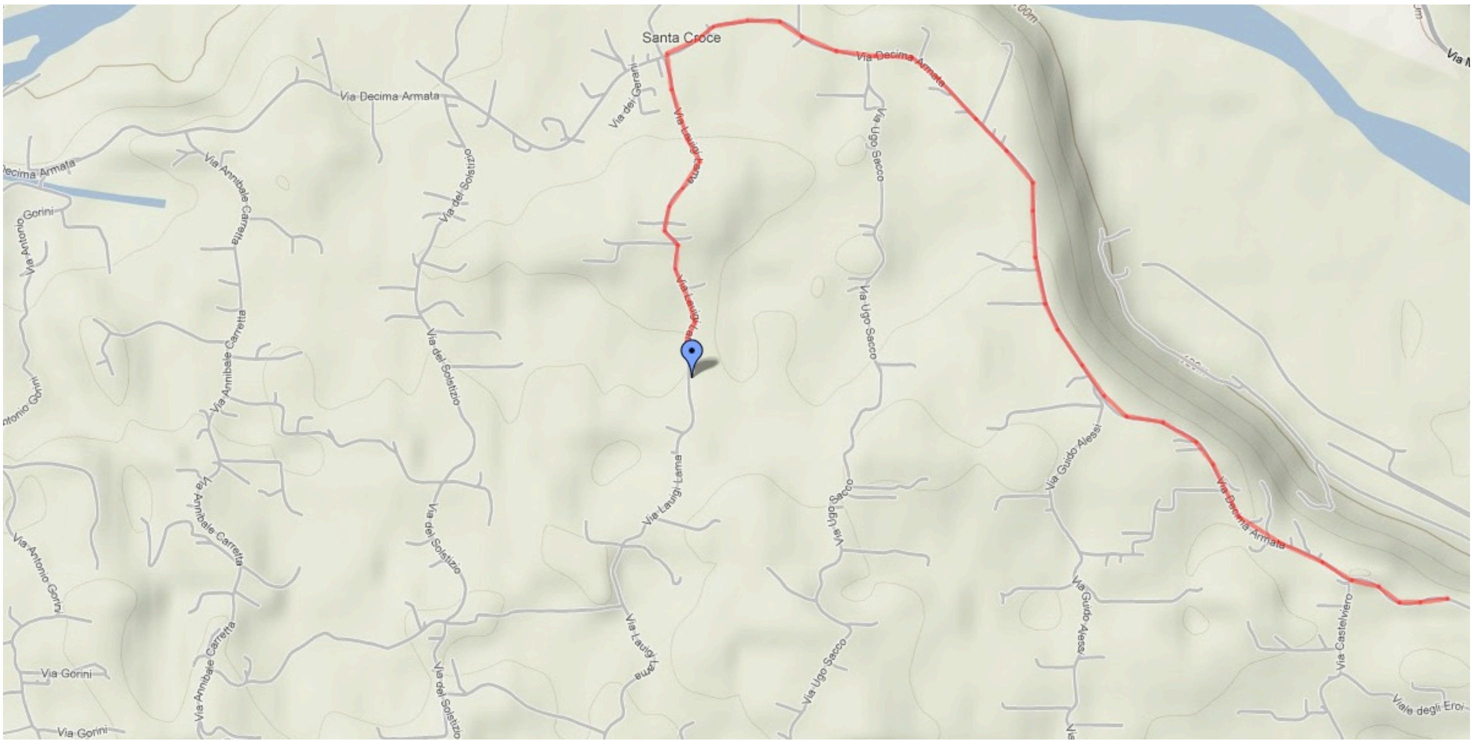
Access: Restricted

4x4 Car: No

Security Level: High

Security System: No

Mobile Fence: No




CN 5
VIETATO
L'ACCESSO
A PERSONE
E MEZZI NON
AUTORIZZATI
ATTENZIONE
GAS

STATION NAME *Prosecco Arman*

REGION *Veneto* CITY *Farra di Soligo*

ADDRESS *Via San Vigilio, Farra di Soligo (TV)*

MT03

LATITUDE 45.898775

LONGITUDE 12.093653

ELEVATION 297.67

SUBSTRATE *bedrock*

MONUMENT *Max Mount 15 cm*

DIRECTION From Treviso to Farra di Soligo turn right in via San Vigilio and follow the indications “Chiesa di San Vigilio”. At the church continue along the steep hill for 100 m. The station is inside the vineyard on the rigth.

NOTES

GSM Signal: Medium

Land Property: Private

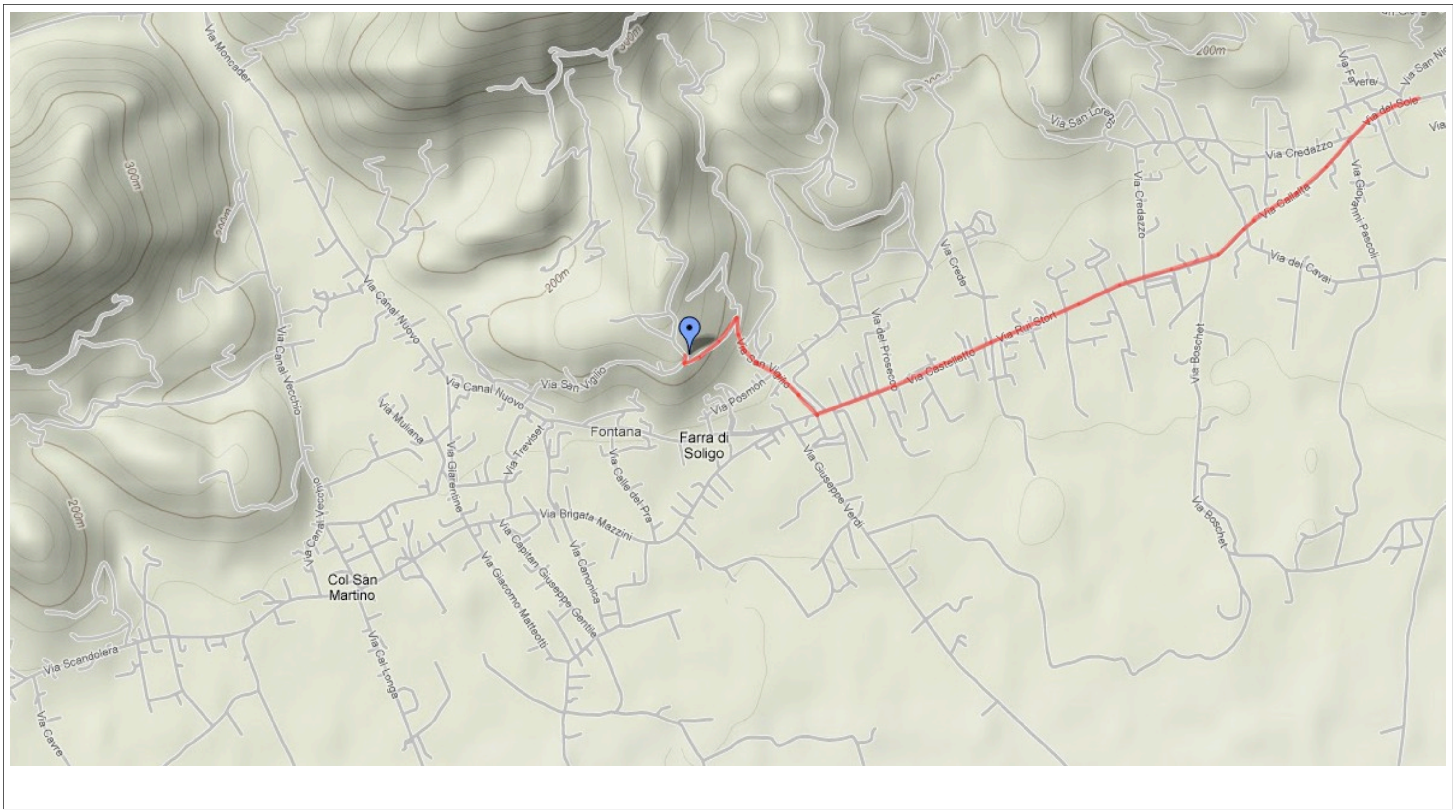
Access: Open

4x4 Car: No

Security Level: Low

Security System: Lock & Steel Cable

Mobile Fence: No



MT04

STATION NAME *Malga Forconeta*

REGION *Veneto* CITY *Valdobbiadene*

ADDRESS *Località Pianezze*

LATITUDE 45.950907

LONGITUDE 12.035963

ELEVATION 1468.35

SUBSTRATE *bedrock*

MONUMENT *Max Mount 10 cm*

DIRECTIONS From Malga Mariech turn right and cross the parking, overcome the enclosures and continue to Malga Forconeta. The geodetic marker is on the rock outcrop behind the house, the receiver and photovoltaic panels are close the wall.

NOTES

GSM Signal: No

Land Property: Public

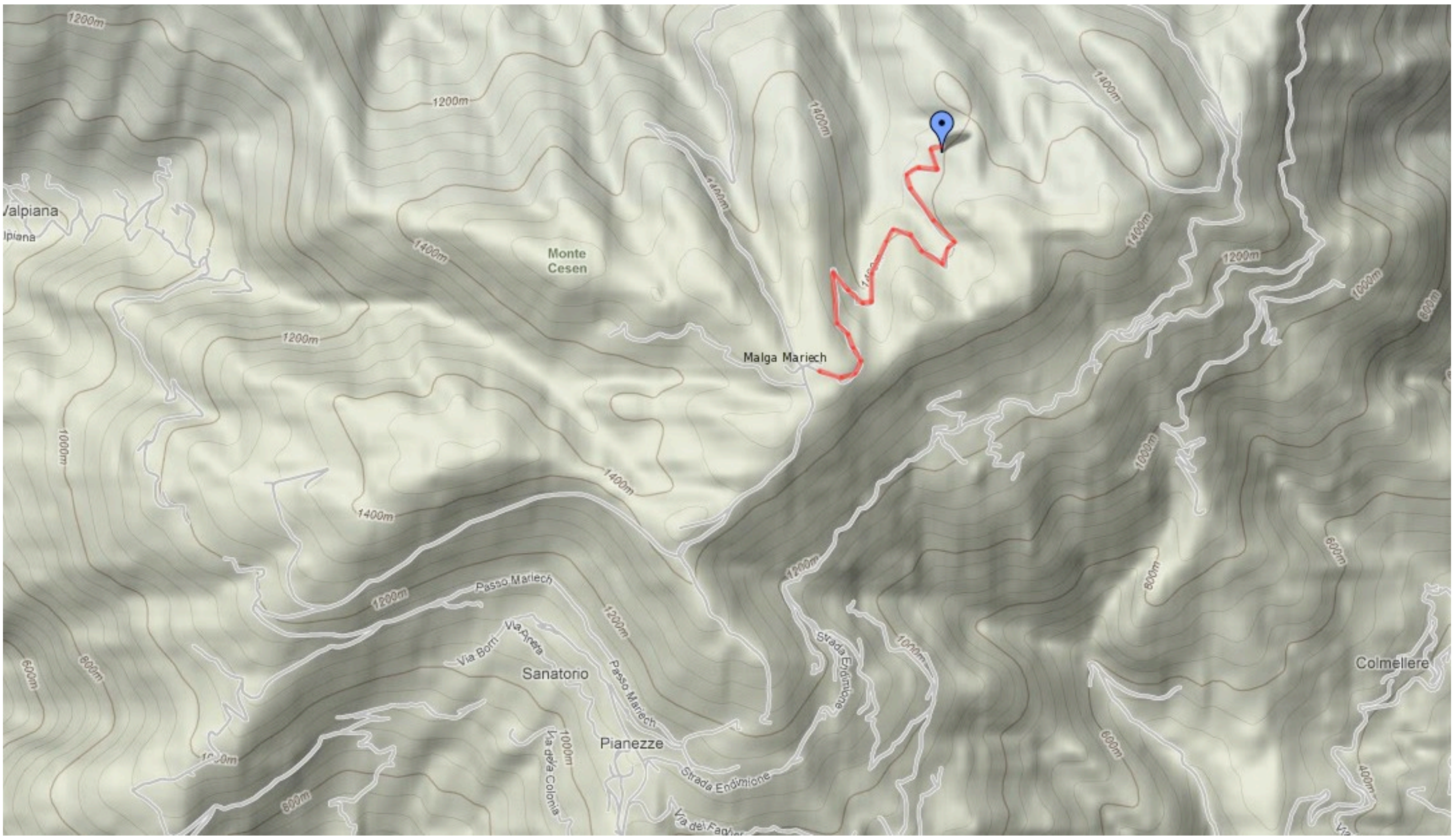
Access: Open

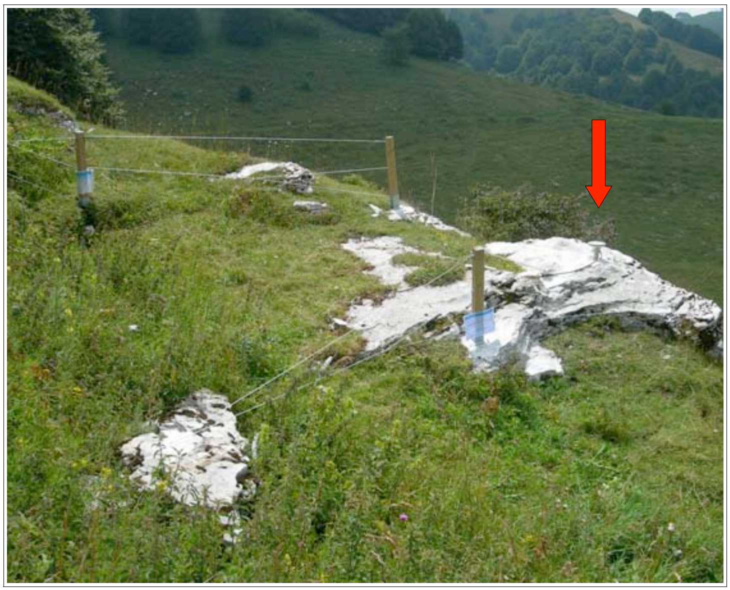
4x4 Car: Yes

Security Level: Low

Security System: Lock & Steel Cable

Mobile Fence: Yes





STATION NAME *Malga Garda*

REGION *Veneto* CITY *Lentiai (BL)*

ADDRESS *Frazione Colderù*

M
T
0
5

LATITUDE 45.97536

LONGITUDE 12.01619

ELEVATION 1300.00

SUBSTRATE *bedrock*

MONUMENT *Max Mount 10 cm*

DIRECTIONS From Lentiai to Frazione Colderù continue for 10 km. Arrived to Malga Garda the station is on the hill on the right. To reach the site you have to open the gate before the cowshed and climb by car.

NOTES

GSM Signal: No

Land Property: Public

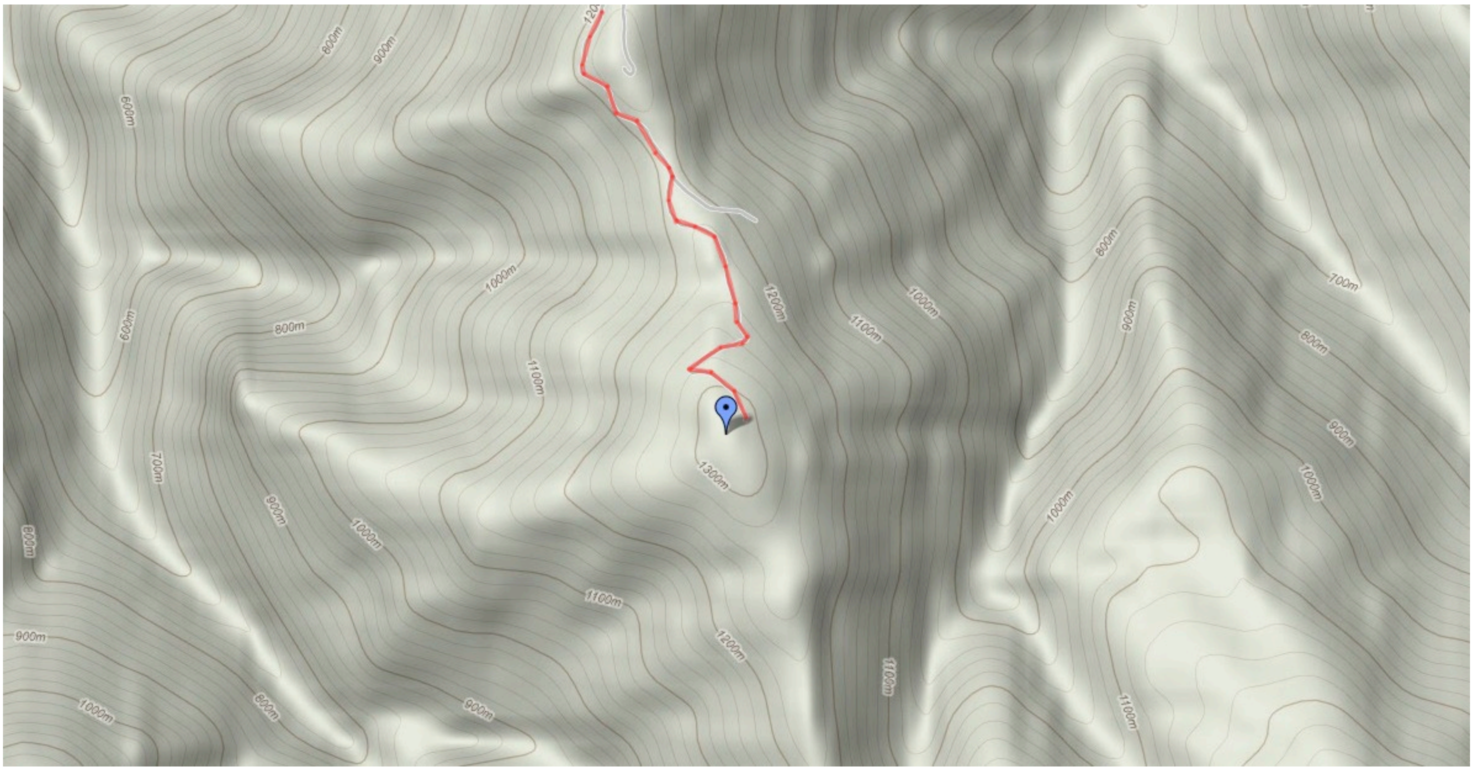
Access: Restricted

4x4 Car: Yes

Security Level: Medium

Security System: Lock & Steel Cable

Mobile Fence: Yes



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