Leading in Education, Research and Decision Support
Competence Center Environment and Sustainability
COGEAR: COupled seismogenic GEohazards in Alpine Regions

COGEAR

MODULE 2:

Geodetic measurements and kinematic modeling

Del. No.: 2b

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One objective of this module was to monitor ongoing crustal deformations in the canton Valais by modern geodetic techniques and correlate them with seismicity in view of seismic hazard assessment.

For the determination of vertical movements long time series of levelling data are of great help. Classical geodetic data in Switzerland has been collected for more than 100 years and they revealed an ongoing uplift of the Alps. This uplift reaches a maximum of 1.3 mm/a in the canton Valais relative to the Swiss molasse basin.

Yet, there is little geodetic data which describe horizontal tectonic movements in the study area. In this project we aimed at removing this short-coming by installing a permanent GPS network with new GNSS stations as well as by tying together existing small networks or single reference stations. The installed network extends over a large fraction of the canton (see fig. 1). The western part of the network focuses on a conspicuous seismic belt north of the Rhône valley extending from the Wildstrubel area to the Haute-Savoie, France. The detection of pre-, co- and postseismic slips and the determination of the faulting style by geodetic techniques within this seismic belt are of particular interest. The eastern part of the seismic belt is parallel to the Sion-Courmayeur zone separating two tectonic provinces. The Helvetic and the Penninic nappes differ seismically in the style of faulting. The former is dominated by strike-slip faulting whereas the latter is characterized by normal faulting.

GNSS Network

For tectonic interpretation it is of utmost importance to refer the GNSS measurements to a stable, global coordinate frame. This frame is thought of a well controlled and monitored worldwide coordinate reference frame, to which all regional or local measurements can be related. This ensures that also local networks will be referred to a same reference. To reach this, mm-accuracy has to be achieved throughout the network. As a stable backbone of the COGEAR network the Automated GPS network operated by Swisstopo (AGNES) has been implemented in the solution. The build-up of AGNES began in 1988 when the Federal Office of Topography (Swisstopo) established a new national first-order GPS-based reference network LV95 (Landesvermessung, 95), and in addition implemented first permanent GPS reference stations. Nowadays AGNES network (AGNES) consists of 34 stations. Three of the permanent AGNES stations are located in canton Valais (MART, HOHT, ZERM; see fig. 5).

During recent years this network has continuously been expanded and densified in the Valais region by GGL. See figure 1 and 2 with the red dots indicating the additional GNSS receiver sites.

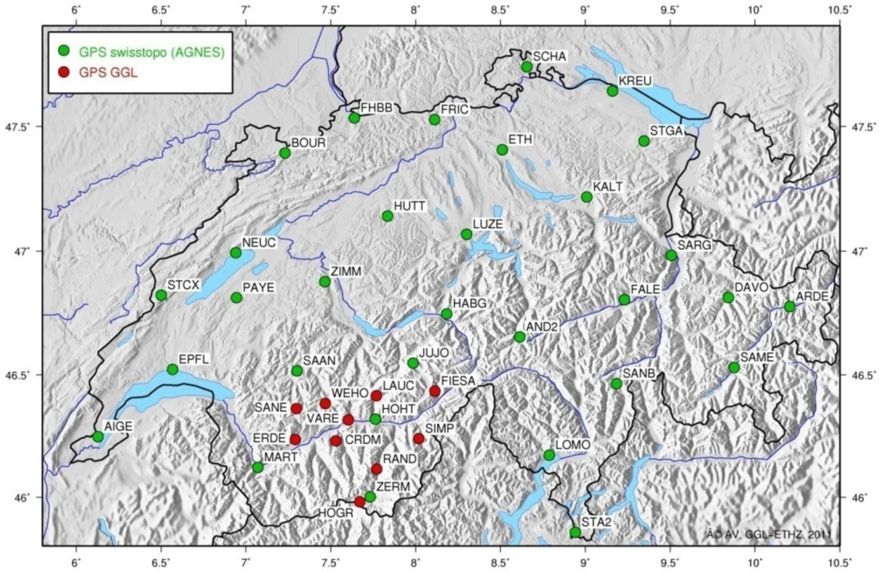


Figure 1: GNSS receiver network: red dots stations implemented by GGL.

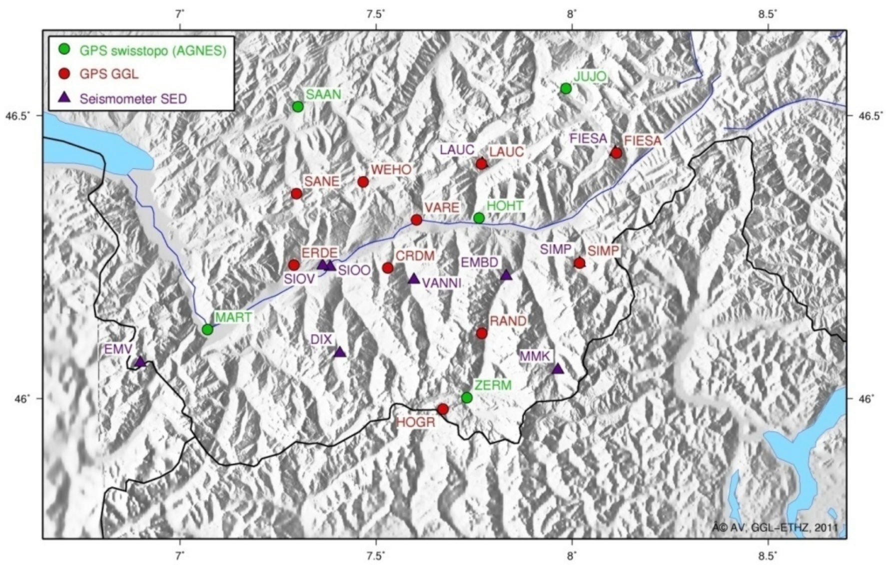


Figure 2: Seismic Stations and GNSS receiver network: red dots stations implemented by GGL.

The main constraints on the site selection were the a) open sky, b) stability, and c) the possibility to co-located the closest possible the antenna with seismometers. The open view is rarely strongly obstructed by the general topography. Close-by obstructions like vegetation and buildings are much more limiting factors. Even on a site very close to the mountain flank of Matterhorn (Hörnligrat) the view is not dramatically reduced. Figure 3.

Set-up of the network

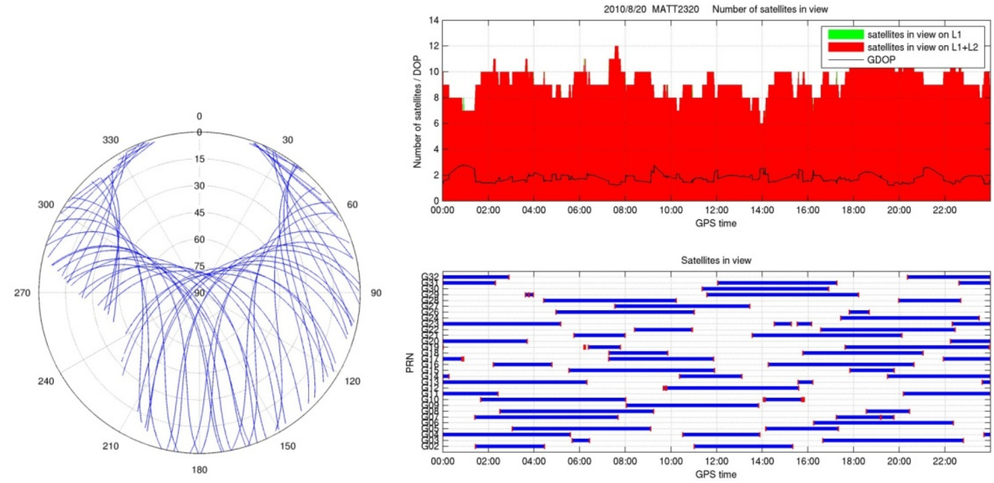


Figure 3a: GPS only constellation seen from GPS site 'Hörnligrat'. The impact of topographic obstruction from Matterhorn is seen in the SW area.

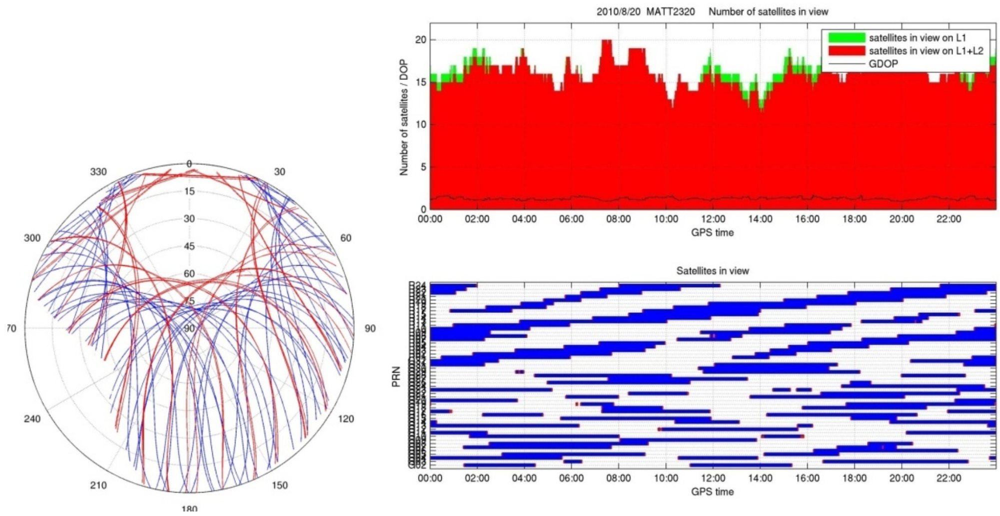


Figure 3b: Improvement of satellite 'density' by utilising the GLONASS. The red lines indicate the tracks of the GLONASS satellites.

Co-location with seismic stations have been realized e.g. at 'Simplon' and 'Fiescheralp'. These stations are running online and deliver data to GGL.

In a joint effort with a second/third party project a permanent GPS station has been installed at Hörnligrat on Matterhorn. That station operates online and wireless as well as sun powered. The stations operate mostly unattended. Small risks of distruction, however, might persist especially for GNSS stations. In a thunderstorm the electronics of two receivers (Erde and Vare) were destroyed. They have been replaced on own funding.

By cooperation within COGEAR (module 3b.1.1) a GNSS double frequency receiver has been installed at the investigation site 'Randa', where a wireless-online operation was realized. The wireless link has been provided by the TIK (Computer Engineering and Networks Laboratory, ETHZ) and is also used to transfer other geoscientific data (COGEAR module 3b.1.1) from 'Randa'-site to the internet. The TIK is co-operating with GGL in a non-CCES rock-glacier monitoring project. The Randa-site is a major data provider for COGEAR module 3b.1.1. This shows one of the synergetic effects of CCES efforts.

Figure 4: COGEAR test site 'Randa': Leica reference station on a tripod system 'swisstopo'. On the photo to the right one recognizes the instrument and battery shelter (hut in the background) (COGEAR module 3b.1.1, Löw, Moore)

Erde (ERDE)

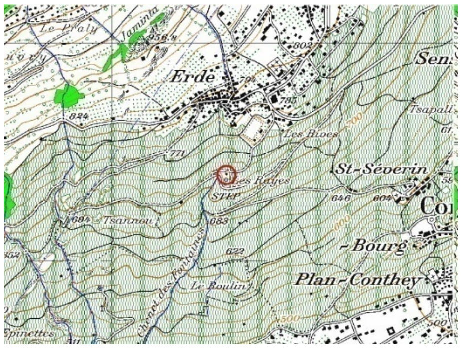
<table>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Location: Sewage plant, Erde</td></tr>
<tr><td>LV95:
2588526 m / 1120395 m
Altitude: 782 m</td><td>WGS 84:
Longitude: 7.2899°
Latitude: 46.2349°</td></tr>
<tr><td colspan="2">Equipment:</td></tr>
<tr><td>Receiver: Trimble Zephyr Geodetic</td><td>Antenna: Trimble NetRS9</td></tr>
<tr><td colspan="2">Settings:</td></tr>
<tr><td>Sampling Rate: 30 s</td><td>Download Connection: Analogue</td></tr>
</table>

Figure 5: Example of the short meta data for the GNSS network. Station 'ERDE'.

Data flow

All data from COGEAR GNSS stations are collected on a GGL file server. There are still two stations (VARE, ERDE) where data collection has to be done manually (figure 6). This will be changed by spring's end 2012 . Then all the stations will be connected to the central server either by analogue modem or ADSL.

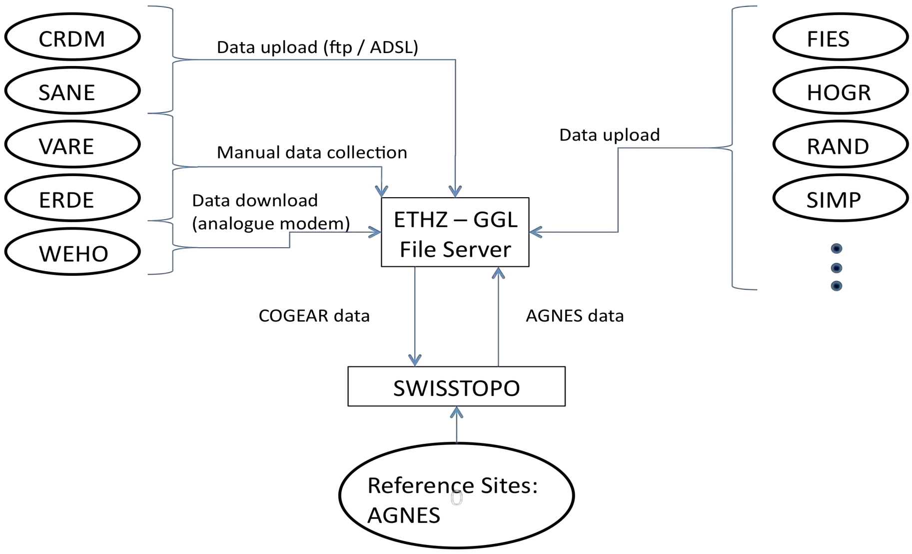


Figure 6: Flow of GNSS data. Ellipses indicate GNSS stations/network

The data is then automatically downloaded by swisstopo from the GGL-server to their file system at their premises where a common calculation with the AGNES network is carried out. In return GGL has the access to reference data from the AGNES network in order to be able to refer all calculations to a common reference. The data is of course also analyzed at GGL where velocities are deduced from time series. For a first analysis and a quick-look to the actual data the positions are automatically processed on a daily basis. An example of such time series at site 'Simplon' is given below (figure 7).

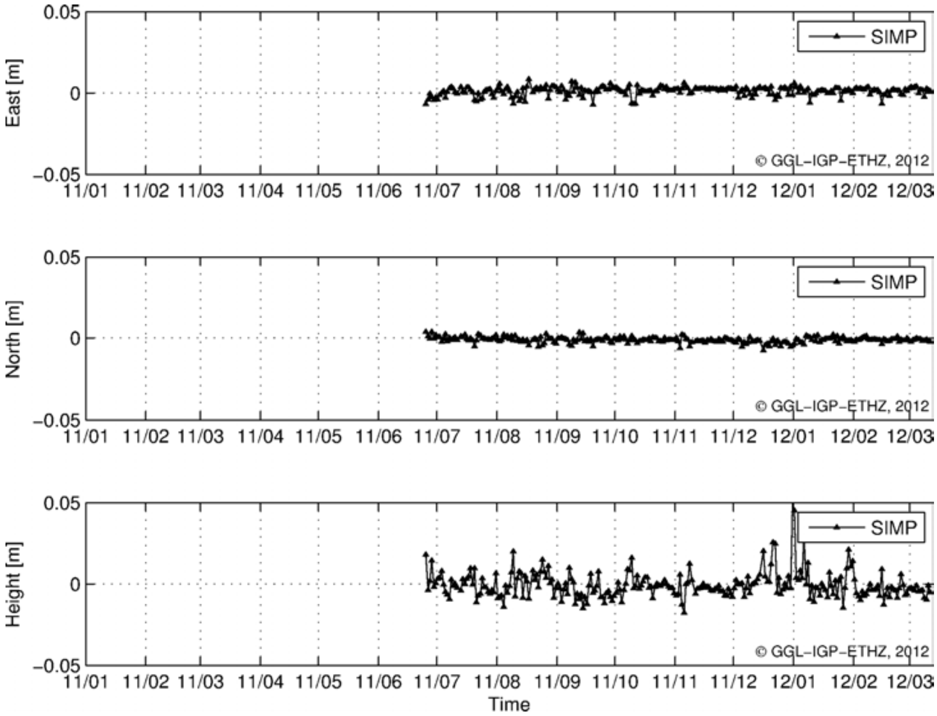


Figure 7: Example of a time series of coordinates: Station 'Simplon' (SIMP), a co-location site with seismometer. The larger variability of the height component is clearly visible in the plot.

New measurements of the Swiss Terrestrial Reference frame (CHTRF)

Many monumentations are surveyed in a repeating schedule. E.g. swisstopo periodically re-measures points in a campaign type format. It is absolutely clear and also evident from results that this kind of data is by far less accurate than the continuously acquired data sets of permanent stations.

The topographic office (swisstopo) repeats the coordinate determination of their fundamental network (**Swiss Terrestrial Reference Frame, CHTRF)** about every 6 years. The last campaign in 2010, the so-called CHTRF campaign 2010, brought further indications and insights to the kinematic deformations in Switzerland. On about 230 points, more or less homogeneously distributed over Switzerland, velocities were determined in order to update the set of velocities, relative to station Zimmerwald. These velocities are mostly below 1 mm/year(see figure 8) and generally smaller than those from the previous processing including measurements up to the forth campaign in 2004 (CHTRF 2004).

From these data velocity and strain maps (figure 8) have been produced by the newly reformulated Adaptive Least Square Collocation (ALSC) strain program. At this point, the project has close contacts to the project swiss4D (A. Villiger) financed by swisstopo.

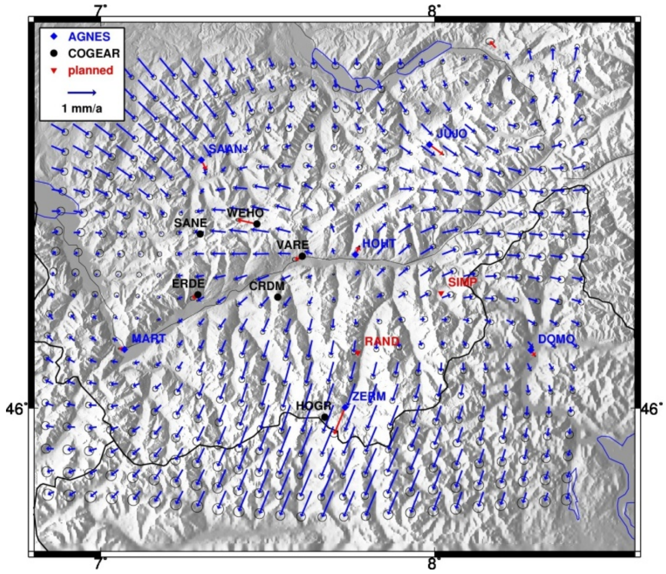


Figure 8: Calculated velocity field determined by GPS in the COGEAR area. Velocity interpolated by the new ALSC method.

High rate equipment

Recent developments in GNSS receiver technology allow data sampling at rates of 10, 20 or even 100 Hz. This enables the full wave analysis of surface deformation at a specific location. To this end a Javad 100 Hz receiver has been installed in parallel with a 20 Hz Leica receiver at Fiescher Alp. This station, call sign FIESA, was selected by SED for the installation of a seismometer and, since at this place the sky is open, GNSS equipment could be co-located at the same spot.

The geodetic contribution to seismology is further explored in an SNF project (common seismology/geodesy project, M. Rothacher, S. Häberling) where among other the usability of high rate, high precision GPS receivers for co-seismic ground motion measurements will be explored. The high rate GPS receivers acquired by GGL have been successfully tested on moving buildings such as bridges and tests are now focussing on experiments on a shaking table in cooperation with the SED. Synthetical seismograms are simulated by SED (Dalguer, Song) with realistic parameters for the Valais region. The aim of the tests are to retrieve this movement by GNSS on the shaking table, first results are depicted below.

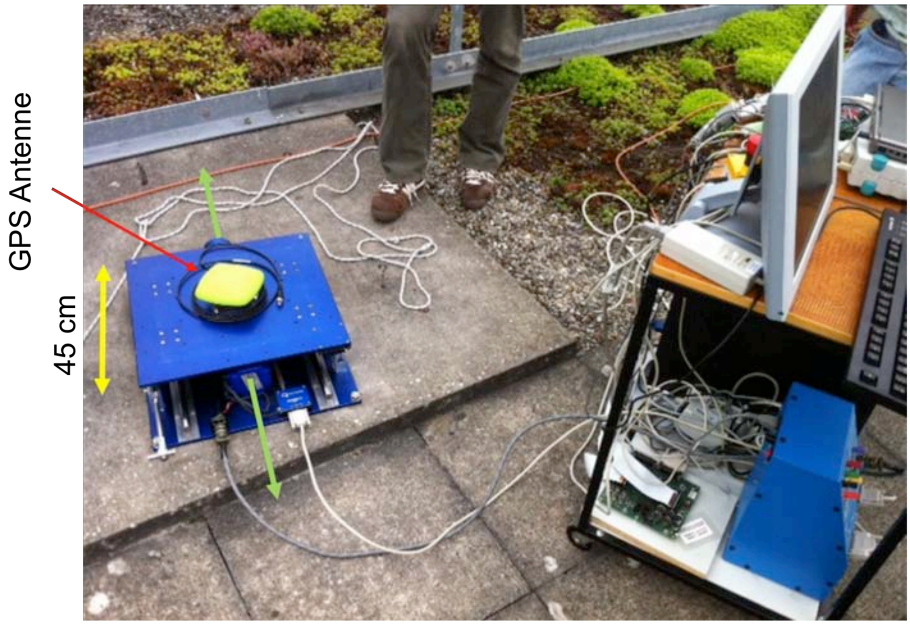


Figure 9: Shaking table with a GPS antenna. The table performs a 1-axis oscillatory movement (green arrows), (from Simon Häberling, 2011)

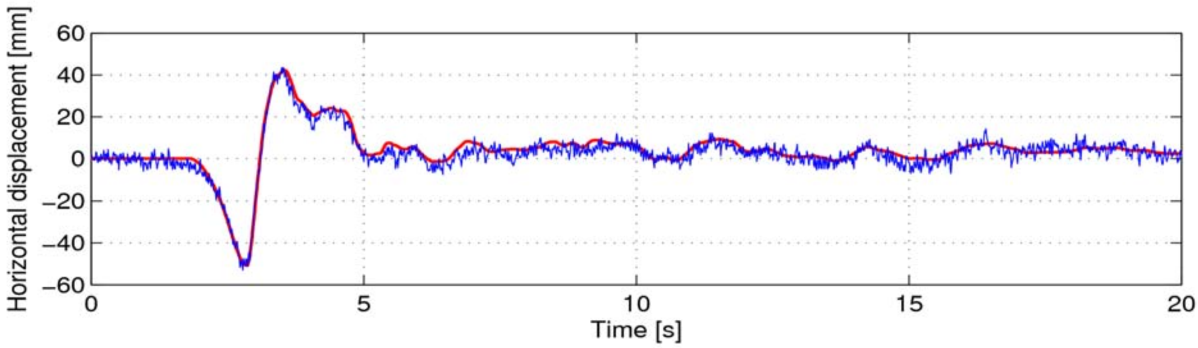
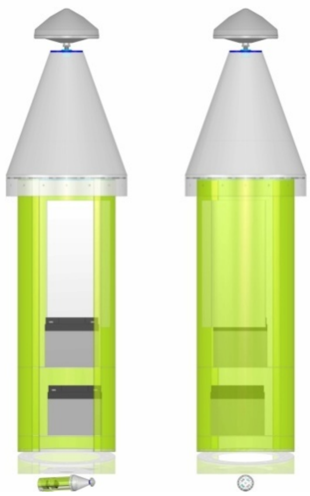


Figure 10: Realistic earthquake M5.0 for Switzerland: Distance from the epicentre ca 2.5km (from Simon Häberling, 2011). Red line: The simulated seismogram calculated by SED is fed to the shaking table and the movement is reconstructed from GPS measurements on the table (blue line).

Outlook and ignition of follow-up projects and works.

As seen from the results (fig. 8), tectonic movements in the investigation area are very small and therefore hardly detectable within a single project's duration unless a very strong earthquake occurs during the measurement period. The stations are therefore installed in a stable way in order to remain operable for several years. Since GGL has committed to CCES to run the stations beyond the duration of COGEAR GGL will keep the stations updated and controlled.



It is even intended to densify the station network and to develop a new compact and stand-alone version of reference stations where the experiences made during COGEAR will be incorporated in the design of the installation (fig. 11). The basic principle is the all-in-one idea where the tripod forms the housing of the complete instrumentation. This should simplify the field installation

Figure 11: New compact and stand-alone version of reference stations.

The interdisciplinary character of the COGEAR project led to some interesting co-operations e.g. with the Swiss Geodetic Commission, University of applied Sciences North Western Switzerland (FHNW), and Uni Bern in a long term project where the deformation on a NS-profile through the Wildstrubel region shall be determined. A different application of GNSS is envisaged in co-operation with SLF and Swiss experiment to further explore GPS measurements in snowy environment.

Future of the GNSS network

The tectonic movements in the area of investigation as determined by permanent GPS stations remain still at the limit of significance. More years of continuous observations are required to get a more reliable picture. By the commitment of GGL the stations will run beyond the duration of COGEAR project, thus delivering a continuous data set over the next years.

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