Monitoring the Automated GPS Network of Switzerland AGNES

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Abstract

Since 1998 swisstopo has been operating the Automated GPS Network of Switzerland (AGNES) which presently consists of 30 permanent GPS stations and serves different applications such as reference frame maintenance and zenith total delay estimates for numerical weather prediction. Furthermore, the positioning service swipos® has been available for commercial use since 2001. Monitoring the quality of the derived products is essential not only on a short-term, but also on a long-term basis.

Different tools, such as an SMS/e-mail messaging system and a web interface, were developed for monitoring the computers, the data flow, the stability of the coordinates, and the availability and quality of the products. The monitoring of coordinates and zenith total delay estimates are realized using the Bernese GPS Software, as well as with the real-time positioning software GPSNet from Trimble. Examples and comparisons are shown, in particular during difficult conditions like, e.g., heavy snow fall.

Networks processed by swisstopo

On a routine basis (daily and hourly) a European-wide network is processed using the Bernese GPS software [Hugentobler et al., 2001]. In 2005 the processing was completely redesigned and was based on the newest version V5.0 of the Bernese GPS software [Schaer et al., 2005 and Wiget et al., 2006].

As a EUREF analysis center, swisstopo analyzes a sub-network of EUREF permanent network (EPN) on a daily basis as a contribution to the reference frame realization in Europe. Furthermore, all 30 permanent AGNES sites are processed together with about 50 sites from the EPN network or from neighboring countries on a daily and hourly basis. Since March 2006, the network has been extended to stations in North America, Africa and Russia. The main goal of the daily analysis is reference frame maintenance in Switzerland. One application of the hourly processing is the generation of hourly zenith total delay (ZTD) estimates in near real-time (NRT) which can be used for numerical weather prediction. swisstopo has contributed the NRT ZTD estimates to the European projects COST-716 and TOUGH since 2001, and at the present to the EUMETNET project E-GVAP. A second application of the hourly processing is coordinate monitoring.

For the real-time positioning service swipos®, the data are analyzed in real-time by the Trimble software GPSNet Version 2.4 (2.5 since 19.05.2006). This program is used mainly for the generation of the virtual reference station (VRS) data. Nevertheless, also information of ZTD estimates and coordinate stability is generated in real real-time [Brockmann et al., 2002]. An overview of the processed networks is shown in Table 1.

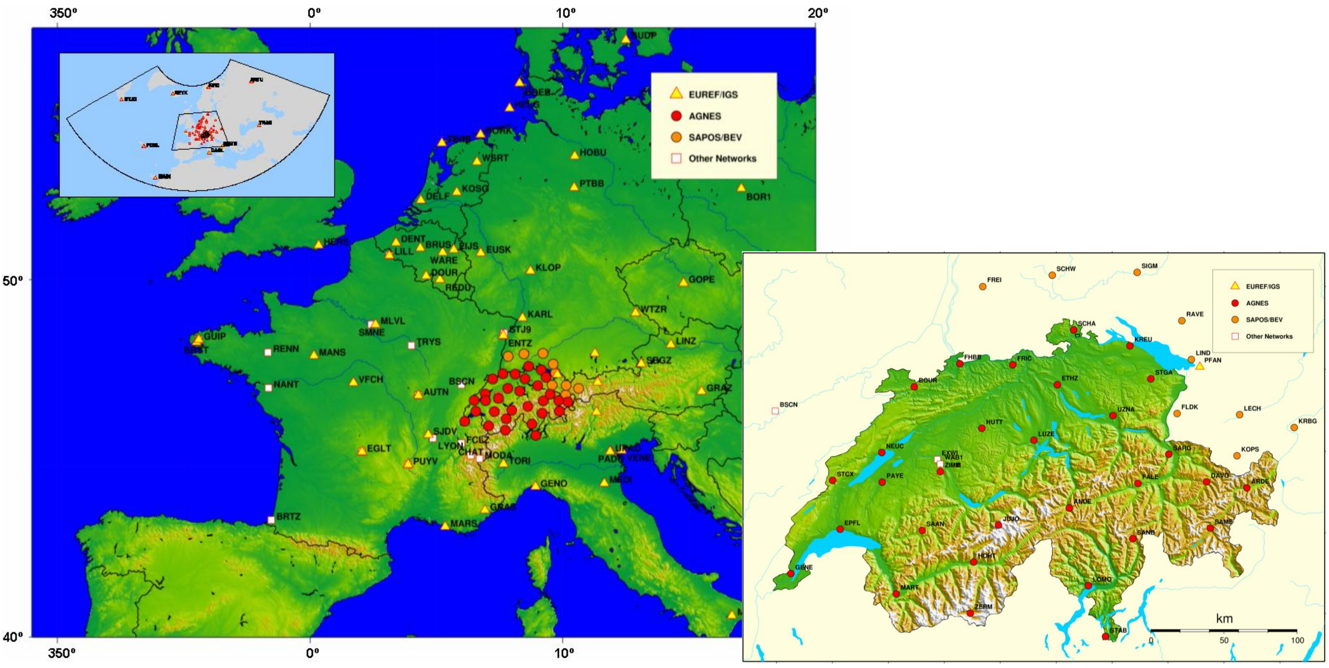

Figure 1: Overview of the permanent GNSS stations processed at swisstopo.

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Network (# stations)	Availability	Comments
EUREF sub-network (28)	100 % daily	reference frame Europe (Bernese)
AGNES + sub-network EUREF (80)	100 % daily	reference frame Switzerland (Bernese)
AGNES + sub-network EUREF (75)	98 % hourly	numerical weather prediction + monitoring (Bernese)
AGNES + D-A stations (40)	95 % real-time	positioning service + monitoring (GPSNet)

Table 1: Permanent GPS networks processed at swisstopo

Monitoring tools

Generally 3 different types of monitoring tools are implemented at swisstopo:

1. SMS/e-mail warnings: both processing programs (Bernese 5.0 and GPSNet) allow e-mails or SMS messages to be sent in case of problems (data transfer, missing data). In GPSNet the Network Model Integrity Module provides non-linear residual errors (differential iononspheric and geometric residual errors) in the network. This can be considered as integrity monitoring for residual interpolation and ambiguity resolution. If the errors reach a critical value (e.g. 5 cm for ionospheric error and 3 cm for geometric error), a warning by e-mail will be generated. For the Bernese processing, additional checks are implemented based on the achieved results. For example, warnings are sent out in case the coordinate repeatability of the last several hours of a specific site was degraded. Furthermore, the computers at the Astronomical Institute of the University of Berne (AIUB) and at swisstopo cross-check themselves to verify if they are operationally available.
2. Detailed log files and plots extracted from the processing are available on Linux machines in order to get a detailed overview of the processing results and in order to detect possible problems.
3. Web pages: Important information from the Bernese processing is used to prepare quite simple web pages in order to display essential information graphically. The GPSNet software allows a graphic view on the operational status of the processing and generates XML report files. The report files are currently available on the WWW3 web server for administrators only.

The focus of this paper is mainly on the developed web tools based on the Bernese processing scheme. Also, a part of the information from the GPSNet program is included (ZTD and coordinate monitoring) in order to compare the results of the two independent systems.

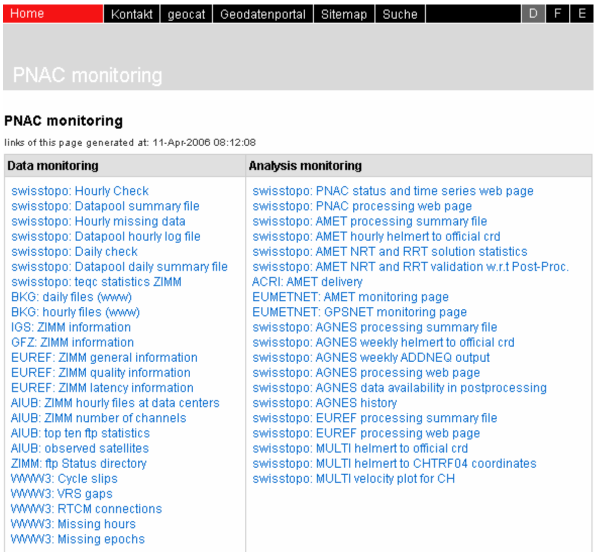

Figure 2: Monitoring web page (http://www.swisstopo.ch/en/basics/geo/permnetworks/pnac/monitoring). The collection of important links is divided in a "Data" and an "Analysis" section.

Web information for the Bernese processing

A simple collection of links (see Figure 2) is the entry point for checking the processing. All developed web pages are in a specific data area of the official swisstopo web system, which allows hourly updates of the information.

In the "Data" section (left-hand side of the web page), information from different internal (information generated by swisstopo, or by the WWW3 web server of the swipos® service) and external (BKG, AIUB, EUREF, IGS) sources can be displayed. The external sources display information only with respect to the fundamental station Zimmerwald (ZIMM) because the data of the other AGNES sites are not publicly available.

In the "Analysis" part (right-hand side of the web page) mainly information from the swisstopo processing is displayed. Two additional links display validation information for the swisstopo NRT ZTD submissions generated externally by the EUMETNET project.

An overview of the current status is generated twice an hour in a graph. Information can be displayed by following the link "swisstopo PNAC status and time series web page" (see Figure 3). In the first two sections, this web page shows the availability of hourly RINEX files for the area of Europe. The different color codes are borrowed from the traffic lights (green: ok, yellow: warning, red: error).The black color is used if RINEX files have already been missing for several months.

Generally the page allows the display of the two regions "Europe" and "Switzerland" and the three types of information concerning:

- RINEX data
- Available NRT ZTD estimates
- Possible warnings in case of a degraded coordinate repeatability

A different interpretation of the color codes is assigned to the different subjects.

In the future it is planned to display also basic information on the positioning service swipos® to the public.

In the lower part of the web page, plots of the different time series can be accessed.

If available, the following plots can be displayed for each site (examples are shown in Figure 4):

a) Long-term coordinate repeatability based on weekly coordinates (and hourly / daily coordinates for the most recent 3 weeks) for the components north, east and up.

b) 1 month of coordinate residuals based on hourly processing (daily residuals of 3 weeks, hourly residuals of the last 7 days).

c) Coordinate repeatability of hourly coordinate estimates based on Bernese NRT processing for the last 3 days. In addition, residuals of a Bernese kinematic adjustment are displayed every 30 seconds for the AGNES stations. In this kinematic solution the solved ambiguities of the hourly run, which uses an 8 hour moving window, are used. As the third information, the coordinate residuals of the GPSNet program are displayed.

d) Several days of ZTD estimates are displayed. For the AGNES sites also the information derived from GPSNet is displayed.

Generally, the coordinate monitoring by means of hourly Bernese NRT solutions can be realized with an astonishing high quality. Possible coordinate jumps on the 1-2 cm level should be significantly detectable.

Also astonishing is the high quality of the kinematic coordinates derived from the Bernese solution (rms horizontally below 2 cm, vertically below 4 cm)

The GPSNet coordinates are usually very smooth due to the tight constraining in the Kalman filtering.

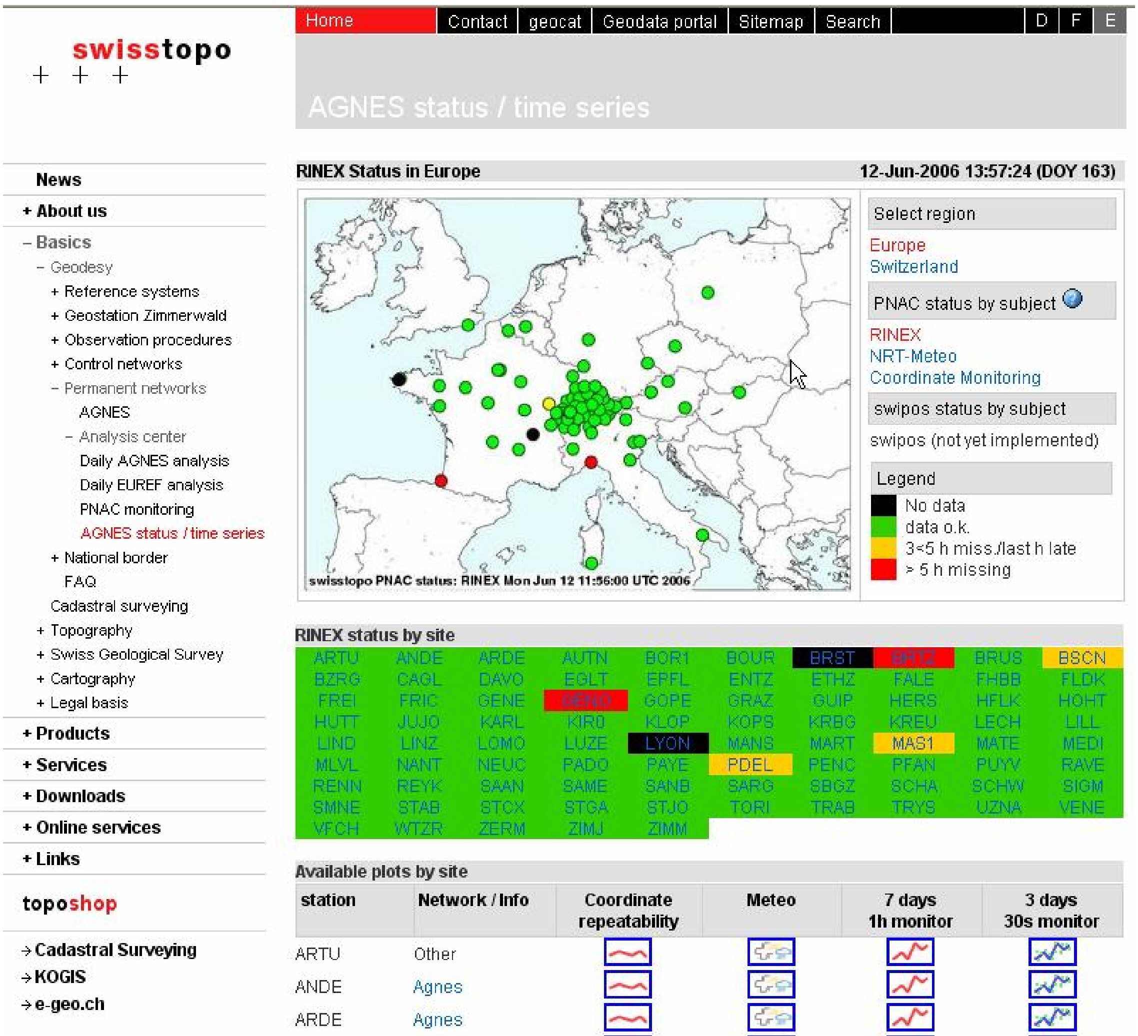

Figure 3: Overview of the available hourly RINEX files at swisstopo.

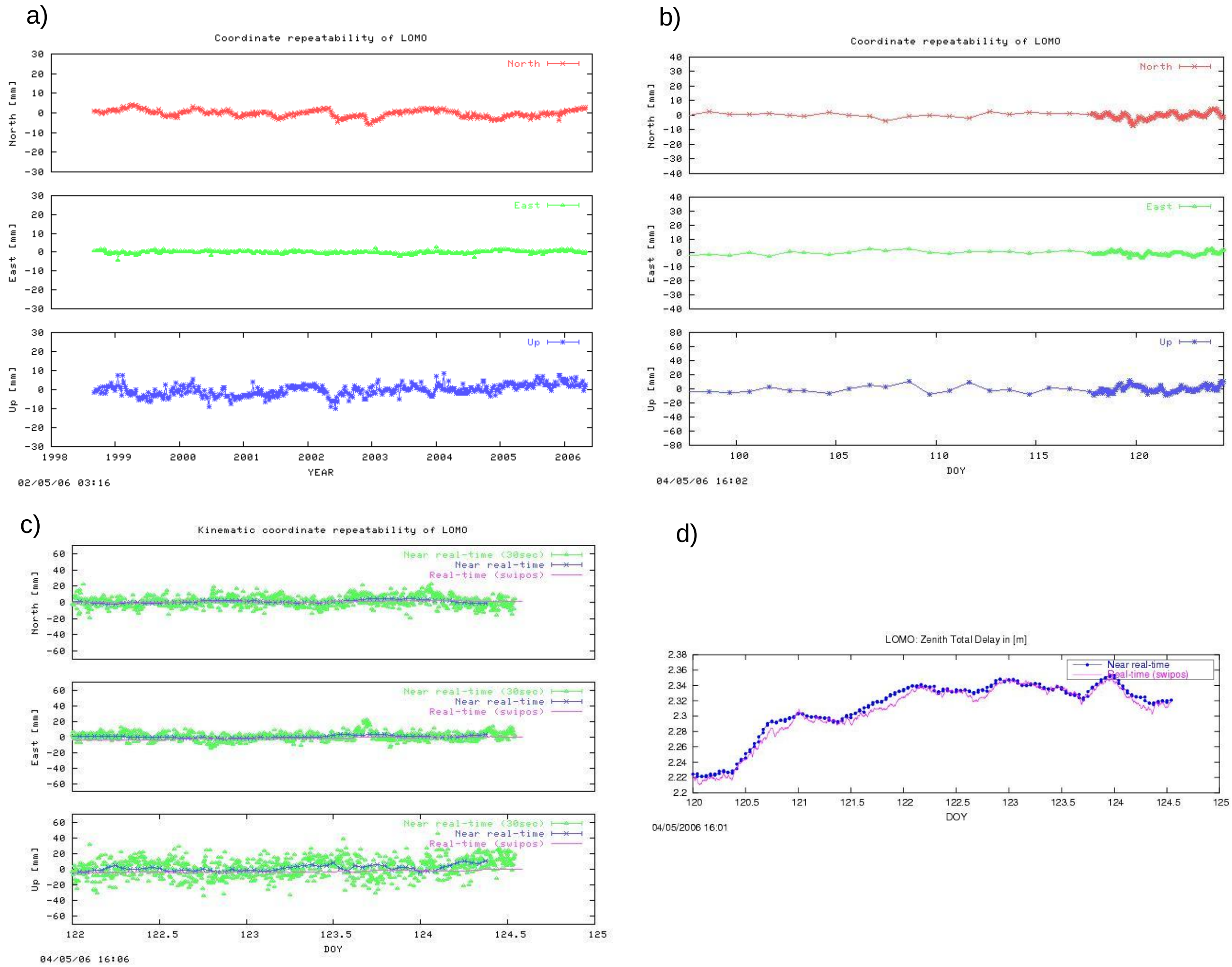

Figure 4: Available time series for the AGNES site Locarno Monti (LOMO): a) long-term coordinate residuals in north, east and up; b) 1 month with daily and hourly residuals; c) 3 days hourly and kinematic coordinates (Bernese and GPSNet); d) several days of ZTD estimates (Bernese and GPSNet).

The long-term monitoring is mainly important for the reference frame realization. Therefore, a combination of all available weekly solutions since 1998 is computed as soon as the most recent week is analyzed based on final IGS products. The gap between this week, which is usually 3 weeks delayed, and the current week is filled up with weekly solutions based on the hourly solutions. Included in this combination is also an estimation of velocities [Brockmann et al., 2005]. Presently, only the site SARG (Sargans) seems to be located on an unstable ground. SARG moves about 2-3 mm per year towards the south. Thus, the station will soon be moved to a new, more stable location. An alternative would be to regularly update the corresponding station coordinates.

Site	Residuals in [mm]		
	North	East	Up
SARG	15.1	0.6	-2.3

Table 2: Residuals of the last weekly solution (GPS week 1370) with the officially publicized coordinates for site Sargans

At this time, the north component of the last estimated week differs from the officially publicized coordinates by 15 mm. The maximally accepted difference is 20 mm.

Examples

Two examples of the monitoring in the event of problems are shown below. Both problems are due to snowfall occurrences in the winter 2005/2006. The degraded coordinate repeatability in the case of accumulated snow on the antenna has already been known for several years in the international permanent networks (IGS, EUREF) and also in the long-term time series computed for the AGNES network. In mountainous regions such as Switzerland, the problems due to snow are more serious compared to regions with moderate altitudes. The examples here focus mainly on the quick detection of problems due to snow effects.

Snow in April 2006

Very late snowfall on April 5-6 and 9-10, 2006 caused a degraded coordinate repeatability for many permanent GPS sites in Switzerland. Due to the very wet snow at low altitudes, mainly the sites in the foothills of the Swiss Alps were affected (see Figure 5). The e-mail messaging tool sent out 11 alarms from April 5 to 7 as shown in Figure 6. A second snow event with even more snow took place on April 9-10. Residuals for station (BOUR) are shown in Figure 7. Both Bernese solution types (hourly and 30 second kinematical) show large residuals up to 8 cm in station height.

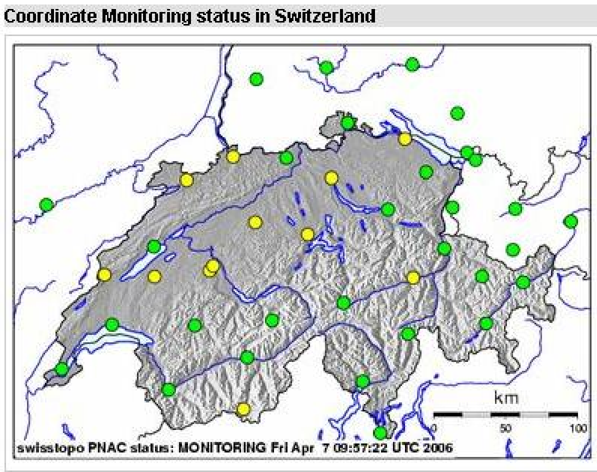

Figure 5: Coordinate monitoring status on April 7, 2006, 10:00 UTC; yellow circles indicate degraded coordinate repeatability.

STA/05/09:55: ALARM_OUTLIER_ZIMJ: I	Mi 05.04.2006 09:55
STA/05/11:55: ALARM_OUTLIER_HUTT:	Mi 05.04.2006 11:55
STA/05/12:55: ALARM_OUTLIER_FALE: I	Mi 05.04.2006 12:55
STA/05/13:55: ALARM_OUTLIER_LUZE: I	Mi 05.04.2006 13:56
STA/05/15:55: ALARM_OUTLIER_ZIMM:	Mi 05.04.2006 15:55
STA/05/18:55: ALARM_OUTLIER_PAYE: I	Mi 05.04.2006 18:55
STA/05/19:55: ALARM_OUTLIER_FHBB: I	Mi 05.04.2006 19:55
STA/05/20:55: ALARM_OUTLIER_ETHZ: I	Mi 05.04.2006 20:55
STA/06/00:55: ALARM_OUTLIER_KREU:	Do 06.04.2006 00:55
STA/06/03:55: ALARM_OUTLIER_STCX: I	Do 06.04.2006 03:55
STA/07/02:55: ALARM_OUTLIER_BOUR:	Fr 07.04.2006 02:55

Figure 6: E-mail messages received due to degraded coordinate repeatability

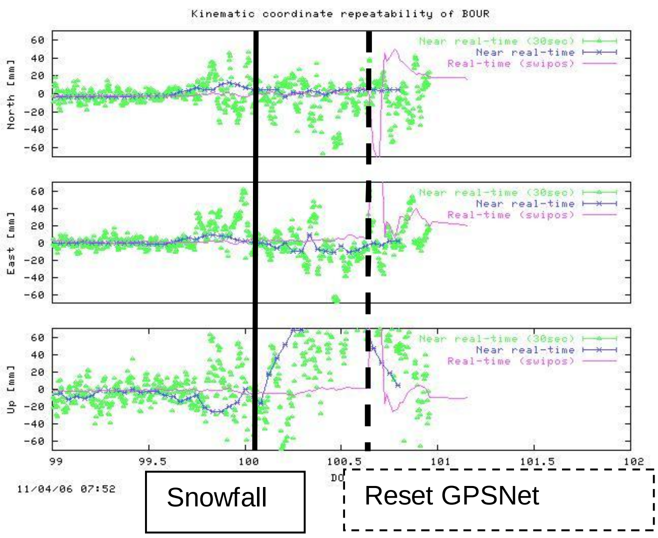

Figure 7: Kinematic coordinate residuals for station BOUR on April 10, 2006 (Day of year 100) together with the snowfall event and the GPSNet restart

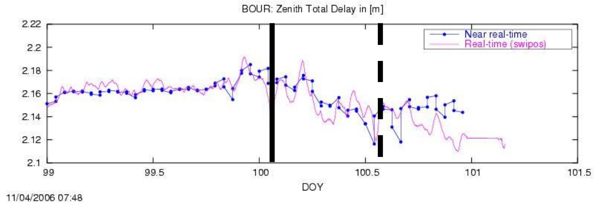

Figure 8: Zenith total delay estimates for station BOUR on April 10, 2006 (Day of year 100) together with the snow fall event and the GPSNet restart

The GPSNet coordinates are almost unaffected. We assume that the weighting scheme used in the Kalman filtering of GPSNet constrains the coordinates too heavily. In the afternoon of that day, the GPSNet system was restarted. This explains the greater variations in the coordinate estimates. Several hours after the restart, the monitor coordinates were again of good quality and in good agreement with the Bernese solutions. The zenith total delay estimates shown in Figure 8 were also slightly affected by the snow fall.

Snow tests in San Bernardino (Jan.-Feb., 2006)

In order to study the snow effect seen at the sites of the AGNES network, the "VRS monitor", developed by swisstopo [Grünig et al., 2004], was installed close to the AGNES station San Bernardino (SANB: altitude 1700 m) [Grünig et al., 2006] between January and February 2006 as shown in Figure 9. The VRS monitor is able to simulate a typical RTK user in the field using the positioning service "swipos®-GIS/GEO". Every hour (can be configured) the system connects to the swisstopo GPSNet server via mobile phone, downloads the VRS data, and saves the obtained coordinates and additional important information such as time, time to resolve the ambiguities and number of tracked satellites.

The system has the option of using solar panels as a power supply. In SANB this was not necessary. The location was also selected because a contact person is available during the day. It was planned to manually remove the snow from the rover antenna if necessary (a typical surveyor also measures with a snow-free antenna).

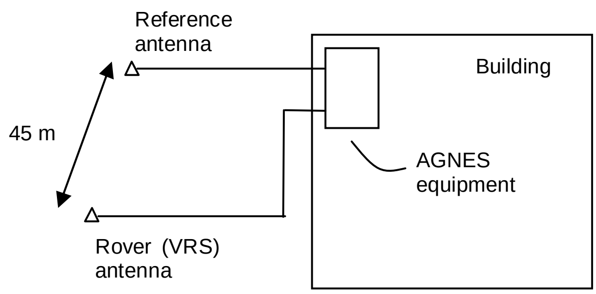

Figure 9: Setup of the snow test at AGNES station SANB

The snow fall in SANB was very moderate in January and February. Larger events with more than 40 cm per day took place at the end of January and mid February. The reference antenna SANB on February 27, 2006, the day of the de-installation of the test equipment, is pictured in Figure 11. The vertical residuals of the VRS results and the daily Bernese solutions together with the amount of snowfall are shown in Figure 10. Under normal conditions the height estimates derived from a 30s RTK fix solution vary with a standard deviation of 15 mm. Not directly during the snow fall but about 2 days later, the height residuals varied by a factor 2 (rms 32 mm for the time period January 28 to February 1). For the same period other performance indicators were also degraded:

- Initialization time is 38 seconds instead of 18 seconds
- Incorrect solutions 22.8% instead of 2.5%

The Bernese solutions showed outliers in the height residuals almost directly together with the snowfall. But even after the event, residuals with opposite signs were visible. It is assumed that the consistency of the snow on the antenna (light consistency during snow fall, wet snow during high temperatures and icy snow in cases of warming and freezing snow) is responsible for that. The smaller rover antenna of the VRS monitor which is covered by a thinner snow layer or was cleaned manually from the snow could also be a reason for the different behavior.

The influence of the reference station SANB, should be quite a large contribution to the generation of the VRS data.

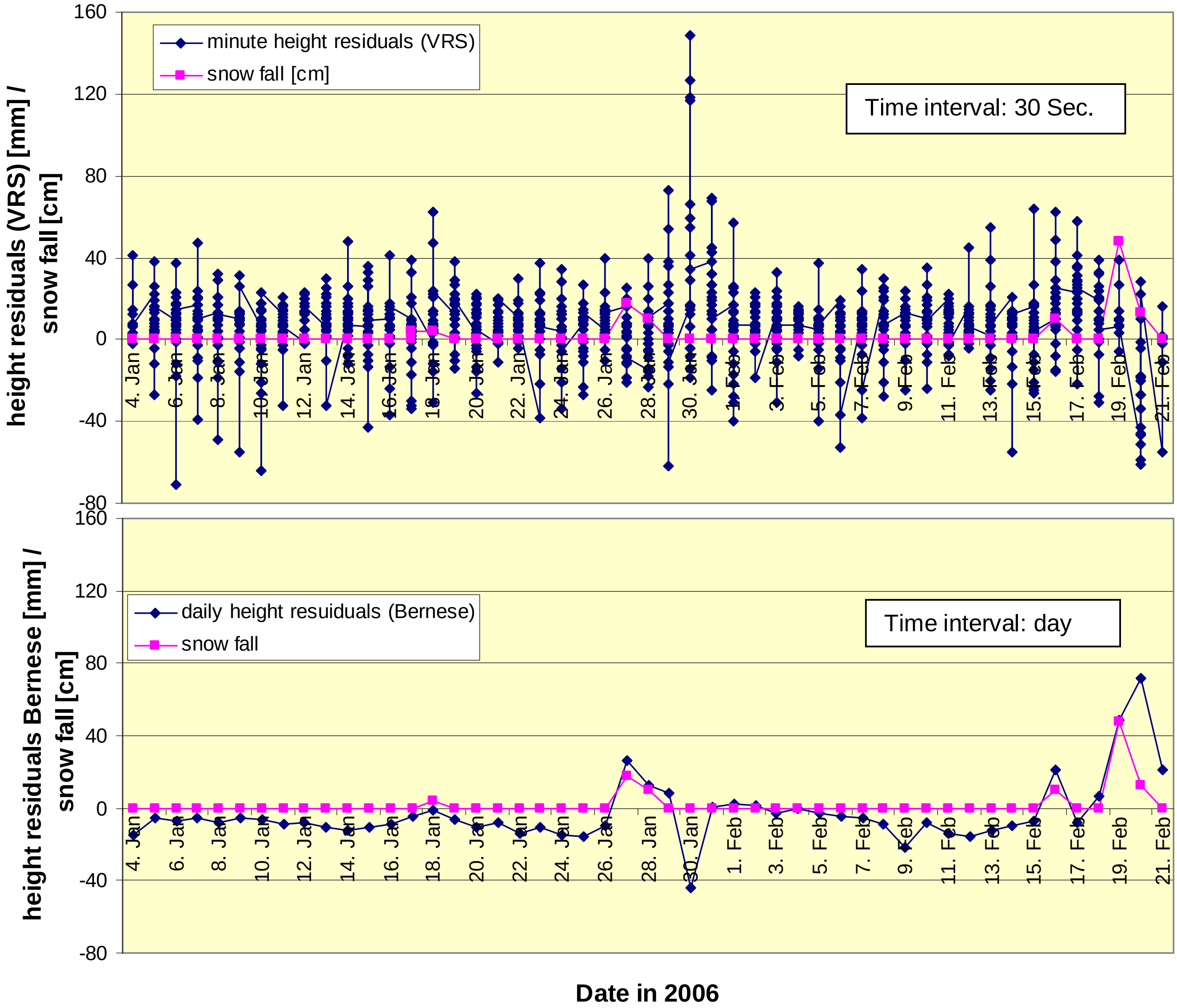

Figure 10: Height residuals of the VRS monitor using the positioning service swipos® (upper diagram; 30s coordinates) and the residuals of the reference station SANB using the Bernese final results based on daily files (lower diagram). In both diagrams the snow fall is also indicated.

Figure 11: Reference antenna SANB on February 27, 2006

The fact that the residuals of the VRS Monitor are not affected 1:1 indicates that the surrounding AGNES reference stations seem to contribute to the VRS data generation and thus smooth out the snow effect of a single antenna.

In both cases the horizontal coordinate residuals are much less affected by the snowfall.

Summary

The products of the AGNES network are routinely checked by automated analysis procedures based on different time intervals (minute, hourly, daily, weekly, multi-yearly) using the scientific GPS software Bernese 5.0. For these solutions, different tools (SMS/e-mail messages and web interfaces) were developed which support the operation of the AGNES network. However, it is still necessary that this information is interpreted by a GPS specialist.

Coordinate monitoring and zenith total delay estimation is also realized by the GPSNet software (Version 2.4, new 2.5) from Trimble. On the whole, both programs generate results which are quite comparable. Especially in the case of station coordinate problems with a duration of 1-2 days due to snow fall or other events, the GPSNet software is not capable of detecting such events. Two examples, both related to snow effects, showed clearly the importance of quick monitoring. Coordinates may differ from the nominal values by up to a decimeter in station height in the case of heavy snowfall. But also the monitoring on a long term basis is essential for reference frame maintenance as shown for the instable station SARG.

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