Satellite data reception at Ny-Ålesund, Spitsbergen: From CHAMP to GRACE Follow-On

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Summary

The German Research Centre for Geosciences GFZ operates a satellite-receiving station at Ny-Ålesund, Spitsbergen, to receive data from scientific satellites in polar orbits. The station has received data from the satellite CHAMP since 2001, but soon also from other satellites like those of the GRACE-mission. Notable is the continuous provision of received data through this station at low latencies and operation costs, which helped, e.g., to establish GNSS radio occultation measurements on satellites as a novel observation type for weather forecasts. The station efficiency has been improved constantly with technical and operational amendments over the years, so that it could even be qualified to serve for the actually most important task as the primary downlink station of the GRACE Follow-On satellite mission.

Zusammenfassung

Das Deutsche GeoForschungsZentrum GFZ betreibt eine Satelliten-Empfangsstation in Ny-Ålesund auf Spitzbergen, um Daten von wissenschaftlichen Satelliten in polaren Umlaufbahnen zu empfangen. Die Station empfing ab 2001 die Daten des Satelliten CHAMP, bald darauf aber auch von anderen Satelliten wie z.B. denen der GRACE-Mission. Bemerkenswert ist die kontinuierliche Bereitstellung der empfangenen Daten durch diese Station mit kurzen Wartezeiten und niedrigen Betriebskosten, was z.B. dabei half, GNSS-Radiookkultationsmessungen auf Satelliten als neuen Beobachtungstyp für Wettervorhersagen zu etablieren. Die Leistungsfähigkeit der Station wurde über die Jahre durch technische und operationelle Updates ständig verbessert, sodass sie sogar für den aktuell wichtigsten Einsatz als primäre Empfangsstation der GRACE Follow-On Satellitenmission qualifiziert werden konnte.

Keywords: NYA ground station, GRACE-FO primary downlink station, S-band, GNSS radio occultation, Svalbard

1 Introduction

Most scientific satellites produce huge amounts of observation data which must be sent to ground to be processed and evaluated. The minimum required frequency and the distribution over time of contacts for data downloads between a specific satellite and ground stations depend on the rate of on-board data generation, the on-board data storage capacity and the downlink data rate (transmission path to ground). Even more frequent contacts might be needed to reduce data availability latencies for time-critical applications, such as weather forecasts. This was the case for the satellite mission CHAMP (Reigber et al. 2006), where all on-board data was received by ground stations in Germany, but most of it with too high latencies to be useable for operational processing chains of weather forecast centres. A solution for this issue was found in the operation of an additional receiving antenna at Ny-Ålesund, Spitsbergen, which provided sufficiently frequent contacts with CHAMP and later to other satellites as well.

Fig. 1: Satellite receiving station NYA at Ny-Ålesund

DOI 10.12902/zfv-0290-2020

2 Determining characteristics of the location

The most important feature of the satellite receiving station at Ny-Ålesund (short name NYA, Fig. 1) is the high number of daily possible contacts to polar orbiting satellites, which follows from the high latitude location (78° 55′ N, 11° 56′ E). Fig. 2 shows the areas of visibility for receiving antenna elevations of 5° and above (typical for satellite tracking) at the ground station NYA (green circle) and at Potsdam, Germany, as a lower latitude reference (red circle, 52° 23′ N, 13° 04′ E).

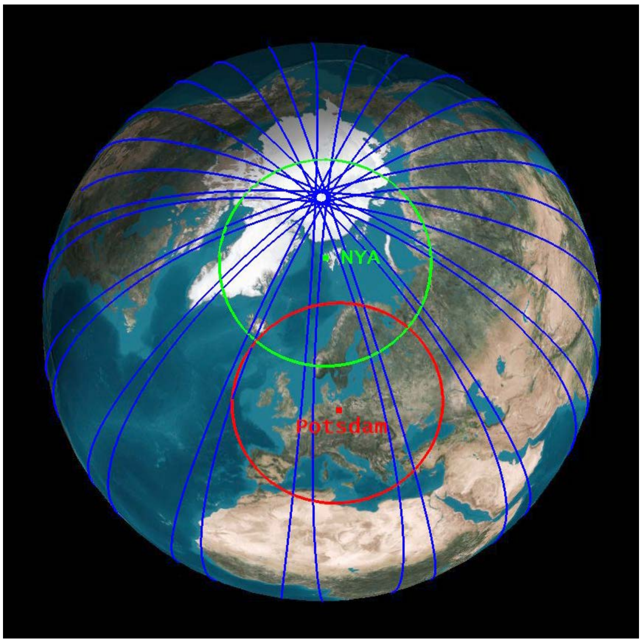

Fig. 2: Areas of visibility for NYA and Potsdam

Typical polar Low-Earth Orbit (LEO) satellite ground tracks (satellite altitude 500 km, orbit inclination 89°) for a period of 24 hours are displayed as blue lines. The parts of the tracks which are inside an area of visibility can be used for telemetry contacts. It is evident that only 4 or 5 of the daily orbits (15 to 16) could be accessed from Potsdam, but all of them by NYA. Such frequent contacts, respectively the shorter periods without contacts, are in practice indispensable for a low latency provision of satellite data and frequent satellite status monitoring. More contacts result also in a higher total contact time and thus effectively in a higher data reception capacity.

Ny-Ålesund is declared as a radio quiet area (20 km radius). The regulation is particularly strict for signals between 2 to 32 GHz, as that frequency range is used by local VLBI[1] radio astronomy facilities (a VLBI antenna is visible on the left in Fig. 4). It prevents NYA from transmitting to satellites, which is why it is only a receiving station (no uplink). The local radio ban includes even WIFI and Bluetooth, which must be switched off by visitors before arriving at Ny-Ålesund. However, NYA also benefits from that situation, as it reduces the probability of radio interference from local sources and thus the effort to handle them. Fig. 3 shows exemplary the

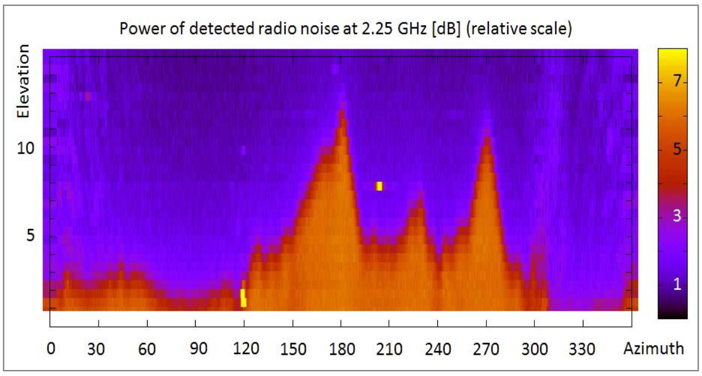

Fig. 3: RF-power scan of environment at 2.25 GHz

received radio power as it was detected at a telemetry receiver input port at a typical S-band satellite downlink frequency (2.25 GHz) when one of the NYA-antennas scanned the local horizon up to an elevation of 15°. The orange colours correspond to the detected natural (thermal) radio emission of the environment (local horizon with mountains) in contrast to the colder sky behind it. Only one manmade radio source on ground, actually spurious emissions of a local instrument (DORIS[2] beacon) in 120° azimuth direction, and one in the sky, probably from a passing satellite (not seen there on other scans), were found with low signal levels in the experiment (about 8 dB over coldest background directions).

In spite of being located close to the North Pole (distance about 1230 km), Ny-Ålesund is reachable through regular travel connections (small aircrafts and ships) and has a moderate climate. Practically all kind of local infrastructure and services (airport, harbour, road system, energy, board and lodging etc.) is provided by the Norwegian Kings Bay Company. Glass fibre cables from Ny-Ålesund to the European mainland guarantee excellent data transfer connectivity (since 2015). Occasional needed hands-on support for the NYA station is granted by the local German-French AWIPEV[3] research station.

3 Station history

The first satellite telemetry receiving antenna at the station was purchased in 1996 as part of a so called mobile ground station, which was initially funded and operated jointly by GFZ and DLR for campaigns in other areas of the world (Roessner et al. 2001, Xia 2002). GFZ wanted to stimulate the operational assimilation of GNSS radio occultation data (GNSS-RO) by weather forecast centres with frequent downlinks from CHAMP, which was launched in 2000 and the first satellite that could

1 Very Long Baseline Interferometry
2 Doppler Orbitography and Radiopositioning Integrated by Satellite
3 Alfred-Wegener-Institute and Institut polaire français Paul-Emile Victor

provide such data regularly (Wickert et al. 2001). DLR had an interest in frequent contacts with their satellite BIRD (launched 2001). Both satellites were in polar orbits and Ny-Ålesund was identified as an excellent location to install an antenna for the desired additional downlink contacts. GFZ already had good relations to some institutions onsite for many years, e.g. with the Norwegian Mapping authority (Statens Kartverk), for the operation of GPS- and PRARE[4]-stations (Falck et al. 2013). As a consequence the antenna was supplemented with a basic S-band receiver system in 2000 (executed by DLR) and installed at Ny-Ålesund in spring 2001 (managed and financed by GFZ).

From the beginning there have been more contacts per day at Ny-Ålesund with CHAMP than with BIRD.

Fig. 4: Installation of the second antenna (NYA-2) in 2005

BIRD suffered from technical problems on-board which affected the satellite operation (Attitude and Control Subsystem, breakdown in 2004). The practical cooperation between GFZ and DLR for the antenna (later named NYA-1) phased out slowly (last DLR maintenance visit at Ny-Ålesund in spring 2002), but GFZ wanted to continue the data reception from CHAMP and even to extend activities, e.g., with the reception of data from both GRACE satellites (launched 2002). Thus GFZ invested in the replacement of already aged components, new versatile and redundant receiving systems, an extension of the operation cabin and an additional, second antenna (Fig. 4), and built up in-house competence to operate the station independently from other parties.

The single antenna site at Ny-Ålesund grew to a small ground station with significantly increased capacity and exclusive control by GFZ and supported more satellite missions (GRACE, SAC-C, TerraSAR-X, TanDEM-X, Flying Laptop, GRACE Follow-On). However, all receiving activities except for GRACE-Follow-On were and are executed on a best effort basis, meaning without stringent commitments for GFZ.

4 Precise Range And Range-Rate Equipment

4 Qualification for GRACE-FO mission

The US-German GRACE-Follow-On mission (short GRACE-FO), with measurements for the determination of the Earth's gravity field (Flechtner et al. 2016) and GNSS-RO based atmospheric sounding on two satellites (Fig. 5), is jointly managed by NASA and GFZ.

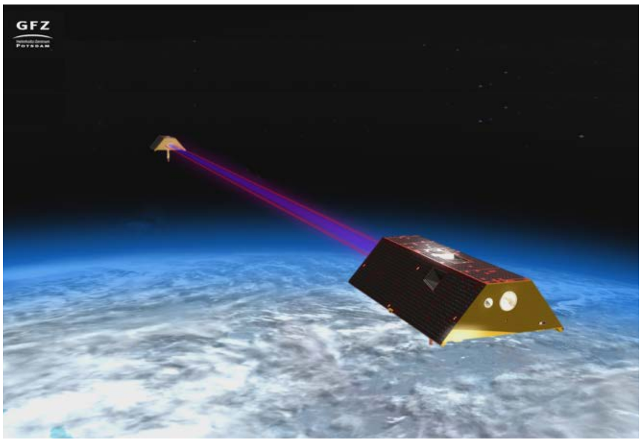

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Fig. 5: GRACE-FO satellites

In the planning phase of the project (phase A) it became clear, that the satellites had an at least three times higher on-board data generation rate, compared with the preceding GRACE mission, which required increased data downlink capacities. The original concept with an accordingly three times higher downlink data rate and a limited number of daily contacts with ground stations in Germany was not sufficient to receive all of the satellite data. One possible solution was to change the layout of GRACE-FO's telemetry system from S-band to X-band, which could provide higher bandwidth, but at higher costs. The other option was to plan for more daily downlink contacts to ground stations, which was even more costly, at least if the additional contacts had to be acquired from well-established stations as operated, e.g., by DLR, ESA or NASA. More daily contacts were strongly preferred anyway, as they promised additional benefits, e.g., a proper support of the well-proven GNSS-RO processing chains and the possibility for a closer monitoring of GRACE-FO's on-board systems. Taking into account the reliable operation of NYA for CHAMP, GRACE and other satellites over more than a decade and the comparable low operation costs, it was decided to qualify and set in NYA, if possible, as the primary downlink station for GRACE-FO.

The qualification of NYA actually meant to achieve, prove and document compatibility to the mission's requirements and to react on concerns of a critical review board which engaged external and NASA experts. These addressed of course all relevant technical details, but also questions about redundancies and the perspective of sustainability. As a consequence, GFZ invested, e.g., in another two new telemetry receivers and a local stock of essential spare parts.

New software for the operation and complementary supervision of both antennas was developed by GFZ as well as new software for the precise control of local system clocks with GPS, which improved the performance, reliability and perspective of sustainability of the station (Falck 2018). The software includes special features that support the determination of the antenna radiation pattern and the ratio of the antenna gain to system noise (G/T), which had to be known for the link budget calculation of contacts with the GRACE-FO satellites (Falck 2015). The GFZ-made operation monitoring and data processing software system at Potsdam was modernized and backed up with a second installation at the GFZ subsidiary at Oberpfaffenhofen.

Fig. 6: NYA receiver at Airbus-DS facilities for RF-compatibility tests with GRACE-FO telemetry downlink system

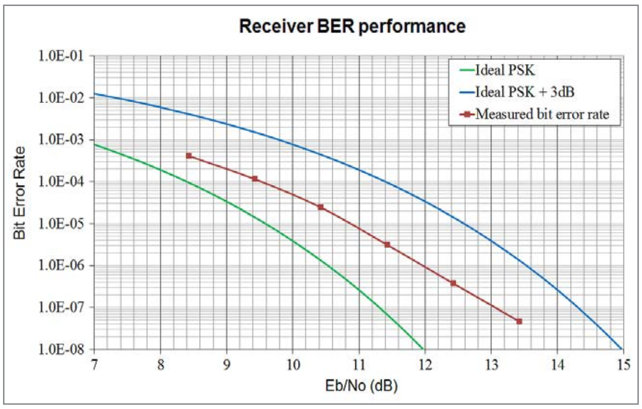

Fig. 7: Example of BER-test result

Another example for the qualification activities are the RF (radio frequency) compatibility tests with one of the NYA telemetry receivers ("blue box" on table in Fig. 6) in a direct connection to the satellite telemetry systems (flight models) at the satellite manufacturer's facilities (Airbus Defence and Space, Friedrichshafen, Germany). It had to be shown, among other things, that the bit error rate of the telemetry downlink path (BER, red graph in Fig. 7) was below a certain limit (blue graph) over a range of defined signal to noise ratios (green graph corresponds to theoretical optimum).

All qualification tasks were concluded successfully and the compatibility of NYA for GRACE-FO was confirmed. NYA was selected by the GRACE-FO project as the primary (main) downlink station and received first signals from a GRACE-FO satellite already in its first orbit, 80 minutes after launch (May 22, 2018). It now routinely receives all data from both GRACE-FO satellites with an excellent performance and reliability, which enables the desired constantly frequent low latency data distribution to all project partners.

5 Actual station design

NYA employs two S-band (2.2–2.4 GHz) antenna systems with parabolic reflectors (diameter 4 m), which are sheltered against the rough climate conditions on Spitsbergen by heatable radomes. The antenna positioning systems have a different layout of their axes orientations. NYA-1 uses an "elevation over azimuth" system (Fig. 8a) and NYA-2 a "X over Y" system (Fig. 8b), which has a better performance for contacts with satellites passing close to zenith.

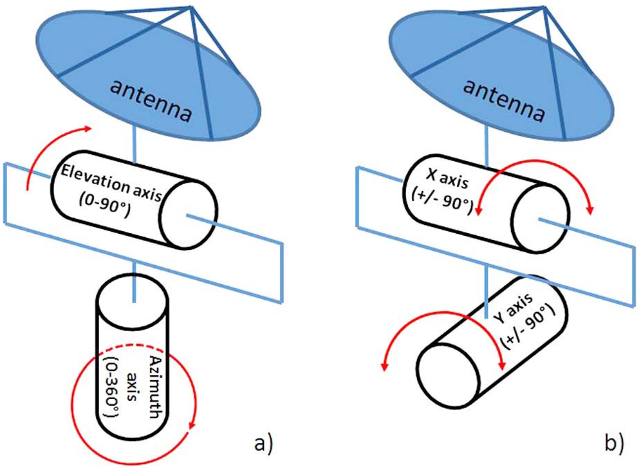

Fig. 8: Layout of NYA antenna positioning systems

The antenna feed of NYA-1 is currently capable to receive right hand circular polarisated (RHCP) signals only. The antenna feed of NYA-2 allows the simultaneous reception of RHCP and LHCP (left hand circular polarised) signals, in principle also in the X-band, but this feature is not fully implemented yet. Both antennas are directed to the passing satellites on the basis of actual, respectively predicted satellite orbit information. This information must be as precise as possible as there are no provisions to detect (and compensate) actual antenna pointing errors during satellite contact times (no auto-tracking).

All receivers and devices for antenna operation are placed in a small operation cabin between the radomes (Fig. 1). At least single redundancy is installed for almost all devices and functions (Fig. 9). Each of the three dual channel telemetry receivers can receive signals from both

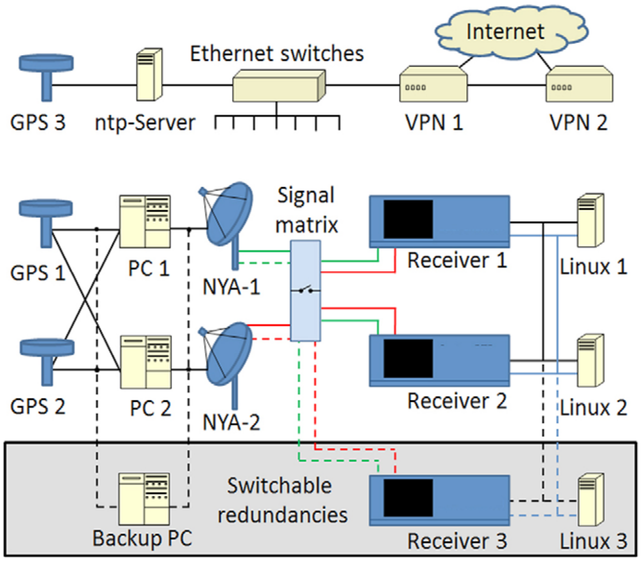

Fig. 9: NYA system design

antennas simultaneously (IN-SNEC 2006). Anyway, two receivers are always operated in parallel and provide hot redundancy. The third receiver is on standby (cold redundancy). Also the antenna operation computers with their GPS-based timing systems have a redundant layout and remotely switchable local spares. The clocks of devices with lower timing requirements, such as monitoring cameras or remote control systems, are synchronised to a local ntp-server (network time protocol), which can also serve as a provisional backup for the antenna operation. An independent and isolated backup communication network (ethernet) is in place for the essential receiver operation, in case of problems with the prime network, which is connected to the Internet (like the other devices) via VPN (Virtual Private Network encryption).

6 Regular station operation

NYA has been operated unmanned all year round since 2001. This kind of operation requires extra equipment for remote control and monitoring and a high level of automation. Even the contact scheduling process is highly automated, but not fully automatic, as the receiving activities must be correlated with changing satellite operation plans and fluctuating orbits. Accordingly, GFZ prepares NYA operation schedules once per week or at any time when there is a need for short-term changes, and sends them to NYA as so called jobfiles (Falck et al. 2017). The jobfile structure is rather simple but contains sufficient information for an automatic system configuration and satellite tracking at the station. A precise antenna pointing in spite of fluctuating satellite orbits is addressed by frequent updates of orbit information. These are based especially on the latest data from the satellite on-board GNSS measurements and sent to the station up to five times per day.

Fig. 10 visualizes an exemplary scheduling for both antennas over one day and the tracking times of five satellites, symbolized by small coloured bars. Each of the 16 rows in the graph represents 90 minutes of the day (starting with hours on left scale), the upper part of each row is the scheduled activity of NYA-1 and the lower part is the scheduled activity of NYA-2. The scheduling is done automatically and usually there is no need for manual corrections. These are required only occasionally, e.g., due to special requests for not tracking at certain times. In the example (Fig. 10) the times of satellite visibility were partly overlapping in the morning time. In such a case GRACE-FO contacts are scheduled with the highest priority (green, orange) while some of the other contacts with TerraSAR-X, Tandem-X and Flying Laptop (TSX, TDX and FLT) were shortened or skipped.

The illustration shows also a measure to prevent possible data gaps due to eventual technical problems with one of the antennas, which is regularly applied for GRACE-FO reception. The GRACE-FO satellites fly in a twin-constellation with a nominal distance of 220 km. They thus appear at the station very close in time and could be tracked simultaneously in principle, each with one of the two antennas. However, only one of the GRACE-FO satellites is tracked at a time, but with both antennas in parallel as displayed by the green and orange double bars in Fig. 10. In the next orbit the other GRACE-FO satellite is tracked, again with both antennas. This approach results in a higher data delivery latency of up to two orbital periods, but improves the reliability of the downlink process. Other satellites than GRACE-FO are usually tracked with one antenna only.

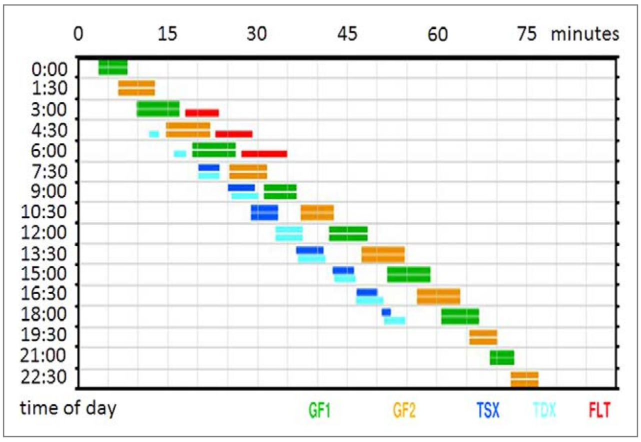

Fig. 10: Example of NYA schedule for 1 day and 5 satellites

The antenna tracking and satellite data reception itself are fully automatic and usually do not need any local or remote attendance at any time, but are monitored from remote, at least occasionally, during regular office hours. Tailored monitoring tools allow a prompt control of the downlink success. They visualize received versus transmitted (scheduled) satellite data and the status (colour coded) of on-board instruments and also the antenna and receiver operation records, such as antenna directions,

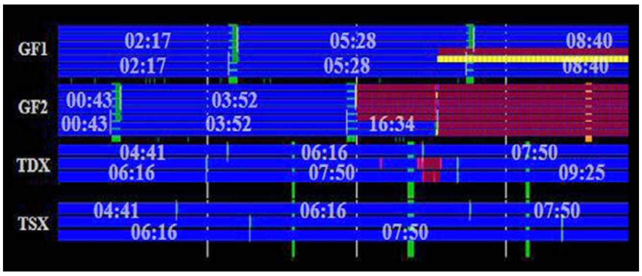

Fig. 11: "GFZ dump-browser" tool providing a quick view on received satellite data

signal strengths and Doppler offsets. In the example of Fig. 11 (cut-out from "GFZ dump-browser" screenshot) there was an outage (traces lose nominal blue colour) of the both inter-satellite ranging instruments (K-band microwave and laser) on GRACE-FO-2, which caused signatures on the corresponding traces for GRACE-FO-1 as well (opposite side of inter-satellite tracking).

There are also functions for automatic failure detection at the station and at GFZ. These detect data gaps or problems as discussed above or somehow smaller problems, e.g., too high deviations between commanded and reported antenna directions, and send corresponding alert emails and SMS messages to related staff at GFZ. The station's activity is logged in great detail in principle (e.g., antenna movements and receiver settings) necessary also to fulfil one of the requirements of the Norwegian authorities, which enforce the regulations of the Svalbard Treaty (international Spitsbergen contract). A Norwegian control commission visits NYA twice per year to check the station's compliancy with the contract (e.g., non-military usage) and other related laws and regulations (Norwegian and local).

All satellite data from NYA is automatically transferred to GFZ immediately after reception. At GFZ it is forwarded to project partners and pre-processed, where applicable, which includes further decoding and sorting to the different data sources (instruments, house-keepings). Pre-processed data is provided to several processing chains, e.g., for satellite orbit determination, atmospheric sounding (for weather forecasts) and gravity determination and also to operation monitoring tools such as shown in Fig. 11.

7 System maintenance and enhancement

Regular maintenance is required to preserve the reliable function of the NYA station. All systems are monitored permanently and some maintenance (e.g., small software patches) can be done from remote at any time, but real hands-on maintenance on-site is only once per year.

Usually GFZ staff visits the station in the summer season. An obvious reason for that time is the more friendly weather conditions, another is the continuous visibility of the sun (polar day). The sun is used as a natural broadband radio frequency signal source for tests with the antenna systems, which avoids conflicts with the local radio emission restrictions. The direction to the sun is constantly changing of course, but precisely computable for any actual time of measurements. The signal strength (activity) of the sun is also known with sufficient certainty, as the solar flux is monitored by related observatories. The antenna pointing accuracy and the system's gain to noise ratios are checked regularly with this approach.

Other important maintenance tasks are the lubrication of the antenna turntable systems (Fig. 12), the control and cleaning of fans and air filters, software updates, and the replacement of faulty or aged components, such as hard disks and computers. Major software modifications, e.g., w.r.t. antenna operations or internet connectivity, are tested and implemented only onsite, to prevent damages or problems in case of eventually required system recoveries.

Fig. 12: Maintenance work at NYA-2 antenna

Examples for enhancement works in the last years are the installation of additional UPS (uninterruptible power supply) capacities, redundant signal and power cables in extra trenches to both antennas and advanced automatic reporting functions. Many of these upgrades were triggered by the GRACE-FO mission. In 2020 it is planned to continue tests that have already started for a possible future reception of X-band signals at NYA. X-band systems are more complex than S-band systems, but used by several satellite missions, as they allow higher data-link bandwidths (compared to S-band).

8 Outlook

The NYA satellite receiving station will continue to serve as the primary downlink station for the GRACE-FO mission and to receive data from the other currently supported satellite missions. More satellite missions may be supported in the future, possibly even with additional downlink capacities in the X-band, which are planned to be developed in the near future.

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