Local Ties and Repeated Stability Measurements in Ny-Ålesund

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Abstract The Ny-Ålesund geodetic observatory has undergone a significant modernization during recent years. The old VLBI antenna was decommissioned and replaced with a new twin telescope following VGOS requirements. When an SLR is in place in 2024, the observatory will be a so-called fundamental station co-locating VLBI, SLR, Doris, and GNSS. Such stations form the backbone of the global reference frames like ITRF [1]. To fully exploit such a station, the local ties between the reference points of the different techniques are mandatory.

Ny-Ålesund is located in the Arctic and the observatory is exposed to extreme climate conditions. The consequences of climate change are larger than in most other places. Temperature rises several times faster than the global average; the permafrost is melting and glaciers retreating. This might challenge the foundation of the instruments. To ensure the stability of the observatory over time, local-ties measurements using both total station, leveling, and GNSS vectors have been performed annually since 2018. Positions of markers and reference points of the instruments are estimated.

We present the results of the local tie measurements, including coordinate time series of major control points and reference points. Some control points are unstable, but the coordinates of estimated reference points and markers on VLBI, SLR, GNSS, and Doris are stable within the uncertainty level.

Keywords Ny-Ålesund, local-ties, Stability measurements

Norwegian Mapping Authority

1 Introduction

The Ny-Ålesund geodetic observatory (Figure 1) will—when the SLR is operational—be the northern most geodetic fundamental station. It will co-locate all the major geodetic techniques (VLBI, SLR, GNSS, and DORIS) and be crucial for the realization of the ITRF [1]. The new observatory replaces the old 20-meter legacy antenna (Figure 10) that was decommissioned in the fall of 2023.

The station is located in the Arctic and is exposed to extreme climate conditions. The consequences of climate change are larger than most other places on the earth. Temperature rises several times faster than the global average; the permafrost is melting and glaciers retreating. The uplift in Ny-Ålesund varies between 5 mm/yr and 12 mm/yr [4], and the height component has a large seasonal signal due to changes in ice and snow. This might challenge the base of the foundation of the instruments [3, 4].

In ITRF2020 [1], the stability of the scale determined from VLBI was questioned. The IVS established a Working Group on Scale. The irregular uplift at Ny-Ålesund was pointed out as a possible explanation. It has therefore been of the utmost importance to control the local movements and stability.

To ensure the stability of the observatory over time, local-ties measurements using both total station, leveling, and GNSS vectors have been performed annually since 2018. Local ties between the legacy antenna and positions of markers and reference points of the instruments are estimated. The reference point of the legacy antenna was also estimated in 2002 [5].

Fig. 1 Ny-Ålesund geodetic observatory.

2 Data and Analysis

The Ny-Ålesund geodetic observatory contains several geodetic instruments, control points, and local markers. To maximize the value of this infrastructure, the different components have to be brought together and connected through local measurements. A total station (Leica TS 15) was measuring horizontal directions, zenith angles, and distances to prisms on markers and control points (see Figure 2). The total station observed to all control points with visible lines of sight (see Figure 3). Five readings in both theodolite positions and four full sets were measured. The analysis of the observations was performed with the least-squares adjustment software COMP3d v5.19 from IGN France (Damien Pesce, private communication).

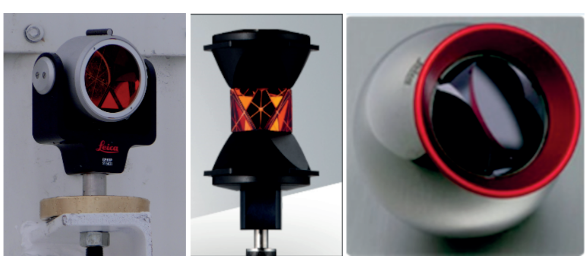

Fig. 2 Prisms used on control points (left), on rotation of VLBI around vertical axis (middle), and inside azimuth cabin (right).

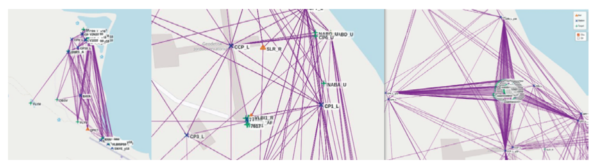

Fig. 3 Observation lines between the old and new observatories (left), around the new observatory (middle), and towards rotating reflectors on the VLBI dish.

2.1 Local Reference Frame

The IGS station NYA1 was established in 1997, close to the VLBI legacy antenna. NABG was established in 2019, close to the VGOS antennas and is included in the ITRF and IGS networks (Figure 4). All coordinates are relative to the ITRF2020 value of NYA1. NABG is used for the local orientation. The deflection of the vertical in east-west (η = 8.4 arcsec) and north-south (ξ = 4.21 arcsec) direction are based on the Arctic

Fig. 4 GNSS antennas: NYA1 (left) and NABG (right).

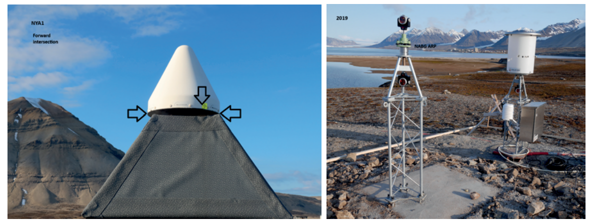

Fig. 5 Measurements point for forward intersection at NYA1 (left) and reflectors for forward intersection at NABG (right).

Gravity Project geoid (arcgp-2006-sk), locally refined by local GNSS-leveling points. The input and output coordinates used are in the UTM 33N projection, but the computations were done in local stereographic projection.

There are two different methods for connecting GNSS stations to a local tie network: using a total station or employing GNSS vectors.

For the past 20 years, regular GNSS campaigns have been conducted in the Ny Ålesund area and its surroundings. These campaigns, which included several control points within the local tie network, lasted one week, producing a week's worth of observations for all involved points. These observations form the basis for processing highly precise L1 vectors to control points generally surrounding those in the local tie network. The L1 vectors are processed using the Wasoft software. The campaigns used in this report took place in 2016 and 2022.

At the GNSS station NYA1, measurements were made using a total station in 2021, 2022, and 2023. These measurements were to a tape marker with a known offset from the ground plane that was attached to the antenna to determine the height and angle measurements to determine the horizontal position (see Figure 5). These measurements enabled the determination of the physical position of the Antenna Reference Point (ARP) relative to the control points.

The antenna at the NYA1 station lacks individual calibration; therefore, the ITRF/IGS coordinates from this station are derived from GNSS and type calibration. When GNSS vectors from NYA1 to the control points are introduced into the network adjustments, it becomes obvious that the GNSS position does not align with the physical position of the ARP (see Table 1). Therefore, it was deemed necessary to constrain the local tie network adjustment to only GNSS vectors for this station.

Table 1 ARP by forward intersection relative to GNSS.

	East (m)	North (m)	Height (m)
2023 (rel. GNSS)	0.0023	−0.0033	−0.0012
2022 (rel. GNSS)	0.0017	−0.0009	—
2021 (rel. GNSS)	0.0032	−0.0015	−0.0028

The new IGS station NABG at the Brandal Observatory was established in 2019. The antenna for this station was calibrated at the University of Bonn. Measurements to the antenna, taken with a total station using the forward intersection method to a prism before the GNSS antenna was mounted (see Figure 5) and to the prism beneath the antenna, align well with the GNSS vectors to the network's control points. On NABG, both GNSS vectors and measurements derived from total stations are utilized.

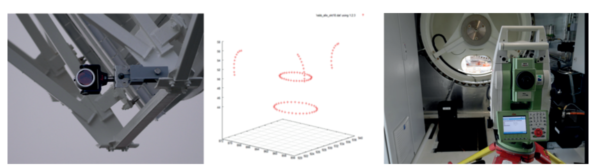

Fig. 6 (left) Reflector on the VLBI dish; (middle) observations of rotating reflector points; (right) total station measurements inside the azimuth cabin.

2.2 Axis Offset

The invariant points for all three VLBI antennas were determined by outside prisms and moving the antenna around the horizontal and vertical axes (see Figure 7).

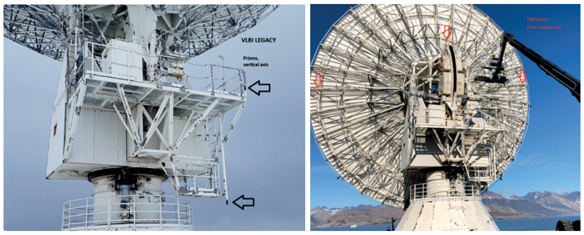

Fig. 7 Reflector points to determine the invariant point of the legacy antenna, by rotating around the horizontal axis (left) and the vertical axis (right).

The axis offset for the legacy antenna was 0.5237 m in 2023 (resp. 0.5235 m in 2018). For VLBI-S (resp. VLBI-N), the axis offset was 0.0002 m (resp. 0.0001 m) in 2018. The invariant points to VLBI-S and VLBI-N were, in addition, determined by local markers inside the azimuth cabin (determined by the manufacturer Asturfeito). The differences between the two methods are less than 1.0 mm in all components: (0.4 mm, −0.4 mm, 0.6 mm) for VLBI-S and (0.7 mm, 0.0 mm, 0.5 mm) for VLBI-N in (east, north, and up).

2.3 GNSS Vectors

In Figure 8 the time series of the height component between the two old GNSS stations is plotted. GNSS observations showed no significant change in the height vector component over 23 years of observations. In Table 2, relative velocities between GNSS sites are included, and a small drift in the horizontal between NYAL and NYA1 can be noted. In [2] the velocities between NYA1 and NYAL were compared to neighboring GNSS stations, and it was concluded that NYA1 emerges as the stable one. There is also a small drift between NYA1 and the new GNSS stations (NABD and NABG) established in the vicinity of the new observatory. However, especially for NABG, due to the short duration of the time series, it is too early to draw any conclusions.

Table 2 L1 vector velocities between Ny-Ålesund GNSS stations.

	East (mm/yr)	North (mm/yr)	Height (mm/yr)
NYA1 – NYAL	−0.40	−0.24	0.04
NABD – NYA1	0.20	0.02	0.28
NABG – NYA1	0.62	0.27	0.30

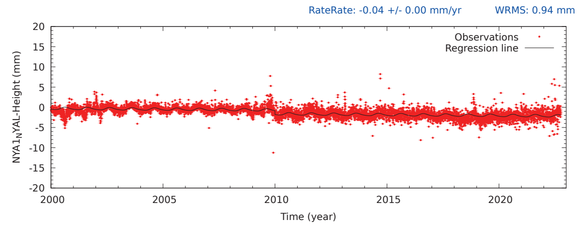

Fig. 8 Up vector between NYA1 and NYAL.

3 Results

The Ny-Ålesund geodetic observatory contains a number of geodetic instruments, control points, and local markers. In this paper, we gave the locations of the invariant points of the legacy 20-meter VLBI (VLBI-L), the two new VGOS antennas (VLBI-N and VLBI-S), a marker on the DORIS platform (Figure 9), and a marker on the SLR fundament (Table 3). Other control points and markers, both permanent and temporary, are measured and used in the estimation, but the results are not included. More details can be found in [6]. This report includes results based on 2019 and 2020 local-tie campaigns including the full covariance matrix in SINEX format used in ITRF2020.

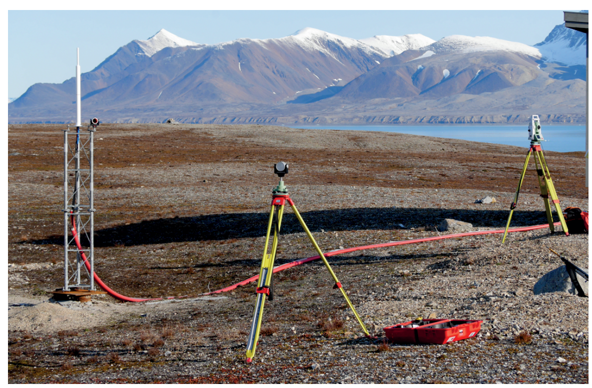

Fig. 9 DORIS beacon with reflector and auxiliary points.

4 Conclusions

Repeated local-tie and stability measurements with leveling, GNSS, and total station have not revealed any significant deformations at Ny-Ålesund. Despite its lo-

Table 3 Locations of main geodetic instruments. All coordinates are relative to the ITRF2020 epoch 2015.0 coordinates of NYA1. The years refer to the respective local-tie campaign.

	East (m)	North (m)	Height (m)
GNSS-NYA1			
	432836.6775	8763915.4791	84.3110
SLR			
2023	432714.9414	8765426.2481	41.8623
2022 (rel. 2023)	0.0000	0.0000	−0.0001
2021 (rel. 2023)	−0.0012	−0.0003	0.0002
2020 (rel. 2023)	0.0008	−0.0005	−0.0004
2019 (rel. 2023)	−0.0004	−0.0006	0.0001
2018 (rel. 2023)	−0.0005	−0.0008	0.0002
VLBI-L (NYALES20)			
2023	432927.9136	8763861.0052	87.4100
2018 (rel. 2023)	−0.0008	−0.0025	−0.0008
2002 (rel. 2023)	−0.0022	−0.0009	−0.0060
VLBI-S (NYALE13S)			
2023	432703.2509	8765382.7849	53.624
2022 (rel. 2023)	0.0000	0.0004	−0.0020
2021 (rel. 2023)	−0.0007	0.0000	0.0008
2020 (rel. 2023)	0.0009	0.0012	−0.0017
2019 (rel. 2023)	−0.0009	0.0007	−0.0022
2018 (rel. 2023)	−0.0012	−0.0007	−0.0033
VLBI-N (NYALE13N)			
2023	432693.7797	8765467.5589	53.62560
2022 (rel. 2023)	0.0014	−0.0001	−0.0013
2021 (rel. 2023)	0.0007	−0.0006	0.0004
2020 (rel. 2023)	0.0019	−0.0001	−0.0011
2019 (rel. 2023)	0.0012	−0.0010	−0.0019
2018 (rel. 2023)	0.0004	−0.0013	−0.0018
DORIS			
2023	432398.1253	8765226.1565	64.6968
2022 (rel. 2023)	0.0008	0.0020	−0.0010
2021 (rel. 2023)	0.0000	0.0017	0.0010
2020 (rel. 2023)	0.0057	0.0020	0.0065
2019 (rel. 2023)	0.0028	0.0013	0.0022

cation in the Arctic's extremely harsh environment, the instruments and main markers at Ny-Ålesund geodetic observatory appear stable. Studies like [3, 4] have shown that Ny-Ålesund experiences non-linear movements and proved that the observed irregularities in uplift seen in Ny-Ålesund stations could be explained by the melting of glaciers at Svalbard. The local-tie vectors are stable over time, and we can assume equal velocities for all main instruments. There is no physical reason to have different velocity models for different stations.

Fig. 10 Sunset at the old Ny-Ålesund 20-meter VLBI antenna (Photo B.-O. Holmberg).

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