Determination of Local Ties at Ny-Ålesund

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Abstract. The Ny-Ålesund Geodetic Observatory is equipped with two permanent GPS units which are part of the IGS network and the VLBI telescope close by. A DORIS beacon is operated in the vicinity. This paper gives an overview about measurements that have been carried out at Ny-Ålesund in two local survey campaigns in August 2000 and August 2002 and the corresponding results.

1 Introduction

Due to its extreme northern location the co-location site Ny-Ålesund plays an important role in global geodetic and geodynamic studies. In close vicinity to each other a VLBI telescope (Fig. 1) and two GPS units (Fig. 2) are operated routinely in global monitoring programs by the Norwegian Mapping Authority (NMA). A DORIS beacon (Fig. 3) is located on top of the French polar research station in about 1.5 km distance from the VLBI telescope and the GPS units.

The data collected with these space geodetic observing platforms are used for example for Earth rotation investigations (VLBI and GPS) or precise orbit determination (DORIS and GPS). All platforms also provide crucial data for the establishment and maintenance of the International Terrestrial Reference Frame (ITRF) (Altamimi et al. 2001).

Two general requirements have to be fulfilled for successful investigations of the areas mentioned above. For global geodynamic studies the stability of the reference points has to be monitored regularly with high accuracy in order to separate local effects from global phenomena like plate tectonics or crustal deformation. At sites with multiple observing platforms the eccentricies, i.e.

Figure 1: The Ny-Ålesund VLBI telescope.
Figure 2: The GPS units NYAL (left) and NYA1 (right).
Figure 3: The DORIS beacon.
the 3D vectors between the observing instruments, have to be determined and kept up-to-date for the maintenance of the terrestrial reference frame. Both aims can only be reached by repeated precise local surveying. Therefore, two surveying campaigns have been carried out in August 2000 and in August 2002.

The main focus of this paper is on the determination of the local ties between the space geodetic reference points. Results concerning the stability of the reference points can be found in Steinfort et al. (2003) or Kümpel and Fabian (2003). Most methods and observing principles used in the campaigns were already described extensively in recent publications (e.g. Lidberg et al. 2002, Nothnagel et al. 2001, Nothnagel et al. 2002 or Steinforth et al. 2002).

2 Space Geodetic Reference Points at Ny-Ålesund

In geodetic VLBI all parameters estimated in the data adjustment are referred to the so-called VLBI reference point. In the case of an azimuth-elevation mount the reference point is either the point where both axis intersect or, if they do not intersect as in the case of the Ny-Ålesund telescope, it is the point of the azimuth axis where the distance to the elevation axis is minimal (Fig. 4) (e.g. Ma 1978, Nothnagel et al. 1995). This point should be invariant to any antenna movements necessary for the VLBI observations.

The reference point of the Ny-Ålesund telescope is not directly accessible and cannot be materialized, either. In order to determine the reference point, the end points of the elevation axis have been materialized by small pop rivets which were placed in the centric bores of the elevation bearings (Fig. 5). When rotating in azimuth each end point of the elevation axis ideally describes a circle about the VLBI reference point. Determining the 3D positions of the markers at different azimuths subsequently permits the computation of the VLBI reference point as the center of the circles. The average height of the two end points represents the height of the reference point. For full visibility coverage of the targets at the elevation axis end points, three auxiliary survey points on tripods were established augmenting the existing network of concrete surveying pillars (Fig. 6).
The GPS antenna reference point (ARP) is, in contrast to the somehow virtual reference point of a VLBI antenna, physically defined. Its height is related to the bottom of the pre-amplifier (BPA) of the GPS antenna. The horizontal position of the ARP can be represented by the center of the ground plane. The height components of the ARP and the center of the ground plane differ by 35 mm according to the IGS database (antenna type AOAD/M_T) (Fig. 8).

Since the GPS antenna could not be removed and there was no direct line of sight to the BPA the reference point had to be determined indirectly. In order to determine the reference point four tape markers were used which were affixed to the ground plane at four directions (North, South, East, West, Fig. 7). These tape markers materialize the lower edge of the circular ground plane.
After measuring the 3D positions of the tape markers relative to a control network of tripods through forward intersects it is possible to estimate the position of the ARP as the center of a circle.

The reference point of the DORIS beacon (Starec type) is normally the 400 MHz phase center of the antenna (Fig. 9). If the 400 MHz and 2 GHz phase centers are not on the same vertical line (tilt of antenna) the height reference...
of the antenna is the 400 MHz phase center, but the horizontal position is referred to the 2 GHz phase center (H. Fagard, personal communication).

The DORIS beacon is located on a balcony at the building of the French polar research station in Ny-Ålesund village (cf. Fig. 3, Fagard 1999). The local tie between the DORIS antenna and the other techniques was observed by GPS since the distance is too long for a position transfer by terrestrial surveying methods (adverse error propagation).

In a first step, the centering of the DORIS beacon with respect to its nominal position marked by a brass bolt was checked in order to remount the beacon in its proper position (cf. Fig. 9). Then the beacon was dismounted and replaced by a GPS antenna for a 5-day continuous GPS measurement (Fig. 11). At the end of the GPS measurements the DORIS antenna was replaced and the centering was checked again.

3 Forward Intersection vs. Radial Point Determination

This section provides a comparison of two methods for the determination of target points on telescope or antenna structures by classical surveying methods. Figure 12 shows the trigonometric forward intersection, fig. 13 the radial point determination.

The following formulas are used for determining the coordinates of a point \( P(y_p, x_p) \) (on a telescope) by forward intersection:

\[
\begin{align*}
y_p &= y_A + AP \sin t_A^p \\
&= y_A + \frac{AB \sin \beta}{\sin(\alpha + \beta)} \sin t_A^p \\
x_p &= x_A + AP \cos t_A^p \\
&= x_A + \frac{AB \sin \beta}{\sin(\alpha + \beta)} \cos t_A^p
\end{align*}
\]

and by radial point determination:

\[
\begin{align*}
y_p &= y_A + AP \sin t_A^p \\
x_p &= x_A + AP \cos t_A^p
\end{align*}
\]

using the parameters of figures 12 and 13. The error propagation uses the partial derivatives of the coordinate components w.r.t. to the observations and parameters introduced from the ground network. Assuming that the uncertainties of the coordinates of \( A(y_A, x_A) \) are not of interest here the error propagation law for forward intersection is

\[
\begin{align*}
\sigma_{y_A}^2 &= \left( \frac{\partial y_p}{\partial t_A^p} \right)^2 \sigma_t^2 + \left( \frac{\partial y_p}{\partial \alpha} \right)^2 \sigma_\alpha^2 + \left( \frac{\partial y_p}{\partial \beta} \right)^2 \sigma_\beta^2 + \left( \frac{\partial y_p}{\partial AB} \right)^2 \sigma_{AB}^2 \\
\sigma_{x_A}^2 &= \left( \frac{\partial x_p}{\partial t_A^p} \right)^2 \sigma_t^2 + \left( \frac{\partial x_p}{\partial \alpha} \right)^2 \sigma_\alpha^2 + \left( \frac{\partial x_p}{\partial \beta} \right)^2 \sigma_\beta^2 + \left( \frac{\partial x_p}{\partial AB} \right)^2 \sigma_{AB}^2
\end{align*}
\]
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with

$$\frac{\partial y_p}{\partial r_d} = AP \sin t_d^p$$

$$\frac{\partial y_p}{\partial \alpha} = -AP \cot(\alpha + \beta) \sin t_d^p$$

$$\frac{\partial y_p}{\partial \beta} = \frac{BP}{\sin(\alpha + \beta)} \sin t_d^p$$

$$\frac{\partial y_p}{\partial AB} = \frac{\sin \beta}{\sin(\alpha + \beta)} \sin t_d^p$$

$$\frac{\partial x_p}{\partial r_d} = AP \cos t_d^p$$

$$\frac{\partial x_p}{\partial \alpha} = -AP \cot(\alpha + \beta) \cos t_d^p$$

$$\frac{\partial x_p}{\partial \beta} = \frac{BP}{\sin(\alpha + \beta)} \cos t_d^p$$

$$\frac{\partial x_p}{\partial AB} = \frac{\sin \beta}{\sin(\alpha + \beta)} \cos t_d^p$$

and for radial point determination

$$\sigma_{r_d}^2 = \left(\frac{\partial y_p}{\partial r_d}\right)^2 \sigma_{\alpha}^2 + \left(\frac{\partial y_p}{\partial AP}\right)^2 \sigma_{AP}^2$$

$$\sigma_{\alpha}^2 = \left(\frac{\partial x_p}{\partial r_d}\right)^2 \sigma_{\alpha}^2 + \left(\frac{\partial x_p}{\partial AP}\right)^2 \sigma_{AP}^2$$

with

$$\frac{\partial y_p}{\partial r_d} = AP \cos t_d^p$$

$$\frac{\partial y_p}{\partial \alpha} = \sin t_d^p$$

$$\frac{\partial x_p}{\partial \alpha} = -AP \sin t_d^p$$

$$\frac{\partial x_p}{\partial \beta} = \cos t_d^p$$

The comparison of the formulas shows that both types of coordinate determinations, forward intersection and radial point determination, as well as their error propagation contain contributions of the distance to the target point \(P(\overline{AP})\) or of the baseline between the control network points \(A\) and \(B(\overline{AB})\). In the case of the radial point determination each distance \((\overline{AP})\) for...
a number of target points depends on the accuracy of the electronic distance measuring instrument and, in addition, has to be measured for every point anew. Both facts may contribute some additional uncertainty, either by a scale factor or an additive error. For the forward intersection method the baseline $AB$ is normally determined within a complete network of ground points. Therefore, the scale of the network is robustly determined on the basis of redundant distance measurements which control each other and avoid additive errors. Thus, using the forward intersection method applied from a network of ground stations contributes to the stability of the coordinate determination of (telescope) points.

4 Results

The analysis of the trigonometric measurements was carried out with the least squares adjustment program Panda (GeoTec 1998). After some testing the topocentric coordinates of point F93, the East and North component of F95 and the Up component of F91 were fixed in the least squares adjustment to the coordinates used in the 2000 campaign (e.g. Nothnagel et al. 2002). The topocentric coordinates for the VLBI and the GPS reference point were then estimated in this local frame (Tab. 1).

<table>
<thead>
<tr>
<th>East</th>
<th>$\sigma$ [mm]</th>
<th>North</th>
<th>$\sigma$ [mm]</th>
<th>Up</th>
<th>$\sigma$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI</td>
<td>432927.7704</td>
<td>0.8</td>
<td>8763860.7518</td>
<td>0.1</td>
<td>87.2926</td>
</tr>
<tr>
<td>GPS</td>
<td>432836.5156</td>
<td>0.1</td>
<td>8763915.2683</td>
<td>0.1</td>
<td>84.1872</td>
</tr>
</tbody>
</table>

Table 2: Geocentric Coordinates of the VLBI and GPS reference points after transformation

<table>
<thead>
<tr>
<th>X</th>
<th>$\sigma$ [mm]</th>
<th>Y</th>
<th>$\sigma$ [mm]</th>
<th>Z</th>
<th>$\sigma$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI</td>
<td>1202462.7055</td>
<td>0.7</td>
<td>252734.4291</td>
<td>0.8</td>
<td>6237766.0458</td>
</tr>
<tr>
<td>GPS</td>
<td>1202433.9070</td>
<td>0.2</td>
<td>252632.2608</td>
<td>0.1</td>
<td>6237772.5076</td>
</tr>
</tbody>
</table>

Eccentricity vectors between different observing techniques to be used in the computations of the ITRF are normally given in geocentric X,Y,Z coordinate differences. Since the coordinates of the surveying pillars have been computed in both systems, i.e. in global X,Y,Z and in topocentric North,East,Up coordinates, it is possible to transform one system into another by a simple 7-parameter Helmert transformation (Tab. 1 and 2).
Table 3: Geocentric Coordinate Differences relative to NYA1 (VLBI - NYA1 and DORIS - NYA1 resp.)

<table>
<thead>
<tr>
<th>to point</th>
<th>Year</th>
<th>dX [m]</th>
<th>σ [mm]</th>
<th>dY [m]</th>
<th>σ [mm]</th>
<th>dZ [m]</th>
<th>σ [mm]</th>
<th>Distance [m]</th>
<th>σ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VLBI</td>
<td>2002</td>
<td>28.798</td>
<td>1.0</td>
<td>102.168</td>
<td>1.0</td>
<td>-6.462</td>
<td>1.0</td>
<td>106.344</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000</td>
<td>28.794</td>
<td>2.0</td>
<td>102.162</td>
<td>2.0</td>
<td>-6.470</td>
<td>2.0</td>
<td>106.339</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td></td>
<td>28.797</td>
<td>1.7</td>
<td>102.167</td>
<td>1.5</td>
<td>-6.464</td>
<td>1.0</td>
<td>106.341</td>
</tr>
<tr>
<td></td>
<td>DORIS</td>
<td>2002</td>
<td>360.061</td>
<td>1.7</td>
<td>1530.850</td>
<td>1.5</td>
<td>-162.944</td>
<td>5.7</td>
<td>1581.043</td>
</tr>
</tbody>
</table>

Table 3 summarizes the geocentric eccentricity vectors between the NYA1 GPS reference point and the VLBI and DORIS reference points. The standard deviations of the values derived in the 2000 campaign are mainly influenced by the determination of the NYA1 reference point. This was measured by GPS only in the precise point positioning mode (NMA, personal communication). In order to calculate a reasonable weighted mean and to mitigate a disproportion of the two campaigns the standard deviations of the 2002 eccentricities were fixed to 1.0 mm giving the NYA1 reference point measured by terrestrial methods a stronger weight. In addition, the standard deviations of the mean values (cf. Tab. 3) were also fixed to 1.0 mm which corresponds approximately to the accuracy of the terrestrial measurements. The resulting mean values are intended as updates to the previous figures originating from the 2000 campaign and will be published in the SINEX format.

It should be mentioned here that the vectors as computed from the ITRF2000 coordinates of these reference points (VLBI-NYA1 $\Delta X = 28.794$ m, $\Delta Y = 102.166$ m, $\Delta Z = -6.475$ m; DORIS-NYA1 $\Delta X = 360.060$ m, $\Delta Y = 1530.851$ m, $\Delta Z = -162.949$ m, Distance $= 1581.044$ m) show a good agreement with the vectors determined in this study.

The survey setup chosen here also offers a good opportunity to check the antenna axis offset. The results of the two campaigns agree quite well (difference 0.6 mm, Tab. 4) again confirming the significant discrepancy of the value provided by the manufacturer from the value determined on site.

Table 4: Axis offset

<table>
<thead>
<tr>
<th>Year</th>
<th>Offset [m]</th>
<th>σ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>manufacturer</td>
<td>0.5080</td>
</tr>
<tr>
<td>2000</td>
<td>0.5245</td>
<td>0.3</td>
</tr>
<tr>
<td>2002</td>
<td>0.5239</td>
<td>0.3</td>
</tr>
<tr>
<td>mean</td>
<td>0.5242</td>
<td>0.2</td>
</tr>
</tbody>
</table>

One of the reasons for such a big discrepancy may be the fact that the VLBI reference point cannot be materialized and that the manufacturer determined this value just by trying to measure it with the help of a CAD software. In addition, the actual telescope construction at Ny-Ålesund is not necessarily the same as it was projected (H. Digre, personal communication).

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