Proposed Establishment of a new Fundamental Geodetic Station in Antarctica

L. Combrinck, A. de Witt, P. E. Opseth, A. Færøvig, L. M. Tangen, R. Haas

Abstract The Global Geodetic Observing System (GGOS) requires a globally distributed network utilizing next generation Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) technology to meet the objectives of GGOS. It is expected that about 30 core sites will be established globally to ensure adequate network density and geometry. The proposal presented here highlights opportunities for VLBI network densification. We consider both southern Africa and Antarctica sites for the establishment of new VLBI sites. We have made *u*-*v* coverage plots and geodetic VLBI simulations for several sites, and evaluate these in terms of their scientific value. Both the southern Africa and Antarctica sites should be equipped with VGOS compatible antennas.

In particular we propose the establishment of a new core fundamental station in Antarctica, operated and funded by an international consortium. This core GGOS site could be located at either the Norwegian (Troll) or South African Antarctica (SANAE IV) bases. Troll is located 235 km from the coast in Dronning Maud Land at $72^o01' S$, $2^o32' E$, at a height of 1270 m above sea level on the Jutulsessen nunatak. SANAE IV is located 170 km from the coast at a height of 800 m on the Vesleskarvet nunatak in Queen Maud Land at $72^o40' S$, $2^o50' W$. Unlike most other Antarctica research bases, both these stations are located on exposed bedrock, not on ice, making them suitable for geodetic installations. A specially designed Geodetic/Astrometric antenna (perhaps equipped with a radome) suitable for the harsh Antarctica environment will have to be constructed for installation in Antarctica. The Antarctica locations will create the longest possible North-South baseline (at this stage).

We further propose the relocation of the geodetic VLBI antenna (20-m) currently located at Ny-Ålesund at $79^o N$, Svalbard to South Africa (Matjiesfontein) or even another suitable site such as Gamsberg in Namibia to form part of the African VLBI Network (AVN).

Simulations have shown that adding a station in Antarctica has a very positive improvement on *u*-*v* coverage, with Matjiesfontein being the second best option. We present an overview of the envisioned GGOS stations, details and modalities of these projects and expected scientific and other benefits.

Keywords GGOS, Antarctica, VLBI, GGRF, AVN

1 Introduction

During March 2016 a suggestion was made by Statens Kartverk (Norway) that the currently operational 20-m VLBI radio telescope located at Ny-Ålesund (see Fig. 1) be donated to HartRAO (South Africa). This antenna can thus be relocated and installed at an appropriate location in South Africa, or elsewhere in Africa. There are several possible re-location sites, Mauritius, Madagascar, Matjiesfontein (South Africa), Gamsberg (Namibia), or Kilimanjaro (Kenya). A possible location could be Gamsberg if it is decided to rather make the 20-m part of the African VLBI Network (AVN); this could then be the first astronomy/astrometric/geodetic antenna within the AVN. For details on the AVN see Gaylard et al. (2012) and Loots (2015). For the simulations presented in this article, we included Antarctica to estimate what the effect of including a new antenna on this continent would have compared to a standard VLBI geodetic network. The idea of including Antarctica as a possible site stems from the fact that current geodetic infrastructure on Antarctica is very sparse. Currently there are two VLBI antennas located on Antarctica (O'Higgins and Syowa), these are both small antennas (9 m and 11 m re-

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spectively) and are not fully dedicated to geodesy or astrometry, although both have made very important contributions to the geodetic networks. Therefore the installation of a geodetic/astrometric quality antennna will drastically improve network geometry and *u*-*v* coverage. There is no Satellite Laser Ranging (SLR) equipment either, therefore such a VLBI antenna installation should be done with the view towards a complete Fundamental Station for Antarctica, which includes the installation of all other major geodetic equipment as well as supportive geophysical instrumentation.

We made *u*-*v* coverage plots and performed geodetic VLBI simulations for different sites to evaluate their scientific merit. Astrometry simulations will be done at a later stage to also compare the accuracy of source positions.

Logistically some sites are easier than others, the science case for Antarctica is the most convincing, however it is also the most challenging installation due to difficult logistics and harsh weather conditions. These are not insurmountable, as both Norway and South Africa have extensive experience of construction and the difficult logistical requirements that will be required for such a project.

The Ny-Ålesund antenna will be suitable for installation at a selected site in southern Africa after some upgrades and renovation (new motors, encoders, modern servo drives and control systems, receivers and cooling systems) but will be unsuitable for installation in Antarctica due to its age and possible deficiencies. A new, specifically designed antenna for Antarctica, with specifications to be VGOS compatible and be large enough to allow celestial reference frame work will have to be designed and manufactured for installation in Antarctica. The structural requirements for Antarctica are severe due to the harsh environment and high velocity winds encountered.

We had our first meeting concerning the 20m-antenna project at Hønefoss during 12-14 February 2017 followed by a site visit to Ny-Ålesund during 22-24 May 2017. It was estimated that the 20-m antenna will be phased out over 3 years (twin VGOS antennas replacing the 20-m), so that the 20-m should become available for disassembly and removal from about June 2020.

The proposal expressed in this paper is twofold, on the one hand we propose to relocate the Ny-Ålesund 20-m to southern Africa (upgraded to be VGOS compatible as far as practical), and on the other hand we propose to develop a complete Fundamental Geodetic Station in Antarctica, part of the GGOS network, part of the Global Geodetic Reference Frame (GGRF) infastructure, operated and maintained by a global consortium (i.e. an internationally funded and operated station).

Fig. 1: The Ny-Ålesund 20-m VLBI antenna. The antenna was constructed during the summers of 1993 and 1994, and has been operational since 1 January 1995. Its pedestal consists of steel subsections, making removal and re-assembly practical.

2 Simulations

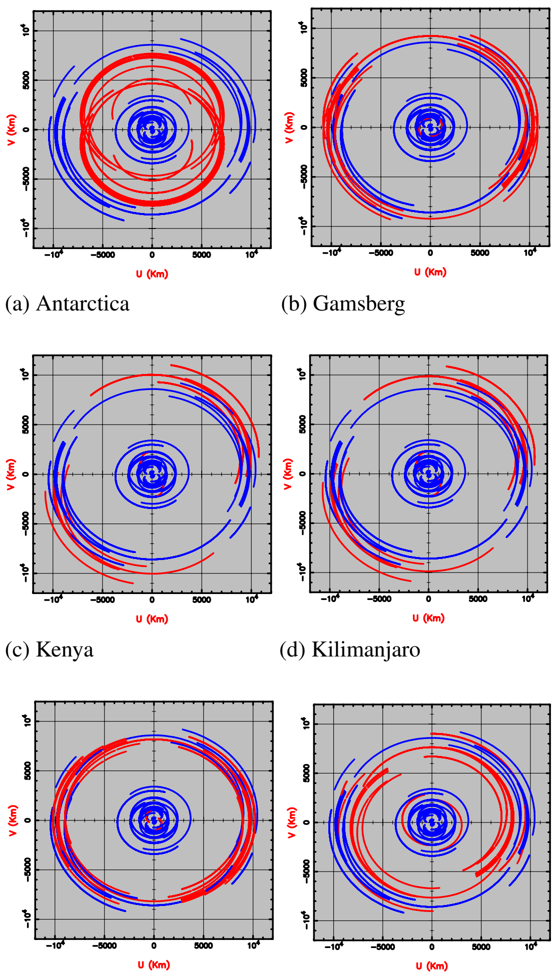
We performed geodetic VLBI simulations in terms of Earth Orientation Parameters (EOP) errors as an indicator of proposed site suitability. The reference network is based on the standard IVS-R1675 network configuration. The Vienna VLBI Software (VieVS; Böhm et al., 2009) was used for scheduling, simulating and analysing these sessions. The scheduling parameterisation resembles the IVS-R1675 sessions as closely as possible. For the simulation of observations the default atmospheric turbulence parameters in VieVS ($C_n = 2.5 \cdot 10^{-7}\ m^{-1/3}$, $H = 2000$ m, $v_e = 8\ m/s$, etc.) were used for every station. This does not resemble the true troposphere variability at every site but at the moment there is not enough information about troposphere turbulence at these stations. In order to get statistical information about the estimated parameters, the sessions were Monte Carlo simulated 50 times and then analysed. A standard geodetic analysis was performed with the same models and parameters for every session. The results are tabulated in Tab. 1. The best total relative improvement results from adding a station to Antarctica (using the coordinates of the Norwegian Troll base) followed by Matjiesfontein (South Africa). This is not surprising as the extended north-south baselines decrease the y pole error substantially; measurement of UT1-UTC also improves.

The quality of a VLBI image can be determined by the density and distribution of *u*-*v* tracks in the *u*-*v* plane, therefore one can use this characteristic to eval-

Table 1: Average formal EOP errors and their standard deviations using R1675 as reference. It is clear that Antarctica is the best choice followed by Matjiesfontein, with Gamsberg a close 3rd (based on sum of errors).

Network	UT1 - UTC (ms)	x_pole (μas)	y_pole (μas)	dX (μas)	dY (μas)	sum_{error}
R1675	3.27 ± 0.08	27.28 ± 0.70	51.41 ± 1.32	24.04 ± 0.62	22.94 ± 0.59	128.94 ± 3.30
R1675 + Antarctica	2.72 ± 0.07	20.88 ± 0.50	37.90 ± 0.91	19.94 ± 0.48	18.91 ± 0.45	100.35 ± 2.40
R1675 + Matjiesfontein	2.91 ± 0.07	20.60 ± 0.51	43.94 ± 1.08	19.40 ± 0.48	18.82 ± 0.46	105.67 ± 2.60
R1675 + Gamsberg	2.81 ± 0.07	20.40 ± 0.53	44.61 ± 1.17	20.10 ± 0.53	19.17 ± 0.50	107.09 ± 2.80
R1675 + Kilimanjaro	3.05 ± 0.06	22.15 ± 0.45	45.76 ± 0.94	20.82 ± 0.43	20.32 ± 0.42	112.10 ± 2.30
R1675 + Mauritius	2.99 ± 0.08	23.00 ± 0.64	45.29 ± 1.26	20.94 ± 0.58	20.29 ± 0.56	112.51 ± 3.13
R1675 + Kenya	2.99 ± 0.07	22.86 ± 0.55	47.04 ± 1.14	20.73 ± 0.50	20.34 ± 0.49	113.96 ± 2.75

uate the benefits of densifying a particular VLBI network or to ascertain the benefits by creating extended baselines by adding additional stations to increase the geometrical size of the network. These *u*-*v* tracks are created through the 2-D projection of the various VLBI baselines on the *u*-*v* plane; this plane is perpendicular to the line of sight of the antenna when pointed to a radio source. In Fig. 2 we show the *u*-*v* plots for various sites added to the standard VLBI network in the Southern Hemisphere. A new station in Antarctica provides by far the best improvement in *u*-*v* coverage.



(a) Antarctica (b) Gamsberg

(c) Kenya (d) Kilimanjaro

(e) Matjiesfontein (f) Mauritius

Fig. 2: Plots of the *u*-*v* coverage for a source at -60° declination, observed over a period of 24 hours. The blue tracks are from the standard Southern Hemisphere VLBI network and the red tracks due to an additional station as labelled in figures (a) to (f).

3 Possible locations for the 20-m VLBI and new-built antennas

There are 3 sites which warrant serious consideration for a geodetic/astrometric antenna. In the southern part of South Africa (Matjiesfontein) and then either the Norwegian Troll (Fig. 3) base or the South African SANAE IV base (Fig. 4), which both are located in Antarctica within about 200 km from each other. The basic logistics for transporting an antenna to Antarctica exists. These are not greenfield sites and adding a fundamental geodetic station should be within the capacity of the existing infrastructure, even if some expansion or capacity increase may have to included in the station design.

3.1 Antarctica (new-built)

1. Both South Africa (SA Agulhas II) and Norway have supply ships capable of transporting large equipment to Antarctica
2. Both countries have snow tractors and sledges of adequate capacity
3. The antenna could be moved from the ice shelf to either base
4. Both bases have airstrips; aeroplanes can land at Troll throughout the year (the only base where this is possible)

3.2 Matjiesfontein (re-located 20-m)

1. This is a green-fields site (no major infrastructure).
2. High speed optical fibre is 4 km distant
3. The site is suitable for radio and optical equipment (semi-arid, low rainfall)
4. A geophysical and a GNSS station have already been installed.

Fig. 3: The Norwegian Antarctica base (Troll). The photo was taken during the summer of 2007.

Fig. 4: The South African Antarctica base (SANAE IV), the photo was also taken during the summer of 2007.

5. A major paved road and train line is 4 km distant so access is relatively easy

4 Site surveys

Site surveys/evaluations need to be conducted during the next three years to ascertain the suitability of candidate sites. The southern Africa sites are easy to access, however the Antarctica sites require interaction with other stakeholders (Norwegian Polar Institute, South African National Antarctica Programme) and will need much preparatory work and institutional approval and support. Basic site surveys should include:

1. Wind direction and strength (Fig. 5)
2. Topography (Fig. 6 and Fig. 7)
3. Geology (bedrock type, stability, strength)
4. Logistical support/additional requirements
5. Power, communications
6. Accessibility (ship, plane, sledge, helicopter)
7. Most appropriate location on site
8. Other

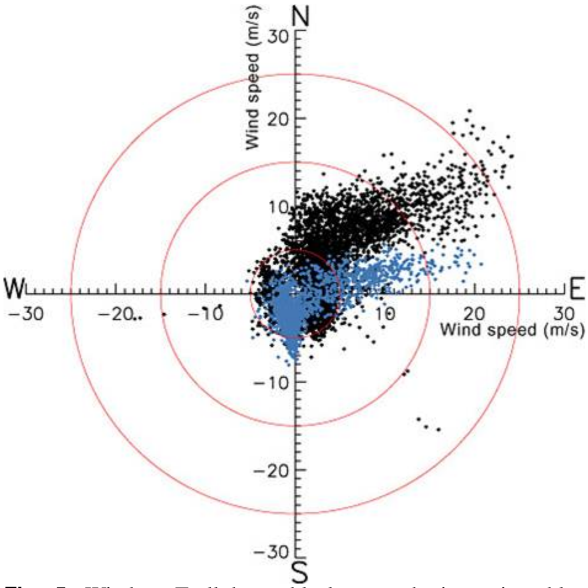


Fig. 5: Wind at Troll base: black-atmospheric station, blue-airfield (Hansen, 2009).

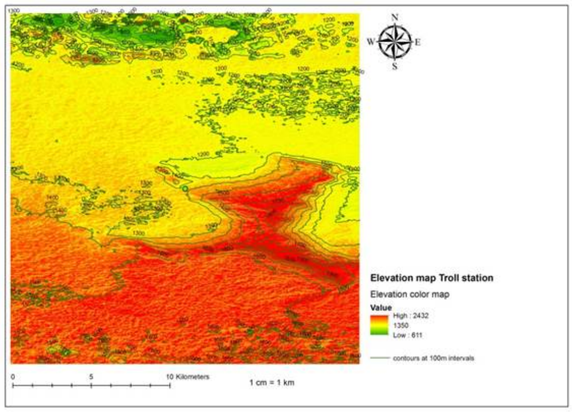


Fig. 6: The topography at Troll base exhibits a hilly terrain. A safe location for the new-built VLBI antenna must be found to shield it from the prevailing north-east winds (see Fig. 5). Data from the Shuttle Radar Topography Mission (SRTM; USGS, 2004) was used to generate elevation maps for the Troll and SANAE IV (Fig. 7) sites.

5 Conclusions

In the near future there will be an opportunity to relocate the Ny-Ålesund) 20-m VLBI antenna to southern Africa. This relocation has a good science case. The funding model for this could be linked to the AVN project, and this needs to be explored.

Establishment of an international consortium will be required for a Fundamental Station in Antarctica and it should lead to the establishment of a GGRF/GGOS node in Antarctica; the science case for this is very good.

In summary, we see two opportunities for VLBI and geodesy; southern Africa and Antarctica. Each of these locations have their own challenges; Norway and South

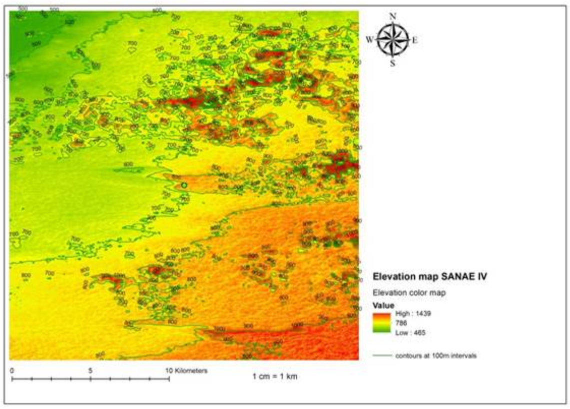


Fig. 7: The topography at the SANAE IV base is flat in general, except for a cliff which breaks the flatness of the terrain. In general it is more exposed than the Troll base.

Africa can play a major role in both these two ventures, with benefits to the global community, improvement in geodetic and astrometric products as well as global reference frame support.

The issue of data transfer will be a challenge, as there is no optical fibre to Antarctica at this stage (although this is a well known requirement, there are many practical obstacles due to the moving ice on the continent). Other options will have to be considered, and perhaps, such a requirement will provide enough impetus for the first fibre optic cable to be laid to Antarctica.

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