# VGOS Observing Plan

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Over the past several years, VGOS development has been guided by the VLBI2010 Project Executive Group (V2PEG) and VLBI2010 Committee (V2C) with the V2C focusing on completion of the VLBI2010 system and the V2PEG concentrating on network expansion. In this document the V2PEG presents an operational plan to bridge the gap between the bold targets of VGOS and the current operational programmes of the IVS.

As an initial operational target, VGOS aims for sustained daily product performance at the level of the CONT sessions or better by the end of 2017. This represents a daily performance improvement that gives the IVS an unambiguous direction for the next four years; and it makes clear the IVS's resolve for a significantly improved VLBI component in a tangible time frame.

This plan provides an operational context for VGOS broadband stations and hence motivates both new and legacy stations to seek funds to upgrade to broadband capability. It places a priority on early high quality but cost effective ***daily*** operations with performance improving as operational capacity increases. It assumes that most of the new broadband antennas will be dedicated to VGOS operations and will not be shared with other applications such as astronomy or spacecraft tracking.

## Deployment of VGOS Systems

The VGOS system design is described in detail in the VLBI2010 project specification (Petrachenko et al. 2009). Over the past year a number of actions have been undertaken in the realization of the concept:

- Broadband feed, digital back end (DBE) and recorder comparisons have been completed including information on commercial availability.
- The broadband systems have been improved—specifically towards increased reliability and greater compliance with VLBI2010 specifications.
- Geodetic tests have been successfully undertaken (so far only on the GGAO to Westford baseline).
- An RFI study was undertaken indicating that:
    - A large number of stations will be able to operate in the full 2–14 GHz range without front end saturation.
    - A small number of sites will be limited to operating in the 3-14 GHz range to avoid front end saturations.

Over the next year it is recommended that the following further steps be encouraged:

- RFI studies continue at potential VGOS sites.

- The DORIS/SLR RFI co-location problem is addressed.
- Geodetic broadband observations continue on the GGAO-Westford baseline.
- Broadband observations begin with a third more distant station (e.g. Kokee or Wettzell) to demonstrate performance over longer baselines.
- Broadband development continues with the goal of achieving full VLBI2010 compliance (with commercial availability wherever possible), specifically including
    - cryogenic front ends for both QRFH and Eleven Feed.
    - DBE's with 1-GHz bandwidth.
    - flexible down converters with full 2–14 GHz.
    - completion of high capacity data systems.
    - a cable calibration system.
    - demonstration of the DBBC3 direct sample system.
    - demonstration of a Stirling cycle cryogenic system.
- A convenient and effective 'mixed-mode' methodology (i.e., legacy S/X with VGOS broadband in S/X mode) needs to be developed so that strong geodetic ties can be developed between new VGOS stations and the legacy S/X network.
- Short baseline phase delay measurements be made between new antennas and co-located legacy antennas.

**Expansion and Testing of the VGOS Network in 2014**

By the end of 2014 as many as eight antennas are expected to have achieved broadband capability (see Table 1 and Figure 1).

*Table 1. Antennas achieving broadband capability by the end of 2014.*

| Station | When | Antenna | Notes |
|---|---|---|---|
| GGAO12 | Now | Fast | |
| Ishioka | Mid-2014 | Very fast | 2 years of S/X/Ka legacy ties |
| Kokee | 2014 | Legacy | Very fast antenna in 2015 |
| Noto | 2014 | Legacy | Direct sampling approach |
| Sheshan | 2014 | Very fast | |
| Westford | Now | Legacy | Shared with Lincoln Laboratory |
| Wettzell | Mid-2014 | Very fast | |
| Yebes | Mid-2014 | Very fast | |

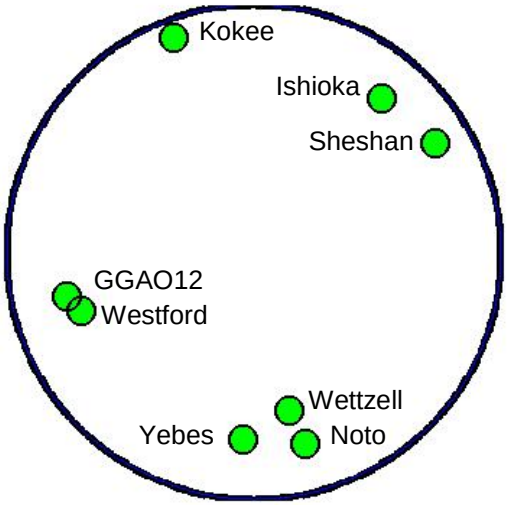


*Figure 1. North polar projection of antennas achieving broadband capability by the end of 2014.*

Throughout 2014 there will be four main VGOS-related activities:

1. the qualification of new VGOS stations as they come on line in broadband and (if RFI permits) S/X modes;
2. preparations for the VGOS trial operations scheduled for 2015 (see next section for details of the trials). Preparations include ensuring that adequate station, media and correlator resources are available and that as many processes as possible are automated for smooth and sustained operations;
3. the development and testing of processes for mixed-mode (legacy S/X with VGOS broadband in S/X mode) operations including the qualification of digital back ends at legacy S/X stations; and
4. the execution of mixed-mode sessions (i.e., VGOS broadband stations in S/X sessions, e.g., T2, R1, R4) to establish strong ties between legacy and VGOS sites.

To help achieve the first two items, the OPC has scheduled seven sessions in 2014 specifically for VGOS operations. If needed other ad hoc sessions (e.g., for fringe tests) can also be added. In order to have a clean spectrum for VGOS broadband observing, the VGOS sessions are planned to operate solely in the 3–14 GHz range. The V2PEG encourages stations to seek the required funding to join the VGOS sessions of 2014 and the VGOS trial operations of 2015.

For the latter two items it is recognized that RFI around the current S-band frequency may preclude the use of a full 2–14 GHz broadband receiver at certain locations, so that these broadband stations will not be able to participate in mixed-mode observations. If RFI does not inhibit observation at 2–3 GHz, however, broadband conversions and new broadband facilities should be encouraged to cover the full 2–14 GHz VGOS range.

**Trial Operations of the VGOS Network in 2015**

During 2015 there will be three trial VGOS campaigns to evaluate and improve aspects of VGOS operations. To properly assess the sustainability of the three aspects of operations, each trial will last at least 6–8 weeks thus ensuring that the full 'schedule–acquire–ship/transmit–correlate/process/analyse–ship/transmit' cycle can be completed without developing a back-log. Each trial should further be separated by 8–10 weeks to allow for the eventuality of a back-log, to assess performance, to recommend improvements, and to prepare for the next trial. This effort will be coordinated by the IVS Coordinating Center.

**Trial 1:** *Sustained Weekly 24-hour Sessions, Jan–Feb.* This trial involves observing one 24-hour session each week in VGOS broadband mode. The network will include all available qualified VGOS stations, i.e., about 8 stations. Schedules will be optimized to best use all VGOS characteristics, in particular the very fast slewing of the new antennas. It is recommended that the broadband day be inserted as day 7 (e.g., B7nnn) to best bridge the largest gap in the week between R4 and R1 and start at 0 hr UT to match the satellite geodetic techniques (see Figure 2). Although an observation on the weekend is required, this should not be a problem for a fully qualified VGOS antenna that can safely operate in automated or remote control mode. As broadband operations mature, it should be possible to record a full 24-hour session on a single recording module. [Given a detection limit of SNR=10 per band, a typical source flux distribution and a minimum correlated flux of 250 mJy, the average observation at a station should require only about 10 GB. At 10 GB per observation, a single 32-TB module will record up to 3200 observations (i.e., 1 observation every 27 s), more than enough to record a full 24-hour session on a single module even for "very fast" VGOS antennas.] For sustained operations, a pool of four 32-TB modules per station will be required along with funds to ship one module per station per week back and forth between the correlator and station.

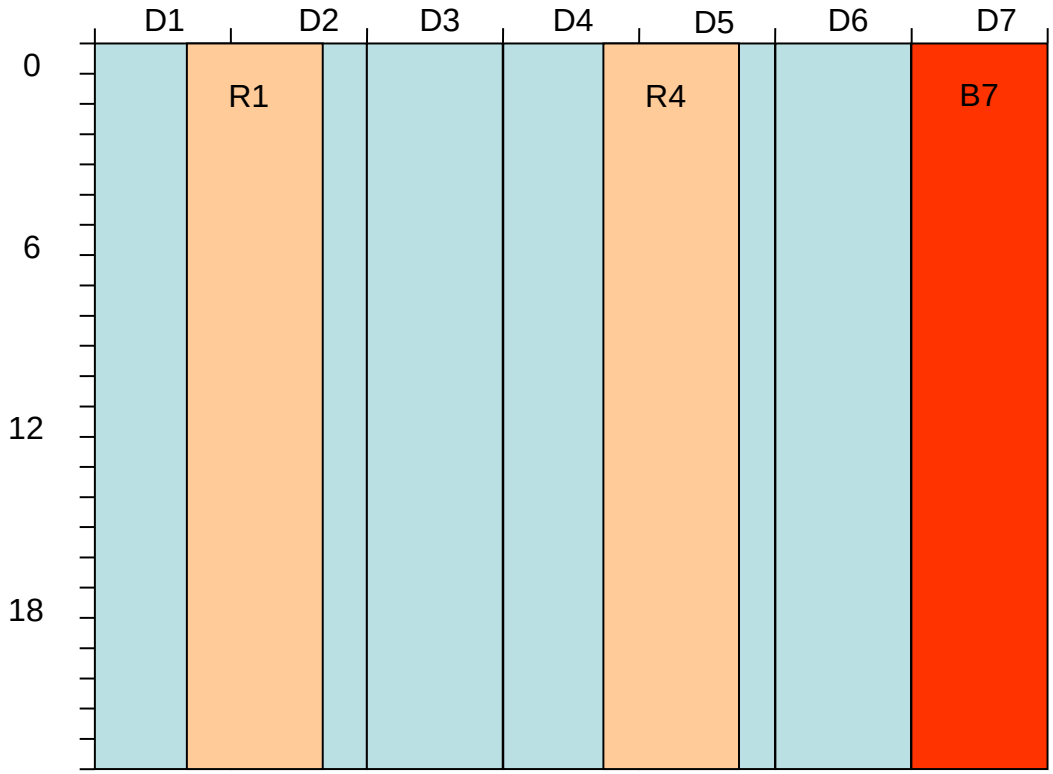


*Figure 2. Trial 1: Sustained Weekly 24-hour Session, Jan–Feb. The VGOS Day 7 (B7nnn) broadband session is represented in red.*

**Trial 2:** *Sustained Daily VGOS EOP Sessions, May–June.* VGOS broadband observations will be carried out on a daily basis using a consistent network. VGOS stations that cannot guarantee daily availability because of additional other roles (e.g., Noto and Westford) can be added when available on a tag-along basis, which does not impact the scheduling of the core network. In recognition of the fact that, at the start of VGOS operations, some stations will not have the resources to maintain full 24/7 observing, this trial involves a reduced duty cycle schedule in which daily sessions are made up of four one-hour bursts spaced equally in time, i.e., one burst every six hours (see Figure 3). This type of schedule still allows determination of all EOP, strongly attenuates diurnal and semi-diurnal signals, and reduces both time variable network biases and source selection biases. Aliasing of high frequency EOP due to the gaps between bursts in the daily sessions is not expected to be a major negative factor. For this type of schedule, all operational costs including data transmission, wear and tear on equipment, and power consumption will be equivalent to scarcely more than a single day of operations per week. It is assumed that the bursts can be turned on and off in an unattended mode so that additional staffing resources will be minimal. The purpose of this trial is to exercise sustained daily operations at the stations without regard to timely transmission of data to the correlator. Data will be shipped once per week to the correlator and will require only a single module per station. Hence the media pool and shipping requirements are the same as for Trial 1.

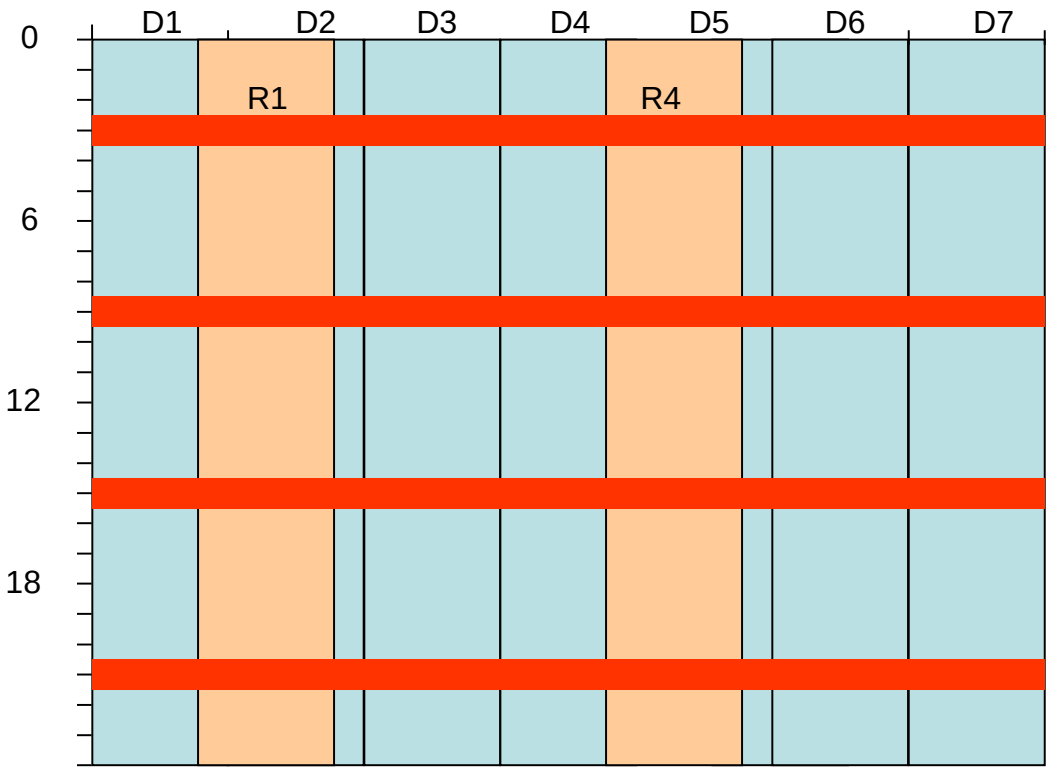


*Figure 3. Trials 2 & 3: Sustained Daily VGOS EOP Sessions, May-June and Sept-Oct. Daily hour-long VGOS bursts are represented in red.*

**Trial 3:** *Repeat of Sustained Daily VGOS EOP Sessions but with Timely Transmission of Data, Sept-Oct.* The observations for Trial 2 and Trial 3 are identical (see Figure 3). However, the focus of Trial 3 is the timely transport of data to the correlator. As much as possible, the data will be transported electronically. With this reduced duty cycle mode of operation, a sustained data rate of 500 Mbps will be sufficient to transmit the full 4 hour data volume within a day, even for the fastest antennas. For stations where the required data rate cannot be sustained, media will need to be physically transported. Daily shipment of disk packs only ~15% full is highly inefficient. Efficiency can be increased by transferring data to a single disk before shipping. [Note: In the future, as more hours of data are collected per day, higher data rates will be required with 3 Gbps being sufficient to transmit a full 24 hour session within a day.]

**VGOS Pilot Project in 2016**

Given the successful completion of the three sets of trial operations, a VGOS Pilot Project can begin at the start of 2016 and continue throughout the year. The purpose of a pilot project is to gain experience with an operational mode without making a full commitment to product delivery. Operations in this period will be a combination of all aspects of the trial campaigns. There will be a single 24-hour VGOS session per week and daily VGOS EOP sessions on the remaining days (see Figure 4). Data will be

transmitted to the correlator in a timely fashion with as much data transmitted electronically as possible.

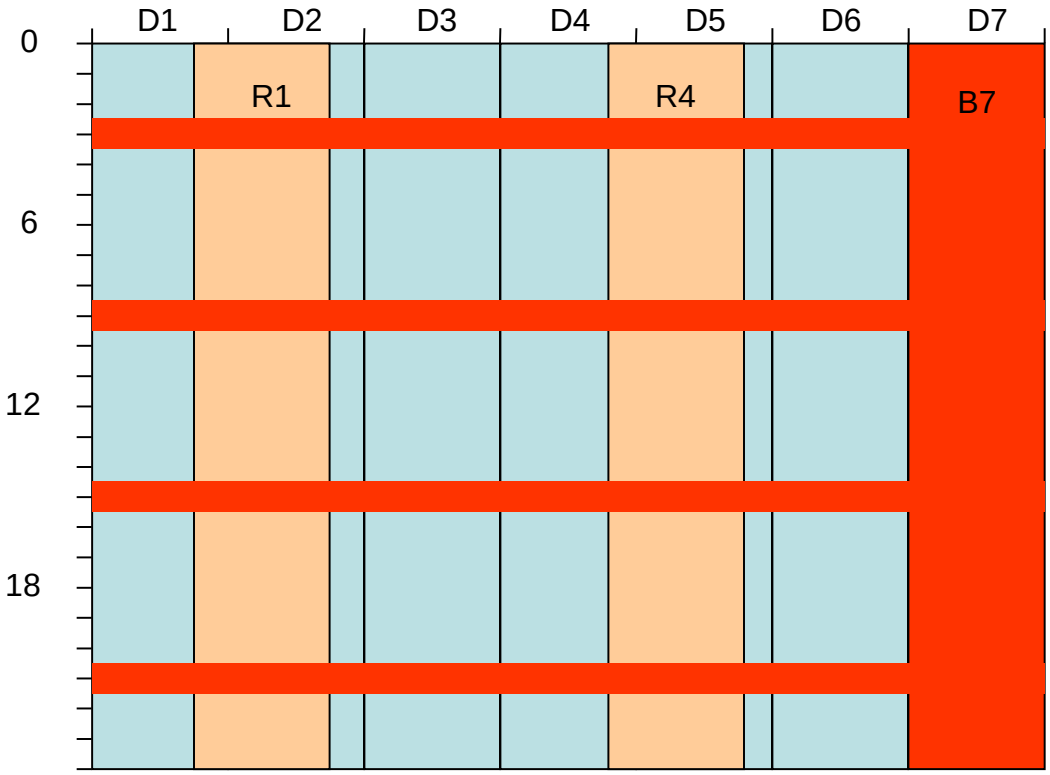


*Figure 4. VGOS Pilot Project: One 24-hour VGOS Session and six Daily VGOS EOP Sessions per week, 2016.*

As new VGOS stations come on line, they will initially be qualified by tagging along with the B7nnn 24-hour sessions. This mode of operation leaves six days a week for the newly introduced antenna to deal with problems as they arise. After weekly operations smooth out, the antenna can be added to the daily VGOS EOP sessions.

As more operational resources become available at a particular station, the number of hour-long burst periods at that station can be increased (Figure 5), providing a smooth transition to full 24/7 operation. This can be done on a station-by-station basis, provided enough stations are available to form baselines.

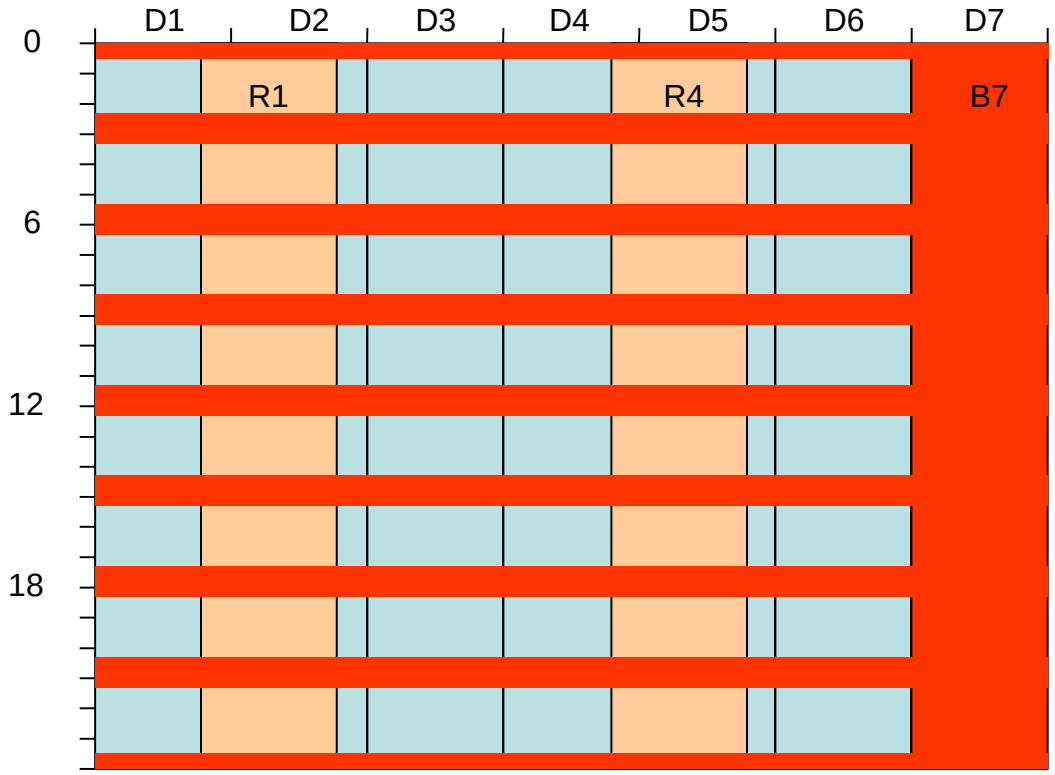


*Figure 5. As operational resources increase at a station, the number of hourly bursts can be increased.*

**Operations of the VGOS Network in 2017 and Beyond**

Given the successful completion of the VGOS Pilot Project in 2016, the pilot project can be converted to standard operations.

By the end of 2017**,** it is anticipated that a substantial VGOS network will be in place (first column in Table 2 and Figure 6). Based on information available today, the network could include as many as 16 stations, 13 of which will be very fast slewing (full VGOS slew rate) antennas. The four Russian antennas will however operate in S/X/Ka-band mode. The network will be unbalanced geographically with 15 antennas in the Northern Hemisphere, one in the Southern Hemisphere, and a significant concentration in Europe. By the end of 2019 the network will be augmented by Ny Ålesund which will be operational by then; in the same time frame it is expected that the NASA Space Geodesy Project (SGP) will also have constructed a number of new VGOS antennas as part of multi-technique GGOS sites (second column in Table 2 and Figure 7). In terms of antennas available, the list represents a fairly conservative estimate since it mainly counts antenna projects that have already been funded. All the same, it represents a significant extrapolation with respect to the number of antennas outfitted with full broadband systems. This is an area where the V2PEG needs to participate actively by organizing and promoting the acquisition of broadband systems as stations become available.

| Station | 2017 | 2019 |
|---|---|---|
| Yebes | 1 | 1 |
| Santa Maria | 1 | 1 |
| Tenerife | 1 | 1 |
| Flores | 1 | 1 |
| Onsala | 2 | 2 |
| Metsahövi | 1 | 1 |
| Wettzell | 2 | 2 |
| Noto | 1 | 1 |
| Ny Alesund | | 2 |
| Badary | | 1 |
| Zelenchukskaya | | 1 |
| Ussurisk | | 1 |
| Kaliningrad | | 1 |
| Kazan | ? | ? |
| Ishioka | 1 | 1 |
| Changchun | 1 | 1 |
| Kunming | 1 | 1 |
| Sheshan | 1 | 1 |
| Greenbelt | 1 | 1 |
| Westford | 1 | 1 |
| Kokee | 2 | 2 |
| NASA (new stations) | | ~3 |
| Total Stations – North Hemisphere | 15 | 23 |
| Hobart | | 1 |
| Katherine | | 1 |
| Yarragadee | | 1 |
| Warkworth | | 1 |
| Hartebeesthoek | 1 | 1 |
| NASA (new stations) | | ~2 |
| Total Stations – South Hemisphere | 1 | 7 |
| Total – South and North | 16 | 30 |

*Table 2. Projection of VGOS broadband network that might be available by 2017 and 2019. [Note: As can be seen in the table, some stations incorporate more than one broadband antenna. Performance benefits are expected at these sites. However, for the purpose of calculating station totals, each pair is considered a single station.]*

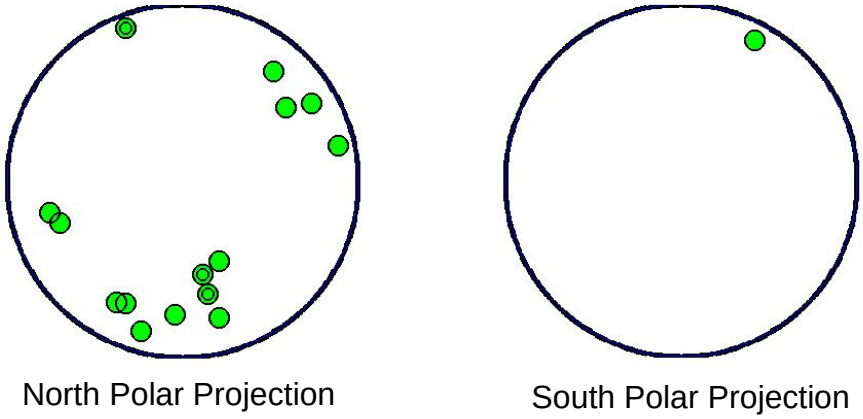


*Figure 6. Projected VGOS broadband network at the end of 2017. Concentric circles represent sites that incorporate two broadband antennas.*

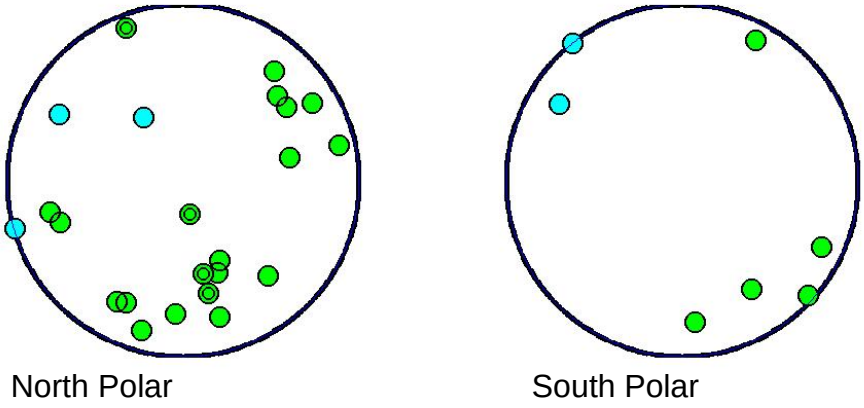


*Figure 7. Projected VGOS broadband network for the end of 2019. Concentric circles represent sites that incorporate two broadband antennas. Cyan dots represent new NASA sites hypothetically placed in Colombia, California, and Alaska in the Northern Hemisphere and Brazil and Argentina in the Southern Hemisphere.*

Petrachenko B et al.(2009): *Design Aspects of the VLBI2010 System. Progress Report of the VLBI2010 Committee*. NASA Technical Memorandum *NASA/TM-2009-214180*.