Recent Progress of VGOS and its Contribution to GGOS

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Abstract

The International VLBI Service for Geodesy and Astrometry (IVS) has strived to establish the VLBI Global Observing System (VGOS) to contribute to Global Geodetic Observing System (GGOS) through providing more accurate, reliable, and continuous products. The key elements of VGOS are fast slewing, 12-m class antenna, capability of receiving broadband quasar radiation between 2 and 14 GHz in a continuous frequency band, and data processing technology at a high data rate of up to 32 Gbps. VGOS Test observation has been performed biweekly with seven stations to develop and improve observing system, accumulate operational knowledge, and establish correlation and analysis procedures of broadband data. In addition, a number of new telescopes have been built or are planned all over the world. Expansion of network and distribution of correlation and analysis procedures might advance VGOS development rapidly in near future.

Introductions

VLBI has played an important role in the realization of the International Terrestrial Reference Frame (ITRF) as one of the multi space geodetic techniques together with SLR, GNSS, and DORIS as well as realization of the International Celestial Reference Frame (ICRF) and provision of a full set of Earth Orientation Parameters (EOP). Geodetic VLBI data for the realization of the ITRF are coordinated and provided by the International VLBI Service for Geodesy and Astrometry (IVS), which was established in 1999 to operate and support international geodetic and astrometric VLBI as a service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU). However, the existing VLBI system is nearly reaching the accuracy limits, which is insufficient for recent scientific requirements arising from sea level change monitoring etc. In order to overcome this situation, the IVS started the study for the next generation VLBI observing system and developed its concept in 2006 (Niell et al., 2006). The goals of this new system are:

- 1mm position and 0.1 mm/year velocity accuracy on global scales,
- continuous measurements for time series of station position and EOP,
- turnaround time to initial geodetic results of less than 24 hours, preferably in near real-time,

to contribute to the Global Geodetic Observing System (GGOS) promoted by the IAG.
The technical specification was defined through various Monte Carlo simulations to achieve the above-mentioned goals (Petrachenko et al., 2009). The key elements of this new VLBI system are “Mid-size fast slewing antenna”, “Broadband”, and “High-rate date processing”. The significant increase of observations with 12-m class fast-slewing (12 deg/s in azimuth angle) antenna would contribute to the reduction of random errors caused by atmosphere. The expansion of received frequency of four 1-GHz bands in the frequency range of 2 to 14 GHz with data rate up to 32 Gbps

Table 1. Specifications of the current VLBI system (Legacy) and VGOS.

Parameter	**Legacy**	**VGOS**
Antenna diameter	5 ~ 100 m dish	~ 12 m dish
Slew speed	~ 3 deg/sec	12 deg/sec in azimuth 6 deg/sec in elevation
Sensitivity (SEFD)	200 ~ 15000 Jy	~ 2500 Jy
Frequency range	S/X-band	2 ~ 14 GHz
Recording rate	0.128 ~ 1 Gbps	8 ~ 32 Gbps
Data transport	Mainly disk shipping some e-transfer	e-transfer disk shipping when required

would be sufficient to realize the 1-mm position accuracy. The specifications of this new system are summarized in Table 1 as compared with those of current VLBI system. From the operational aspect, dedicated antennas are preferable for continuous operations. Recorded data should be transferred via high-speed network and processed with fully automated system to reduce the latency of initial products. The IVS named this new VLBI system "VLBI Global Observing System (VGOS)".

Recent Progress of VGOS

There are six stations which are operational with VGOS setup (GGAO and KPGO in the U.S., Wettzell in Germany, Yebes in Spain, Onsala in Sweden, and Ishioka in Japan). The IVS has performed regular VGOS test observations fortnightly using these stations plus Westford in Massachusetts with the proof-of-concept broadband system for the purpose of the development and improvement of observing system, accumulation of operational knowledge, and establishment of correlation and analysis procedures of broadband data. All data are correlated by the MIT Haystack Observatory after shipped or electrically transferred. The estimated baseline length between GGAO and Westford from sessions over 2-year period shows the feasibility of broadband system despite lower data rate (8 Gbps) due to the limitation of data storage capacity and disk shipping cost (Niell et al., 2018a). In addition, a demonstration of 5-day continuous observation with VGOS stations were carried out in December 2017 as a part of the continuous VLBI campaign "CONT17".

Furthermore, the construction of VGOS telescopes are progressing steadily in the world. Telescopes in Australia, China, Finland, Norway, Azores in Portugal, Russia, and South Africa are under construction or under preparation for broadband operation. Newly VGOS stations are also planned in several area (e.g. Brazil, Tahiti, and Thailand). It is expected that the number of stations will be doubled within several years and the whole network will be more than 20 stations finally (Figure 1).

Issues and Future Prospects

One of the difficulties in expanding VGOS experiment is the striking difference in the correlation and post-processing procedures of VGOS with respect to those of legacy S/X. This difference is caused by the polarization of recorded data and group delay estimation by combining four bands. The MIT Haystack Observatory has tackled this difficulty and the procedure of

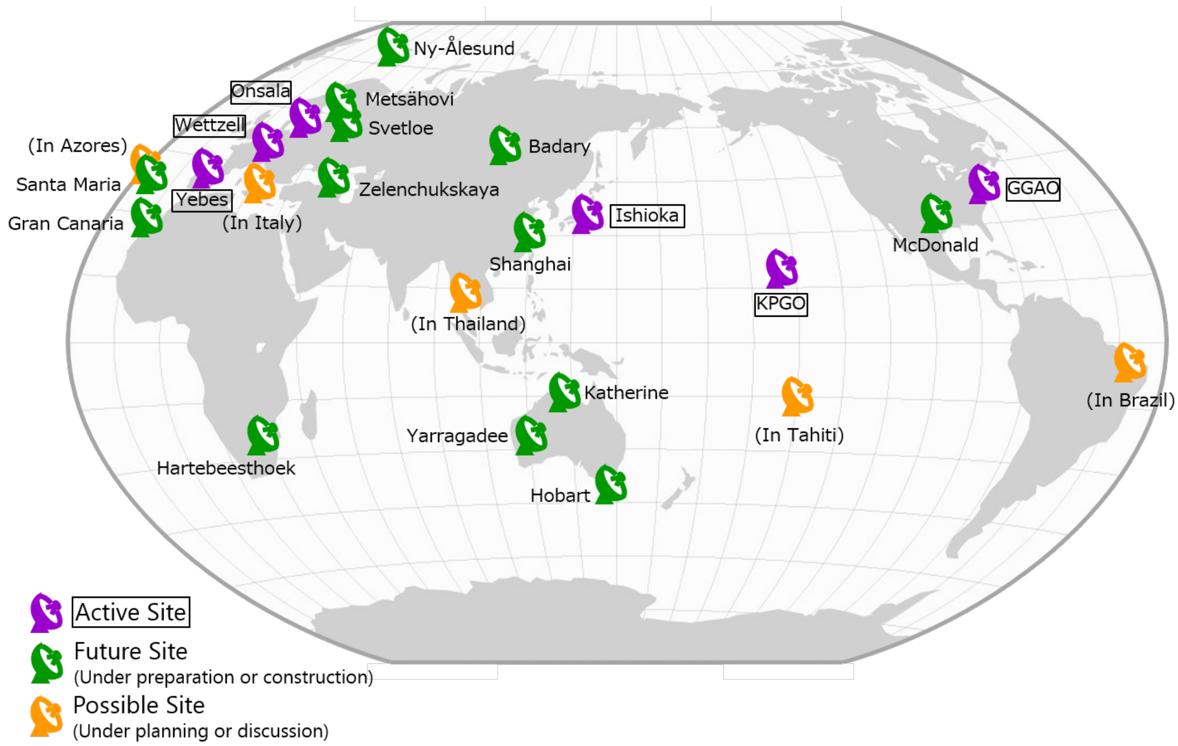

Figure 1. Status of VGOS network as of the end of 2018.

correlation and post-processing of VGOS data is going to be distributed to other correlators through dedicated workshop as well as the publication of the VGOS data handling manual “Cookbook” in 2019. The expansion of VGOS stations and correlators might make a rapid advance of VGOS development in near future.

The transition from current legacy S/X system to VGOS is another significant challenge. Especially, the determination of locations of VGOS stations in the ITRF currently defined by the legacy system is essential to secure the continuity of products such as TRF and EOP. One possibility to achieve such location determinations might be the “Mixed-mode” observation. In the mixed-mode observations, legacy and VGOS stations participate in the same sessions and observe S/X-bands data for correlation. For the realization of the mixed-mode observations, strong RFI in S-band for VGOS antennas has to be taken care of. The first international test was carried out in June 2018 with three broadband stations in the U.S. The correlation and post-processing procedures have been developed by the MIT Haystack Observatory because three different procedures for legacy-legacy, legacy-broadband, and broadband-broadband baseline are necessary to obtain full results. The 2^{nd} test was conducted in December 2018 to establish procedures (Niell et al., 2018b).

In addition to the above-mentioned issues, there are some issues and challenges to be addressed to make VGOS operational. One of the major difficulties for VGOS operation is how to transfer a large amount of VGOS data to correlators and how to distribute and balance workloads among correlators. Moreover, a high level of automation in correlation and analysis is required to deliver VLBI products with low latency (Nothnagel et al., 2016). The flexible and automated scheduling method so-called “dynamic scheduling” has to be considered to secure the robustness of the products against the impact of a station failure during a session, too (Iles et al., 2017). Above all,

IVS should encourage and pursue the construction of new telescopes especially in Africa, South America, and Antarctica.
The VGOS project is proceeding gradually but steadily in the world. The IVS keeps striving toward a realization of VGOS in all aspects to contribute to the GGOS with more accurate, reliable, and continuous products.

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