Current Status of the EU-VGOS Project

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Abstract The EU-VGOS project began in 2018 with the aim of using the VGOS infrastructure in Europe to investigate methods for VGOS data processing. The project is now structured into Working Groups dealing with operations (stations), e-transfer, correlation and post-processing, and analysis. This is a report on the status of the project.

Keywords VGOS, Operations, E-transfer, Correlation, Analysis

1 Introduction

The EU-VGOS project began in 2018 with the aim of determining the optimal methods for VGOS data processing [1]. It is currently a collaboration of about 40 individuals working at different institutes, mainly in Europe but elsewhere around the world.

The structure of the EU-VGOS project is shown in Figure 1. Besides the project management team, there are four Working Groups (WGs) focusing on different steps of the VLBI processing chain. WG Operations coordinates procedures at the VLBI stations and improves the availability of calibration data. WG E-Transfer develops e-transfer tools and carries out performance tests. WG Correlation covers topics related to the transformation of raw observational data into databases for further analysis, with a focus on novel calibration and fringe-fitting methods. WG Analysis analyzes VGOSDBs resulting from EU-VGOS

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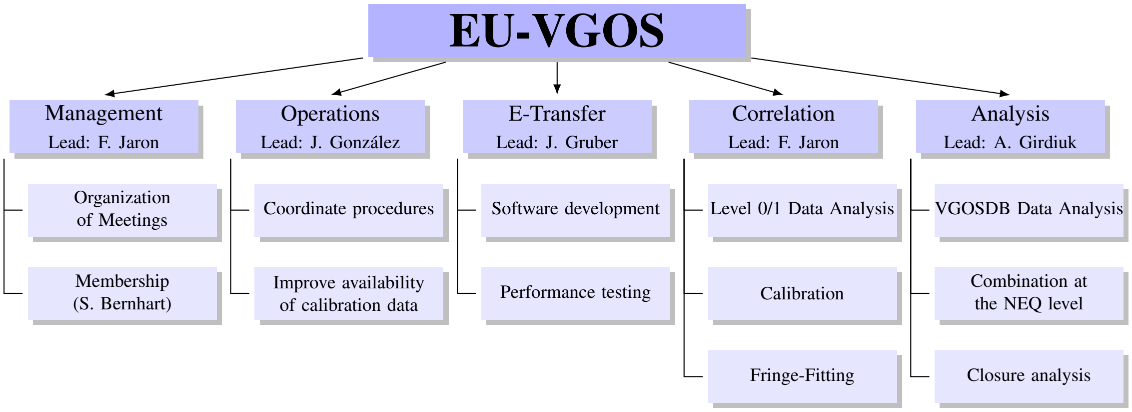

Fig. 1 Structure of the EU-VGOS project.

sessions and also looks into the combination at the normal equation level and closure analysis.

2 WG Operations

The locations of the EU-VGOS antennas are shown as filled circles in Figure 2. Five stations are VGOS-ready, four stations are going to be ready soon. The stations that are ready now are the twin telescopes in Onsala (one of them is currently under maintenance), Wettzell South (Wettzell North will also be ready this year), Yebes, and Ishioka (Japan). Details about the EU-VGOS stations are given in Tables 1 and 2.

3 WG E-Transfer

One important task of this WG is the development and testing of e-transfer tools. Currently there are four options for e-transfer: 1) `jive5ab` + `m5copy`; 2) the newly developed e-transfer daemon/client `etc/etd`; 3) it is possible to combine `etc/etd` with `m5copy`; 4) `tsunami`. Transfer speeds may depend on the data being transmitted. For instance, there can be a large overhead for the transfer of relatively small files. This WG carries out network performance tests under various conditions. Other active investigations currently include the MTU 9000 capability for global e-shipping routes, TCP/UDP benchmarking with different TCP congestion algorithm choices (e.g., Google BBR), and e-shipping limitations due to a particular file system and ethernet topology properties. The duration that it takes to transfer the data from the stations to the correlators is still a bottleneck to be resolved for continuous VGOS operations. For a global VGOS session, data transfer can take up to one month. Reasons for this delay include data rates that are in practice below theoretical values, but also logistical issues can delay the transfer. A subject of this WG is to address these issues. The locations of all institutes that correlate EU-VGOS data are shown in Figure 2 as filled squares, with their network speed in Gb/s.

4 WG Correlation

The scope of this WG is any data processing that is necessary or possible in order to transform raw observational (level 0) VLBI data into databases for further analysis (level 2). The different processing steps are shown in Figure 3. We receive level 0 data from the stations, mainly via e-transfer. Some stations provide the data with frequency bands split into separate files, known as *multi-file* data. Before, these had to be merged prior to correlation (using the tool `vmux`). Multi-file correlation (`DiFX`: multiple datastreams per station) and can now avoid this time consuming step.

We correlate the data using DiFX version 2.5.4, resulting from discussions within our WG. It collected a loose set of post-2.5.3 source code patches and certain DiFX-2.6 features into a consistent DiFX release. Key changes for VGOS: support for multi-file; fixes to phase cal tone extraction; Mk4 and FITS-IDI converter support/fixes for multi-file phase cal data; sup-

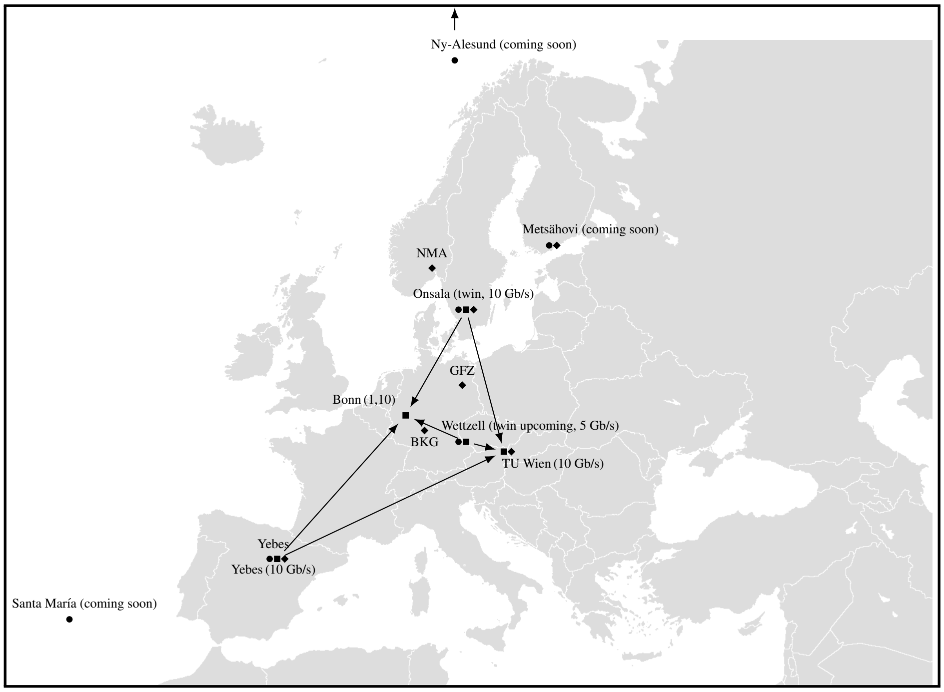

Fig. 2 Map showing the location of infrastructure related to the EU-VGOS project. Approximate antenna positions are indicated by filled circles, Correlation Centers are indicated by filled squares, and Analysis Centers are shown as filled diamonds. Where there are multiple activities at the same site, the corresponding symbols are shown next to each other. Ishioka also participates in the project from Japan, although its position is out of the map bounds.

Table 1 Details about the stations that are part of the EU-VGOS network.

Site	Backend	Recorder	Injection	80 Hz cap	Phase-cal	Cable-cal
Ready						
Ishioka	ADS3000+	K5VSI	Pre-LNA	No	5 MHz	Cable
Onsala East	DBBC3	Flexbuff	Pre-LNA	Yes	5 MHz	CDMS
Onsala West	DBBC3	Flexbuff	Pre-LNA	Yes	5 MHz	CDMS
Wettzell South	DBBC2 / DBBC3	Mark6 / Flexbuff	Post-LNA	No[1]	5 MHz	Cable
Yebes	RDBE-G	Mark6	Pre-LNA	Yes	10 MHz	CDMS
Coming soon						
Metsahövi	DBBC3	Flexbuff	Pre-LNA	Yes	10 MHz	CDMS
Ny-Ålesund	DBBC3	Flexbuff	Pre-LNA	Yes	10 MHz	CDMS
Santa María	Waiting for DBBC3	Mark6	Pre-LNA	Yes	10 MHz	CDMS
Wettzell North	DBBC3	Mark6 / Flexbuff	Post-LNA	No	5 MHz	Cable

All stations are equipped with a noise diode for amplitude calibration.
[1] 80-Hz noise diode is possible with the DBBC3, only power splitters pending to be ready.

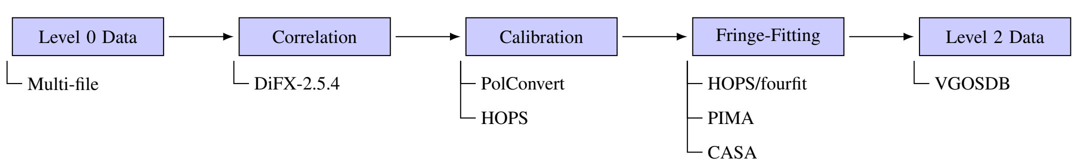

Fig. 3 Data processing steps of the WG Correlation.

Table 2 Details about the stations that are part of the EU-VGOS network (continuation of Table 1).

Site	Sessions observed	Data format	Current status
Ishioka	7	Singlethread-Multifile (4 datastreams/scan)	Ready
Onsala East	38	Singlethread-Multifile	Ready
Onsala West	28	Singlethread-Multifile (8 datastreams/scan)	Maintenance, DBBC3 in Bonn for cooling upgrade
Wettzell South	37	Multithread (needs vmux'ing[2])	Ready[3]
Yebes	37	Multithread (needs vmux'ing[2])	Ready
Metsähovi	0	-	Not ready, switch to VGOS operations in 2023
Ny-Ålesund	0	Singlethread-Multifile (planned)	Not ready, Field System integration pending
Santa María	0	Multithread (needs vmux'ing[2])	Not ready
Wettzell North	0	Multithread (needs vmux'ing[2])	Not ready, switch to VGOS operations in 2022

[2] Vmux operation converts multithread data into singlethread (typically for VGOS: $4 \times 16 \rightarrow 1 \times 64$). This operation takes approximately as long as the recording itself (!).
[3] Observing with DBBC2 systems

port for H/V linear polarization labels; a new HOPS software version; fixed DiFX native support for Mark 6 recorders.

After correlation, to combine the linear polarization products to Stokes I for fringe-fitting, complex cross-polarization bandpass calibration is necessary. We currently investigate two methods: the algorithm implemented in PolConvert [2], and the HOPS VGOS pipeline [3]. After that we use fourfit for Stokes I fringe-fitting, but we also consider the future use of other software packages. We export databases in the form of VGOSDB for further analysis.

One of our goals is to enable true Stokes I fringe-fitting, as opposed to pseudo Stokes I, implemented in the HOPS pipeline. This is achieved by performing a full complex cross-polarization gain calibration, i.e., making use of both amplitude and phase of the cross gains. HOPS only takes into account the phases. For this reason we expect an increase in data quality from true Stokes I. In addition to calibration, PolConvert converts the data from linear to circular polarization, which is more convenient for fringe-fitting.

Total group delays resulting from fringe-fitting polconverted data are plotted against the results from pseudo Stokes I in the left panel of the upper row of Figure 4. The results from both methods are consistent. The one-sigma uncertainties, shown in the middle panel, are also consistent, except for some larger differences, mainly occurring at large uncertainties. Also the signal-to-noise ratio, shown in the right panel, is very similar over a range from 0 to 4,000. The bottom row shows group delay differences as a function of time per baseline. In conclusion, the results from both methods are consistent, and the differences seem to be mostly noise-limited, but there are also hints for some systematic trends. The constant offset of the group delays is absorbed by the clock model in the final geodetic analysis and is not a matter of concern.

Table 3 Analysis Centers of the EU-VGOS project.

Institute	AC	Software
Finnish Geospatial Research Institute	FGI	VieVS
German Federal Agency for Cartography and Geodesy	BKG	Calc/Solve
German Research Centre for Geosciences	GFZ	PORT
Metsähovi Radio Observatory	MRO	Calc/Solve
Norwegian Mapping Authority	NMA	WHERE
Onsala Observatory	OSO	C5++, ASCOT
TU Wien	VIE	VieVS
Yebes Observatory	YBS	VieVS

5 WG Analysis

The main goal of this WG is to investigate how the different calibration and fringe-fitting methods affect the geodetic solutions. At the moment several Analysis Centers (ACs, Figure 2) process the available data based on their specific expertise. Most of the ACs have gained their experience by being member of the IVS Community. The others are organized newly at the observatories to follow their own project goals, which are aligned with the EU-VGOS project. Some Analysis Centers develop their own software: VieVS at TU Wien, PORT at GFZ, ASCOT at OSO, and WHERE at NMA; the others use existing ones as listed in Ta-

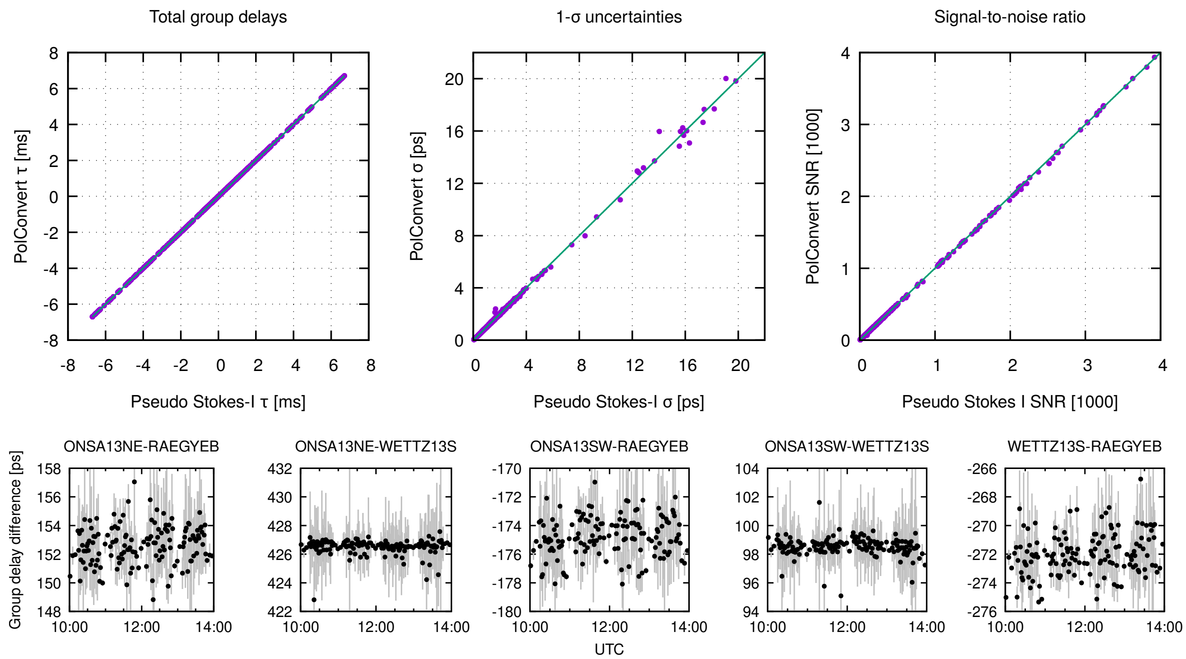

Fig. 4 Comparison of pseudo Stokes *I* and PolConvert on the observable level.

ble 3. All Analysis Centers use nuSolve as the first analysis step for interactive data reprocessing. Every VLBI analysis software is built to be as independent as possible. For this reason, the necessary a priori corrections and their own delay models are employed instead of the pre-computed model by nuSolve. That implies also an implementation of the solution parametrization such as selection of the reference clock, clock model, tropospheric model and station positions, source coordinates, and EOP.

6 Conclusions and Outlook

The EU-VGOS collaboration continues to investigate processing methods for VGOS data. We are currently planning new observations with the aim of improving calibration and to quantify the impact of calibration methods on the geodetic analysis results.

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