Complete Calibration of the VLBI Global Observing System (VGOS)

I. From the Correlator to Full-Polarization Images

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Introduction

VGOS, a high-precision geodetic VLBI system, operates in a wide bandwidth range (2 GHz to 14 GHz). The standard calibration method, based on pseudo-Stokes I, has limitations, as it deals only with total intensity.
To overcome these issues, the EU-VGOS project[1] uses PolConvert software[2], which converts VGOS data from linear to circular polarization after correlation. PolConvert ensures minimal instrumental polarization, enabling retrieval of all four Stokes parameters (I, Q, U, V).
Here we present a complete calibration process for global VGOS observations, from the correlator to full-polarization images.

Observations

The observation presented here corresponds to the IVS experiment with code VO2187, which was observed on July 6-7, 2022. The participating antennas were Goddard (GS), Ishioka (IS), Kokee (K2), McDonald (MG), the twin Onsala telescopes (OE and OW), Westford (WF) and Yebes (YJ).
The total recorded bandwidth was 1 GHz, ranging between 3 and 11 GHz, and divided into 4 bands centered around 3.25, 5.5, 6.75, and 10.5 GHz (A, B, C, and D bands).
There were 74 sources observed (radio-loud AGN), spanning an observing time of 24 hours.

Data Calibration

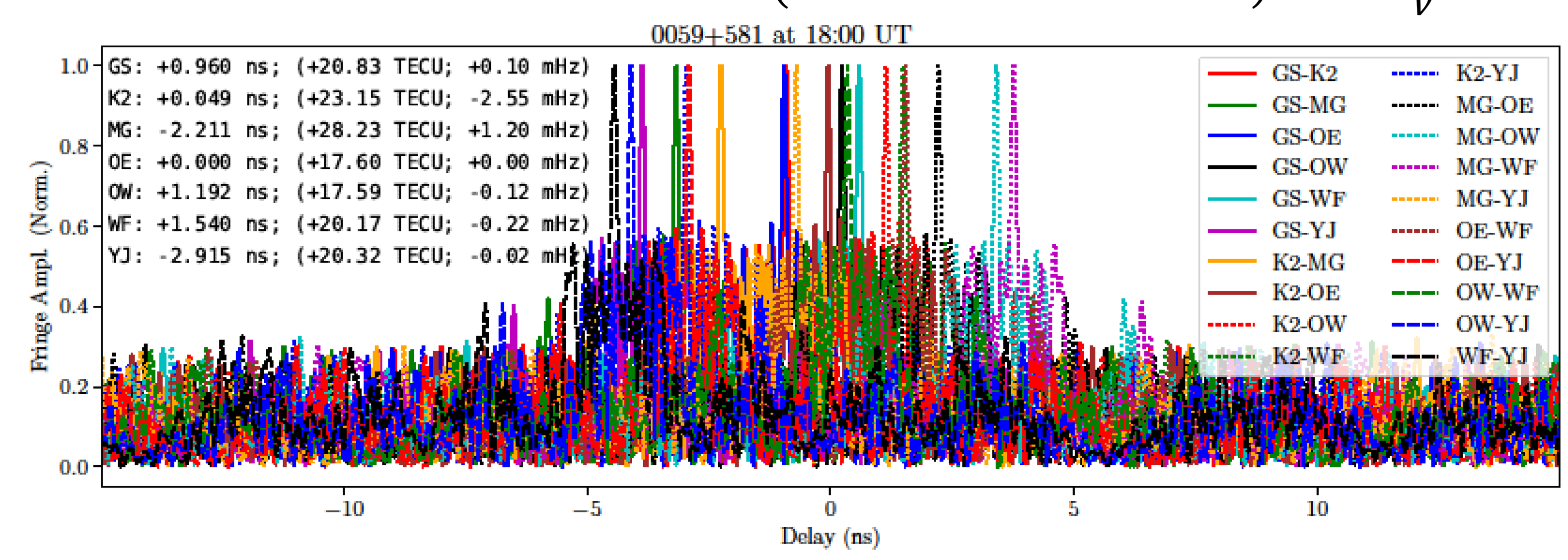
PolConvert Cross-Polarization Bandpass

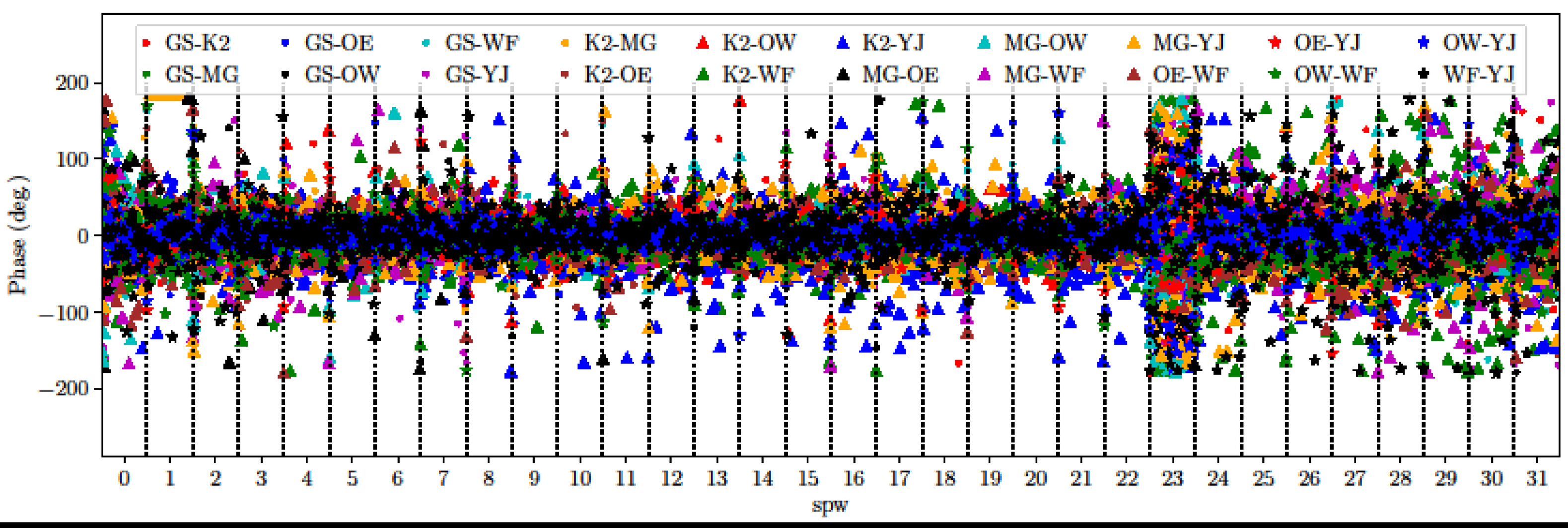
We select suitable **calibration scans** with good SNR (bright sources and long duration), varying parallactic angles and with low fractional linear polarization.
A-priori phase information computed from the phase difference between X and Y **phase-cal** tones for each spw and integration time → Estimate **cross-polarization bandpasses**.
They are applied to the rest of the experiment. They are aligned across the VGOS band and stable over years.

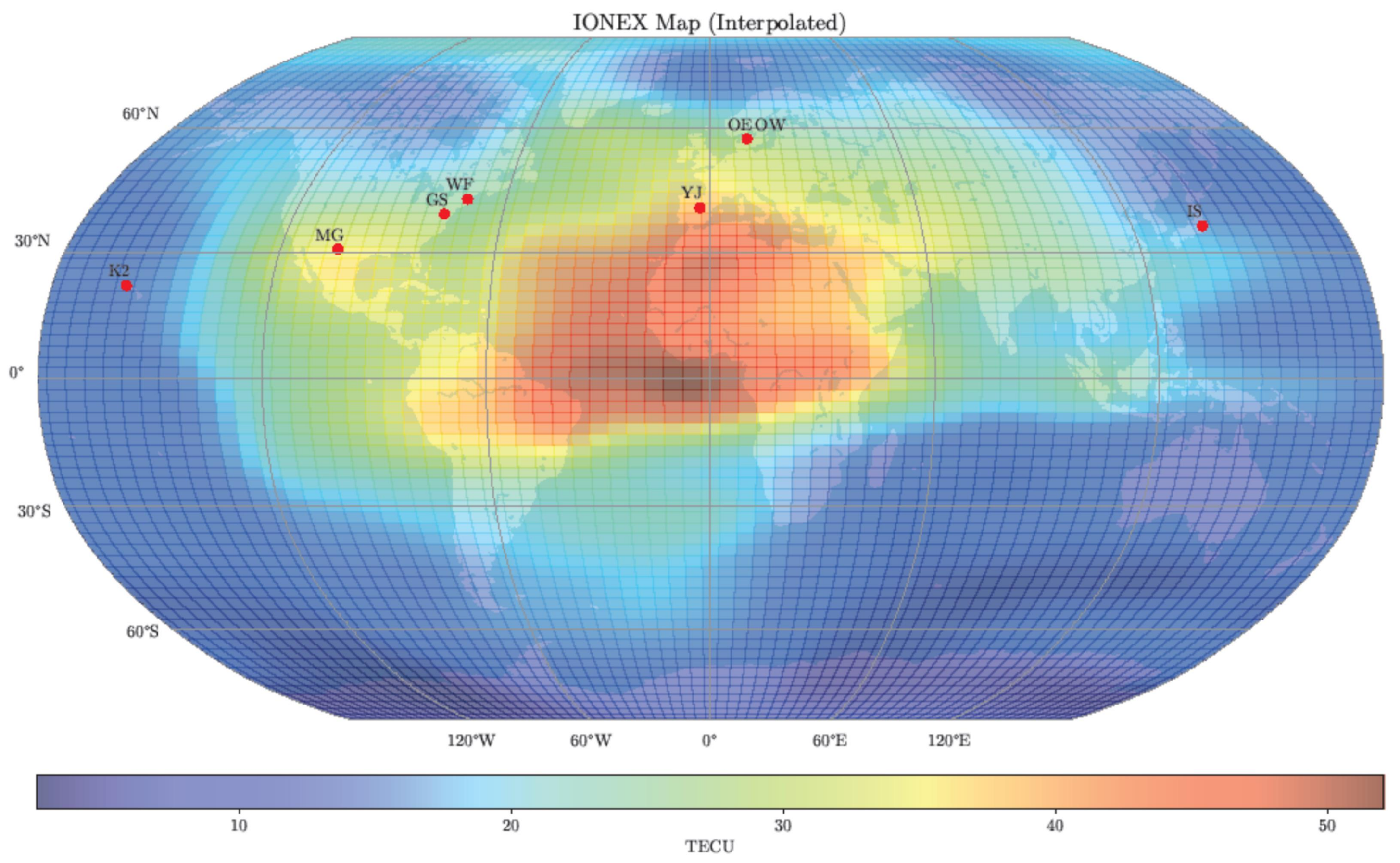
Decoupling group and dispersive delay

We developed PyPhases, which estimates the Total Electron Content (TEC) from **IONEX models** of Jet Propulsion Laboratory (JPL)[5], for removing the bulk of ionospheric effects.

$$\phi_{obs} = \phi_0 + 2\pi\left(\tau_{gr}(\nu - \nu_0) + \dot{\tau}(t - t_0)\right) + \frac{\kappa \cdot dTEC}{\nu}$$







Wide Band Global Fringe Fitting (WBGFF)

The WBGFF algorithm globally solves for **antenna-based quantities**, minimizing the parameter space and providing robust calibration against source-intrinsic effects. By globalizing the solutions, it preserves closure phases, allowing for image deconvolution.
We determine not only the phase and group delay but also the residual ionosphere. Through simulations, we have verified that this method accurately estimates the residual dTEC as long as it remains below 5 TECU.

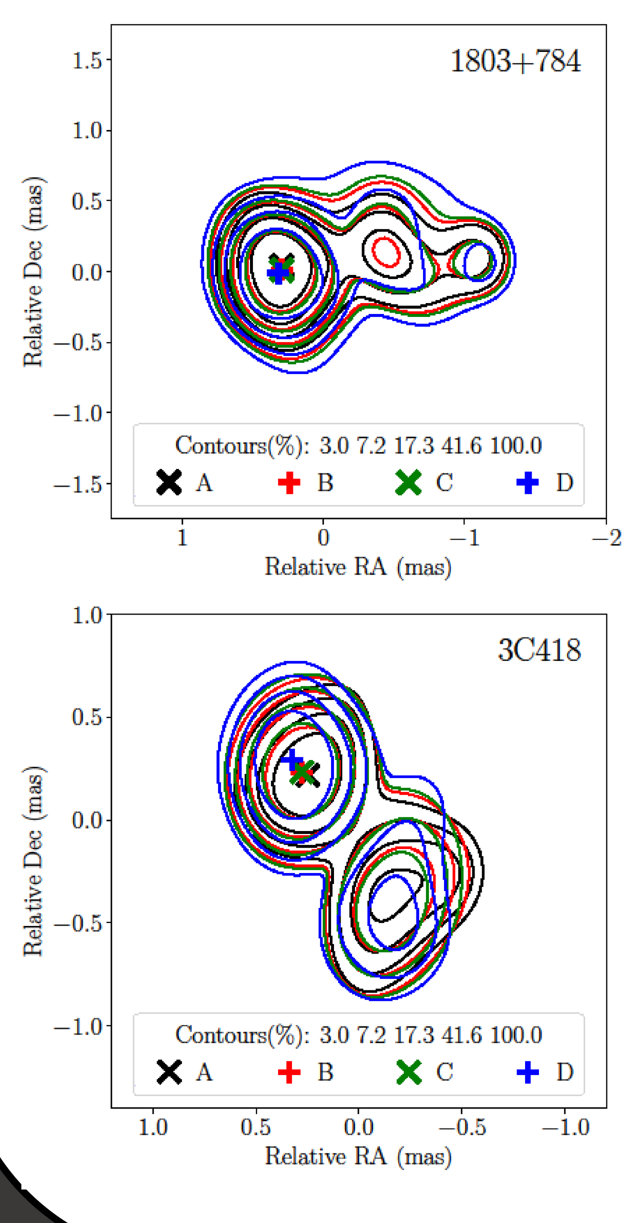
Amplitude Calibration

$$S_{i,j} = amp\sqrt{SEFD_1 \cdot SEFG_2}$$

$$SEFD = \frac{T_{sys}}{DPFU \cdot g(z)}$$

Not all VGOS stations provide the full information required for the calibration, so we estimated the flux density as a function of the uv distance to be able to calibrate amplitudes.

Imaging



We opted for Regularized Maximum Likelihood (**RML**) algorithms, using ehtim[3]:

- Super-resolution.
- Insensitive to antenna calibration errors of atmospheric contributions (using closure quantities).
- Better results with poor uv coverage.
- More user-independent

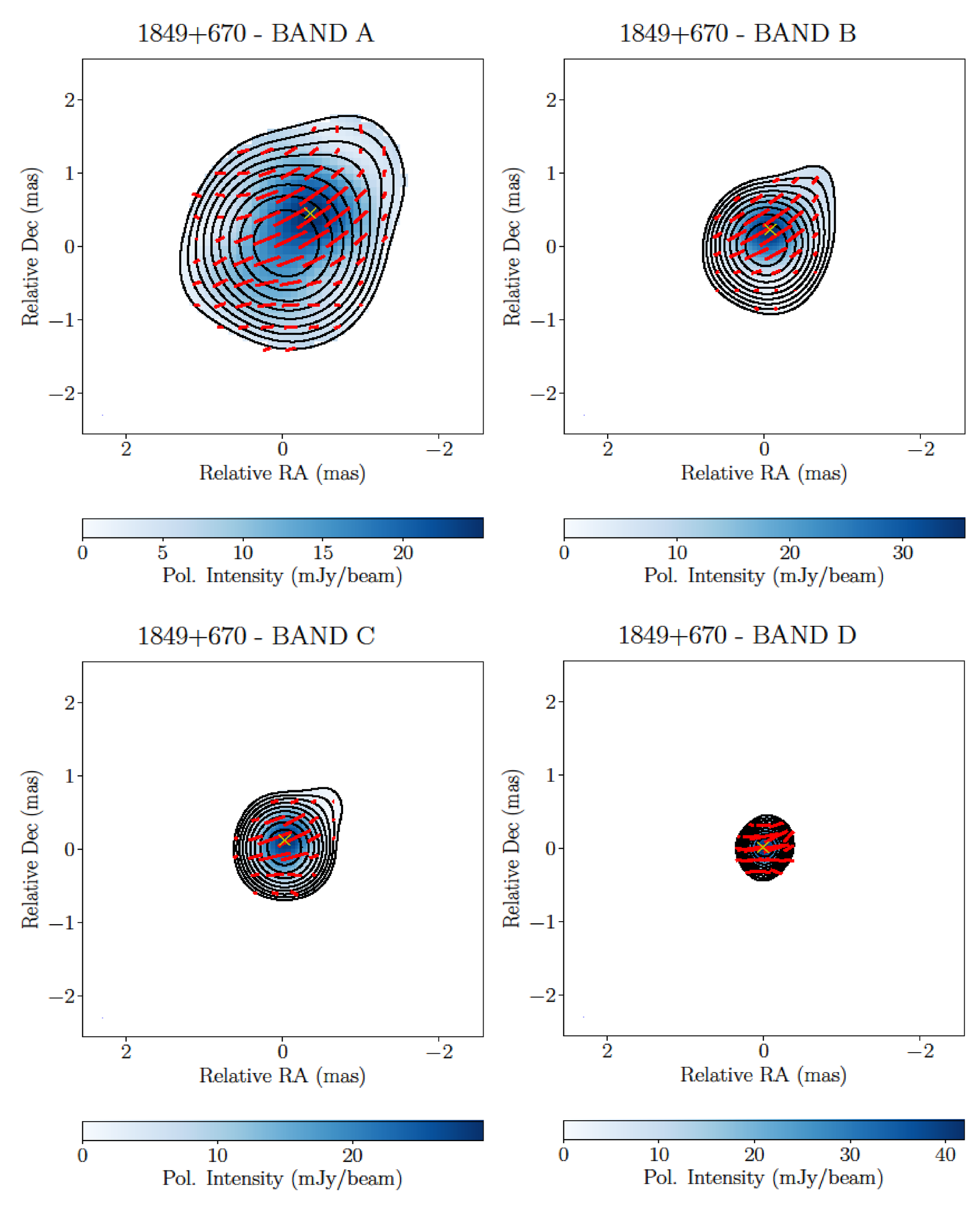
We use a **multi-frequency** deconvolution method:

- Aligning images in different bands.
- Study core-shift and spectral index.

We have developed **genetic algorithms** to select the optimal parameters and regularizers for VGOS observations.

We carry out this process with **all Stokes parameters**:

- Full-polarization images.



Conclusions

Polconversion results in notably higher fringe amplitudes in RR and LL across different sources and observing times.

Cross-polarization bandpasses remain stable over years, as we show by comparing with Jaron+23[4].

Our **Global Wideband Fringe Fitting** leads to smaller phase deviations and in much lower computing time compared to other fringe fitters.

Full-polarization images are reliable and agree with those obtained in other surveys at similar frequencies.

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