MIT HAYSTACK OBSERVATORY

Post-correlation Processing

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Outline

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- Overview
- Nominal data
- Channel-by-channel phase corrections
- Y-X polarization phase/delay offsets
- Mixed pol-product fringe-fitting and database creation

Post-processing overview

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- Objective is an accurate X-band delay with S-band correction.
- Maximize SNR wherever available via baseline-dependent combined polarization products: RR, XR+YR, RX+YR or Pseudo Stokes-I.
- Main assumptions[1]:
  - Sources only weakly polarized.
  - Leakage 'D' terms are small
  - Gain roughly equivalent between X and Y pols at VGOS stations.
- Additive phase corrections still needed, but somewhat less important (no dTEC fit)
- Still need to determine relative phase and delay between the X and Y signal path at VGOS station.

[1] https://ivscc.gsfc.nasa.gov/publications/memos/ivs-2007-011v01.pdf

Nominal input

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The below list is based on the 2019 VGOS workshop, but not all assumptions hold for mixed-mode:

- ~~No large chunks of missing time from any of the stations.~~
- ~~No missing bands or polarizations from any of the stations.~~
- ~~All stations have phase-cal.~~
- No clock jumps.
- No additional hardware issues (warm-receiver, pointing-problems, failed disk on data module, etc.)
- Network wide phase/delay reference-station available/OK.

Note: Generally speaking manual p-cal cannot be used in VGOS sessions, since without p-cal we cannot correct for each band's LO drift w.r.t to each other over time. However, this is not necessarily the case for mixed mode sessions, as S and X bands are fringed separately. It is also important to note that while S-band is recorded from a single sampler, X-band on the other hand, is split across two samplers (VGOS bands C & D) so manual p-cal isn't necessarily guaranteed to work.

Mixed-mode fourfit control file preface

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- Basic control file parameters which are needed.
- This portion does not typically change between sessions.

```
* R&D2006 <190-191>
dr_win -50.e-5 50.e-5 mb_win -1. 1. sb_win -2.0 2.0
pc_mode multitone
pc_period 5
start -3
mixed_pol_yshift90 true

*channel labels (using new relabeling feature)
chan_ids abcdefghijklmno 2225.99 2245.99 2265.99 2295.99 2345.99 2365.99 8212.99
     8252.99 8352.99 8512.99 8732.99 8852.99 8892.99 8932.99 8912.99

* Use B.E.C's updated refrence frequencies 3/25/21
if f_group X
  ref_freq 8512.99
* Set proper S band reference freq.
if f_group S
  ref_freq 2295.99
```

- Must be augmented further before mixed-pol fringing can be done.
- Highly desirable: manual p-cals (where needed), `pc_tonemask`, and notches.

pc_phases (VGOS stations*)

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For **both** S and X band:

- Construct initial control file (usually informed from last session).
- Pick a network reference station, it must be a S/X station. For consistency we have nearly always used Ny Alesund R-pol.
- Fringe fit all baselines to reference station with initial control file for all valid pol-products (XR,YR,RX,RY).
- Select candidate scans for each baseline.
  - Apply cuts, typically SNR$>$ 30 and q-code, $>$ 6 (no need for dTEC cuts).
- Use circular mean of channel phase residuals to determine the channel-by-channel phase corrections `pc_phases_x/y`.
- Output new control file with appropriate `pc_phases_x/y` (note: S-band channel 'e' is not accessible with current mixed-mode configuration).

```
if station G and f_group X
  pc_phases_x ghijklmn -2.1 -0.6 0.1 4.2  1.5  0.9  0.1  -4.1
  pc_phases_y ghijklmn -3.1 1.4 -1.4 2.8  3.0  1.8  0.1  -4.7
if station G and f_group S
  pc_phases_x abcdef -13.0 2.6 10.4 10.2  0.0  -10.4
  pc_phases_y abcdef -10.8 2.9 9.6 8.0  0.0  -9.6
```

*Scripting could be extended to SX stations, but we have been treating them manually.

Using ffres2pcp_mixedmode.py

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- The process detailed on the previous slide is automated with the script `ffres2pcp_mixedmode.py`
- Experiment directory needs to contain Mk4, (ovex) root files, type-1, and type-3 data for mixed-baselines.
- Essentially the same as what is done for VGOS session, except ref. station is SX, options documented with –help.
- Requires initial control file (a priori pc_phases nice, but not strictly necessary).
- Specify the network reference station, and additional stations for which to generate corrections.

```
ffres2pcp_mixedmode.py ./cf_3741_initial N EGHIMTZ ./
```

- Will generate a report .json file which can be use to generate some diagnostic plots.
- Mostly automated, however, at the moment user must stitch together S and X band lines if they wish them to be present in the same (production) control file.

Y-X polarization phase/delay offsets

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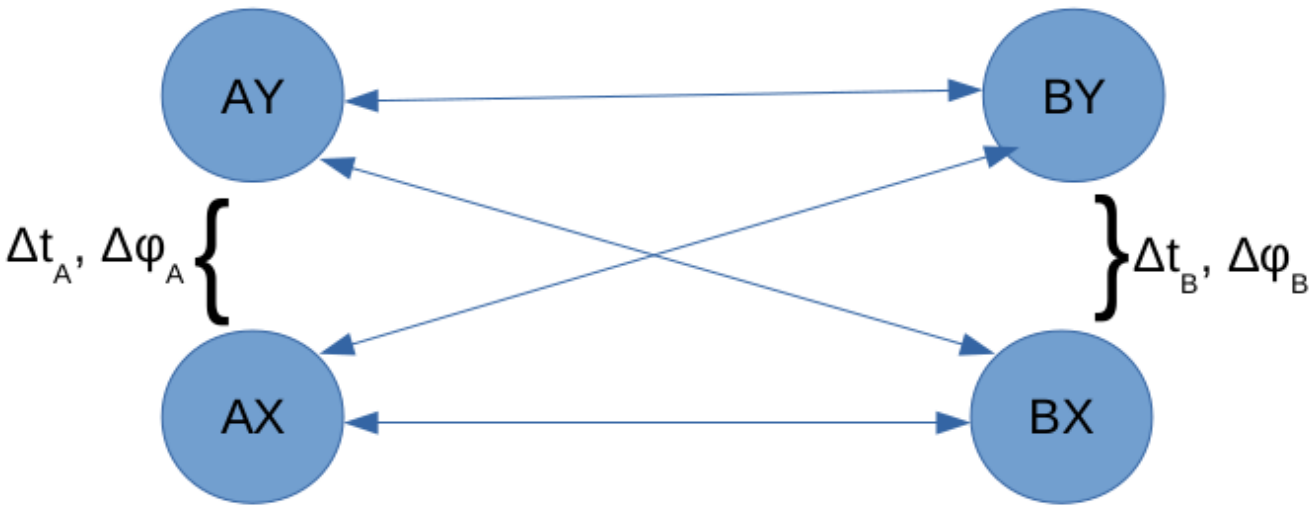
- Like regular VGOS session we need to estimate the Y-X phase/delay offsets at the VGOS stations.
- However, there are two complications:
  - For mixed-mode, this has to be done individually for both bands S and X.
  - There is only one Y-X phase offset per station, but we use it for both a physical phase shift and a (baseline-dependent) change of basis (circular $\leftrightarrow$ linear).



Fringes used to determine Y-X phase/delay offsets for VGOS

Y-X polarization phase/delay offsets (mixed)

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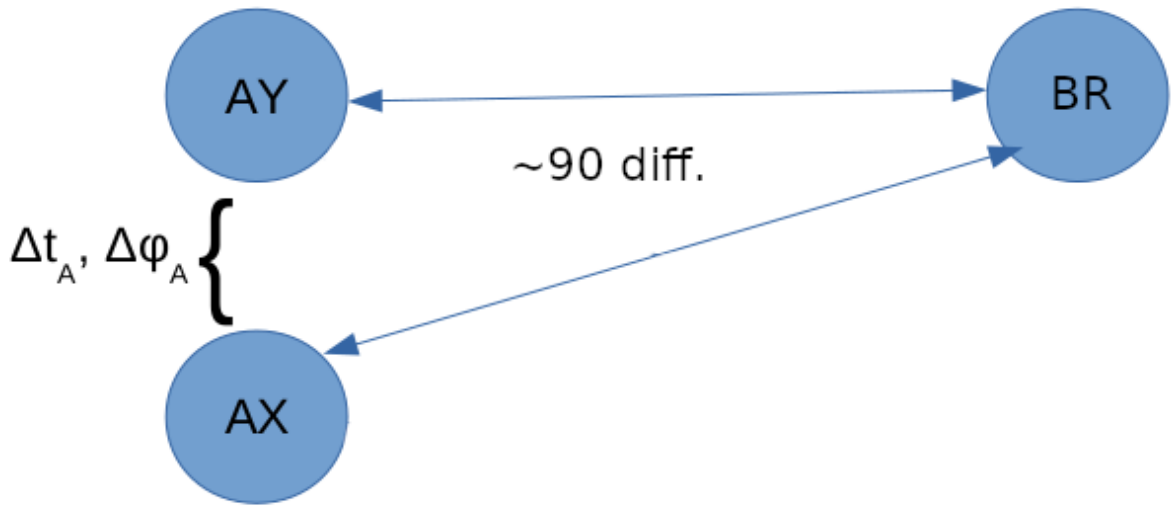
- If the VGOS station (linear pol) phase offsets are derived w.r.t. a circular pol. reference station, there will be a built-in ∼90 degree phase shift in the derived phase offset.
- This would work just fine if we only wanted form mixed combined pol. products (RX+RY or XR+YR).
- However, we cannot use the Y-X $\Delta\phi$ value derived w.r.t. R-pol, for pseudo-Stokes-I (XX+YY+XY+YX), or we will not get a coherent sum.
- $\rightarrow$ We need to apply an opposite sense 90° shift wherever the YR or RY pol. product appears.
- This is done with new fourfit feature `mixed_pol_yshift90`



Fringes used to determine Y-X phase/delay offsets for VGOS

Generating Y-X phase/delay offsets

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So long as `mixed_pol_yshift90` is used, this proceeds in the same way as a VGOS session, except we do not need to worry about dTEC differences for different pol-products.

- Re-fringe fit entire session for all baselines/bands/pol-products with new control file containing updated `pc_phases`.
- Select candidate scans for each baseline, apply SNR based cuts.
- Assume phase/delay closure over pol-products to calculate phase and delay offsets between Y, X polarizations at each station.
- Find mean value for Y-X phase/delay offsets.

Using fourphase_mixedmode.py

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- The process to generate the Y-X phase/delay offset corrections is scripted by `fourphase_mixedmode.py`.
- Experiment directory only needs to contain Mk4, (ovex) root files, type-1, and type-3 data for mixed baselines.
- Requires the control file generated by `ffres2pcp_mixedmode.py`.
- Specify the network reference station, and additional stations for which to generate corrections

```
fourphase_mixedmode.py ./cf_3741_NEGHIMTZ_pcphases N EGHIMTZ ./
```

- Will also generate a report .json file which can be use to generate some diagnostic plots.
- Mostly automated, but S/X control file stitching needed at moment.

Combined polarization fringe fitting

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- Can go ahead with production fringe-fitting once a full production control file is prepared, containing:
  - manual p-cal where needed
  - notches for RFI and common p-cal tones on short baselines
  - S and X band additive phase corrections (`pc_phases`) for both SX and VGOS stations (X,Y)
  - S and X band Y-X phase/delay offset for the VGOS stations
- Batch fringing SX and VGOS baselines is pretty straightforward, being "-P RR" and "-P I".
- However, the mixed SX-VGOS baselines requires more book-keeping.
- Within fourfit, linear/circular polarizations map to the same indices, with: X $\leftrightarrow$ L and Y $\leftrightarrow$ R
- So it is important the correct baseline-dependent form of the combined polarization product (RX+RY or XR+YR) is passed (otherwise one pol-product will be lost).
- This is automated with batch_fourfit_mixedmode.py, which ensures the correct pol. order is called on each baseline. At the moment each band (S/X) is done separately.

```
batch_fourfit_mixedmode.py -f S -p -n 32 ./cf_3741_final NUVPKFJ EGHIMTZ RR,RX+
    RY,XR+YR,I ./
```

VGOS-VGOS (Broad-band)

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- Every mixed-mode session has a broad-band VGOS session built in.
- The VGOS-VGOS broadband data can largely be post-processed as if it were separate standard VGOS session.
- However, care should be take as:
- There is of course a non-standard frequency setup.
- Some stations have front-ends which cannot access the lower-most frequencies and may be missing S-band channels.
- RFI is more common at lower frequencies and some channels may need to be deleted.
- Alternate p-cal tonemask should be used.
- VGOS station pc_phases structure is entirely different from normal VGOS sessions (must derive a new set of a priori pc_phases).

Proxy-cable cal.

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As some VGOS stations do not have hardware cable cal., we add proxy-cable cal. to both the mixed-mode (and broad-band VGOS) databases.

- As there are not enough tones present in the zoom-banded S/X band data we use the broad-band data to estimate the per-band/pol cable delay.
- We then select the band/pols which exhibit similar delay behavior to be average together to generate the .pcmt (delay) files. This is not always well defined!
- The same .pcmt files are applied to both the mixed-mode database, as well as the VGOS broad-band database.
- May need more study to determine if it is an improvement over no-cable cal for mixed-mode sessions.

Database generation

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- Database generation is essentially the same as done for VGOS sessions, with the same steps:
  - Write correlator report
  - Run vgosDbMake
  - Run vgosDbCalc
  - Run vgosDbProcLogs to import (station logs, hardware cable-cal)
  - Run vgosDbProcLogs (proxy cable-cal)
- Database generation is done twice for two separate experiment directories (1) the mixed-mode SX data, and (2) the VGOS-only broad-band data.
- Upload the database to CDDIS (so far only the mixed-mode data has been uploaded).
- May need to work out the logistics of uploading two databases for the same session.