VGOS MEMO #046

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To: IVS VGOS Technology and Operations Groups
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Subject: The effect on VGOS broadband group delay of losing one or more bands: example: vt7170 (2017/06/19) GGAO12M-Westford

Introduction

The VGOS broadband delay system was designed to use four bands in order to obtain a group delay uncertainty of approximately 4 ps (1 ps = 1.e-12 seconds) or better. In several VGOS sessions one or more bands has been lost due to instrumentation failure. An important question to answer is what is the impact on the delay and geodetic estimation from losing an entire band. In this note the effect of losing Band A, the lowest frequency band, is evaluated for the baseline GGAO12M-WESTFORD (length 600km) by *fourfit*'ing the session vt7170 GGAO-Westford baseline a second time without Band A. The vgosDb was generated and analyzed with nuSolve using the same processing strategy as was done for the processing with all four bands. The broadband delay uncertainties and the post-fit delay residuals were then compared to the four-band values.

The broadband delay comparison illustrates directly the loss in intrinsic delay precision. The comparison of the post-fit delay residuals gives an indication of the effect of the loss of delay precision on the geodetic result, but this is dominated by the un-modeled noise rather than the intrinsic delay precision for the current level of modeling.

Delay uncertainties with and without Band A

Histograms of the group delay uncertainties for the four-band and for the three-band (omitting Band A) processing of all scans of vt7170 are shown in Figure 1. (The mean frequencies for bands A through D are approximately 3.2 GHz, 5.3 GHz, 6.2 GHz, and 10.2 GHz.) The increase in uncertainty for the three-band processing is due to three effects: the loss of SNR from having only three bands; the increase in delay uncertainty due to reduction in spanned bandwidth; and the increased correlation of delay and dispersion (dTEC) due to the reduction in spanned bandwidth. The design goal for delay precision of the VGOS broadband system as obtained from the VLBI2010 studies (Niell et al 2006, Petrachenko 2009) is 4 ps. For the four-band delays 87% of the scans have a group delay uncertainty of 4 ps or less, while for the three-band case only 33% meet that criterion. From this simple test it is clear that losing Band A increases the delay uncertainty beyond the desired level.

To further quantify the penalty induced by the loss of Band A I have calculated the loss of precision (delay uncertainty increase) resulting from the use of only the three highest bands using all of the data in the session. The mean increase in the three-band delay uncertainty over the four-band uncertainty (mean of the ratio σ(3-band)/σ(4-band) over all scans) is a factor of 2.8 with a standard deviation of 0.17.

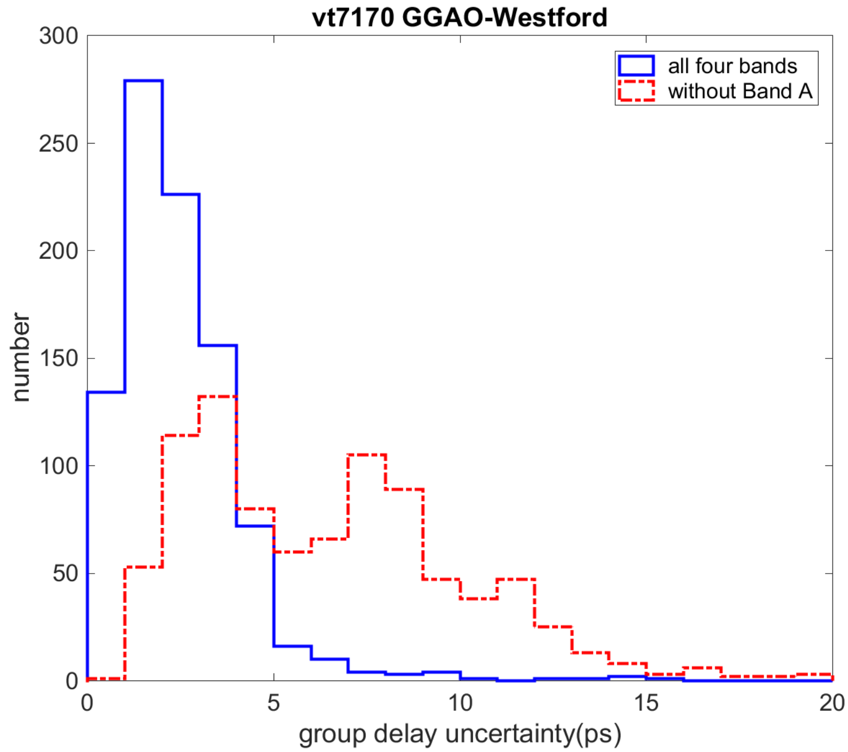

Figure 1. Histogram of the group delay uncertainties for four bands (blue, solid line, median 2.2 ps) and for three bands (red, dashed line, median 6 ps) for the VGOS session vt7170 (2017JUN19) (vt7170_GRdelay_unc_hist_vt7170.png)

Delay uncertainties without Bands B, C, or D

I calculated for the scan 170-1824 (session vt7170; SNR 192.6 for all four bands, both polarizations) the group delay uncertainties that result from the exclusion of Bands B, C, or D. The results are given in Table 1. The worst case is the loss of Band D. Second worst is the loss of Band A. Then, as might be expected, the loss of either Band B or Band C has the least effect, yielding a degradation of about 20% or 10%, respectively, in the group delay uncertainty. The loss of either of the center bands has almost no effect on the dTEC uncertainty relative to having all four bands.

Table 1. Group delay uncertainties (including dTEC estimation) for 170-1824 (vt7170) for four bands and for three bands excluding either Band B, C, or D, as found by running *fourfit* on this one scan.

	group delay uncertainty(ps)	dTEC uncertainty (TECU)
4-band	0.91	0.023
without Band A	2.6	0.111
without Band B	1.1	0.026
without Band C	1.0	0.027
without Band D	3.7	0.059

Geodetic analysis: post-fit delay residuals and lengths

The WRMS post-fit delay residuals (pfdr) for the standard nuSolve analysis are given in Table 2, both for the no-reweight solution and for the solution with-re-weighting to achieve chi-square per degree of freedom (chi2pdof) of approximately 1.0. For both the no-reweight and reweighted cases the post-fit delay residuals are larger for the three-band case, although only marginally.

The estimated lengths for the 4-band and for the 3-band delays, after re-weighting, are given in column 4 of Table 2. The good agreement of both the values of the length and the uncertainties is not un-expected since three-quarters of the bits going into the two solutions are the same.

While the lack of significant improvement using four bands might be seen as an argument for not requiring the fourth band or for relaxing the goal of 4 ps for the group delay residual, it would be ignoring both the likelihood that modeling improvements will reduce the amount of additive re-weight delay needed in the future, and the motivation for the 4 ps uncertainty, which is to provide an intrinsic per-scan uncertainty small enough that it is much less than any mis-modeled error, such as that due to modeling of the atmosphere.

Table 2. WRMS post-fit delay residuals (pfdr) without and with reweighting, and baseline length, for 4 bands and for 3 bands.

vt7170 (17JUN19)	WRMS pfdr no re-weight (ps)	WRMS pfdr with re-weight (ps)	L-600796000.0 +/- re-wtd sigma (mm) (unscaled sigma) (mm)
3-bands (Band A removed)	22.7	39.56	25.90 +/- 1.59
4-bands	20.4	39.44	25.37 +/- 1.62

It is important to note that these evaluations of the loss of a band are for a baseline of length only 600 km. A similar evaluation should be made for a long baseline.

Summary

1. The loss of Band A increases the median group delay uncertainty from 2.2 ps to over 6 ps for the session vt7107, which is well outside the VGOS goal. Thus it is clear that all four bands are needed to meet the goal.

2. If a band is known to be lost, e.g due to a failed UDC or digital backend, the band to be sacrificed, in order, should be C, B, A, D.

3. The lengths and length uncertainties of the re-weighted delay solutions for the 4-band and for the 3-band geodetic solutions agree seemingly too well, but this is due to the large commonality of the data used. The 3-band solution is based on seventy-five percent of the 4-band data with no other independent data.

4. While the WRMS post-fit delay residual is increased by less than approximately 1% after re-weighting of the delays to achieve chi square per degree of freedom of 1.0, this should not be taken as a justification to routinely observe with only three bands. It is hoped that future improvements in modeling of physical

effects that contribute to the delay (e.g. the atmosphere) will reduce the added delay noise, thus increasing the value of the smaller group delay uncertainty.

5. These assessments are made for a baseline length of only 600 km and should be evaluated for longer baselines as well.

References

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