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Use of GPS TEC Maps for Calibrating Single Band VLBI Sessions

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Abstract

GPS TEC ionosphere maps were first applied to a series of K and Q band VLBA astrometry sessions to try to eliminate a declination bias in estimated source positions. Their usage has been expanded to calibrate X-band only VLBI observations as well. At K-band, ~60% of the declination bias appears to be removed with the application of GPS ionosphere calibrations. At X-band however, it appears that up to 90% or more of the declination bias is removed, with a corresponding increase in RA and declination uncertainties of ~0.5 mas. GPS ionosphere calibrations may be very useful for improving the estimated positions of the X-only and S-only sources in the VCS and RDV sessions.

1. GPS TEC Maps

GPS TEC (total electron content) maps are global maps of the ionosphere as determined from GPS observations. Several analysis centers of the International GNSS Service (IGS) [1] produce these maps and submit them to the IGS Data Centers (such as cddis.gsfc.nasa.gov). These maps have a latitude/longitude resolution of 2.5/5.0 degrees and cover a 2-hr period. Each daily file contains 13 maps, from 0:00 hrs to 24:00 hrs. Such maps exist from 1998 through the present.

A set of Fortran subroutines to read, interpolate, and give TEC values for a specific time, location, azimuth, and elevation angle is available from the Institute for Astronomy, University of Berne, at web site ftp://ftp.unibe.ch/aiub/ionex/source. With these subroutines, the ionosphere is treated as a thin spherical shell at a specified height (typically 400 or 450 km). This software has several interpolation options. The one recommended is the rotated map option, where the longitudes on the two bracketing maps with the same sun angle as the target observation are used.

The author incorporated the above software into a database program to compute VLBI ionospheric delays and place them in VLBI databases. It was originally intended for use in calibrating the K-band (~24 GHz) and Q-band (~43 GHz) VLBA[1] reference frame sessions taken by the K/Q collaboration group [2]. In these sessions, it appeared that the lack of ionospheric calibrations was producing declination biases in the estimation of source positions.

To demonstrate the usefulness of these GPS ionospheric delays, we present in Figure 1 plots of the X/S ionosphere corrections versus the corrections estimated from the GPS ionosphere maps for two baselines in a typical VLBI session. The X/S ionosphere values are instantaneous direct measurements and are believed to be very accurate, except that they contain arbitrary offsets due to the different signal paths of the X and S band systems (which do not affect the VLBI results). The GPS ionosphere values suffer from low spatial and temporal resolution, and thus should be noisy on a point-by-point basis. However, if their longer term average values are accurate, then

[1] The VLBA is a facility of the National Radio Astronomy Observatory (NRAO) which is operated by Associated Universities Inc., under cooperative agreement with the National Science Foundation.

their use in VLBI should remove most of the systematic ionospheric effects on global source position estimation. Plots of X/S ionosphere delay corrections vs. GPS ionosphere delay corrections should have slopes of 1.0. But in reality, the slopes typically vary from ~0.8 to ~1.2, and can show large scatter.

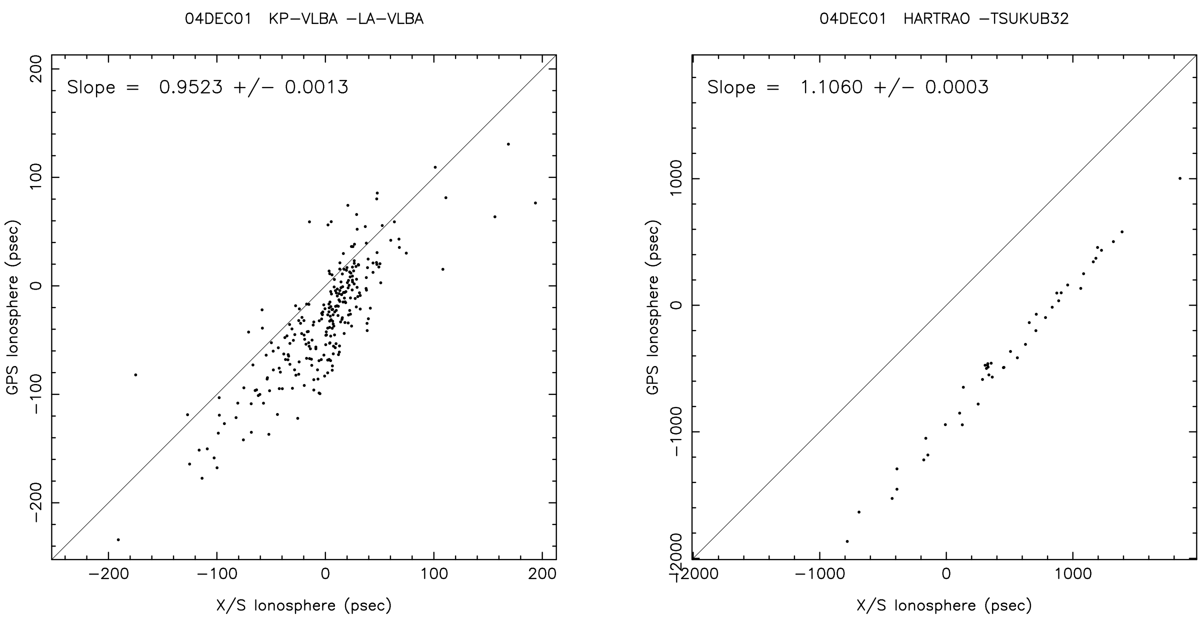

Figure 1. Comparison of X/S ionosphere delay corrections with GPS ionosphere delay corrections for a KP-VLBA to LA-VLBA baseline and a HARTRAO to TSUKUB32 baseline. Slope = 1.0 lines are shown for reference.

2. Application of GPS Ionospheres

GPS ionosphere calibrations were applied to three classes of VLBI sessions: twelve K-band and four Q-band VLBA sessions; ten X/S-band RDV sessions; and thirteen X/S-band VLBA Calibrator Survey (VCS) sessions.

2.1. K and Q Band Results

Twelve K-band reference frame sessions were taken from 2002-2008 on the VLBA. When analyzed with no ionospheric calibration, we find a declination bias (slope of a linear fit) in the Calc/Solve determined source positions of .00635 $\pm$ .00059 mas/deg (Figure 2 left), compared to a standard X/S source catalog. The ionosphere causes sources to appear higher in the sky. This displacement will tend to average out in right ascension, but not in declination. When GPS ionosphere calibrations are applied, this declination bias is reduced to .00253 $\pm$ .00059 mas/deg (Figure 2 right). A similar effect is seen for the four Q-band sessions, from 2002-2003.

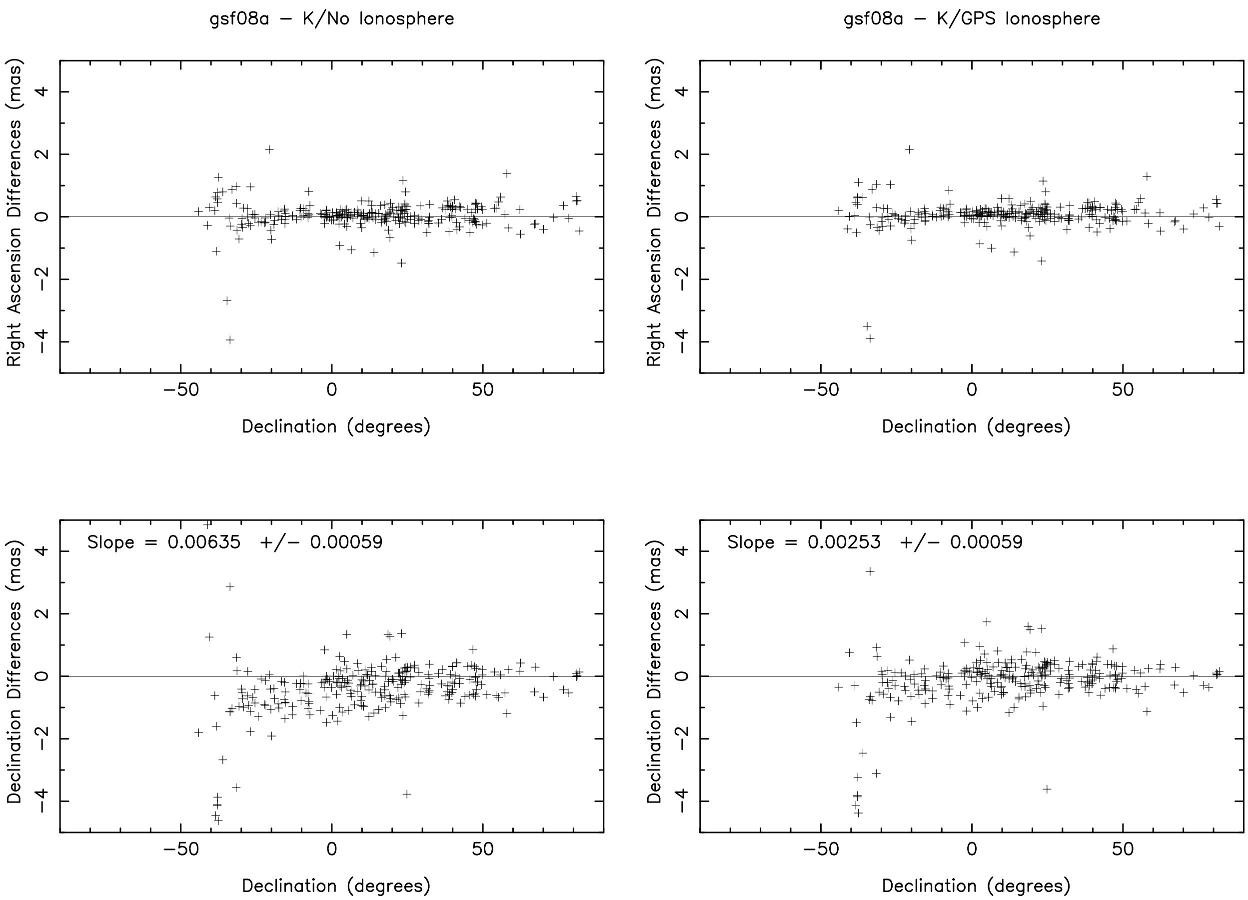

Figure 2. Position differences between a standard GSFC X/S solution vs. K-band only positions (left) and vs. K-band positions calibrated with GPS ionospheres (right).

2.2. RDV Results

For comparison with the K-band results, ten RDV sessions closest in time to the first ten K-band sessions were selected. Using only the VLBA stations, we solved for source positions using the normal X/S ionosphere free combination, using X-band only (no ionosphere), and using X-band with GPS ionophere corrections applied. We get the following declination biases:

No Ionosphere:	$+.02659 \pm .00024$ mas/deg	(Figure 3 left)
X/S Ionosphere:	$+.00011 \pm .00025$ mas/deg	(Figure 3 center)
GPS Ionosphere:	$-.00266 \pm .00024$ mas/deg	(Figure 3 right)

These are plotted in Figure 3. A clear bias is seen when there is no ionosphere correction, and the linear fit is clearly inadequate. The X/S ionosphere case shows no bias, as expected. The GPS ionosphere case shows more scatter, and may slightly overcorrect. When the X/S and X/GPS catalogs are compared, we get WRMS differences of ∼0.5 mas in both RA and declination, indicating that GPS ionosphere usage adds ∼0.5 mas of additional uncertainty to source positions at X-band, in an RSS manner.

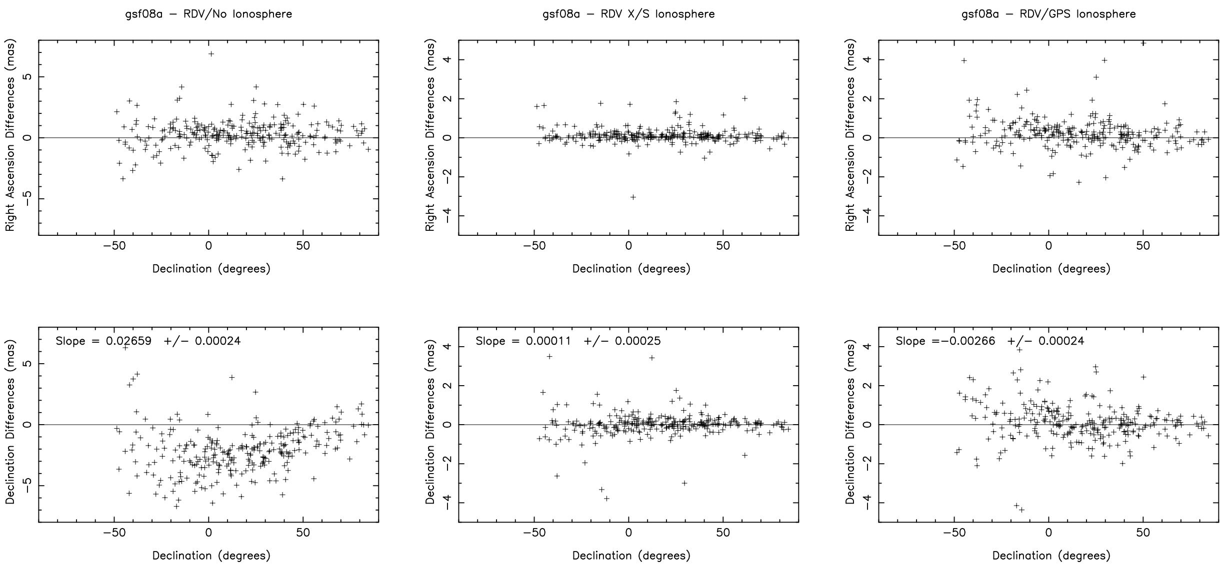

Figure 3. Differences from a standard GSFC X/S CRF solution for: X-band only positions for ten RDVs (left); X/S positions for ten RDVs (center); and X-band positions calibrated with GPS ionospheres for ten RDVs (right).

2.3. VCS Results

We made a similar comparison using the thirteen VCS sessions taken during the VCS2–VCS6 campaigns from 2002-2007 [3, 4, 5, 6, 7]. (The earlier VCS1 sessions [8] from 1994–1997 were too early for GPS ionospheres.) The declination biases found are:

No Ionosphere:	$+.03928 \pm .00032$ mas/deg	(Figure 4 left)
X/S Ionosphere:	$+.00315 \pm .00026$ mas/deg	(Figure 4 center)
GPS Ionosphere:	$+.00442 \pm .00032$ mas/deg	(Figure 4 right)

These are plotted in Figure 4. A bias is clear when no ionosphere correction is used, but not so clear with the two ionosphere options. Both actually show small numerical biases, even the X/S case. This could be due to the lower emphasis on tropospheric sampling in these sessions.

With the VCS/GPS solution, we were also able to solve for an additional 135 sources that do not appear in the X/S analysis. These are sources that are detected in X-band only. The VCS sessions also have a number of S-band only sources, so presumably more additional sources could be solved for in an S/GPS analysis. Also, in the 78 RDV sessions to date, there are some X-only and S-only sources that could probably also be picked up using GPS ionosphere calibrations.

3. Conclusions

The use of GPS ionosphere corrections appears to remove ∼60% of the declination bias at K and Q bands, and ∼90% at X band. The reason for this difference is not clear. At X-band, GPS ionosphere calibrations appear to add ∼0.5 mas to source position RA and DEC uncertainties, in an RSS sense. Application of GPS ionosphere calibrations at X and S bands to VCS and RDV sessions could significantly improve the positions of some 200 or more single band sources in the astrometric catalogs. Future work will concentrate on accomplishing this.

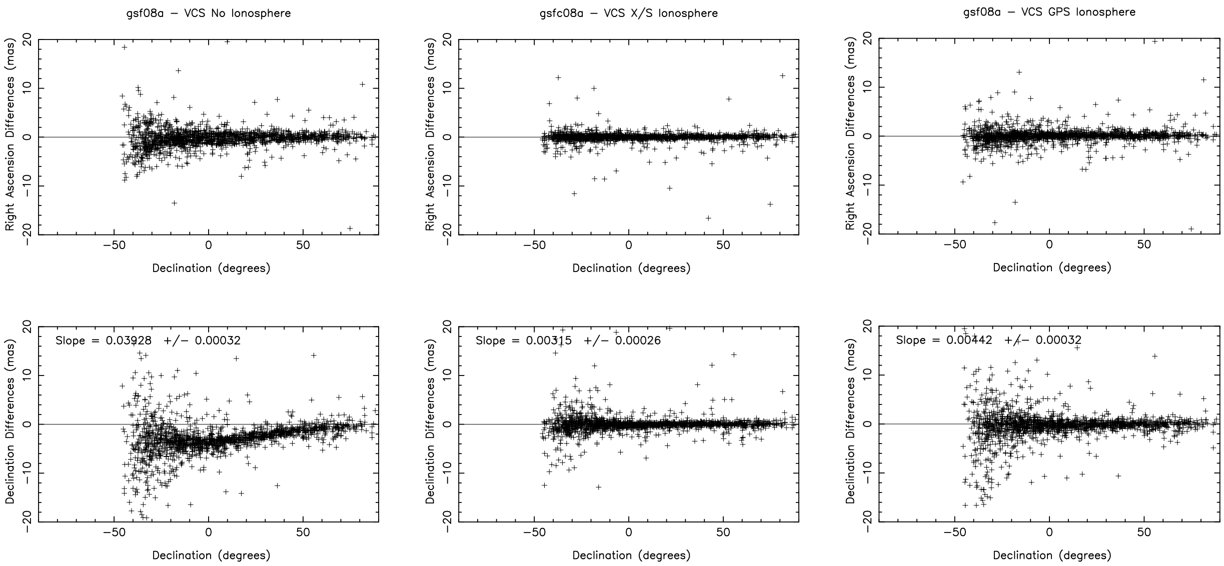

Figure 4. Differences from a standard GSFC X/S CRF solution for: X-band only VCS positions (left); X/S VCS positions (center); and X-band VCS positions calibrated with GPS ionospheres (right).

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