EDGES MEMO #336

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To: EDGES Group

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Subject: Beam correction comparison tests using sky maps at 45 and 408 MHz and correction for antenna tilt.

1] Introduction

Most of the EDGES processing has exclusively used the 408 MHz sky map. Some tests were made in memo 200 using a combination of the Haslam and 45 MHz Sky map of Guzmán et al. (available from www.das.uchile.cl/survey45mhz). This work concentrated on using EDGES data to obtain a more accurate spectral index and improve the ability to test for the consistency of an absorption measurement over a range of GHA. In this memo I compare several schemes for correction of the spectra for the chromaticity using beam models for the lowband2-45 on the 30x30m ground plane on soil with dielectric constant and various conductivities. The “reference” conductivity chosen being 2e-2 S/m. Corrections to the antenna beam for antenna and ground plane tilts are also examined as well as the effects of the balun and balun shield.

2] Beam correction schemes tested

a) Beam convolved with 1024x512 408 MHz map of Galactic longitude vs latitude
b) Beam convolved with 1024x512 45 MHz map of Galactic longitude vs latitude
c) Beam convolved with 408 MHz map where the sky temperature at each point corrected for the spectral index derived from the 45 and 408 MHz maps.
d) Beam convolved with 45 MHz map using spectral index

Schemes c and d are both convolutions with 2-D maps that are now frequency dependent. Maps c and d are slightly different because of the correction for the CMB.

$$s45 = (m45 - cmb) \times (f/45)^S + cmb \qquad (1)$$
$$s408 = (m408 - cmb) \times (f/408)^S + cmb \qquad (2)$$

where s45 and s408 are spectra respectively as a function of frequency, f,
where m45 and m408 are 45 and 408 maps respectively as a function of galactic lat and long
cmb = CMB

$$s = \text{spectral index} = -\left[\log((m45 - cmb)/(m408 - cmb)) / \log(408/45)\right] \qquad (3)$$

For a test the spectral index was also obtained after averaging each map over 7x7 points but this was found to make very little difference.

In each beam correction scheme the convolution is normalized by dividing by the convolution of the beam at one particular fixed frequency, near the center of the band, but the final result of the beam correction is not sensitive the choice of this frequency.

3] Simulations of the effectiveness of the schemes

Table 1 shows the results of simulating spectra using scheme “a” and processing using scheme “a” with a different soil conductivity and schemes b, c, and d.

simulation scheme	Processing scheme	average rms over GHA mK	
a	No beam correction	140.4	
a	b	66.8	
a	c	53.4	
a	d	53.1	
c	d	1	
b	d	19.1	
a	a with soil 4e-2 S/m	21.7	
a	a with PEC ground	90.6	
a	a with 5 deg az error	66.6	
a	a 10 min time error	38	
a	a with 5 K subtracted	22.2	from sky map
a	a with 1 deg tilt	35	

Table 1. Average rms is the average of the rms residuals for 1 hour blocks GHA 0 to 23 hours of simulated data fit with 5 physical terms from 52 – 95 MHz for low2-45

4] Tests using low2-45 data following on memo 335 for which the average of the rms residuals for one hour blocks GHA 0 to 23 hours is 149.8 mK which used scheme “a” 52 – 95 MHz.

processing scheme	average rms over GHA mK	comments
a	149.8	4e-2 S/m
no beam correction	243.4	
a azimuth 43 deg	149.7	
b	170.2	
c	160.2	
d	159.9	
a	145.6	5 deg K subtracted from map
a	125.2	with absorption subtracted
a	114.8 – see Figure 2	with absorp. subtracted and tilt
a with tilt correction	126.9 – see Figure 1	tilt down to the north east

Table 2. Average rms is the average of the rms residuals for 1 hour blocks GHA 0 to 23 hours for low2-45 data from 2020 day 55 to 140 5-term physical 52 – 95 MHz.

Lower residuals were obtained for 4e-2 S/m and this was chosen for the the reference in table 2. It is noted that the average of rms residuals over 1 hour blocks is about 100 mK higher than for simulated data even if the presence of the absorption in the real data in taken into account. Based on the simulations results in table 1 and the tests on real data in table 2 an improvement in the rms of only about 20 mK out of about 150 mK is the result of error in the sky maps. The lowest rms being achieved using a 5 K correction to the Haslam map. In the next section we look at potential sources of added systematics.

5] Estimate of added systematics

a) Calibration and S11 error

Some tests made by applying offsets to the S11 measurements in delay and amplitude have been made to low2-45 data but only a small delay offset of about -10 ps in S11 lowers the average rms of 1 hour blocks over GHA 0 to 23 hours by 5 mK. The subtraction of the absorption reduces the rms from about 150 mK to about 120 mK.

b) Tilt in the antenna and/or the ground plane

Tilt produces a vertical polarization component to the antenna beam which as discussed in memo 288 and tilts the beam. If the antenna and ground plane are both tilted by the same amount this is equivalent to a tilt of the entire structure which for a large ground plane is equivalent to tilting the sky moving the “effective location” of the antenna and ground plane. Simulations show that it takes a tilt of 2 degrees to contribute 30 mK to the average of rms residuals over GHA 0 to 23 hours for 5-terms removed. However, with only 3 terms removed a 2 degree tilt of the antenna on a horizontal ground plane result in a rms of 320 mK but it is harder to distinguish the effects of tilts from other errors with 3-terms. Simple reflection geometry shows that for tilted panels the plane perpendicular to the vector in the direction of the peak of the beam component reflected from the ground plane is tilted in the opposite direction to the antenna panels. Tilt of the antenna panels with respect to the ground plane has to be modeled as the beam is not only tilted it is changed in other ways. For example, the vertically polarized component of the beam produced by the tilt is more strongly reflected from the edges of the ground plane. If the ground plane is tilted due to the terrain while the antenna panels remain perfectly horizontal the reflected beam is changed and is only approximately tilted in the opposite direction by an amount approximately tilted by twice the ground plane tilt. However, the beam from the antenna plus ground plane, which is the sum of the components from the panels and those reflected from the ground plane is only approximately tilted by the ground plane tilt rather than twice the ground plane tilt. In practice there are variations in the ground plane due to uneven ground making accurate modeling difficult.

Table 3 shows the results of tests using FEKO models of the antenna and 30x30m ground plane in which the antenna panels are “tilted” in the direction of the E field and “rotated or “rolled” about the direction of the E field. Positive tilt corresponds to the panels sloping down from south to north and positive roll sloping down from east to west. For correction for a ground plane tilt which slopes down from east to west and down from south to north negative values of tilt and roll are needed.

beam model tilt deg	beam model roll deg	rms mK	offset north deg	offset west deg
-1	0	16	0	0
0	-1	32	0	0
-1	-1	32	0	0
-2	0	29	-1	-1
-2	- 2	66	0	-1
2	2	67	0	1
0	-2	64	0	0

Table 3. Simulations of slope correction using beam models average rms 5-term physical 52 – 95 MHz

The simulations, whose results are given in table 3 were made by generating spectra using scheme “a” and low2_45 beams from FEKO with different tilts and roll and then processing using scheme “a” using the FEKO beam with zero tilt and roll and finding the lowest average rms over GHA with a 3x3 1 deg grid search for the lowest rms. These simulations are done for the location and orientation of low-45 but with a horizontal ground plane and tilted antenna. A negative tilt and negative roll tilts the antenna down to the northeast. These simulations confirm that the beam tilts that minimize the rms are only equal to or less than the tilt and that roll produces little if any beam tilt.

Table 4 shows the results obtained when the FEKO models with tilts and roll are used to correct for any tilt and roll that may be present in the low2-45 data. The FEKO models were run with the antenna at 45 degrees to the ground plane. The lowest residuals are obtained when the whole structure is oriented at 42 degrees azimuth with respect to the local North which places the ground plane orientation of -3 degrees azimuth which is in agreement with the google map view of the ground plane.

beam model tilt deg	beam model roll deg	rms mK	offset north deg	offset west deg
0	0	135.8		
-1	0	132.6	0	1
0	-1	131.3	1	0
-1	-1	126.9	1	0
-0.7	-0.7	127.5	1	0
-0.7	-1.0	130.5	1	0
-1.5	-1.5	129.9	1	0
-2	-2	136.8	1	0
0	-2	142.6	1	0

Table 4. Effects of slope correction using low2-45 data from 2020 day 55 to 140 5-term physical 52 – 95 MHz.

Angle offset between antenna and ground plane deg	rms mK
45	126.9
43	135.3
48	129.3
46	126.4
44	128.8

Table 5. Average rms values for alignment of antenna and ground plane from low2_45 data

Table 5 shows that 46 degrees results in a marginally lower rms and with combined effects of the tilt and roll from table 4 lower the rms by 10 mK or about a 10% improvement.

c) Ground plane and antenna loss

These effects are discussed in memos 327, 328 and 329. The antenna loss has effects that be calculated from the loss alone and has little dependence on the beam. The ground plane loss is more complex but in general is small and scales with the sky noise like the antenna loss without a complex dependence on GHA.

d) Effects of the balun and balun shield

Adding the balun and balun shield to the FEKO models makes a difference of less than a mK to the results in tables 4 and 5.

e) Effects of soil dielectric

The general effects of soil dielectric and the equivalent effect of a gap between the ground plane mesh and the soil were studied in memo 206. The effect of changing the dielectric from 2 to 5 was less than 1 mK in the rms. A separate test was made in which the mesh and antenna were raised 2 cm above the soil and the effect was less than 1 mK in the rms.

6] Large rms at GHA at 21 hours

The rms at GHA = 21 has to be largely the result a beam effect because the structure which is primarily a “bump” at 60 MHz is not present at 20 or 22 hours. If it were due to a calibration error, loss or source in the sky it would be present at 20 and 22 hours owing to the large antenna beam. Effectively the addition of the ground plane or some other nearby object has to be present to produce structure in the beam at the level of 15 degrees which in turn requires a scale of more than 19 meters. Tests show that the bump at 60 MHz is present from day 55 to day 160 at GHA = 21 which makes RFI as an unlikely source since it would have to only be present at the sidereal time corresponding to GHA = 21. The bump is partly due to the ability to fit the combination of the ionosphere, and the absorption partly due to imperfect beam correction. The bump is consistent with the strong sky of the galactic center region convolved with some frequency structure in the beam not present in the beam model like those of the slopes and tilts which help reduce the bump but are not sufficient to remove the bump.

Large residuals are also present at GHA = 2, 3 and 4 hours. This structure is also not well corrected by the beam model and is also likely to be in the ground plane. Figures 1 and 2 show the lowest rms of 126.9 mK obtained without and with the subtraction of the absorption respectively and Figure 3 shows the result of a grid search for the absorption with tau = 7 using average over GHA of the data of Figure 1. See figure 6 of memo 330 for the absorption obtained from the average from GHA 6 to 18 hours.

7] Conclusions

With the best tilt and roll correction, along with the 5 K offset correction to the Haslam map get the rms over GHA down from 136 mK to about 125 mK and removing the absorption down to about 115 mK. While most of the 115 mK is unexplained it is most likely due to a combination of additional systematic S11 error, calibration error, uncorrected losses, ionosphere and complexity in the ground plane structure not included in the FEKO model or possibly other structure near the ground plane.

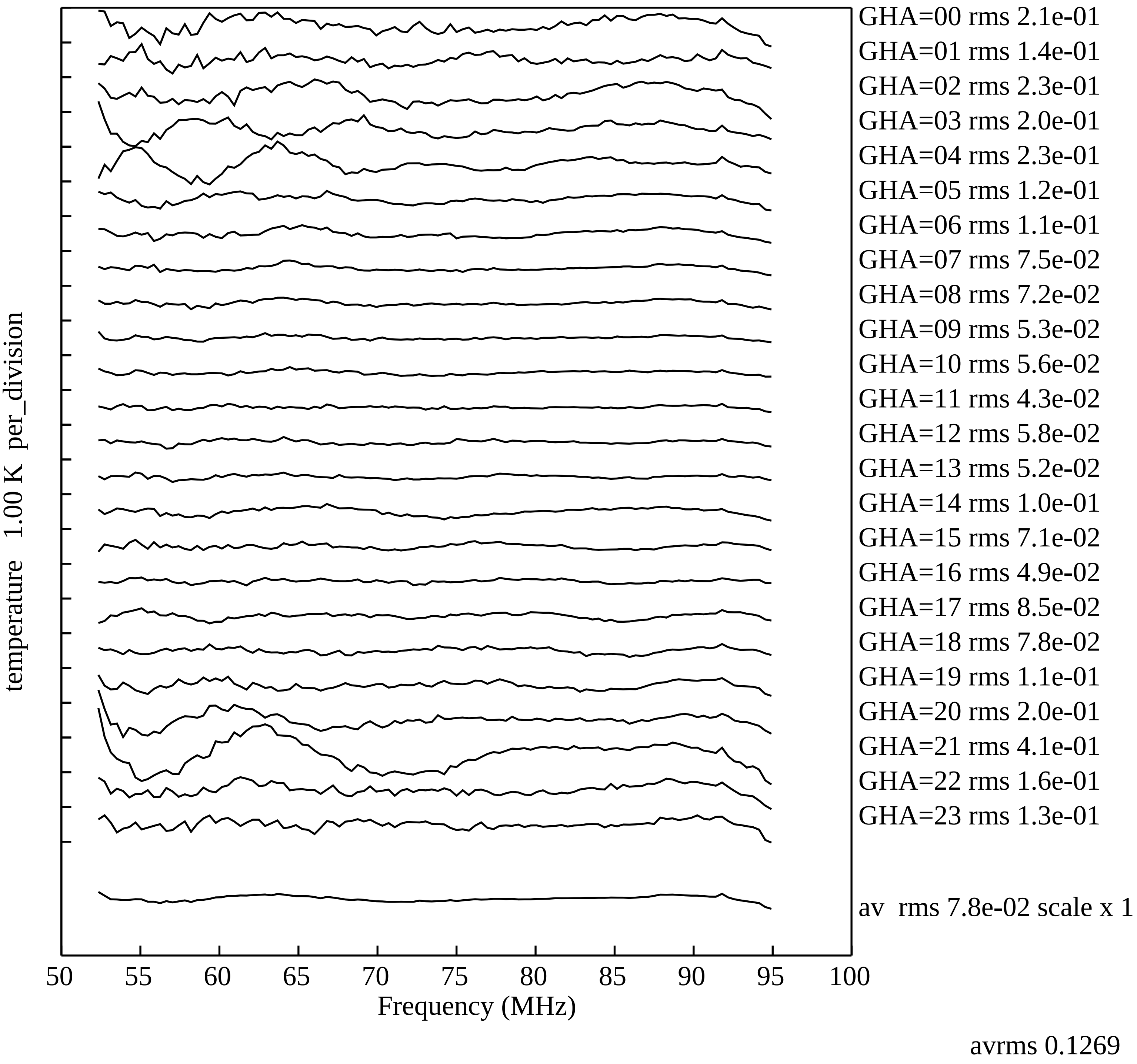

Figure 1. Residuals to low2-45 data from 2020 day 55 to 140 with beam corrections which include the tilt of the ground plane. The foreground and ionosphere are modeled using 5 physical terms.

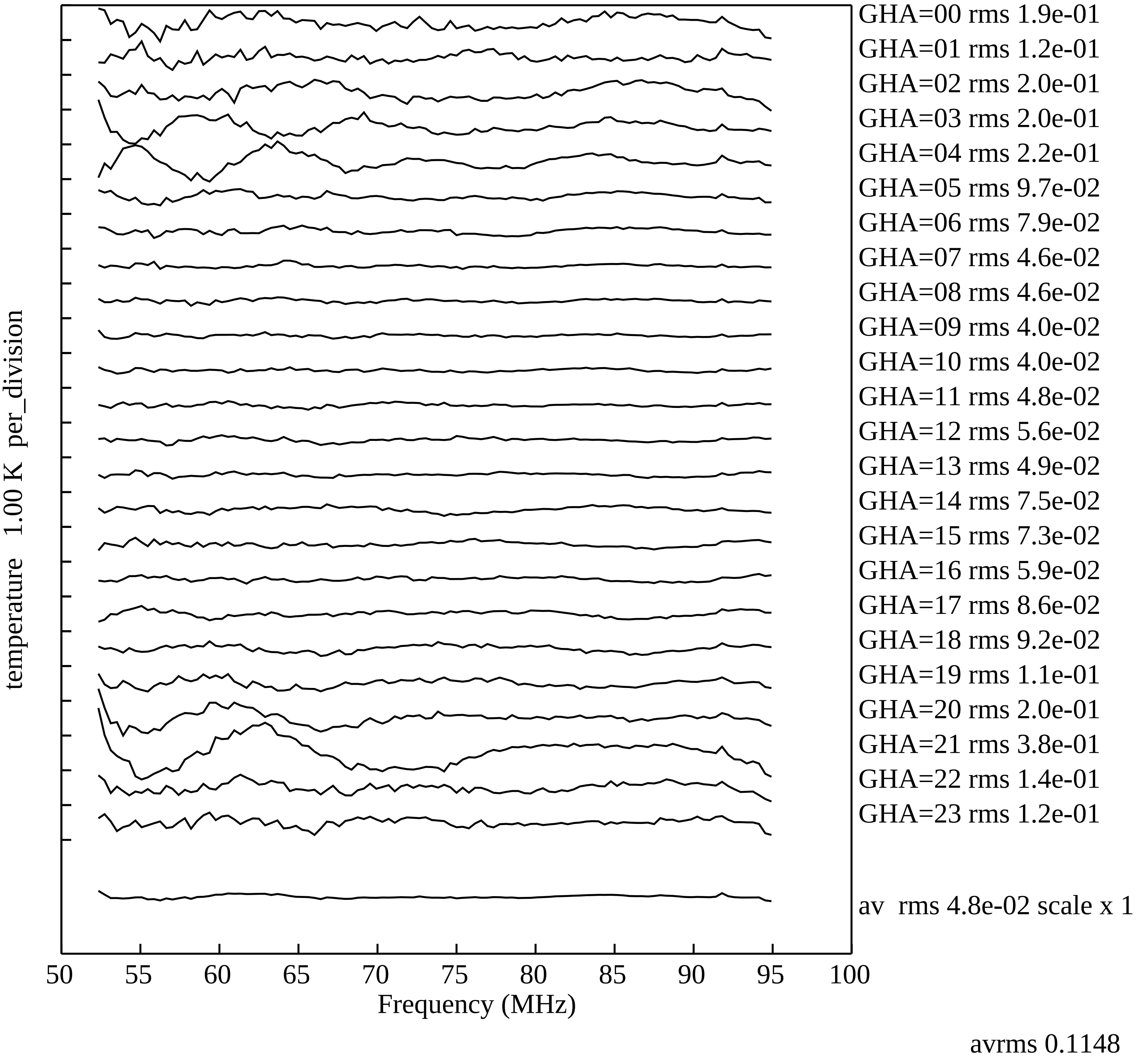

Figure 2. Residuals with the addition of the subtraction of the absorption published in Nature.

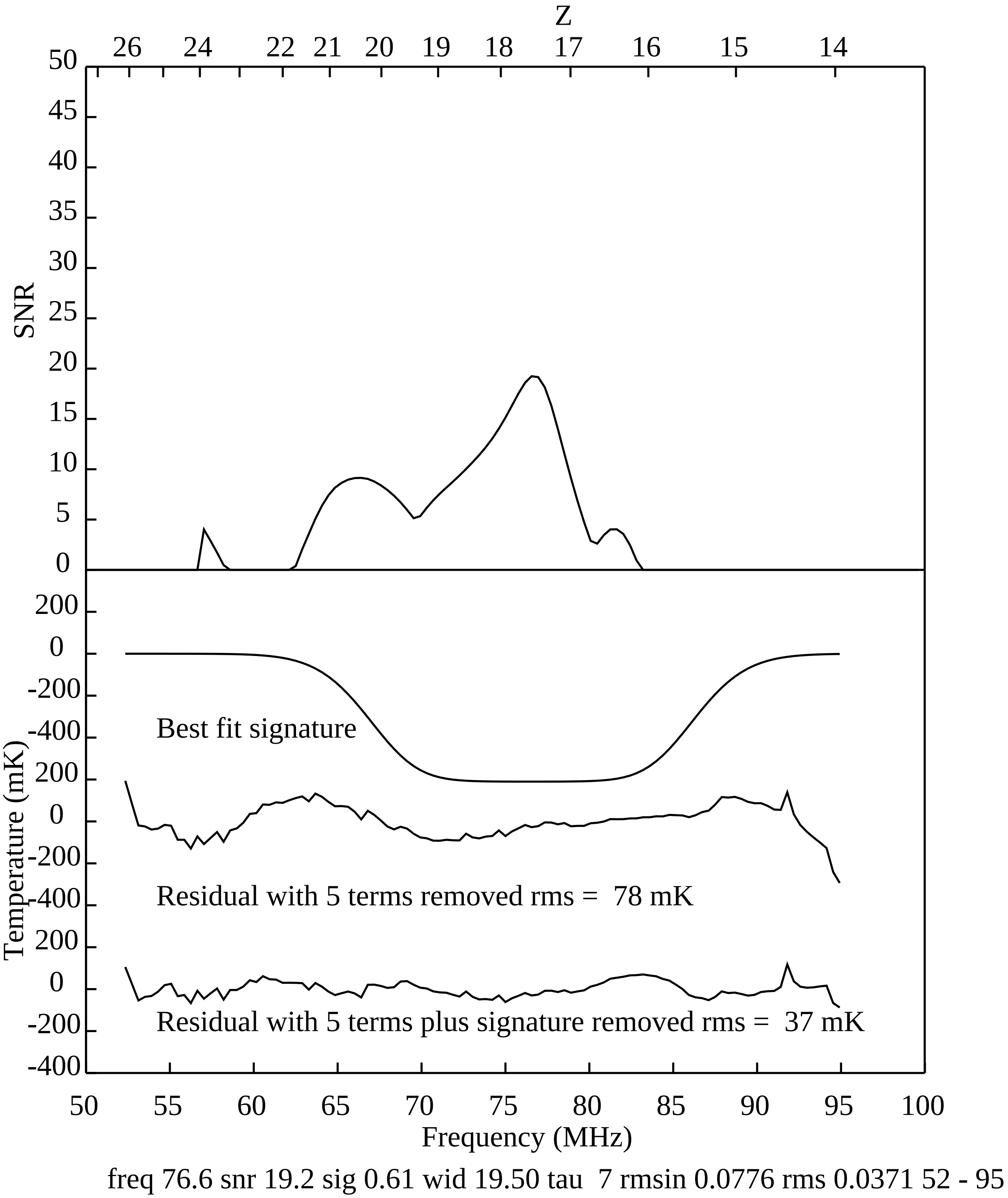

Figure 3. Grid search for absorption at fixed tau = 7 using the average over GHA of all the data in Figure 1.