LoCo Lab EDGES Memo 148
Mid-Band Calibration Comparison

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1 Description

Two complete lab receiver calibrations were performed for EDGES-2 Receiver 1, which was used as part of the Mid-Band instrument. The first calibration was done in 2018-January (before the Mid-Band observations), and the second one in 2019-April (after the Mid-Band observations). As part of the receiver calibration, the internal network centered on the 4-position S11 switch was calibrated on these two occasions, as well as in 2019-March.

In this report we compare Mid-Band sky observations calibrated with using the following combinations:

- Case 1: Receiver 2018-Jan / Switch 2018-Jan for antenna S11
- Case 2: Receiver 2018-Jan / Switch 2019-Mar for antenna S11
- Case 3: Receiver 2019-Apr / Switch 2018-Jan for antenna S11
- Case 4: Receiver 2019-Apr / Switch 2019-Mar for antenna S11

In the cases shown above we use the same antenna S11 measurement taken at the MRO. Specifically, we use the third S11 measurement from day 2018-147. We calibrate this S11 assuming the internal switch S-parameters from 2018-Jan (Cases 1 and 3) and from 2019-Mar (Cases 2 and 4).

We choose to use the internal switch S-parameters from 2019-Mar instead of 2019-Apr because those from March was closest to the end of the Mid-Band observations. Nonetheless the two are very close because they were taken less than a month apart with the receiver staying in the lab the whole time.

The internal switch was calibrated in 2018-Jan using an external 50-ohm load with resistance 50.027 ohms at 25°C, while in 2019-Mar and Apr a different 50-ohm load was used, with resistance 50.15 ohm at 25°C. To the best of our knowledge, in all cases the OSL calibration kit brand and model corresponded to Keysight 85033E.

From the cases analyzed, we find that between 2018 and 2019 there are changes in both, the receiver parameters and the internal switch S-parameters. These changes could have occured on the trip to/from the MRO or in the field. Although this is still under investigation, Cases 1 through 4 above let us explore if the changes in receiver and switch parameters occurred before or after the period of sky observations. Changes in receiver and switch parameters in general would occur independently; i.e., changes in the LNA path do not necessarily lead to changes in the 4-position switch path, and vice versa. This is why we explore the 4 cases.

The calibrations are done and shown here in the frequency range $50-150$ MHz, while the sky observations are shown in the range $60-150$ MHz because below 60 MHz the antenna reflections are too high, which makes the data calibration extremely difficult.

The following section discusses the results.

2 Results

The results are presented in Figures 1-8.

- **Figure 1** shows the receiver calibration parameters obtained from the 2018-Jan and 2019-Apr lab measurements. In the 2018 calibration we used 7 and 8 terms to model the C_1/C_2 and $T_{\rm unc}/T_{\rm cos}/T_{\rm sin}$ parameters, respectively. We found that these are the optimal number of terms for the range $55-150$ MHz. In the 2019 calibration we used 8 and 10 terms, which we found to be the optimal. The most significant differences between 2018 and 2019 seem to be in C_1, C_2, and $T_{\rm unc}$.

- **Figure 2** shows the internal switch S-parameters obtained from the 2018-Jan and 2019-Mar lab measurements. Also shown are the parameters from 2015 before the Low-Band observations, and from 2017 measured at the MRO for the initial Mid-Band observations. The measurements that agree the closest with those done in 2015 are the ones from 2018.

- **Figure 3** shows the antenna S11 from day 2018-147, as well as the difference in calibration between 2018 and 2019 using the nominal resistance values (50.027 and 50.15 ohms respectively). We see that the difference shows ripples around ± 0.02 dB in magnitude and $\pm 0.2^\circ$ in phase. We also show the difference between the nominal calibration from 2018, and calibrations from 2018 and 2019 assuming 50.12 ohms for the external 50-ohm load. This is done for comparison purposes only. We do not calibrate the sky data using that assumption. A correct exploration of this possiblity would also require calibrating the receiver itself assuming this resistance value. Finally, in this figure we also show the difference between the antenna S11 from day 2018-222, calibrated with 2018 and 2019 parameters, and 2018-147.

- **Figure 4** shows the difference (direct subtraction) between spectra integrated over 6-18 hr calibrated using Cases 2, 3, and 4, relative to Case 1. We see that the differences (in absolute value) are of up to 1.5 K for Case 2, and up to 70 K for Cases 3 and 4. This indicates that the largest effect on the total temperature is due to using a different receiver calibration (2019 vs 2018), rather than due to only changing the antenna S11.

- **Figure 5** shows the residuals after fitting and removing a 5-term LINLOG model from the spectrum of day 2018-150 integrated over GHA 6-18 hr. The lowest residuals are obtained for Cases 1 and 2, i.e., using receiver calibration from 2018.

- **Figure 6** shows the same as Figure 5 but for observations from day 2018-188. The lowest residuals are for Case 1, i.e., receiver and switch parameters from 2018.

- **Figure 7** compares the residuals for day 2018-150 using calibration Cases 1 and 2, with the residuals obtained when averaging the switch parameters from 2018 and 2019. This was done to see if averaging the switch parameters produces lower spectral residuals. For this day, the residuals do decrease when using the average.

- **Figure 8** shows the same comparison as Figure 7 but for observations from day 2018-188. Here the lowest residuals are those from calibration Case 1. This suggests that for sky observations from days around 2018-188 the best calibration corresponds to Case 1.

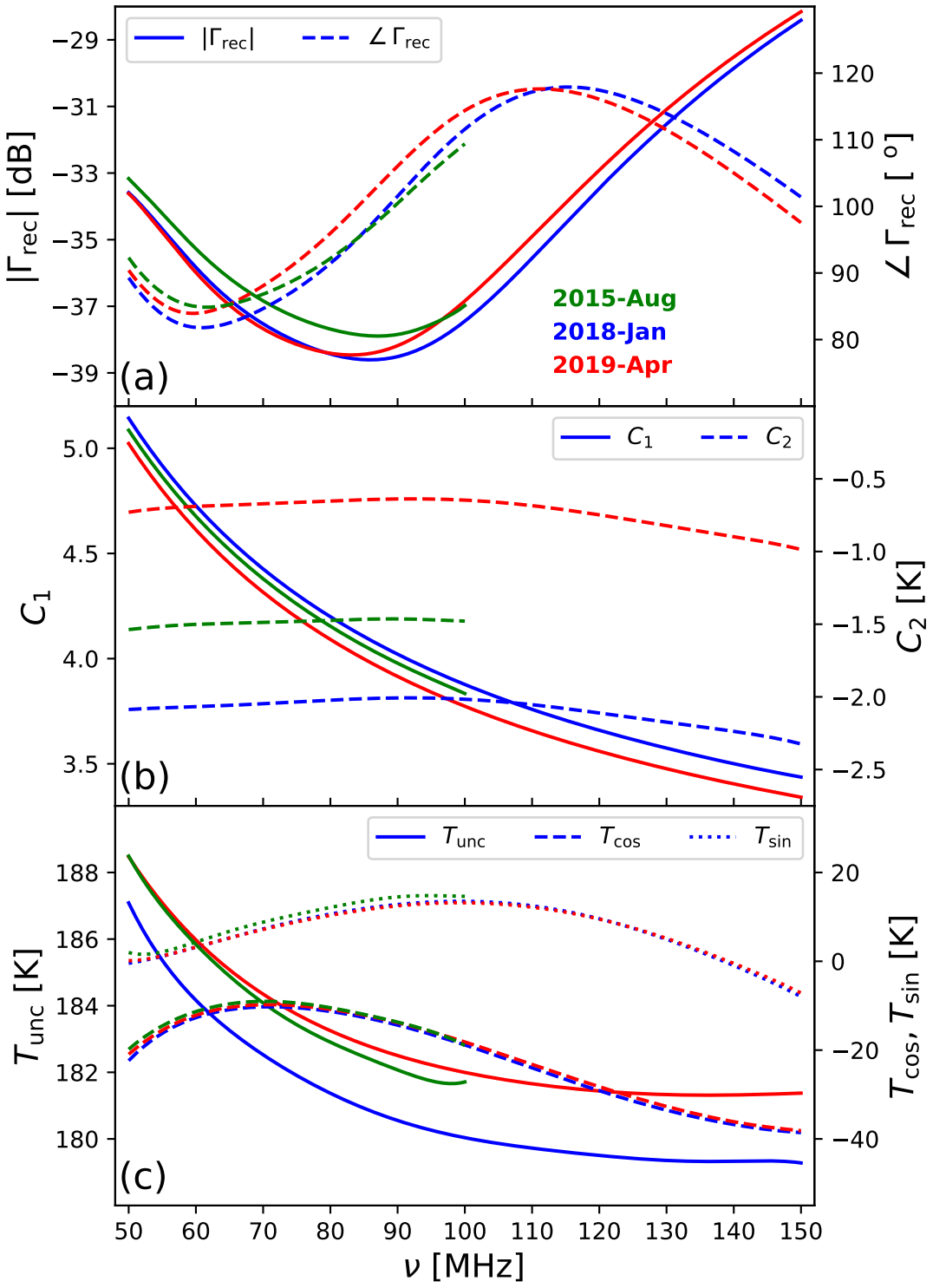

Figure 1: Receiver calibration parameters obtained from lab measurements before (BLUE, 2018-Jan) and after (RED, 2019-Apr) the 2018 Mid-Band observations. Over the 50-150 MHz range, the 2018 parameters were modeled with 7 (C_1/C_2) and 8 ($T_{\rm unc}/T_{\rm cos}/T_{\rm sin}$) polynomial terms, while the 2019 parameters were modeled with 8 (C_1/C_2) and 10 ($T_{\rm unc}/T_{\rm cos}/T_{\rm sin}$) polynomial terms. The most significant differences between 2018 and 2019 seem to be in C_1, C_2, and $T_{\rm unc}$. For comparison we also show (GREEN) calibration parameters from 2015 when the same receiver was being used for Low-Band observations.

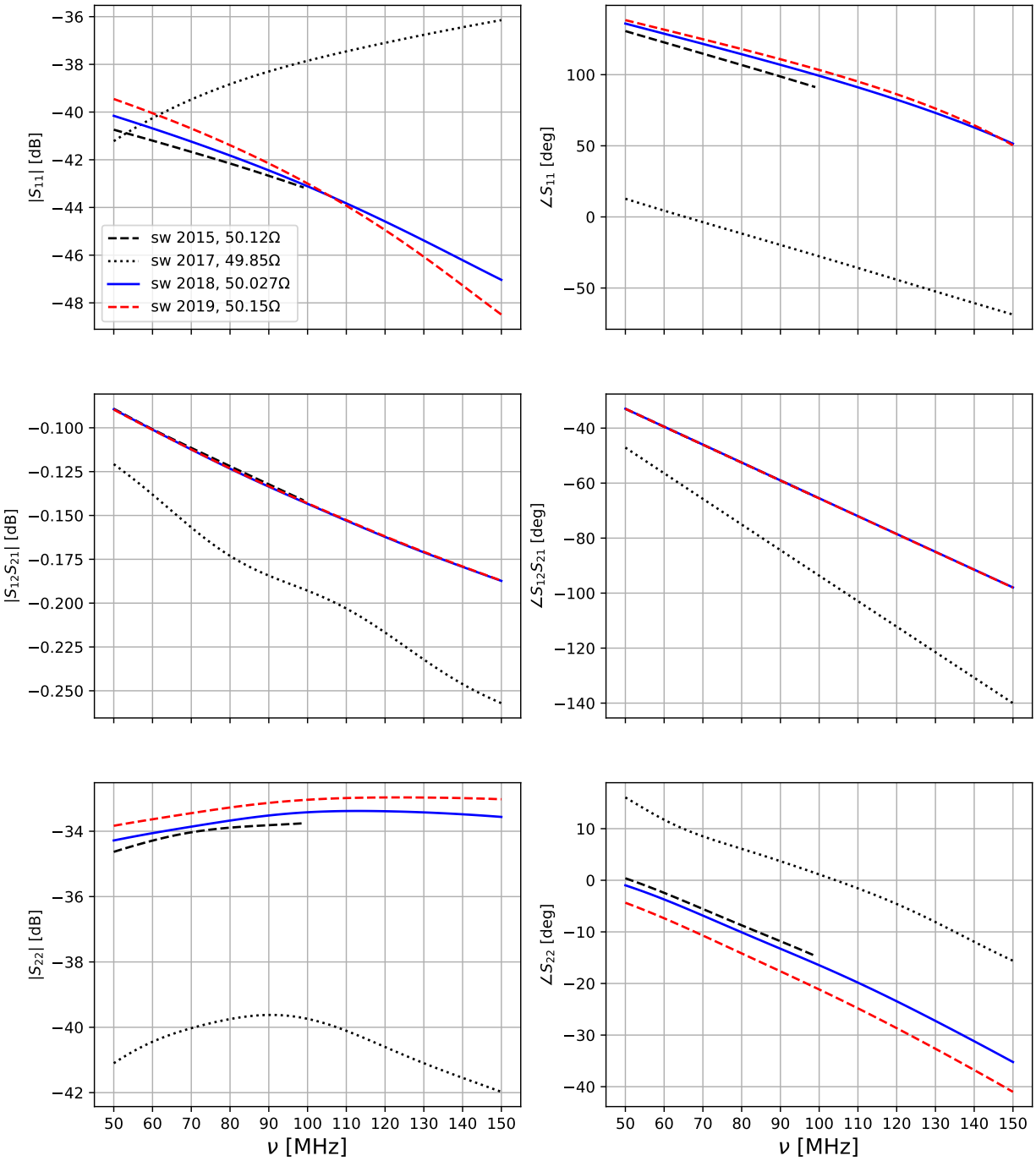

Figure 2: S-parameters of the network for measurement of the antenna S11, centered around a 4-position switch, inside Receiver 1. The legend shows the measurement year and resistance of the internal 50-ohm load. The measurement from 2015 (BLACK DASHED) was used to calibrate the S11 of the Low-Band 1 antenna, while the others (2017, 2018, 2019) were used for the Mid-Band antenna S11. The measurement from 2017 (BLACK DOTTED) was done at the MRO using the Fieldfox portable VNA. The measurements from 2018 (BLUE SOLID) and 2019 (RED DASHED) were done at ASU using the Agilent E5061A benchtop VNA. We see that the measurements at the MRO represent an outlier compared to the others.

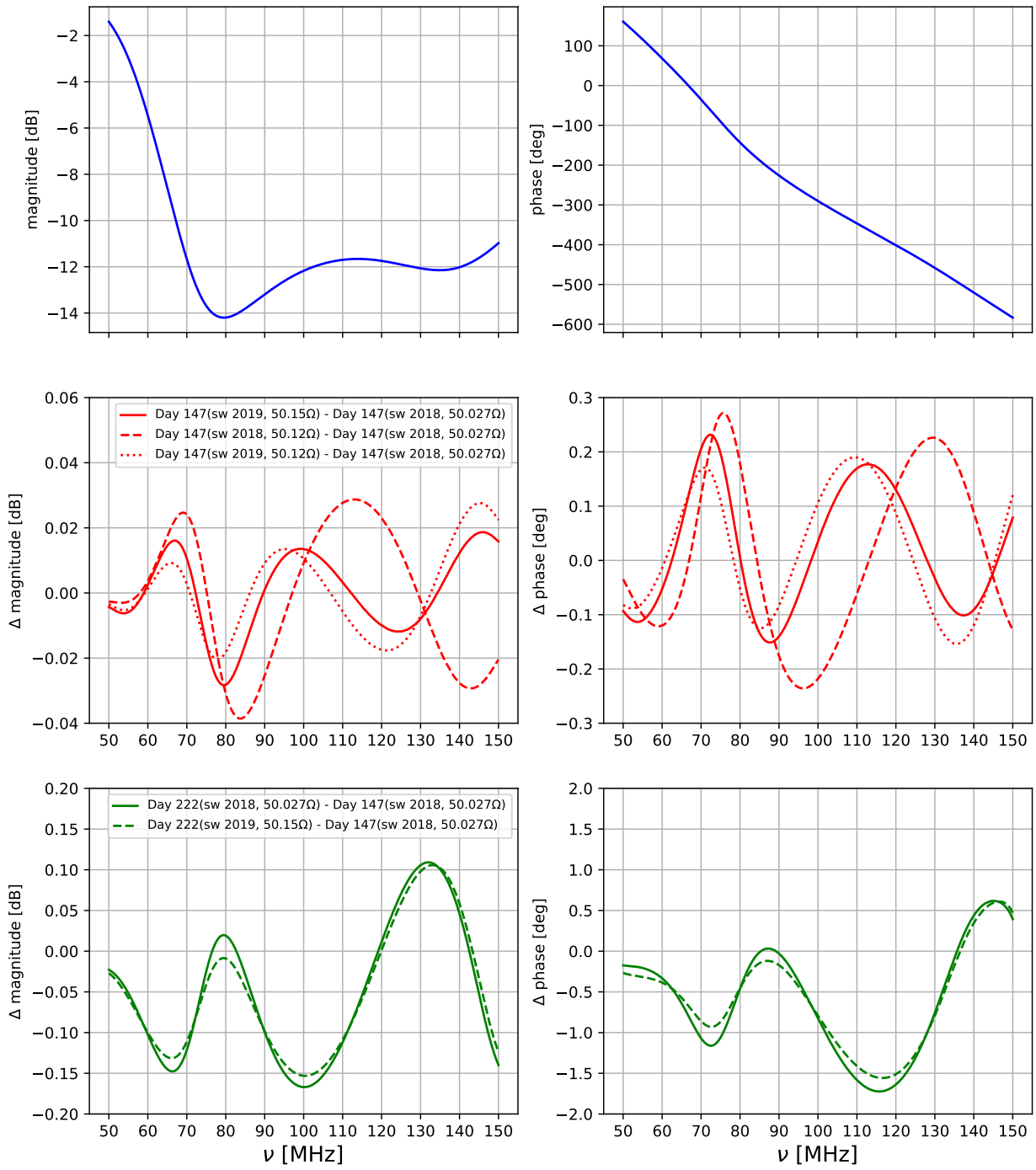

Figure 3: (TOP ROW) Mid-Band antenna S11 from day 2018-147, calibrated with the switch parameters from 2018. (CENTER ROW) Difference in the antenna S11, relative to using the switch parameters from 2018, when calibrated using the parameters from 2019 (RED SOLID). For reference, we also show the difference when using parameters from 2018 (RED DASHED) and 2019 (RED DOTTED) that assume a 50.12-ohm resistance for the external 50-ohm calibration load. (BOTTOM ROW) Difference between antenna S11 from day 2018-222 and day 2018-147. Here the measurement from 2018-222 was calibrated using the parameters from 2018 (GREEN SOLID) and 2019 (GREEN DASHED). The differences (in absolute value) are very large, even > 0.15 dB and $> 1.5°$.

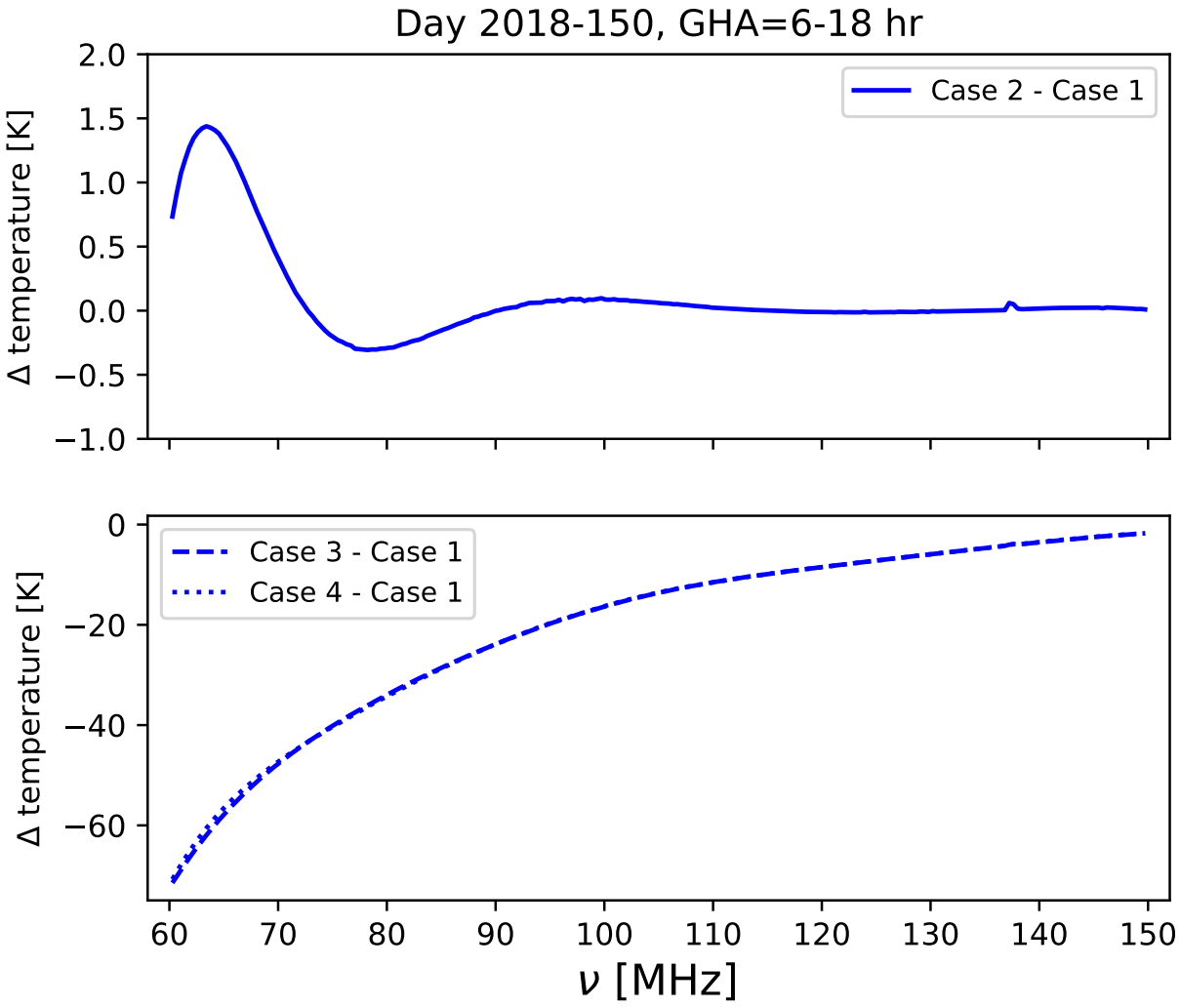

Figure 4: Difference in the sky spectrum when calibrating the observations using Case 2 (TOP) and Cases 3 and 4 (BOTTOM) instead of Case 1. For this example we use observations from day 2018-150 over the GHA range 6-18 hr. The results are almost the same for other days.

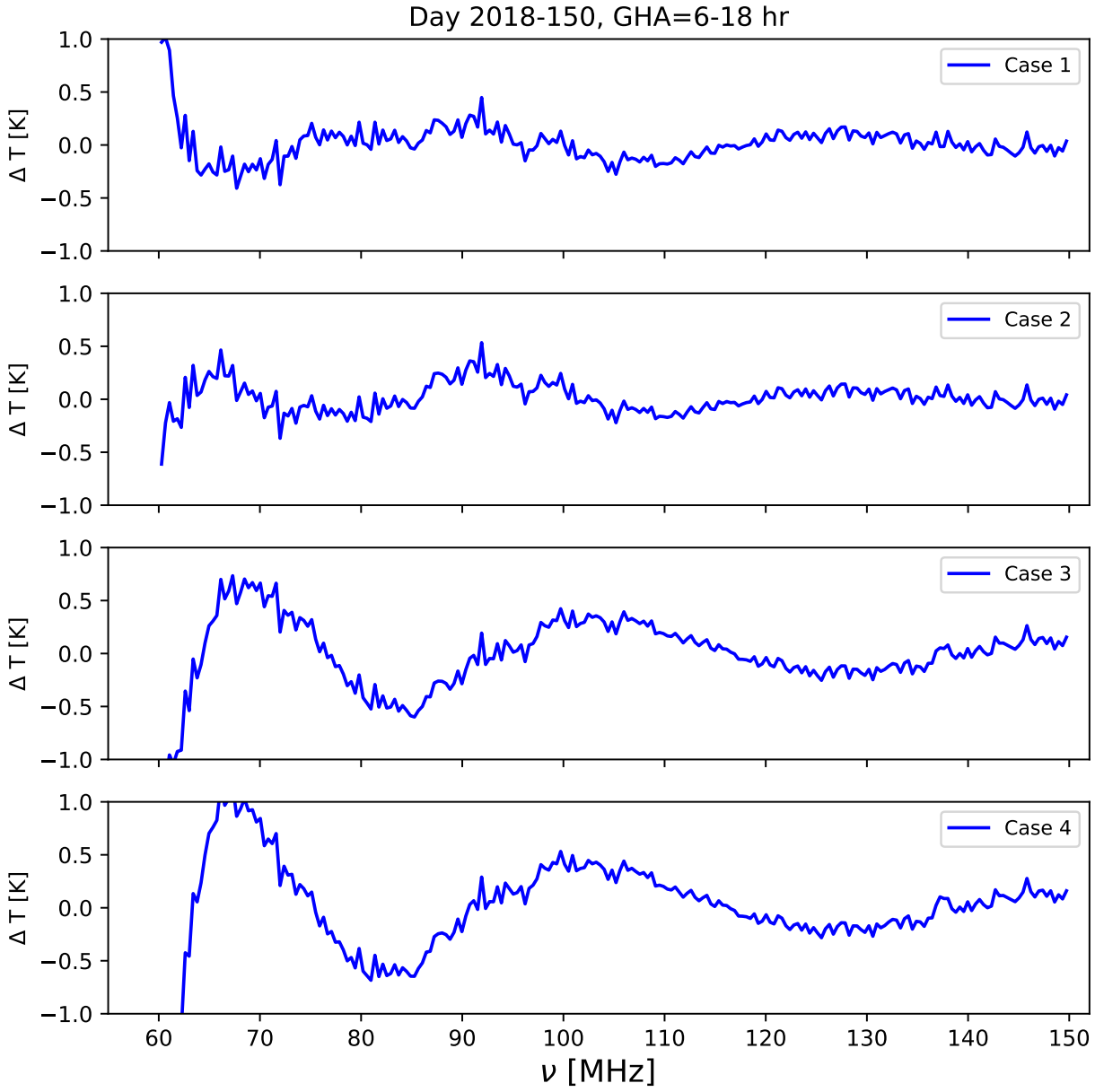

Figure 5: Residuals for the spectrum from day 2018-150 integrated over GHA 6-18 hr, in the frequency range 60-150 MHz, after removing a 5-term LINLOG model. From TOP to BOTTOM the panels correspond to calibration Cases 1 through 4.

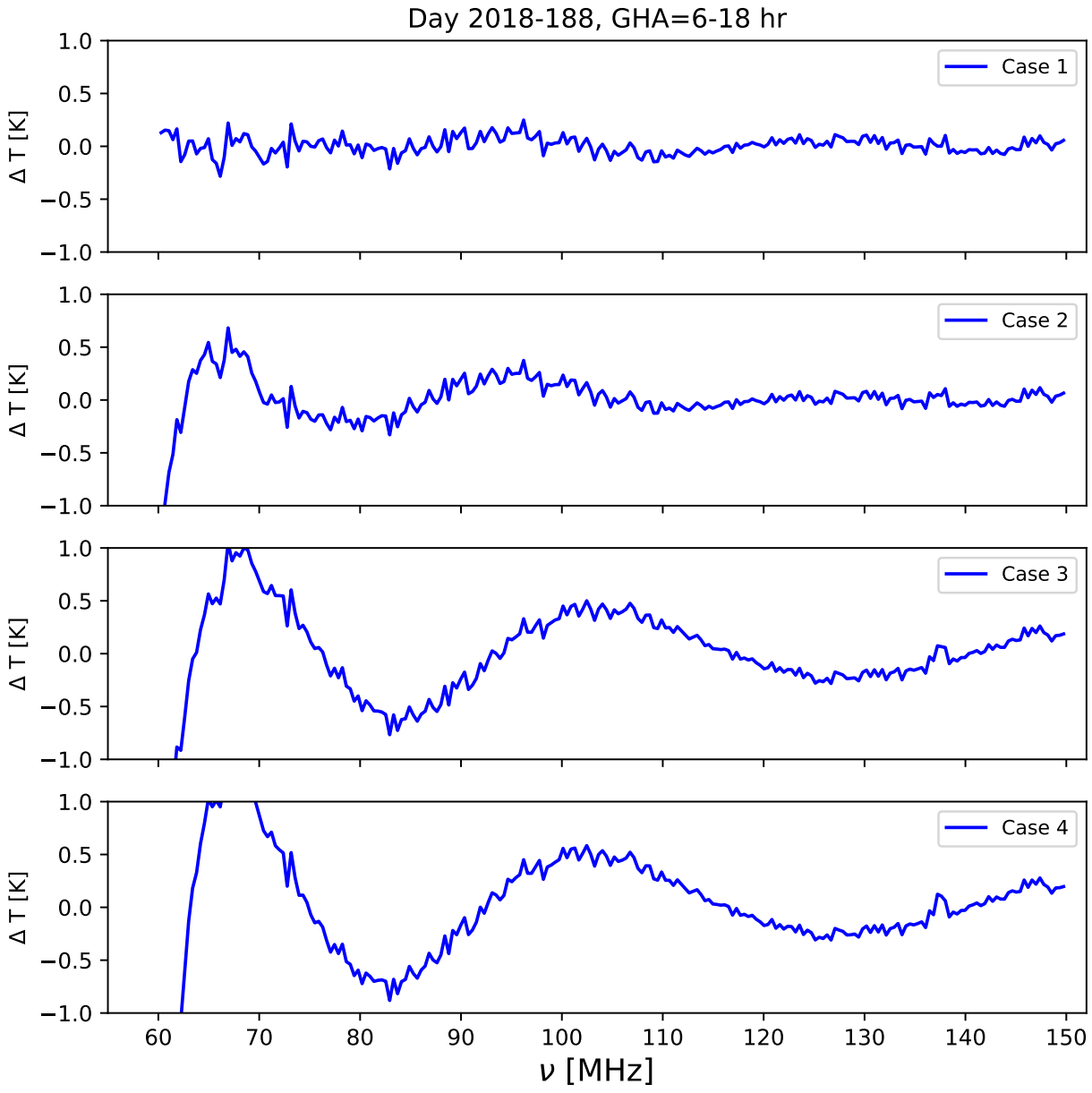

Figure 6: Same as Figure 5 but for the sky spectrum from day 2018-188.

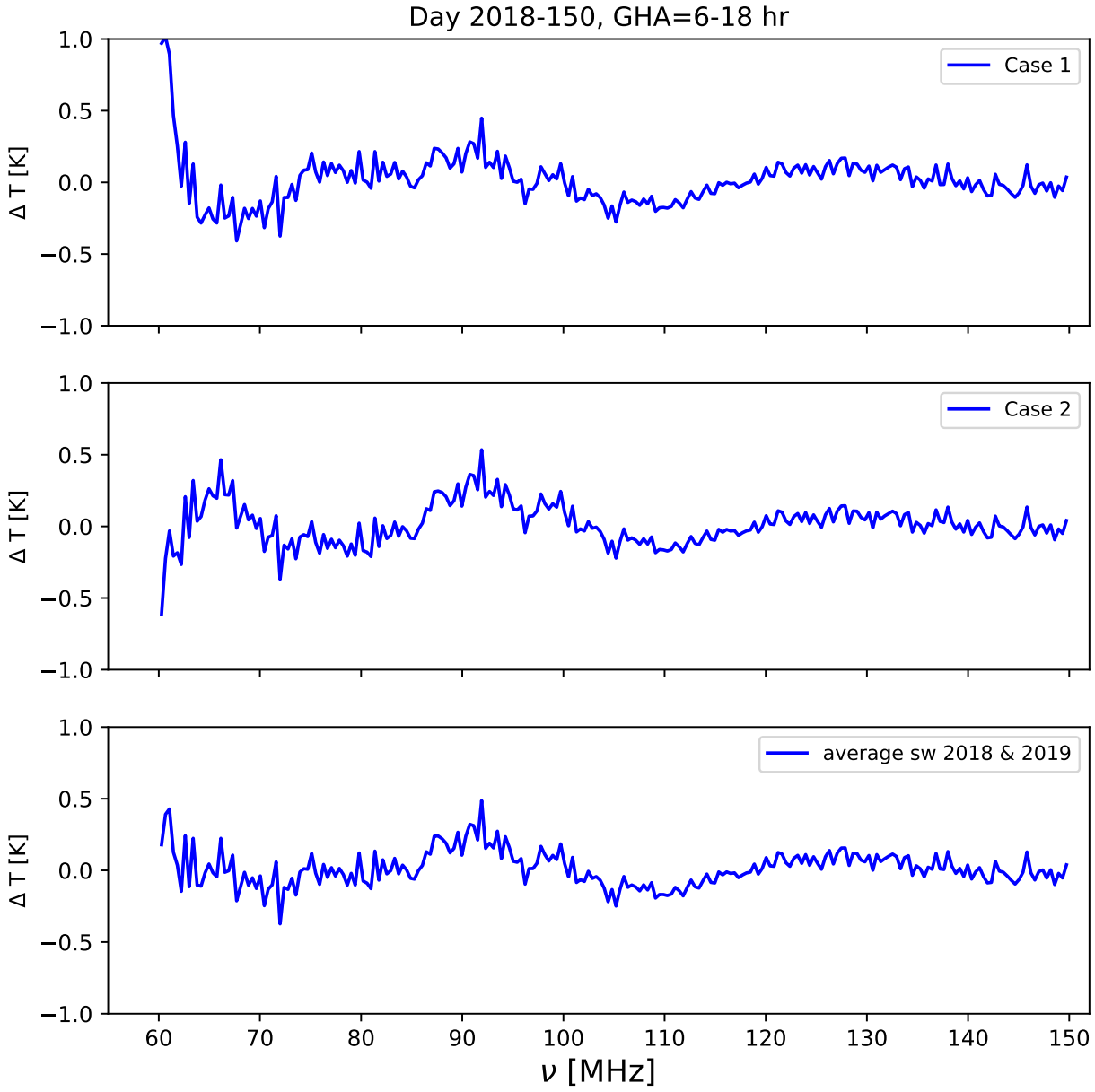

Figure 7: Comparison between residuals for the spectrum from day 2018-150 using calibration Cases 1 (TOP) and 2 (MIDDLE). The BOTTOM panel are the residuals when using receiver calibration from 2018 and switch parameters corresponding to the average from 2018 and 2019.

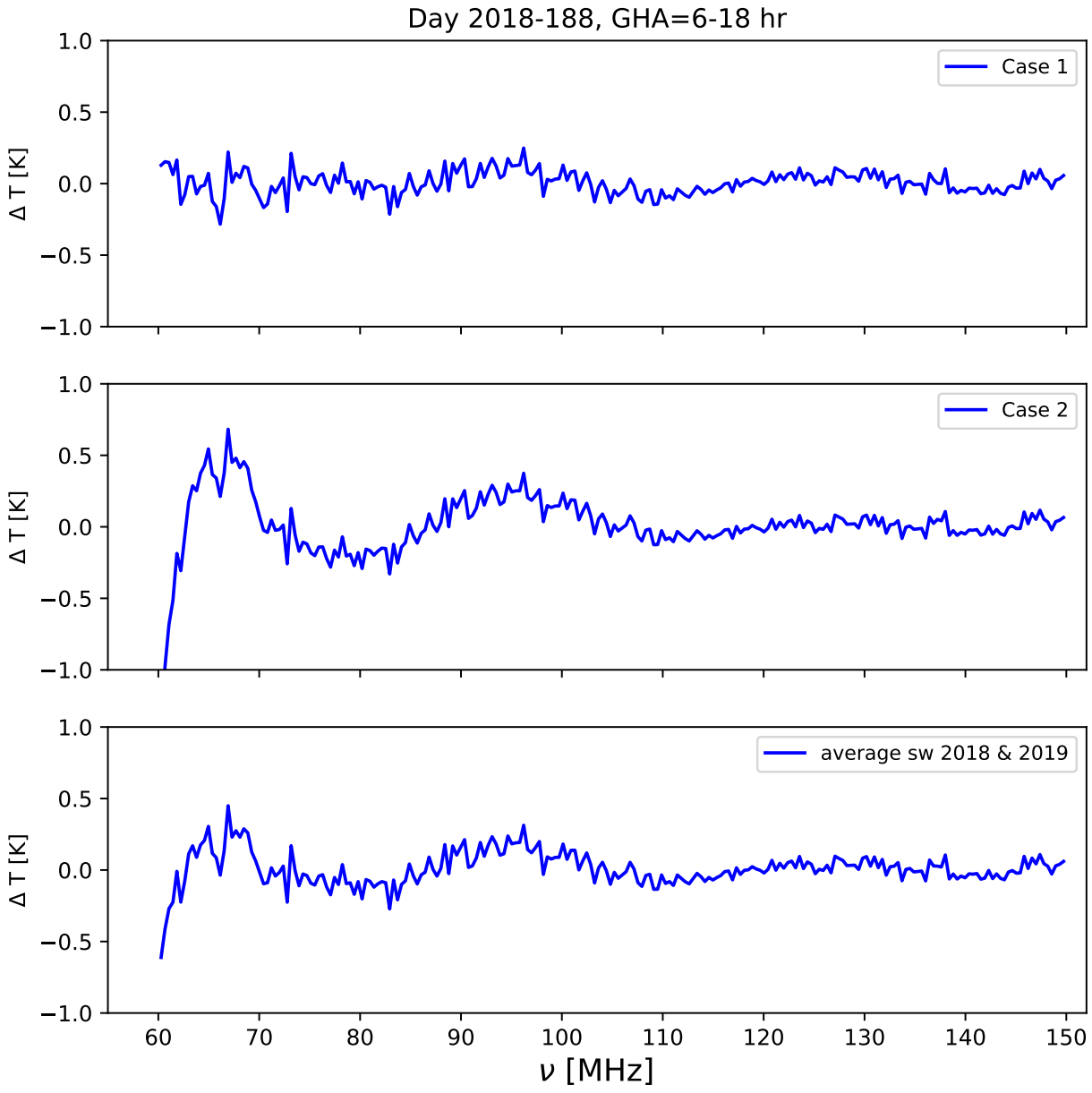

Figure 8: Same as Figure 7 but for day 2018-188.