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July 31, 2014

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Subject: Characterization of RFI at the UNR Gund Ranch

1 Description

A characterization of radio-frequency interference (RFI) was performed in the region surrounding the Gund Ranch between July 17 and July 19, 2014. This ranch is located in the Grass Valley, Nevada, and belongs to the University of Nevada at Reno. It is administered by Mr. Jon Wilker, who conducts several research and commercial activities with livestock. The purpose of this RFI characterization is to determine if the area is competitive for the observation of the redshifted 21-cm line emitted during cosmic dawn.

Two instruments were employed for the characterization:

- A calibrated EDGES system, corresponding to front-end, back-end, digitizing, and recording electronics identical to those used by the instrument currently dedicated to EoR science in Western Australia. Two fourpoint antennas were employed, in order to survey the ranges 50-120 MHz (low-band) and 100-200 MHz (high-band) separately and more efficiently. This instrument is referred to as Instrument 1.
- An instrument based on a spectrum analyzer, an LNA, and a biconical antenna. The purpose of this instrument is to perform quick measurements in order to compare the main features of different promising sites without spending significant amounts of time assembling and disassembling the main system. This instrument is referred to as Instrument 2.

Two practical spots were selected for measurements with Instrument 1. They are shown in red in figures 1 and 2. The criterion used to choose these spots was obtaining an adequate angle of the surrounding mountains - not too high (which could affect science measurements) but not too low (so they provide some RFI attenuation). This pushed us south of the ranch, toward the middle of the Grass Valley, since the homestead is blocked on the east by tall mountains a few hundred meters away. Figures 1 also shows in blue the spots where measurements with Instrument 2 were done. At all the locations the strength of the FM broadcast signal picked up by the car radio was minimal.

The spots in figures 1 and 2 are labeled geographically, with numbers that increase clockwise starting with the westernmost. However, that is not the chronological order in which they were visited and measured from. The chronological order is as follows:

- July 17 (day 1) was devoted to measurements at site 2 with both instruments. With Instrument 1 we were able to measure with the low- and high-band antennas orientated in the north-south and east-west directions, spending 1 hour with each antenna and in each orientation.
- July 18 (day 2), due to rain and lightning most of the day, was devoted to measure with Instrument 2 only, at the other spots shown in figure 1. These measurements were 10-minute long per orientation of the biconical antenna, except for places where rain made us stop sooner.

- The first half of July 19 (day 3) was used for measuring with Instrument 1 at site 1, only with the low-band antenna. One hour of data in the north-south orientation was gathered, while only 40 minutes in the east-west orientation due to incoming rain and lightning.

The coordinates of each site are presented in table 1.

Site	Landmark	Coordinates	
		Longitude	Latitude
1	Grass Valley Rd	116° 42' 40" W	39° 44' 52" N
2	South of Gund ranch	116° 37' 31" W	39° 50' 20" N
3	Homestead	116° 35' 13" W	39° 54' 02" N
4	Fye Canyon	116° 32' 42" W	40° 01' 42" N
5	Highway 278	116° 11' 09" W	40° 00' 18" N
6	Highway 50	116° 19' 43" W	39° 31' 44" N
7	Ackerman Canyon	116° 36' 46" W	39° 31' 19" N

Table 1: Site Coordinates

The pictures in figures 3 through 11 give an idea of the landscape at most of the spots visited.

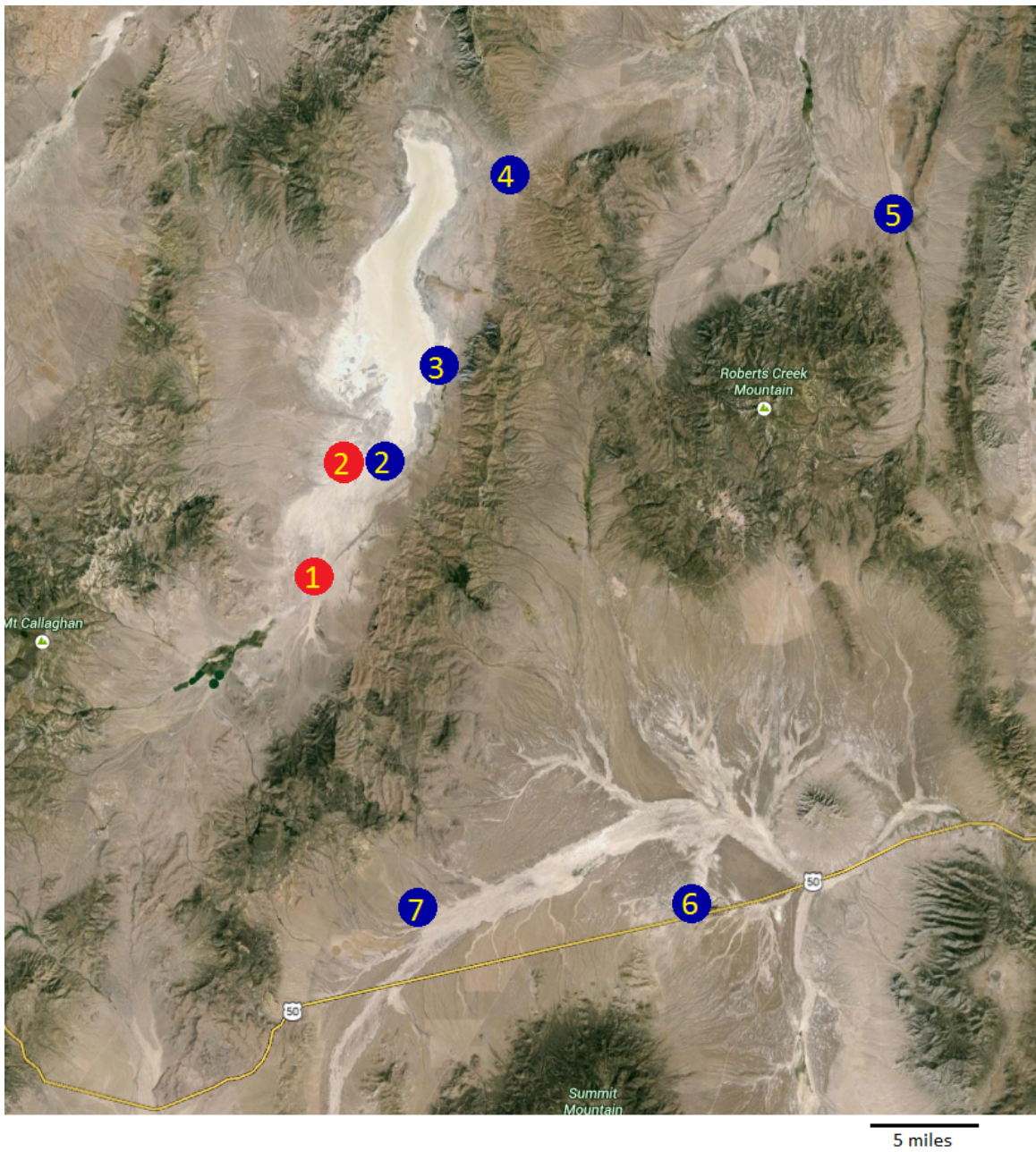


Figure 1: Location of sites from which measurements were conducted. Top is north, and bottom is south. The spots in red are the sites from which Instrument 1 was used, and the ones in blue correspond to Instrument 2. For reference, site 3 correspond to the Gund ranch, and highway 50 is in the lower part of the map.

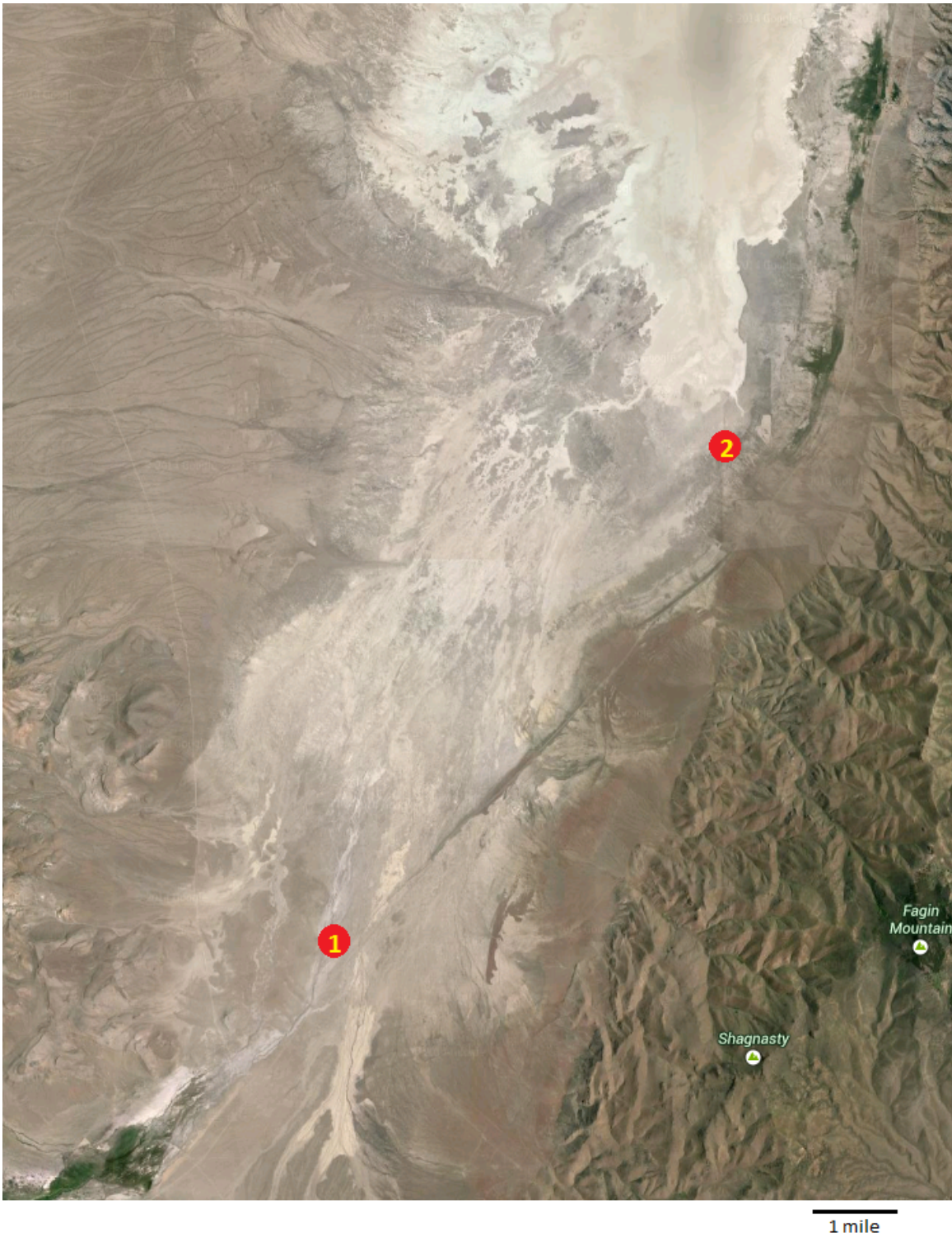


Figure 2: Zoom in on the Grass Valley, west and south of the Gund ranch. The ranch corresponds to the green spot in the upper-right corner. Site 1 is ~ 13 miles south of the ranch, by the road. Site 2 is ~ 5 miles south of the ranch, and a few minutes into the valley following a two-track road.



Figure 3: Overview of the homestead from the south. The uneven mountains in the north do not attenuate signals sufficiently from that direction. Low-voltage lines provide power to the homestead and the actual house of the manager, a few hundred meters south (not shown in the picture).



Figure 4: View from the homestead to the east. Tall mountains located a few hundred meters away become a limitation for considering doing science measurements from this site. Thus, only Instrument 2 was used to characterize this site.



Figure 5: Site 1, looking toward the mountains on the east, during measurements with Instrument 1 and the low-band antenna.



Figure 6: Site 1, looking toward the mountains on the west, during measurements with Instrument 1 and the low-band antenna.



Figure 7: Site 2, looking toward the mountains in the east, and the two-track road that leads to the main road called Grass Valley Rd.



Figure 8: Site 2, looking toward the west, during measurements with Instrument 1 and the low-band antenna. The setup is on top of the two-track road that continues into the valley.



Figure 9: Site 4, looking toward the east, during measurements with Instrument 2.



Figure 10: Site 5, looking toward the north, during measurements with Instrument 2.



Figure 11: Site 7, looking toward the east, during measurements with Instrument 2.

2 Measurements and Results

2.1 Instrument 1

The relevant aspects of measurements with Instrument 1 can be summarized as follows:

- Frequency resolution of ~ 6.1 KHz.
- Temperature calibration assuming 300 and 400 K for the cold and hot loads in the LNA, respectively.
- Ground pickup is higher than with the science instrument since no metal ground plane was used, and sites 1 and 2 had mountains in the horizon of up to ~ 10 degrees.
- Measurements were done with the antenna, the excited panels specifically, orientated along the north-south and east-west axes.
- No correction applied due to ground pickup, imperfect impedance match between antenna and LNA, noise waves, or scale and offset of LNA. Skipping these calibration steps has a small impact, since the focus of the experience is to obtain representative behavior of the RFI with respect to the galactic-noise-limited baseline in order to compare different sites.
- The instrument was run off car batteries, and therefore an inverter was required. The back-end electronics, PC, and inverter were enclosed in a metal box that acted as a Faraday cage. This enclosure was essential for capturing the RFI content of the environment alone, without the contribution of the electronics which was significant, especially in the low-band.
- At site 1 only low-band measurements were taken, with both antenna orientations. The measurement with the north-south orientation lasted 1 hour. With the east-west orientation it lasted 40 minutes due to approaching rain; however, only $\sim 50\%$ of them are useful since the rest was affected by thunderstorms in the vicinity.
- At site 2 it was possible to conduct low- and high-band measurements in both orientations, lasting 1 hour each.

Figures 12 through 17 present waterfall plots of the observations, along with averages of the datasets.

Figures 18 through 23 present the average RFI content in the frequency domain after removing the baseline from the data. In each figure, the upper plot has a vertical scale adequate for visualizing the strongest component between both orientations. The lower plots zoom in to the vertical scale 0-100 K.

Figures 24 through 30 show timestreams of the frequency channels in the low-band that show significant RFI for any of the two sites and orientations, except for the region of FM radio. The baselines in time, corresponding primarily to drifting sky noise, have been removed from these streams. A label in each subplot identifies the frequency channel as well as the service to which it has been assigned as reported by the FCC.

2.2 Instrument 2

Instrument 2 had the purpose of quickly characterizing interesting spots around the ranch in order to compare their main features with those at the sites where Instrument 1 was employed. Its technical details can be summarized as:

- The spectrum analyzer is operated with RBW of 1 KHz and a resolution of ~ 273 KHz in the range 50-200 MHz.
- The short biconical antenna is operated horizontally with the cones orientated along the north-south and east-west axes. It was mounted at a height of ~ 1.6 meters.

- The LNA has a gain of ~ 45 dB and an average noise temperature of ~ 55 K in the range of interest. It was connected to the antenna through a 12-inch cable.
- No calibration was conducted for this instrument, and therefore direct power readings cannot be translated into temperature accurately. Moreover, the return loss of the antenna is very poor (to be expected from such a short biconical antenna) which has the effect of making the system inefficient to sky noise (or RFI). This also produces ripples in the spectra whose period depend on the length of the cable toward the spectrum analyzer. Despite these limitations, this instrument was useful for allowing to compare the strong RFI content at several sites.
- Measurements were conducted for 10 minutes in each orientation. This allowed for the recording of ~ 75 traces per orientation, given the sweep speed of the spectrum analyzer. The exceptions to this are the measurements at site 6 (only 2 minutes of measurements in the NS orientation) and site 7 (only 1 trace in each orientation). These measurements were stopped early due to the risk of imminent rain and lightning.
- Just like for Instrument 1, the baseline of the measurements in the frequency domain was removed by subtracting a low-degree polynomial. Due to bad impedance match, sinusoidal residuals remain in the data, which are of order ± 0.5 dB.

The results of the measurements with Instrument 2 are presented in figure 31, as averages of all the available data in each orientation, where the amplitude corresponds to power relative to the baseline. Site 2 can be used as a reference when judging sites 3 through 7, since at site 2 we also have measurements with Instrument 1.

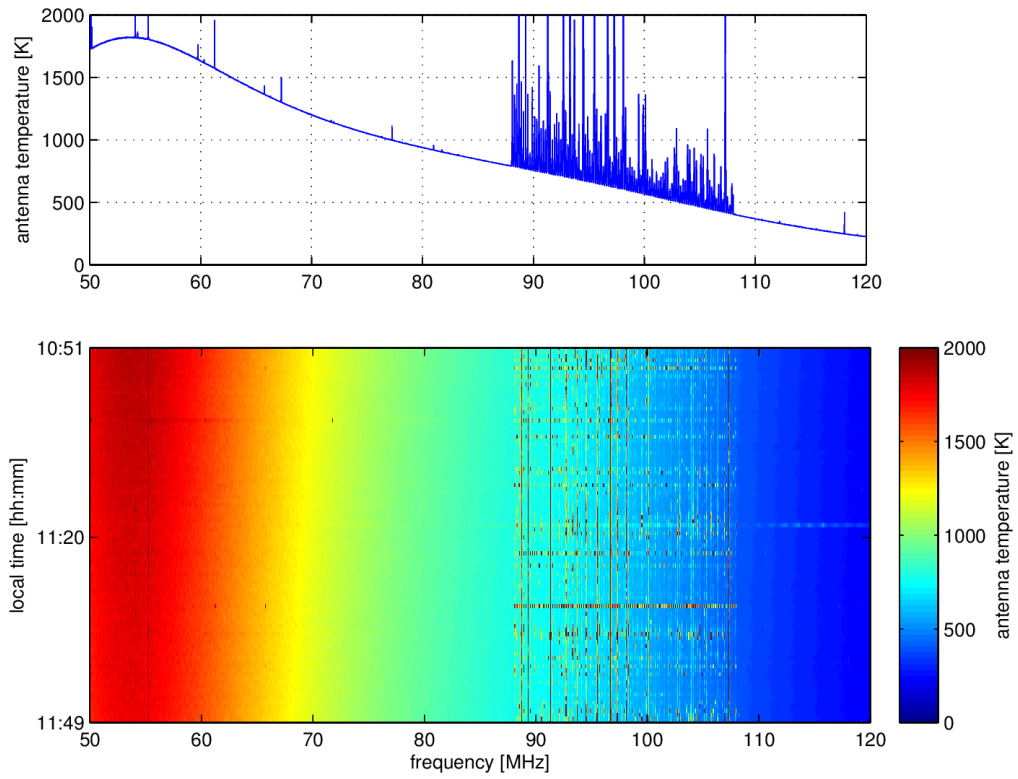


Figure 12: Site 1, low-band, NS orientation.

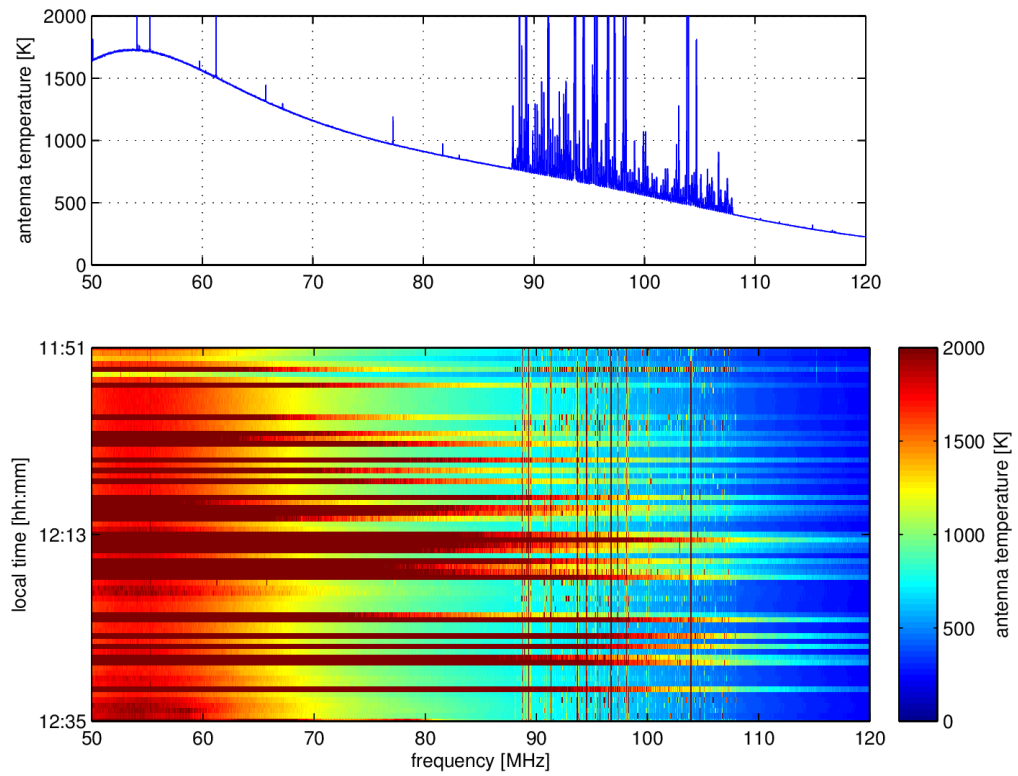


Figure 13: Site 1, low-band, EW orientation. The top panel shows the average after removing from the dataset the spectra affected by thunderstorms in the vicinity.

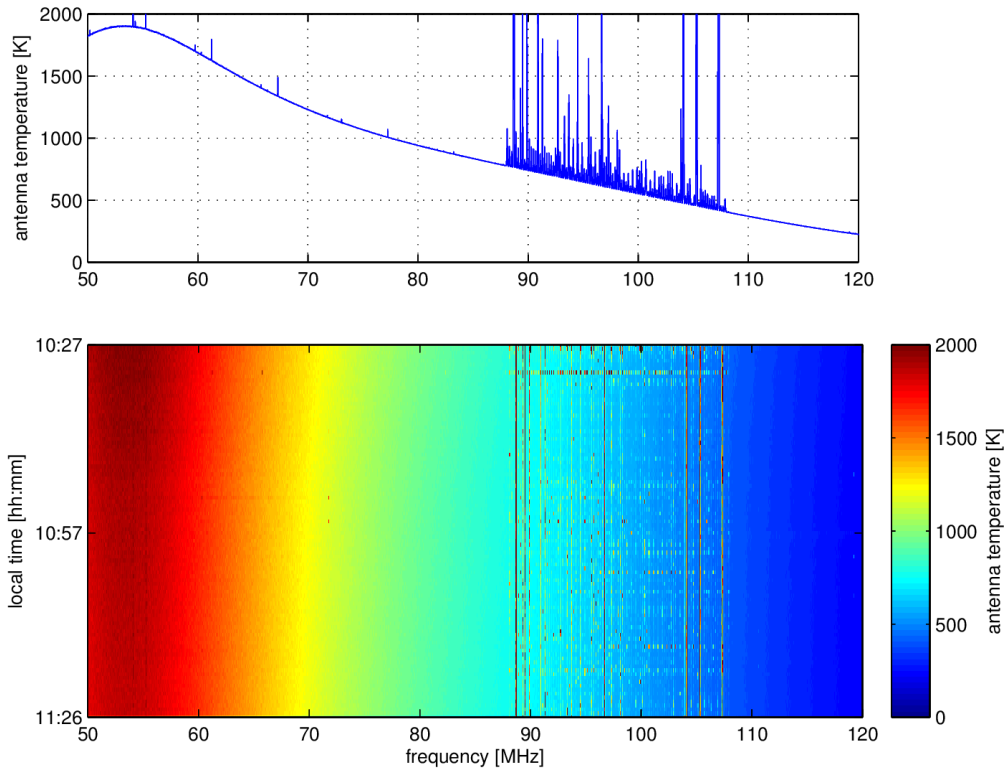


Figure 14: Site 2, low-band, NS orientation.

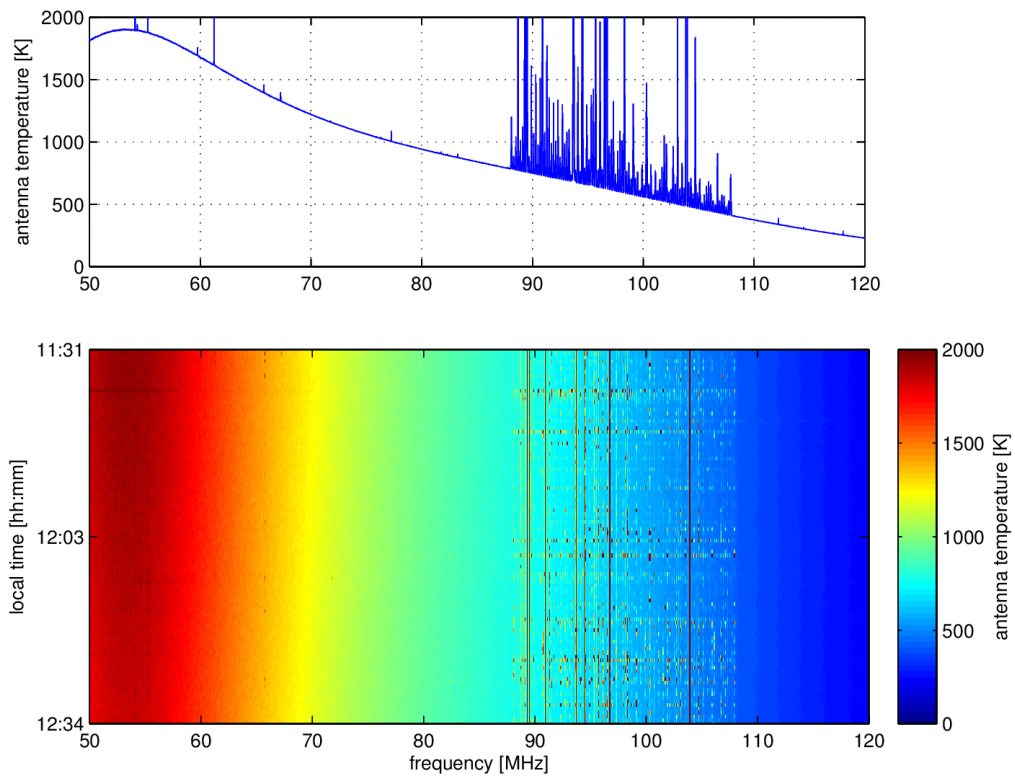


Figure 15: Site 2, low-band, EW orientation.

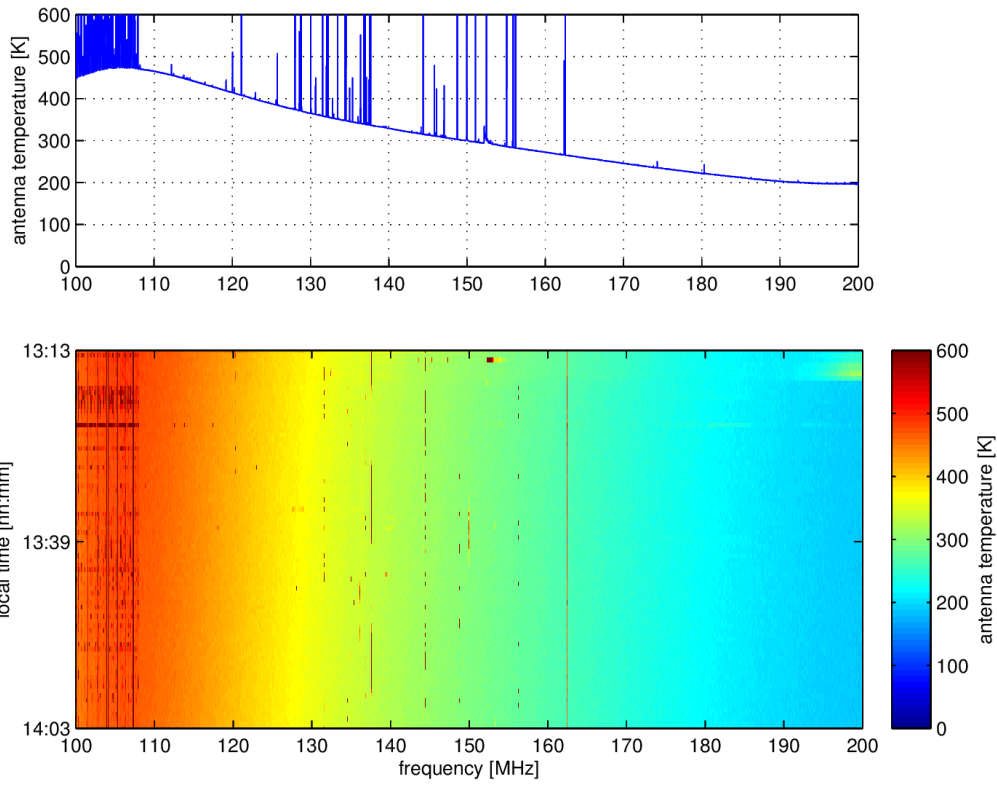


Figure 16: Site 2, high-band, NS orientation.

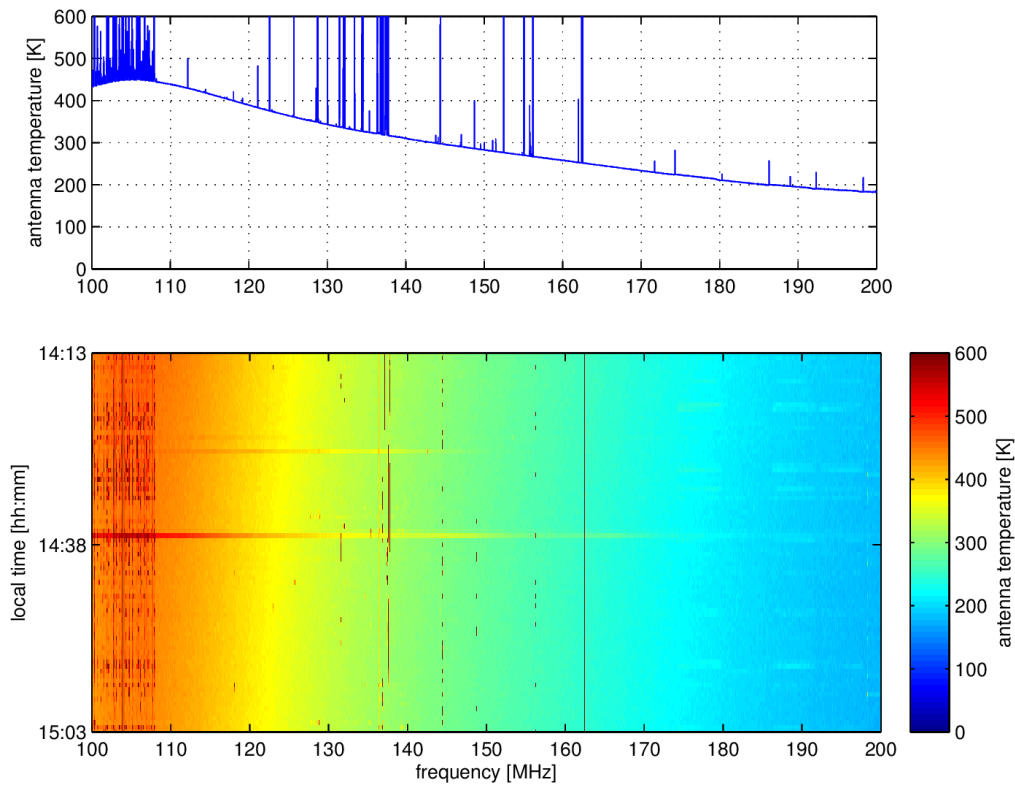


Figure 17: Site 2, high-band, EW orientation.

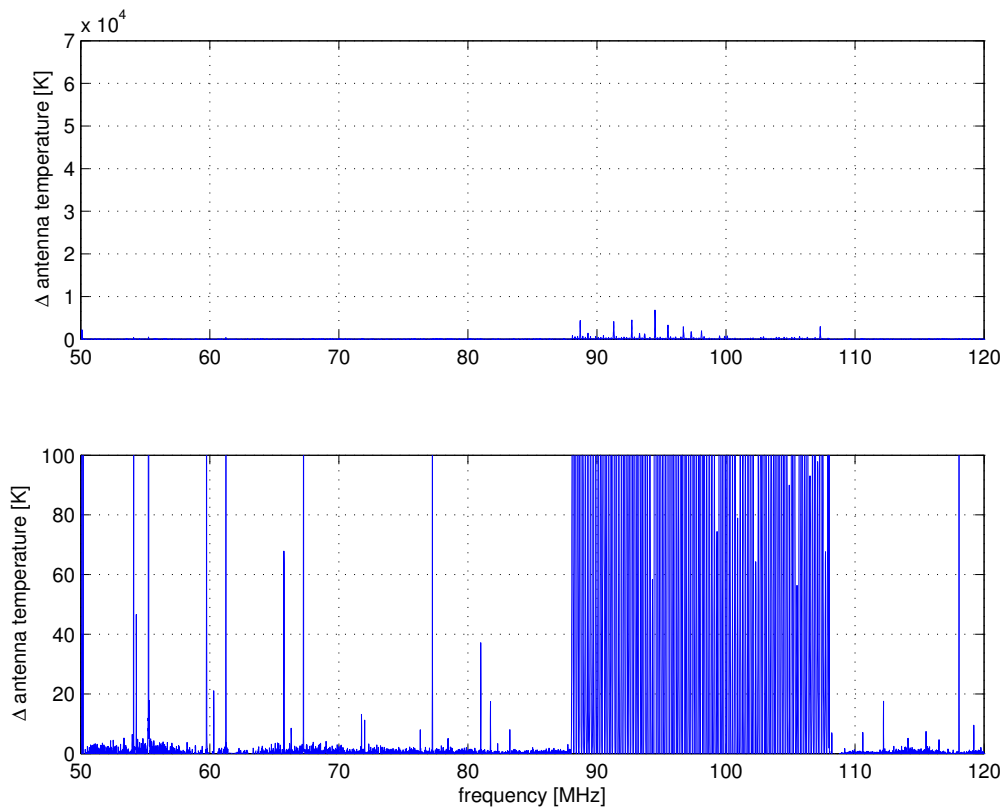


Figure 18: Site 1, low-band, NS orientation.

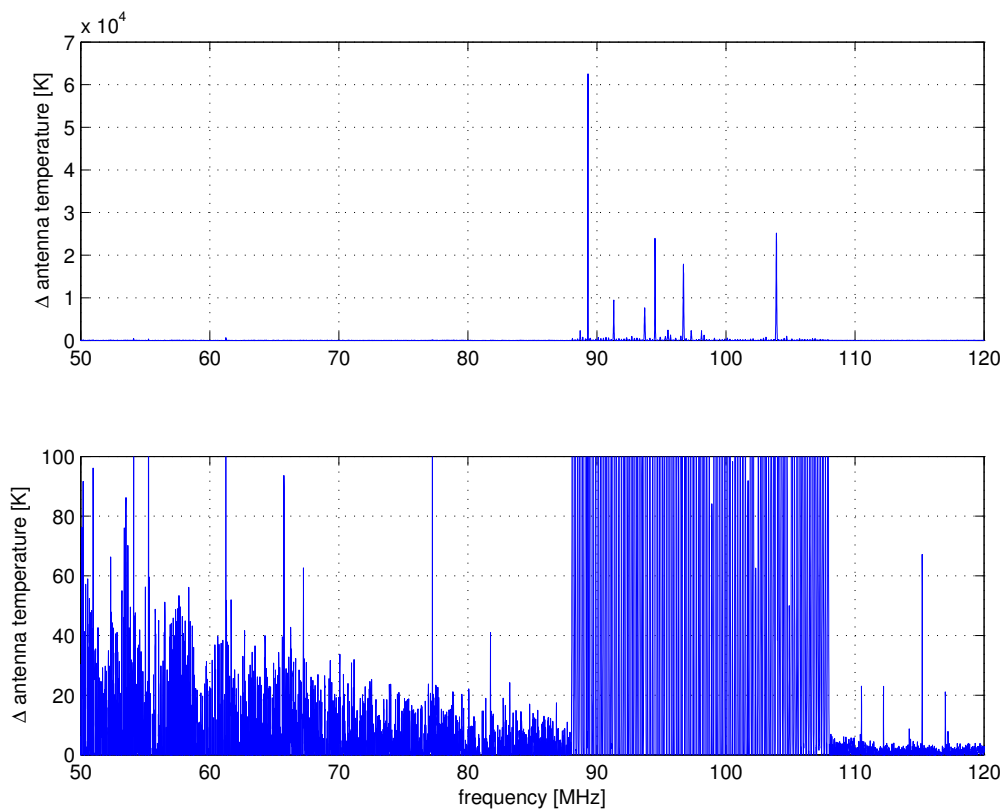


Figure 19: Site 1, low-band, EW orientation. This result is noisier due to the less amount of data available.

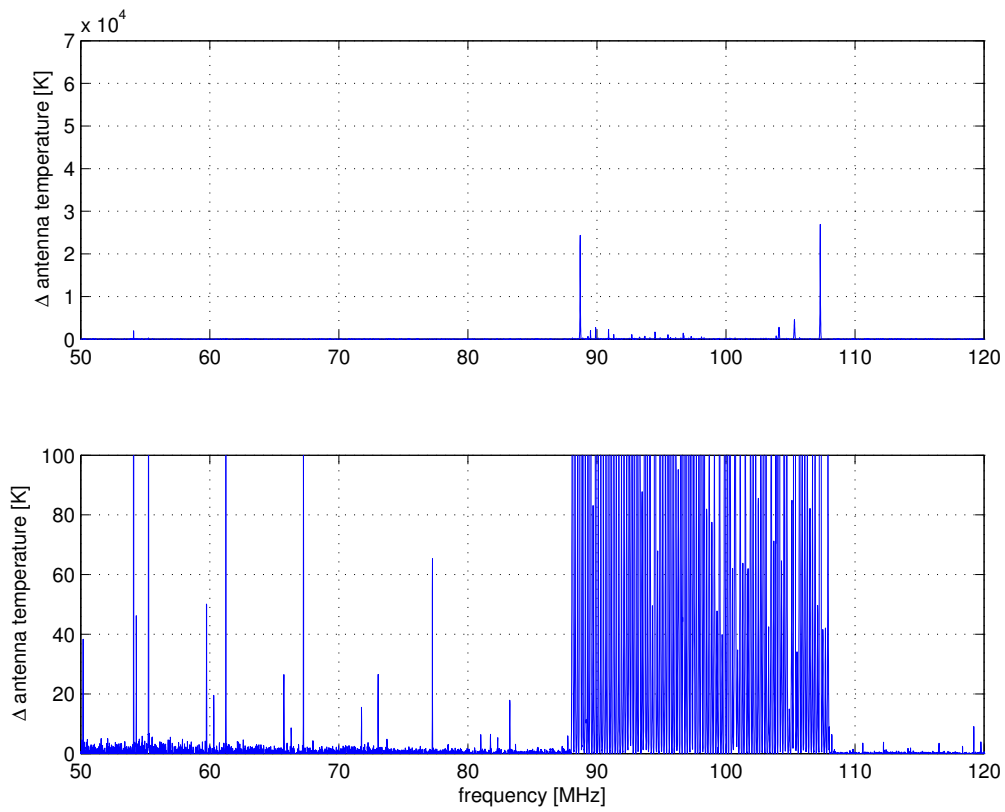


Figure 20: Site 2, low-band, NS orientation.

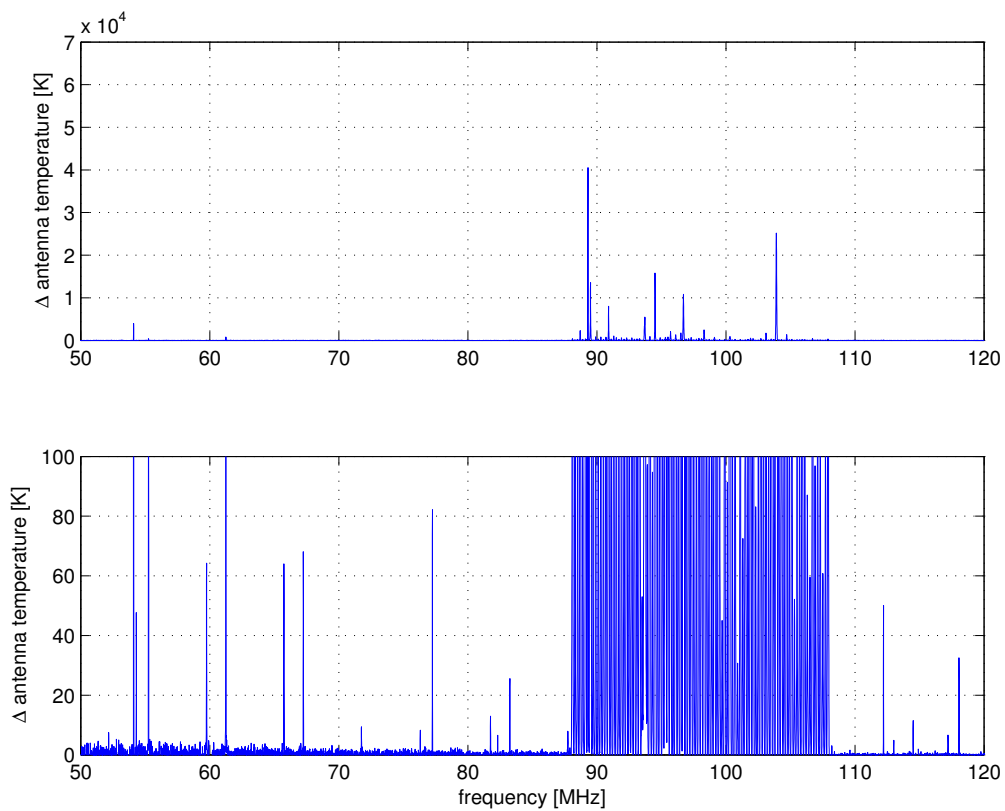


Figure 21: Site 2, low-band, EW orientation.

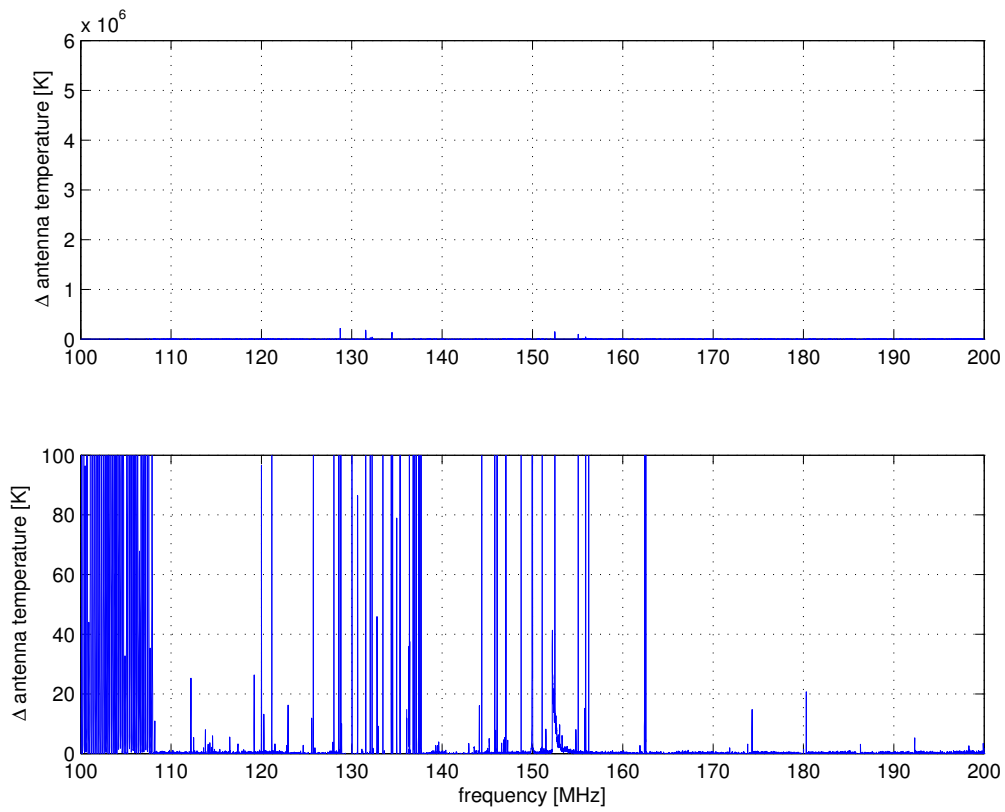


Figure 22: Site 2, high-band, NS orientation.

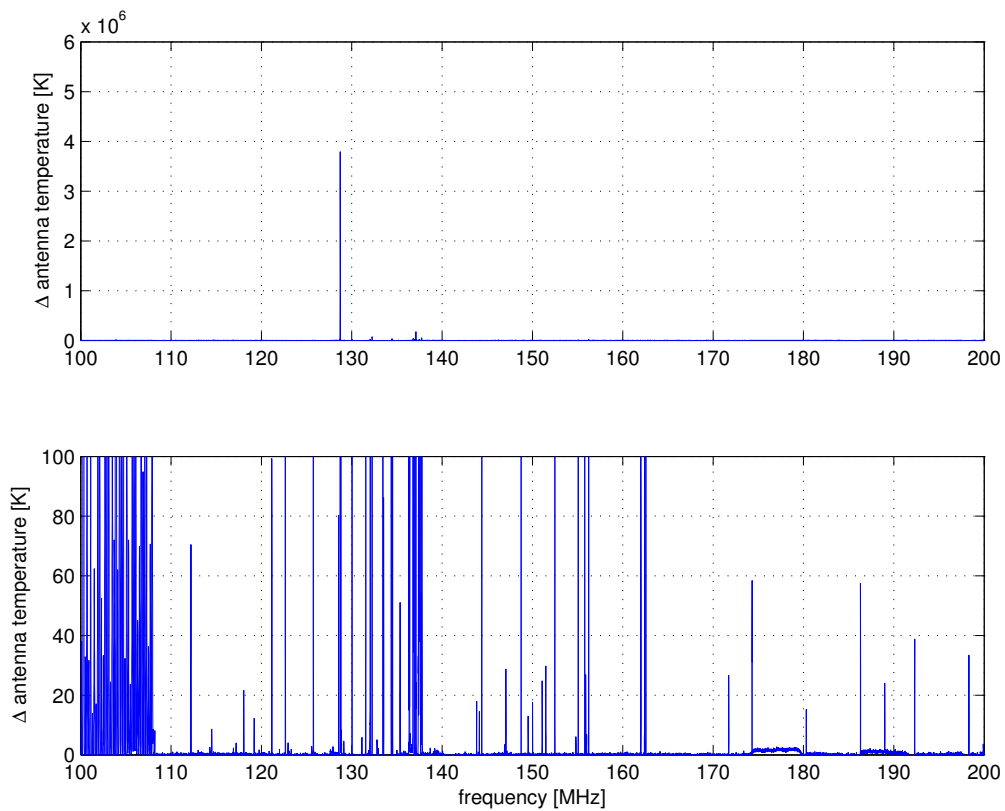


Figure 23: Site 2, high-band, EW orientation.

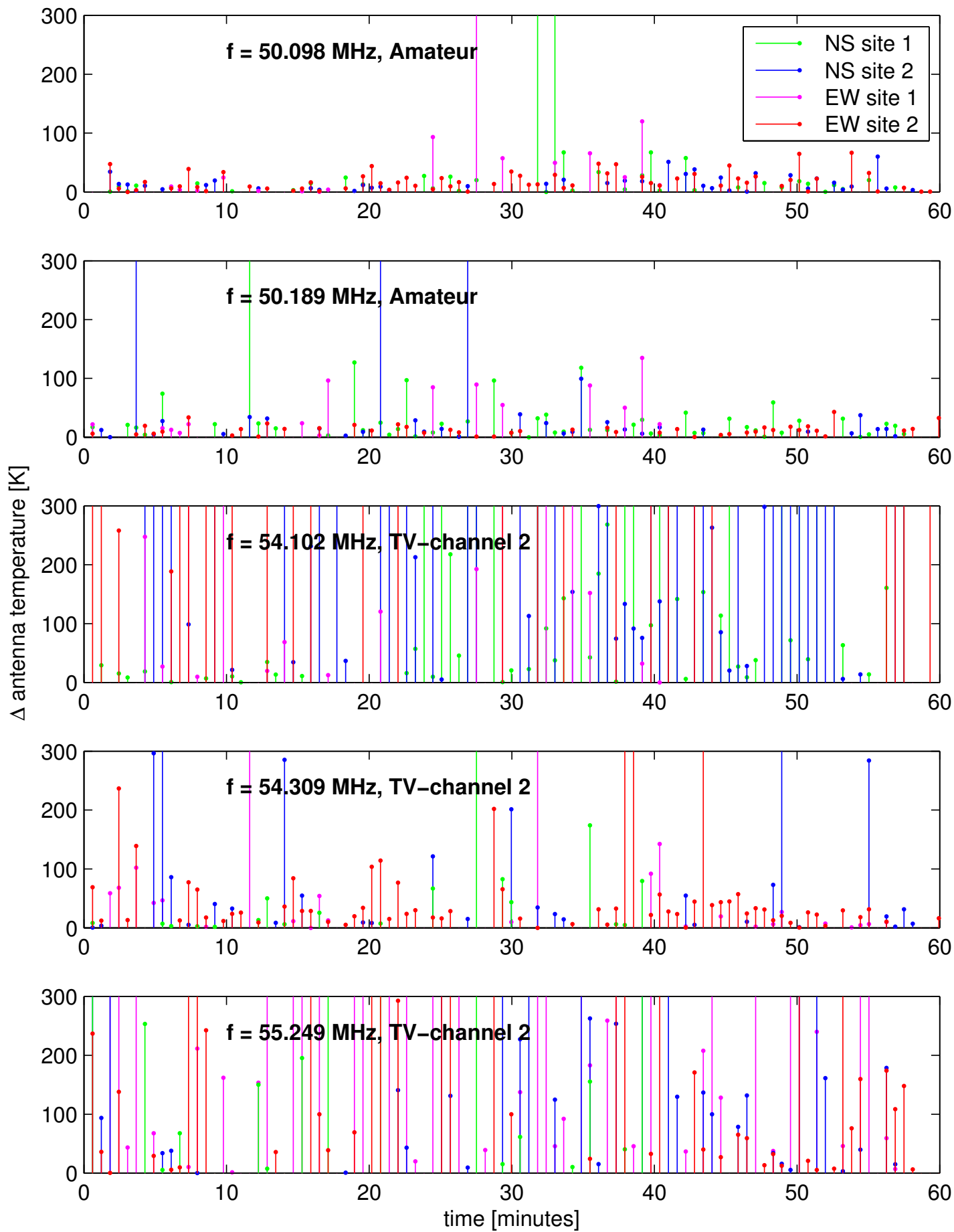


Figure 24: Timestreams of channels with RFI in the low-band (except region of FM radio).

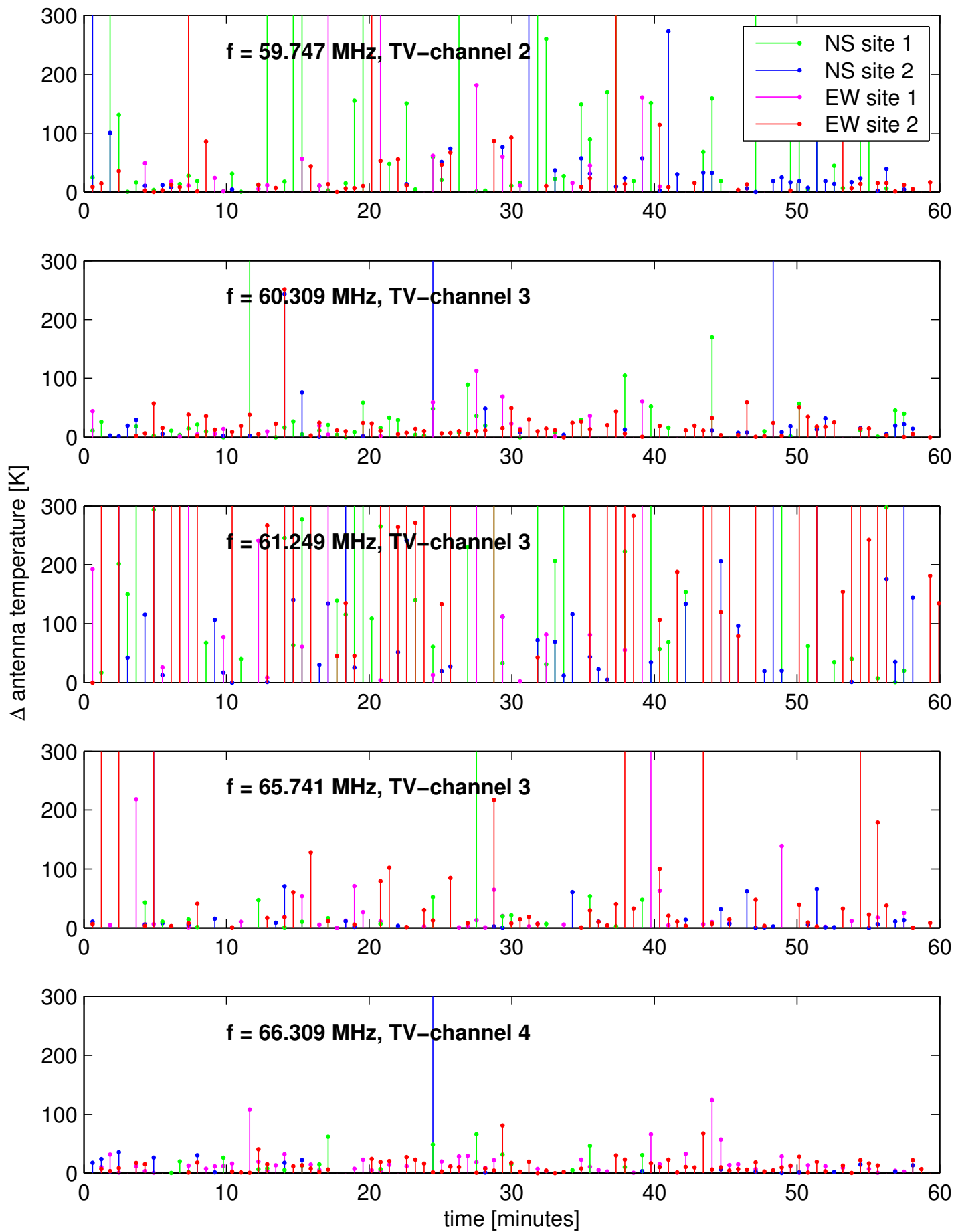


Figure 25: Timestreams of channels with RFI in the low-band (except region of FM radio).

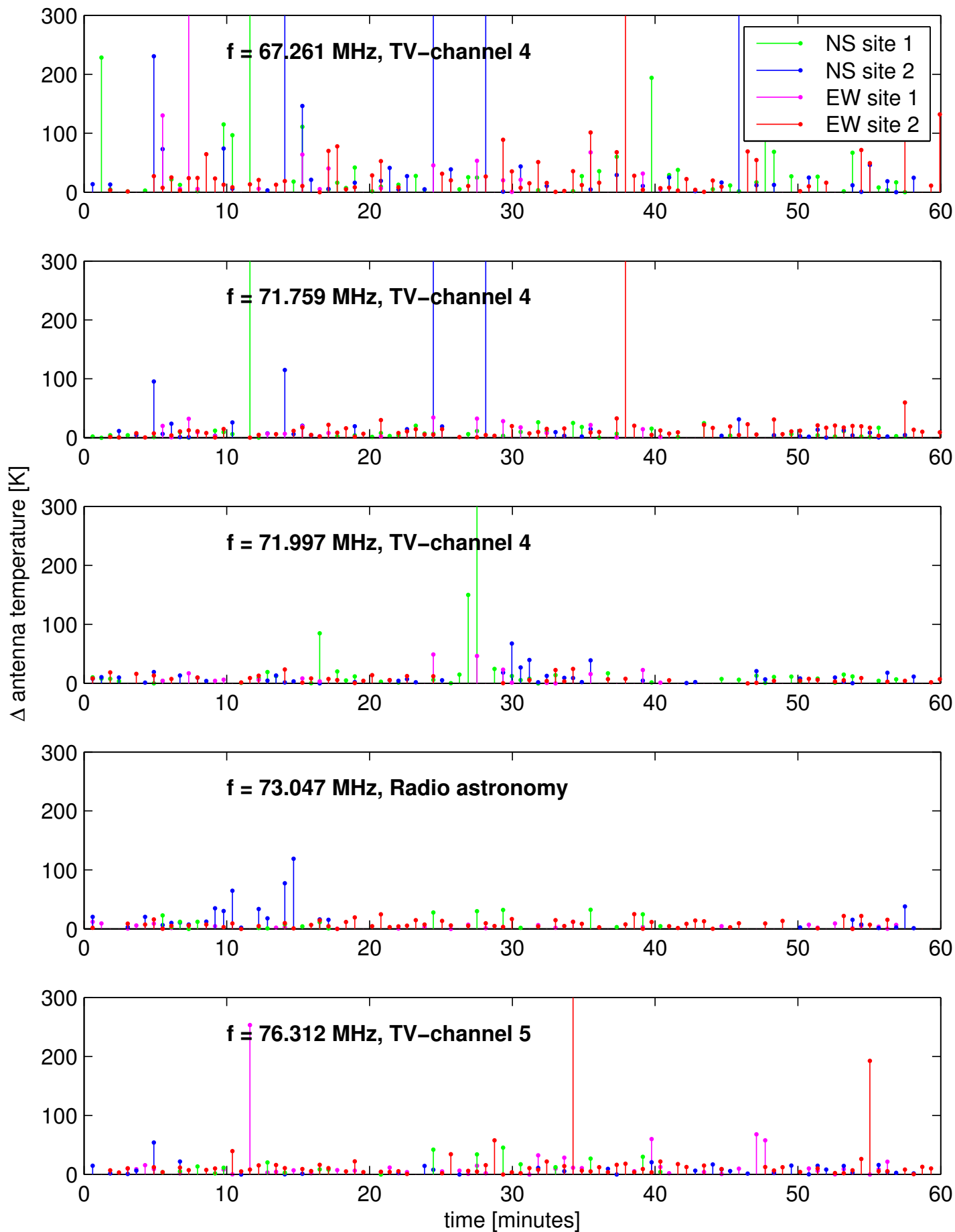


Figure 26: Timestreams of channels with RFI in the low-band (except region of FM radio).

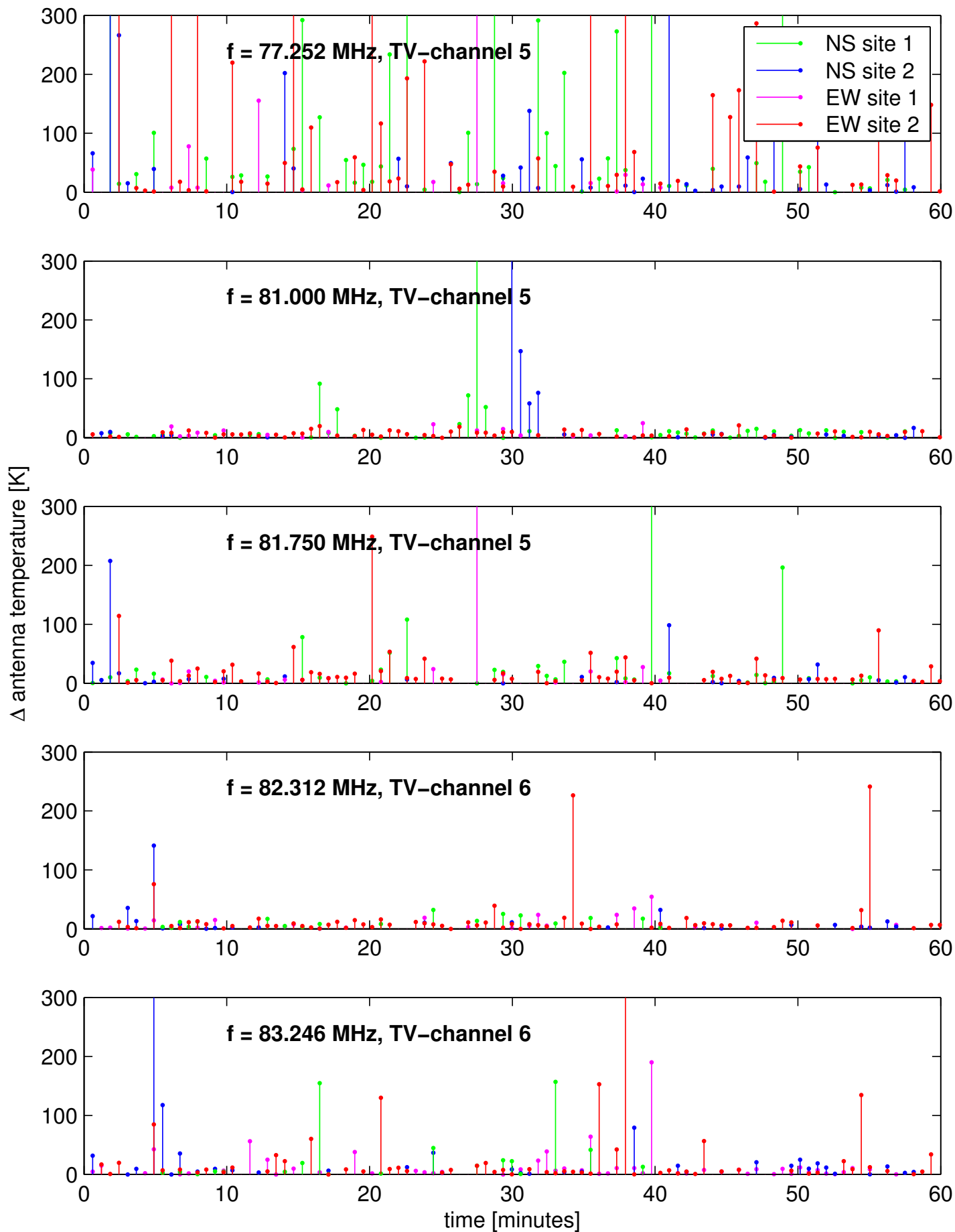


Figure 27: Timestreams of channels with RFI in the low-band (except region of FM radio).

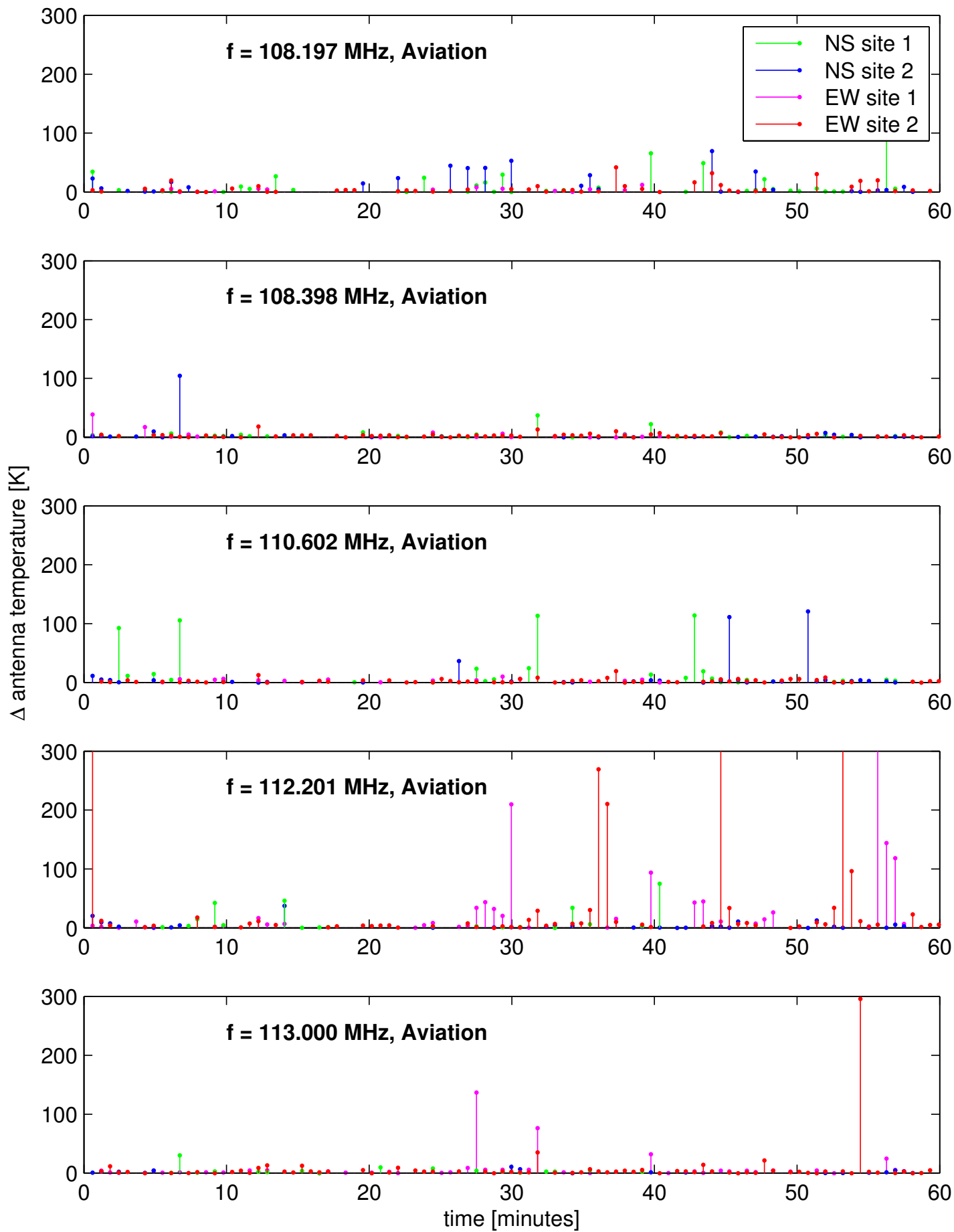


Figure 28: Timestreams of channels with RFI in the low-band (except region of FM radio).

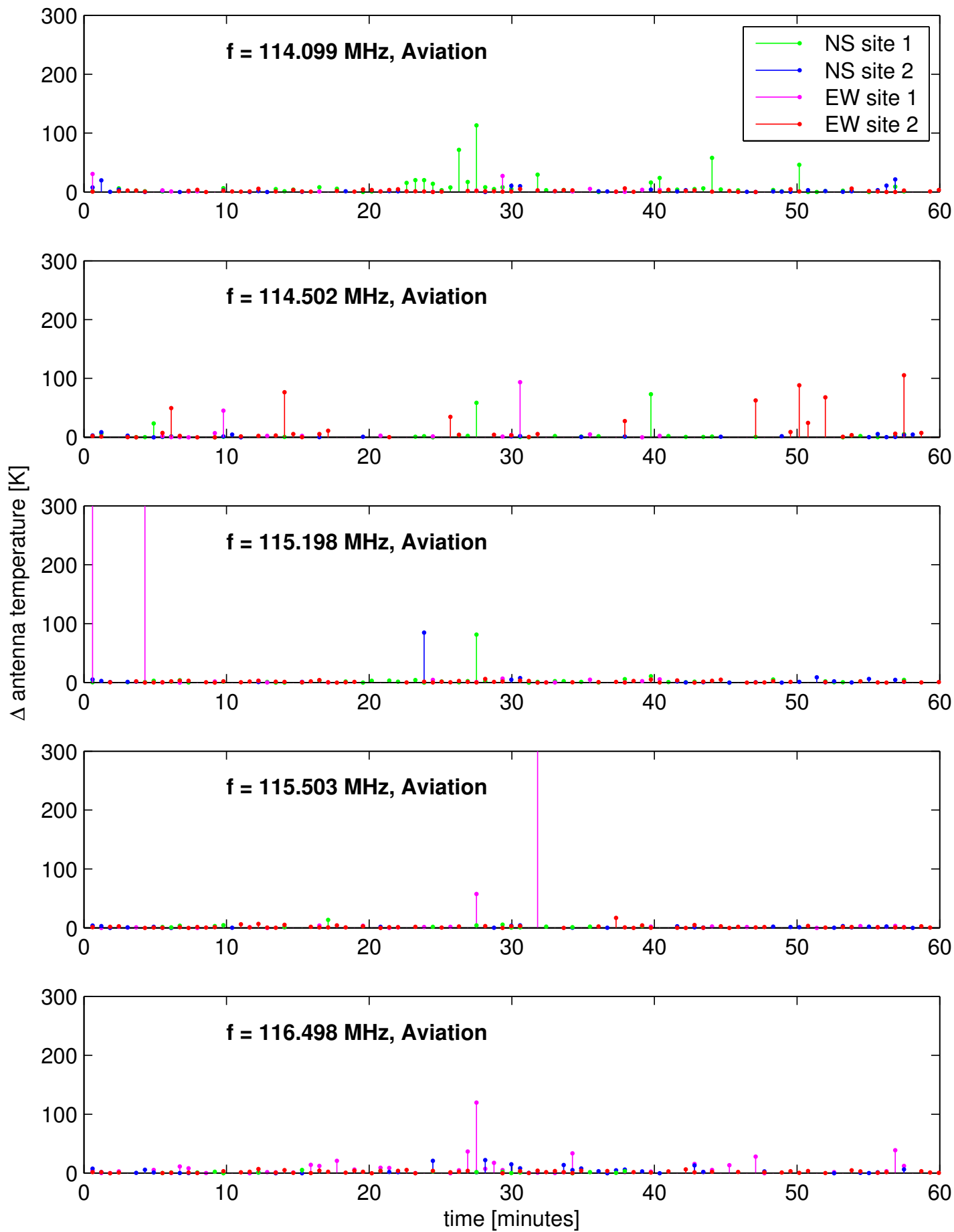


Figure 29: Timestreams of channels with RFI in the low-band (except region of FM radio).

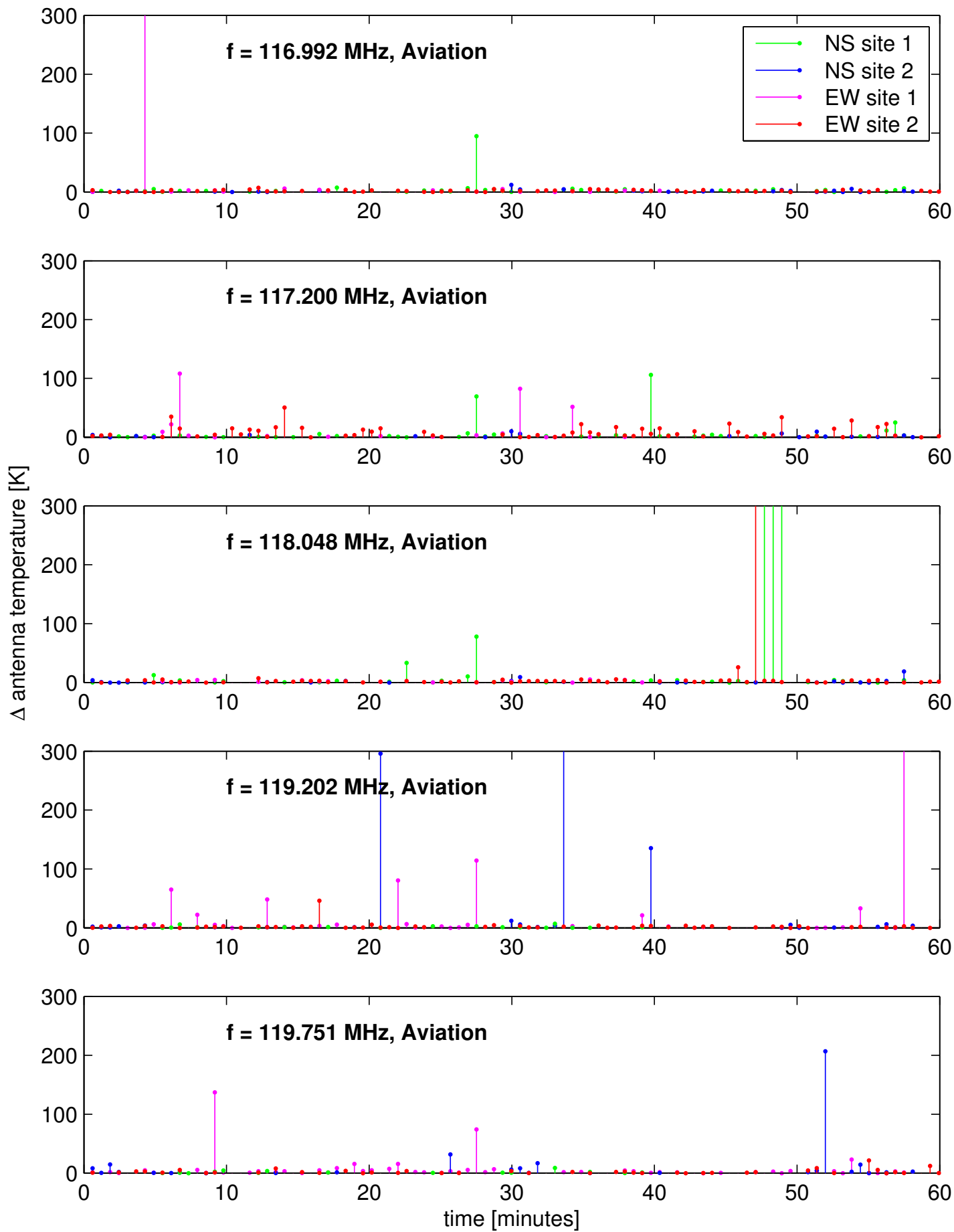


Figure 30: Timestreams of channels with RFI in the low-band (except region of FM radio).

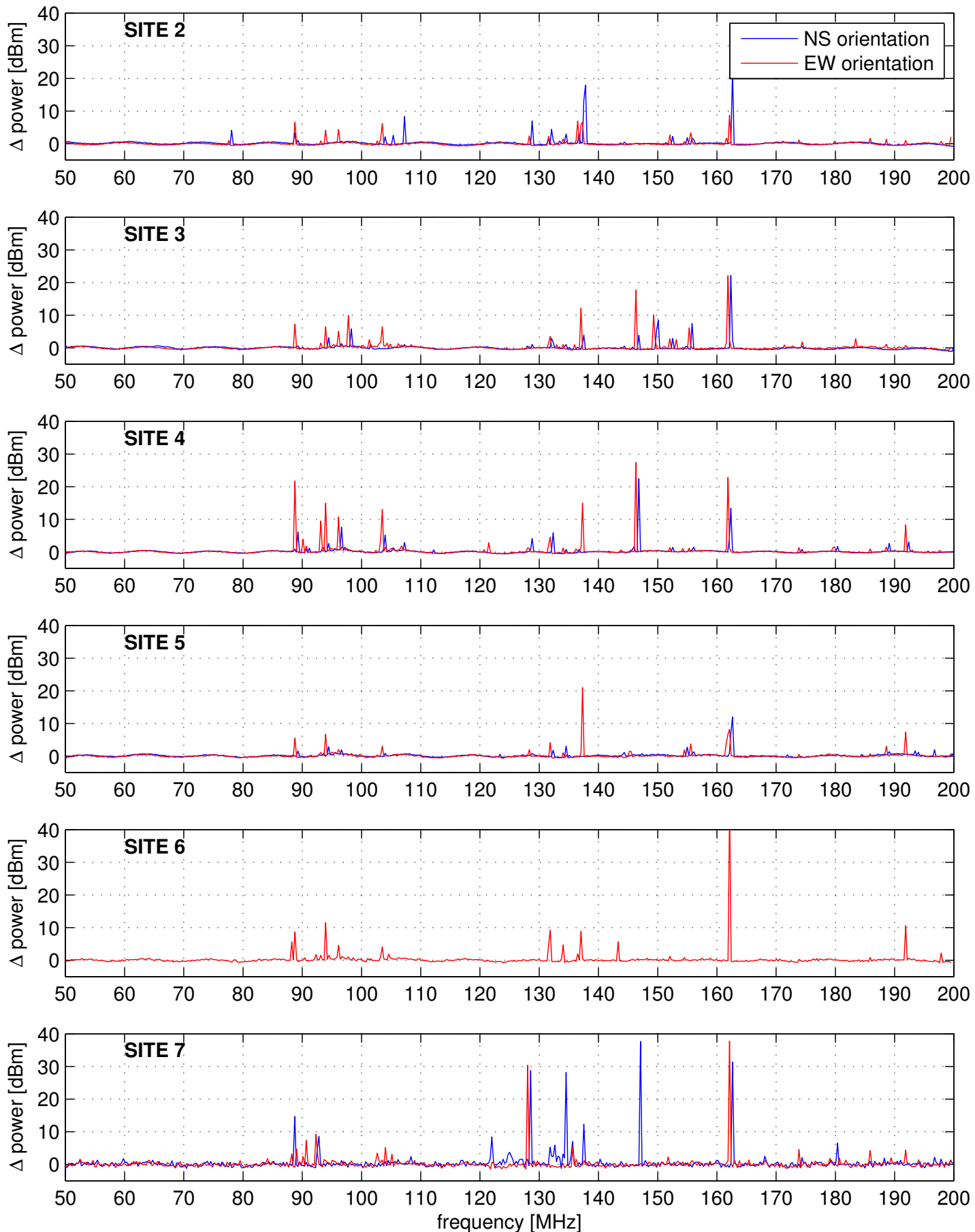


Figure 31: Summary of measurements with Instrument 2, after removing the baselines. Most of them represent 10-minute averages, except sites 6 and 7 for which there are less data available. The EW traces have been shifted 0.5 MHz to the left for better comparison with the NS cases.

3 Conclusions

- In the high-band, Instrument 1 picks up strong but intermittent aeronautical communications (below 137 MHz) and miscellaneous communications (above 138 MHz). In addition, the signature of digital TV channels 7 through 11, including their ATSC pilots, is clearly identifiable above 174 MHz in the EW orientation.
- In the low-band, the only significant contributors to RFI other than FM radio are signals corresponding to channels 2 through 5 (ATSC pilots or analog transmissions), although the wideband signatures of digital channels cannot be distinguished using the data gathered. Other transmissions below FM radio are intermittent and weaker in comparison.
- When comparing site 5 with site 2 using data taken with Instrument 2 it can be argued that site 5 is potentially better in the low-band. This site is off highway 278, in an area with a local dip in the terrain. The exact spot corresponds to the entrance to a private property with houses visible in the distance. Unfortunately we could not do measurements here with Instrument 1.

A Appendix: RFI Characterization at Deep Springs/OVRO

As a reference, this appendix includes results of the RFI characterization conducted at Deep Springs/OVRO by Gregg Hallinan.

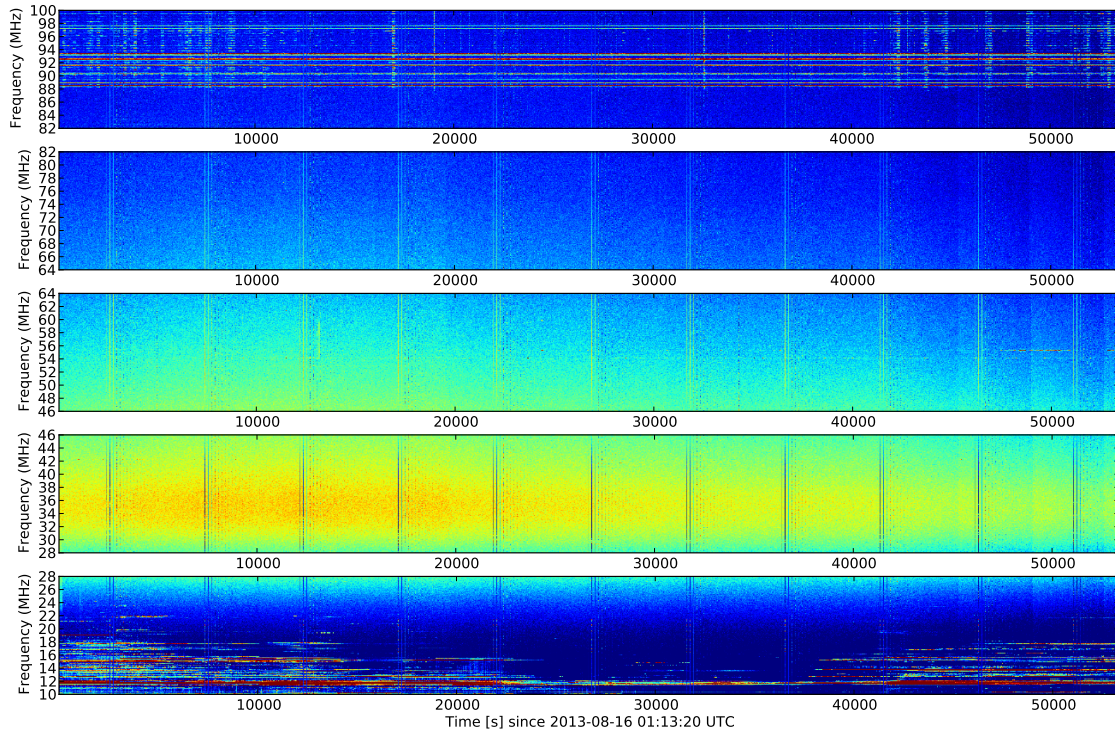


Figure 32: Deep Springs.

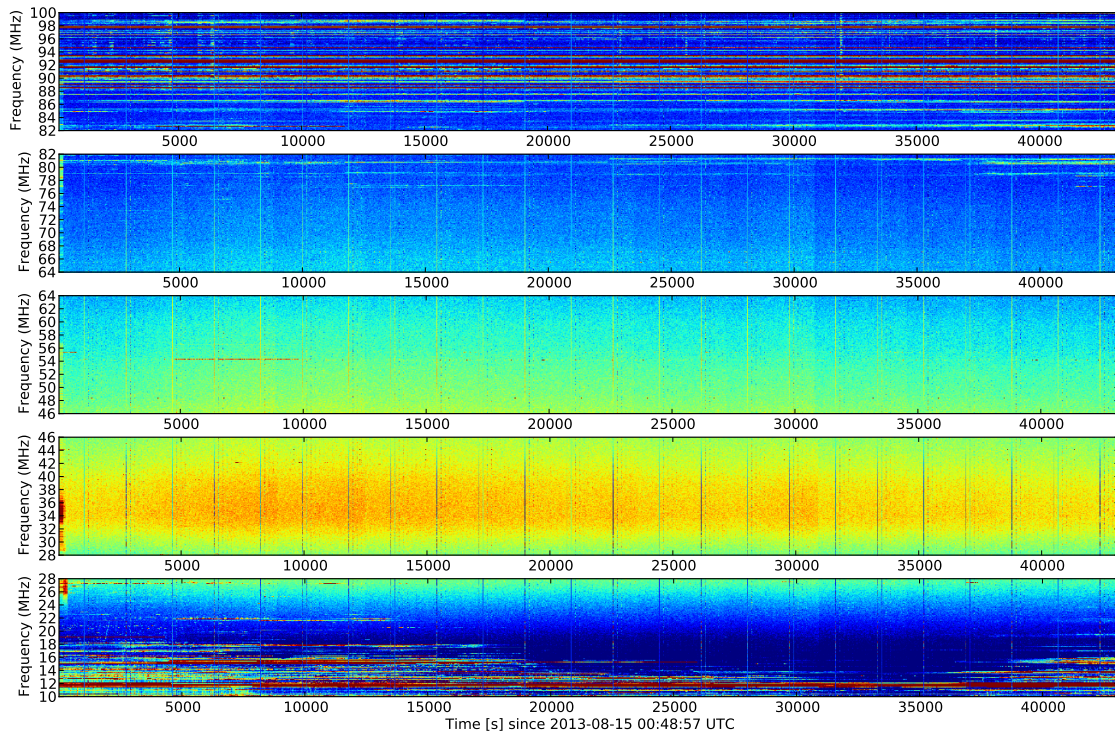


Figure 33: OVRO.

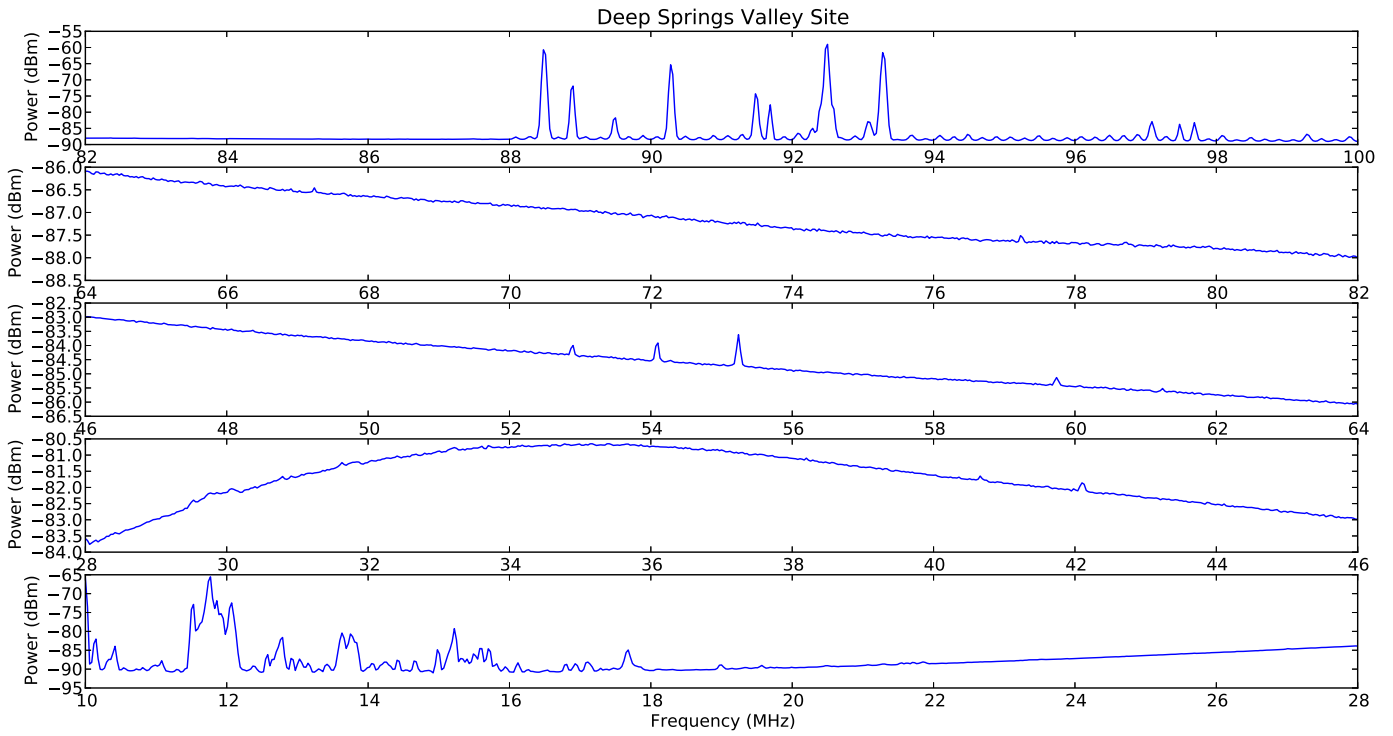


Figure 34: Average Deep Springs.

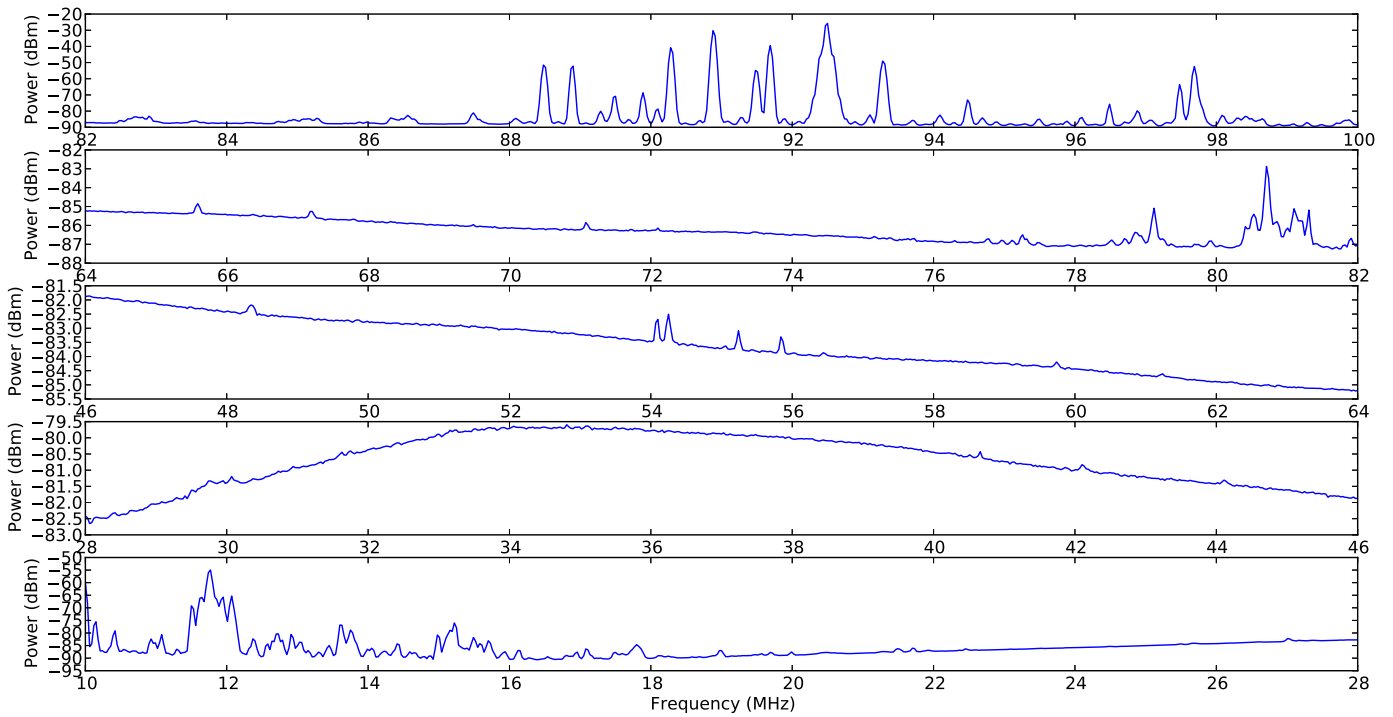


Figure 35: Average OVRO.