Galactic Background Radiation Data Smoothing

Observations from the Radio JOVE Installation at HAARP ~ Gakona, Alaska

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1. Introduction

This article discusses an effort to reduce the effects of periodic radio frequency interference (RFI) on the plots of galactic background radiation at 20.1 MHz received by the Radio JOVE receiver and dual dipole antenna installation at the ***High Frequency Active Auroral Research Program*** (HAARP) facility. The installation is briefly described in {Reeve19}.

Radio-SkyPipe II software is used to record and plot the receiver output after it has been digitized. The plot's baseline represents the background radiation. However, RFI produced by the nearby DigiSonde transmitter corrupts the baseline so data smoothing is used to reduce its effects. The galactic background radiation is produced by near light speed cosmic ray electrons in the Milky Way galaxy spiraling around inter-stellar magnetic field lines. The changing direction of the electron velocity vector means the electrons are constantly accelerating, which causes them to emit electromagnetic radiation (figure 1).

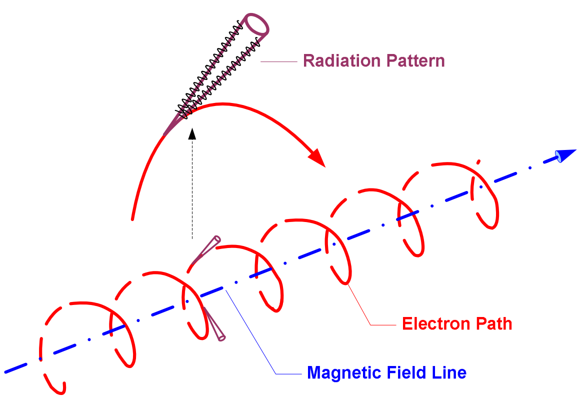

Figure 2 ~ The galactic background radiation is *synchrotron* radiation produced as very high-speed electrons spiral around inter-stellar magnetic field lines. The radiation from a single electron is continuously emitted in a narrow beam that produces a train of very narrow pulses toward the observer. The observer detects a frequency continuum because of the enormous number of pulse sources and variations in electron speeds and magnetic field strengths. The gyration radii are on the order of hundreds of millions of kilometers and the orbital frequency is on the order of a cycle per hour.

From the perspective of a receiver and antenna on Earth, the observed background radiation is strongest when the center of the Milky Way galaxy falls within the antenna's beam. For a fixed broad-beam antenna, such as the dual dipole, a plot of the received radiation has a broad peak and varies over a 24 h period as the Milky Way drifts in and out of the beam. The peak occurs about 4 min earlier each day due to the difference between solar and sidereal time.

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2. DigiSonde RFI

The DigiSonde at HAARP is a digital ionosonde used to measure the electron density as a function of height in the ionosphere above the facility. The DigiSonde transmitter antenna is only 600 m from the Radio JOVE antenna and produces strong pulses as its frequency sweeps through the receiver passband. These pulses occur at approximately 4 min 30 s and 7 min 30 s intervals (figure 1). The transmitter operates 24 h d^{-1}. A plot of the data for any 24 h period shows a solid mass of pulses and somewhat ragged noise floor or baseline (figure 2).

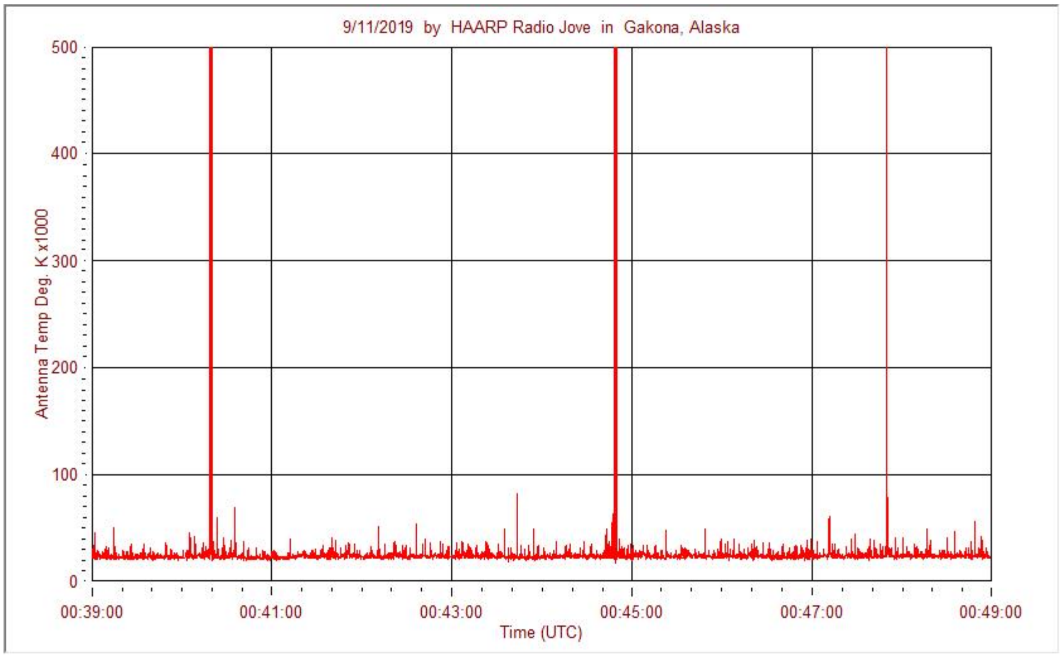
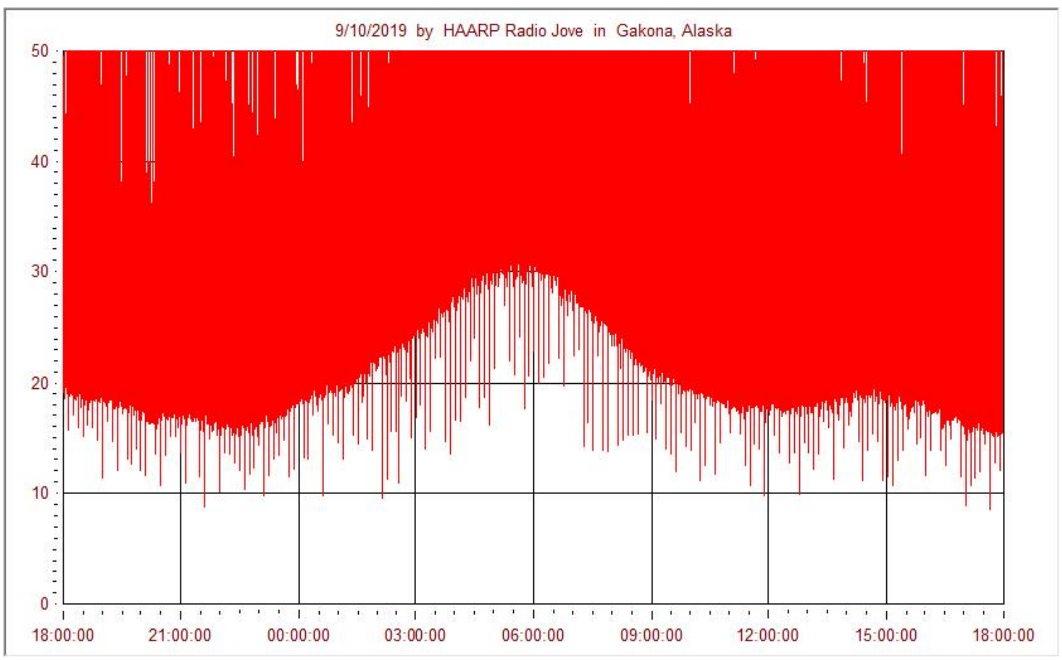


Figure 1 ~ 10 min plot of Radio-SkyPipe data from 11 September 2019 as received by the Radio JOVE receiver and dual dipole antenna at HAARP. Three strong pulses are visible in the plot at 0040:20, 0044:50 and 0047:50. This pattern repeats 24 h d^{-1}. The noise baseline represents the galactic background radiation at 20.1 MHz.



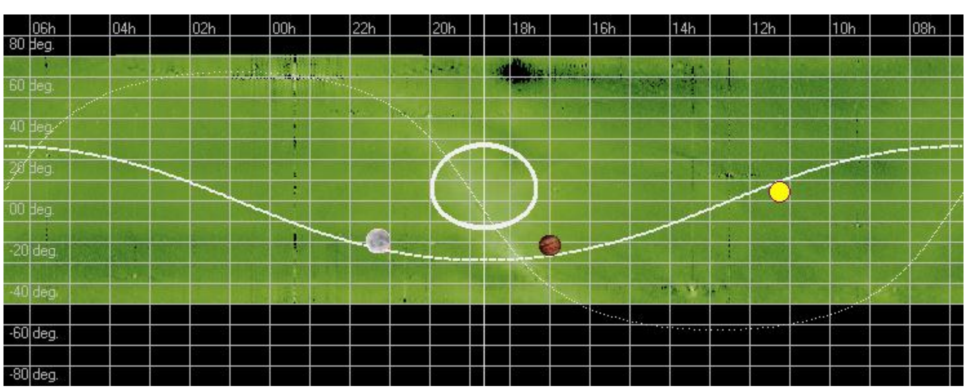


Figure 2 ~
<u>Upper</u>: Unsmoothed 24 h plot of raw Radio-SkyPipe data from 1800 on 10 September to 1800 on 11 September 2019. The data from the two days were combined using the *Stack Charts* function. The DigiSonde pulses over a 24 h period are compressed and appear as a solid mass, and the noise floor is ragged. The broad peak of the radio background occurs at approximately 0530 UTC on 11 September.

<u>Lower</u>: RadioEyes II plot for HAARP coordinates showing idealized antenna pattern superposed on the 35 MHz radio background. The central meridian is set to 0600 corresponding to the time scale above.

3. Data Smoothing

The DigiSonde interference is unavoidable, so the problem is how to handle it. Four data post-processing methods come to mind that *might* work to reduce the interfering effects on a 24 h plot:

1. Remove the pulses by periodically nulling the data and replacing the nulled datapoints with an average value. This method assumes the removal algorithm and pulses are or can be made synchronous;
2. Remove the pulses from the data by a simple amplitude threshold detection scheme that nulls the data exceeding a preset threshold and replaces it with an average value;
3. Reduce the effects of the pulses by *mean* smoothing. Mean smoothing involves selecting a moving range of datapoints and finding and plotting the average value in each range. This method tends to raise the baseline because interference pulses are included in the average;
4. Reduce the effects of the pulses by *median* smoothing. Median smoothing involves selecting a moving group of datapoints and finding the median value in each group. The advantage of this method over mean smoothing is that it may do a better job of preserving the background level because the pulses are included in the averages only occasionally.

I chose to investigate method 3 because it is available in the *Smooth by Averaging* function under the *Tools* menu in Radio-SkyPipe II. Method 4, median smoothing, could be implemented by the *Apply Equations to Data Points* function under the *Tools* menu as described in {Typinski}. However, I found that using a 5-sample window (or bin), median smoothing had no *visible* effect. I did not try other window sizes, but I suspect that median smoothing is not suitable for reducing the type of high-amplitude periodic interference produced by the DigiSonde. Methods 1 and 2 require custom software applications compatible with the Rado-SkyPipe II data. I choses to not pursue their development and they are not discussed further.

In the HAARP installation, Radio-SkyPipe is setup to sample the soundcard at 100 ms intervals, producing 36 000 datapoints in each hour and 864 000 datapoints in each day. Any 1 h period contains approximately 16 interfering pulses. While the number of pulses compared to the total datapoints is small, the pulse amplitudes are orders of magnitude higher than the *natural* datapoints and, therefore, have a disproportionate effect on the average.

The built-in *Smooth by Average* function is a form of lowpass filter that provides a sliding or forward average based on the selected averaging window (bin) size. For example, an averaging bin size of 50 takes the average of 50 datapoints starting at datapoint 1 and plots it. Another 50 datapoints starting at datapoint 2 are then selected, averaged and plotted, and so on. In this way, the averages overlap and move forward with each operation. Six averaging levels, or bin sizes, were tried – 10, 50, 100, 500, 1000 and 5000 (figure 3).

For comparison, I also produced plots with *successive* Smooth by Averaging in which the process has a bin size of 10. The first set of smoothed data is preserved and used in the next smoothing level. Thus, the second Smooth by Averaging operates on the first processed dataset, again with a bin size of 10. It is indicated as 10x10 (figure 4). The dataset is again preserved and then further smoothed. This sequence was repeated for smoothing levels of 10, 10x10, 10x10x10 and 10x10x10x10. As a final comparison I repeated the successive smoothing with a bin size of 50, producing plots for 50, 50x50, 50x50x50 and 50x50x50x50 (figure 5).

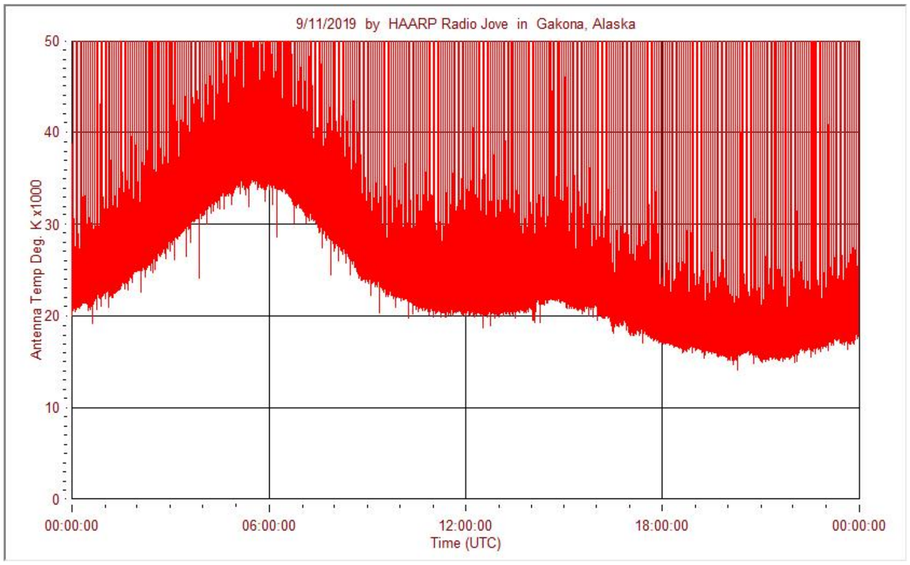


Figure 3.a ~ Averaging bin size = 10. The baseline is less noisy and the pulse amplitudes are reduced compared to figure 2.

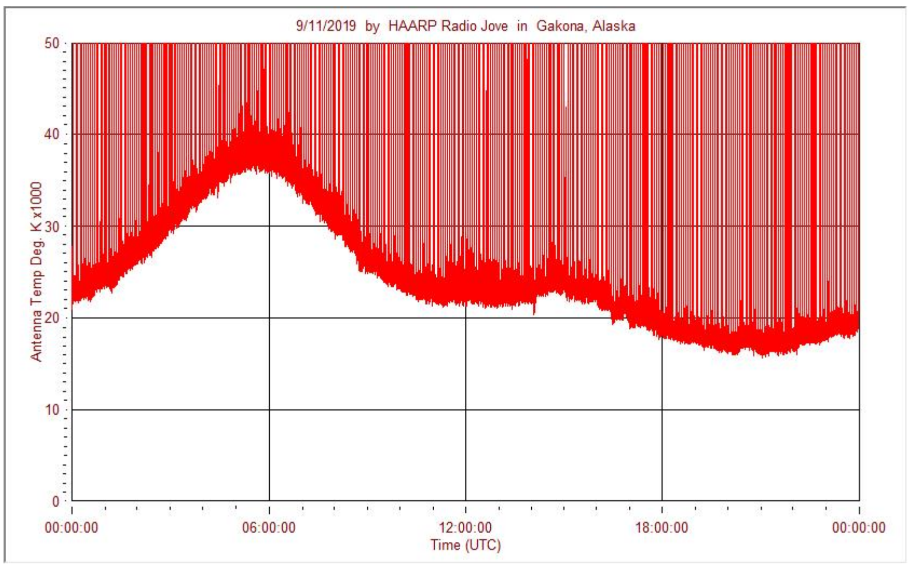


Figure 3.b ~ Averaging bin size = 50. Note the baseline rise of about 1000 K compared to previous figure.

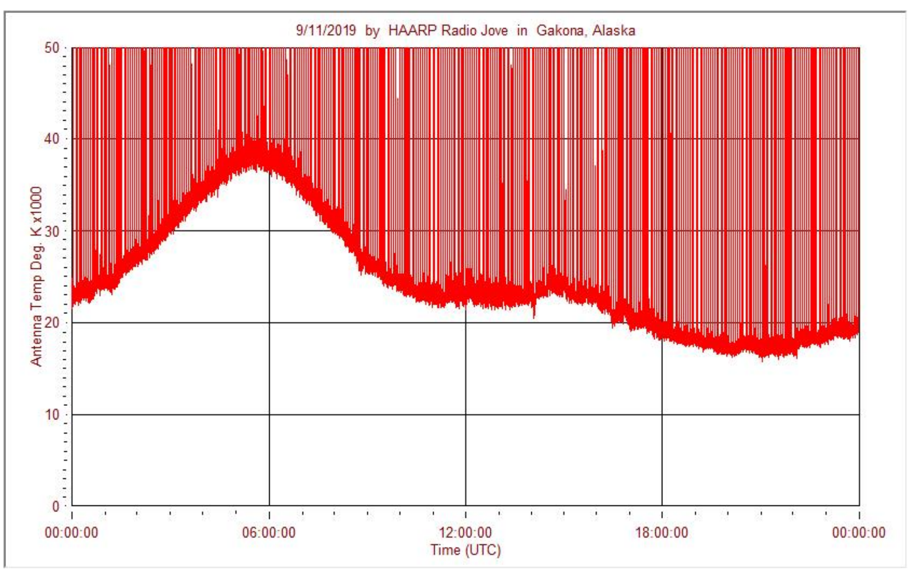


Figure 3.c ~ Averaging bin size = 100. Note the additional baseline rise compared to previous figure.

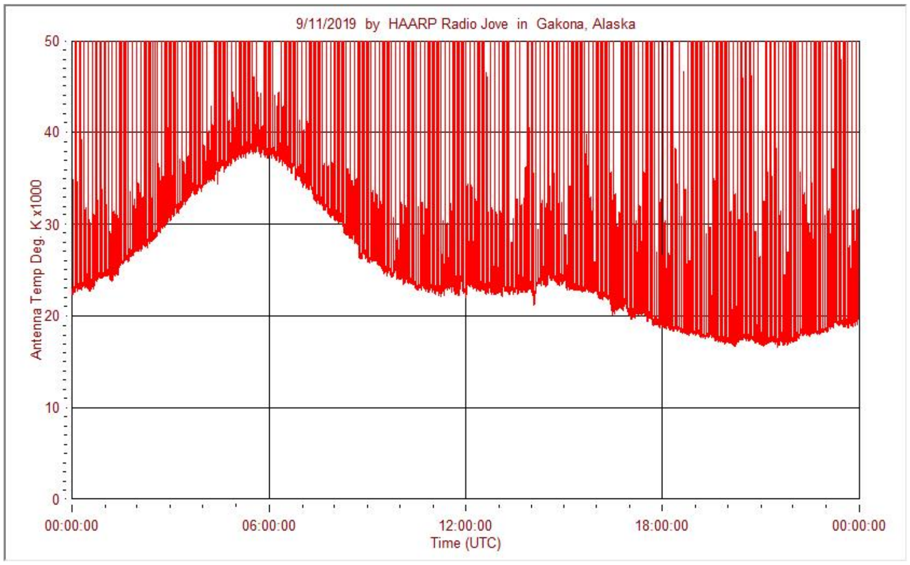


Figure 3.d ~ Averaging bin size = 500. Note the baseline continues to rise.

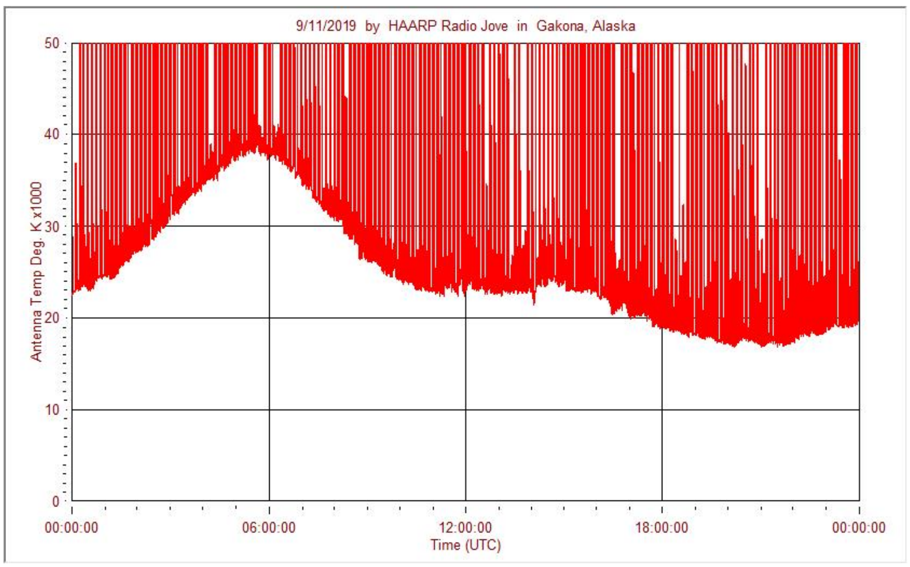


Figure 3.e ~ Averaging bin size = 1000. Compared to figure 2, the baseline amplitude has increased about 2000 K.

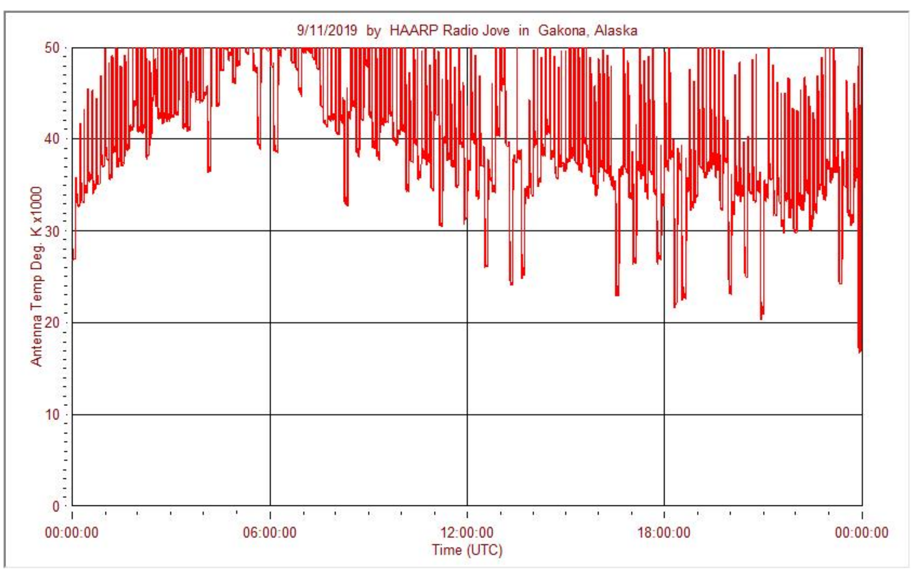


Figure 3.g ~ Averaging bin size = 5000. Note the heavy distortion.

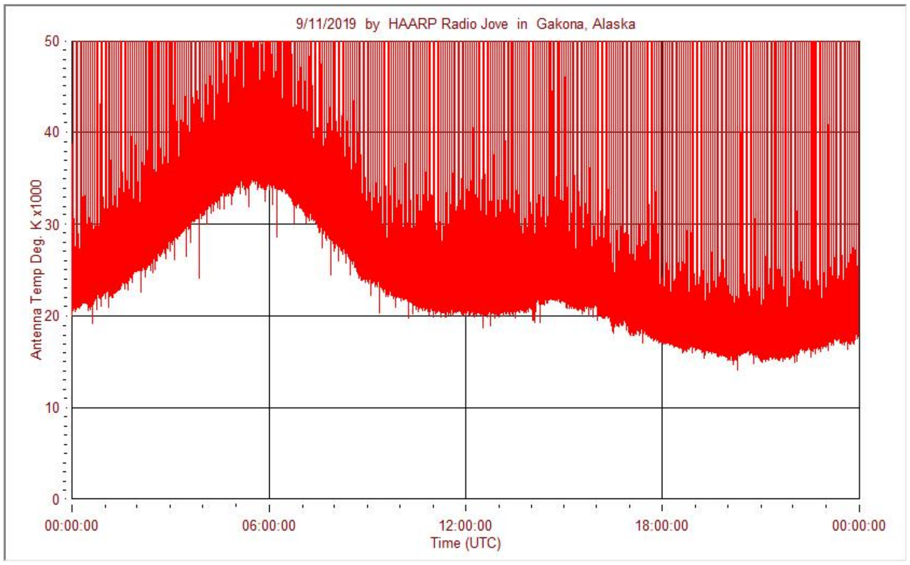


Figure 4.a ~ Averaging bin size = 10. The results are identical to figure 3.a.

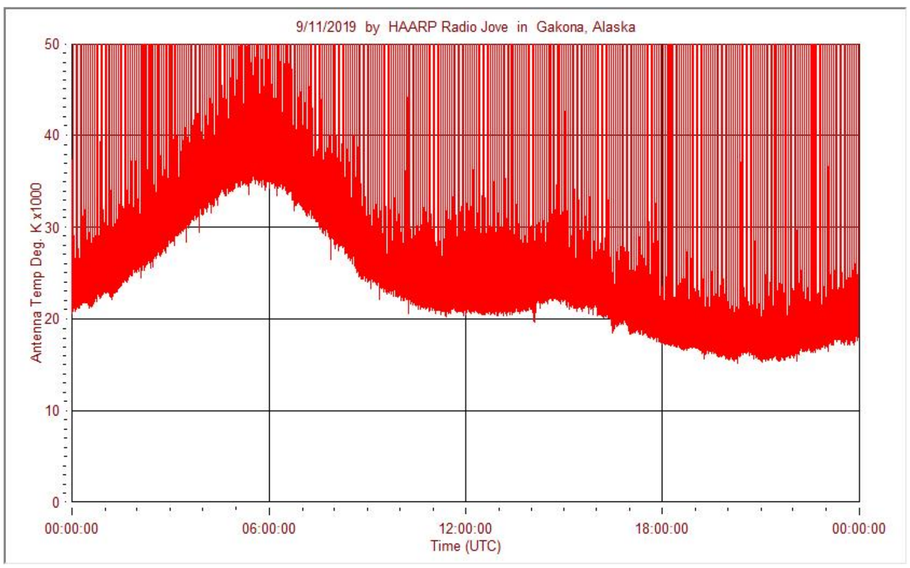


Figure 4.b ~ Averaging bin size = 10x10. Note there is a slight reduction in pulse amplitudes and slight rise in the baseline.

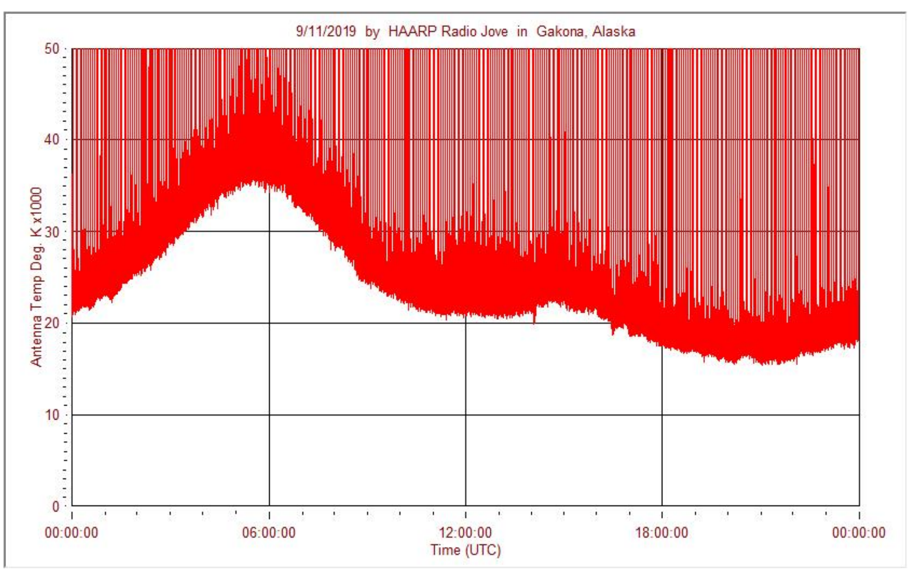


Figure 4.c ~ Averaging bin size = 10x10x10. Note the pulse amplitudes have been reduced slightly and the baseline rise is very small.

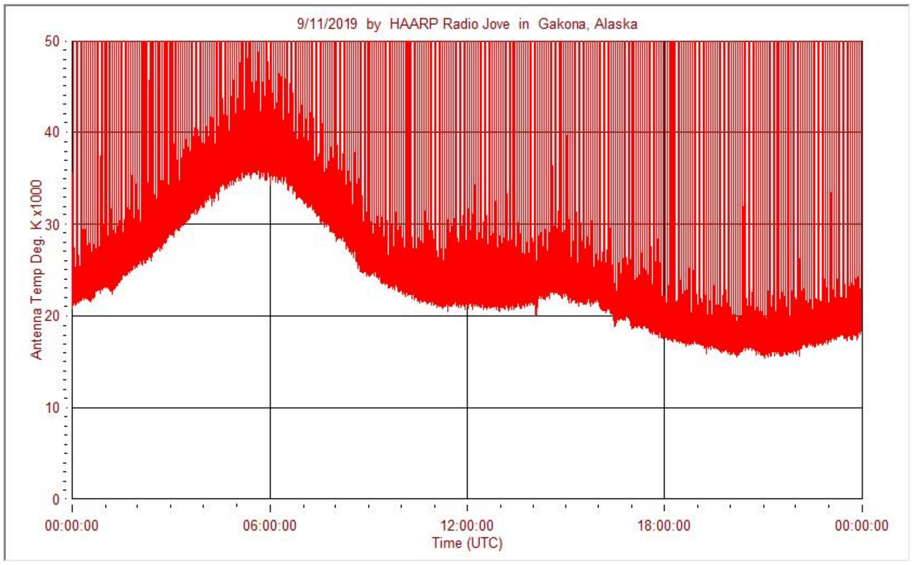


Figure 4.d ~ Averaging bin size = 10x10x10x10. Note the baseline rise is not as high as the ordinary smoothing used in figure 3.

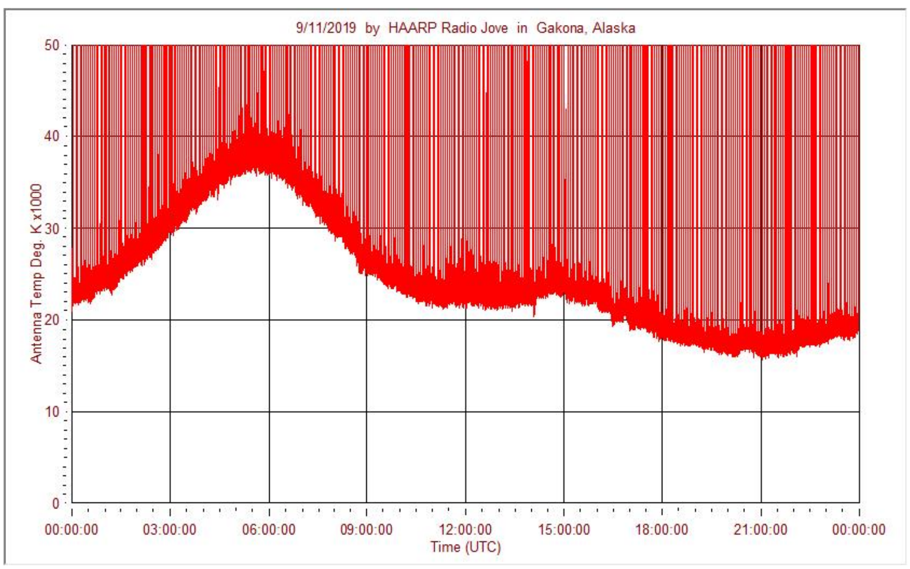


Figure 5.a ~ Averaging bin size = 50. The averaging is more aggressive than with a bin size = 10.

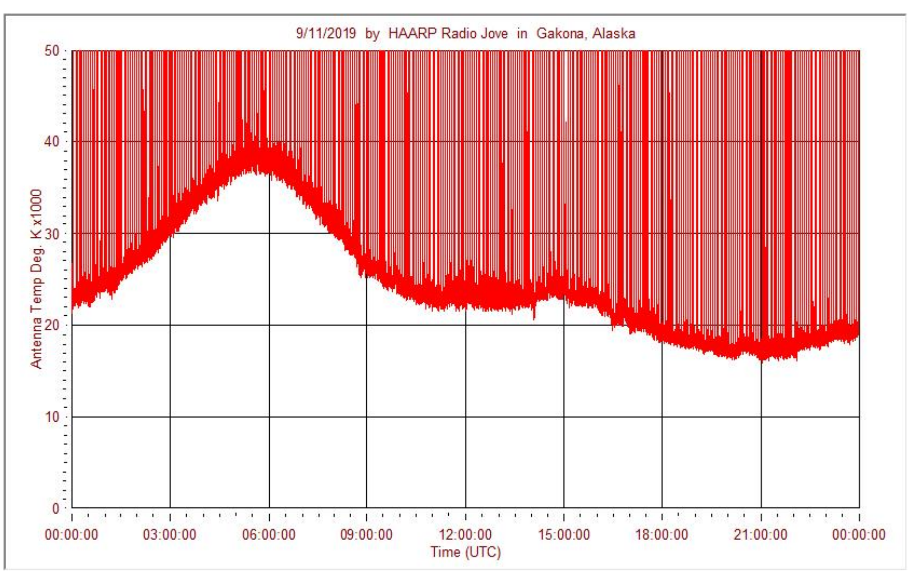


Figure 5.b ~ Averaging bin size = 50x50. Pulse amplitudes have been slightly reduced with a slight rise in baseline.

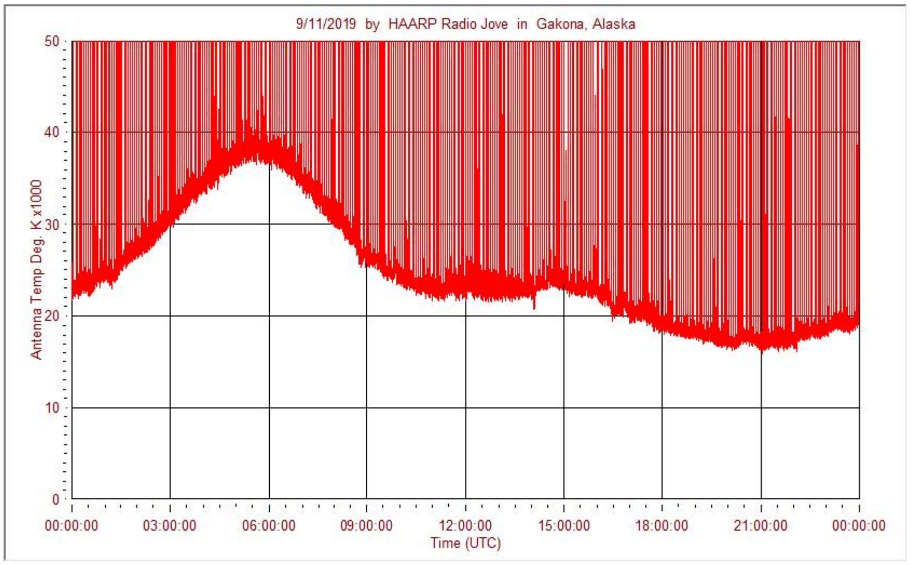


Figure 5.c ~ Averaging bin size = 50x50x50. The changes are slight compared to the previous figure.

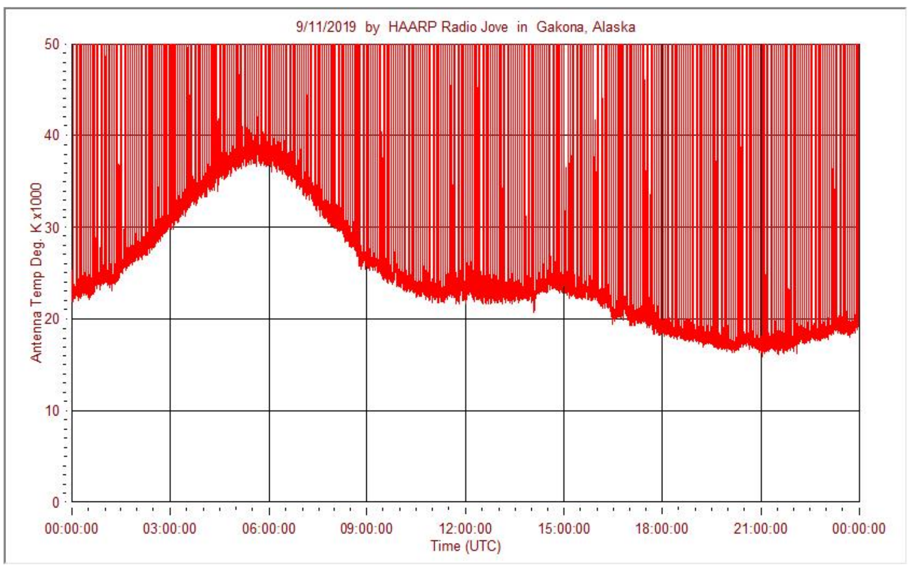


Figure 5.d ~ Averaging bin size = 50x50x50x50. Again, the changes are slight.

5. Discussion

Using the first mean smoothing method described in the previous section, the bin sizes of 50, 100, 500, 1000 improve the *appearance* of the baseline in the 24 h plots. On the other hand, a bin size of 10 has a comparatively noisy baseline, but not as noisy as the original data, and a bin size of 5000 heavily distorts the plotted data and is useless. The perceived noise floor rises slightly for each larger bin size – this is expected because the high-amplitude pulses always are averaged with the other datapoints. The best *appearance* of this data set seems to be for bin sizes of 50, 100, 500 and 1000.

The differences between the first mean smoothing method and the successive smoothing method are subtle especially for bin sizes 10, 50 and 100. One important difference stands out, though, and that is the successive smoothing method has less effect on the baseline. For the successive smoothing with bin sizes of 50, there is very little obvious difference between smoothing level 50x50 and higher, and the baseline rises very little.

To determine maximum and minimum noise temperatures, I zoomed into the corresponding times in the plots, about 0540 and 2040 UTC, respectively, and then used the *Get Avg for View* function. I used around 10 s time periods for the averages and avoided times when the strong spikes were present (figure 6).

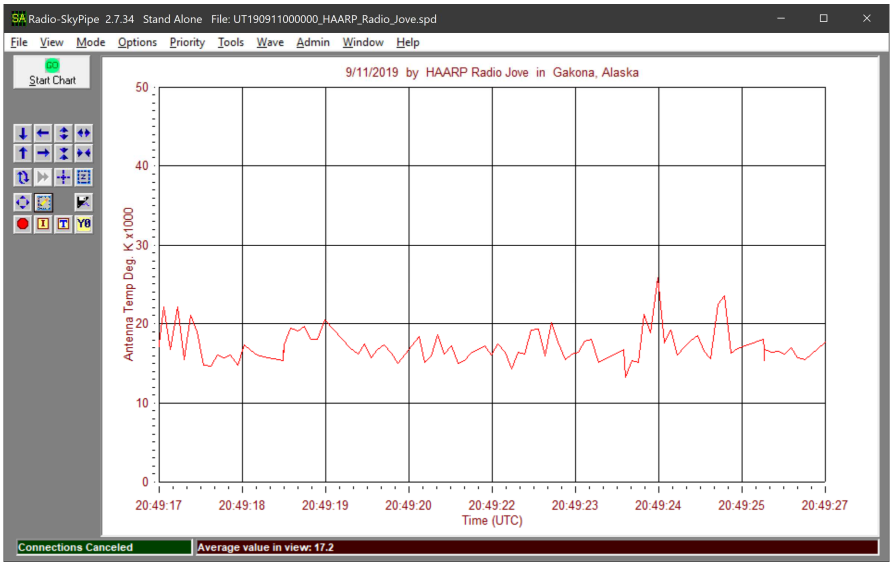


Figure 6 ~ Representative 10 s period starting 2049:17 UTC near the time of minimum background noise level at HAARP. The average of all viewed samples is found by right-clicking the window and selecting *Get Avg for View*. The average value then appears in the lower status bar. For the samples shown here, the value is 17.2, or when scaled is 17 200 K.

I looked at both the original data and successively smoothed data for 50x50x50x50 bin sizes and noted only a small difference in the baseline of perhaps 500 K. Using the Get Avg for View function and raw (unaveraged) data, the maximum noise temperature for 11 September is 38 000 K and minimum is 17 000 K. The ratio of the two is 3.5 dB. Visual estimates of the plots minimums and maximums agree reasonably well with the computed short-time averages.

The Radio-SkyPipe *Event Counter* under the *Tools* menu is used to verify the interval when the radio background most often exceeds a threshold (figure 7). This is found to be 0530 UTC, which agrees with a simple visual estimate of the peak on the 24 h plots previously shown.

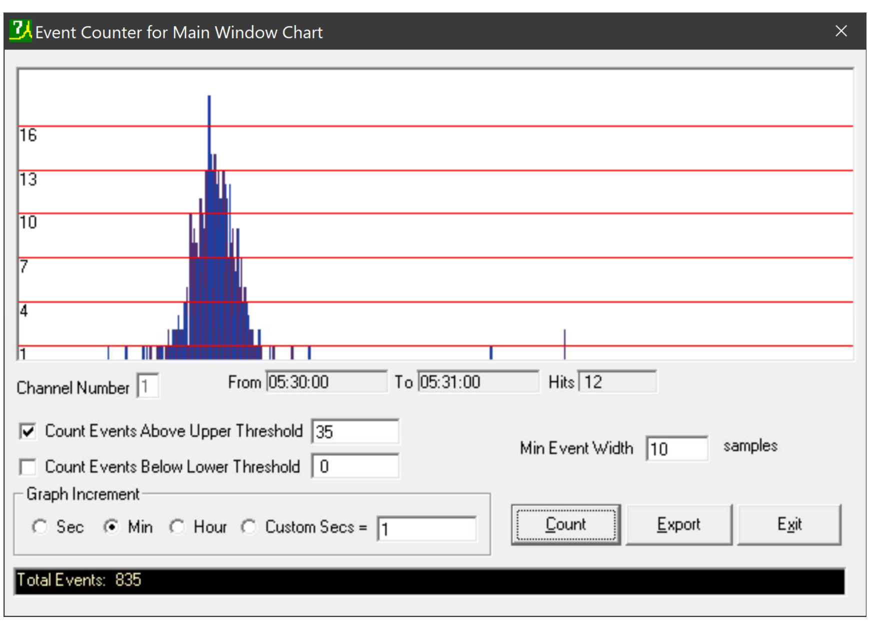


Figure 7 ~ The *Event Counter* is setup to show the number of events that exceed 35 000 K in a 1 min interval with a minimum width of 1 s (10 samples at 100 ms s^{-1}). For this screenshot the mouse cursor was placed at the location of the peak count corresponding to the 0530 to 0531 interval. Although this plot may give the impression that the peak is sharp, in reality it is quite broad.

6. Conclusions

The visual effects of radio frequency interference from the DigiSonde at HAARP on 24 h plots of the Radio JOVE data can be reduced by the *Smooth by Averaging* function in Radio-SkyPipe II. Other smoothing methods were not investigated. The *Smooth by Averaging* function appears to provide the best results when the function is invoked successively. Compared to simply using larger bin sizes, the successive method appears to better preserve the baseline.

7. References & Weblinks

{Reeve19} Reeve, W., New Radio Observatory Established at HAARP in Gakona, Alaska, 2019, available at http://www.reeve.com/Documents/Articles%20Papers/Reeve_HAARP-System.pdf

{Typinski} Typinski, D., Implementation of Median Smoothing in Radio-SkyPipe II, 2012, available at http://www.typnet.net/AJ4CO/Publications/Implementation%20of%20Median%20Smoothing%20in%20Radio-SkyPipe%20II,%20Typinski%20(SARAJ,%202012).pdf

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