

## Green Bank Earth Station Observations of Surfsat

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**OVERVIEW**

In this memo we describe in detail the observations of the Surfsat tracking passes with the Green Bank Earth Station (GBES) from the launch of Surfsat on November 4, 1995 until November 24, 1995.

**DATA ACQUISITION**

Both the downlink frequency and the flux of the signal from Surfsat were measured at the GBES. However, it was not possible to make automated measurements of these two quantities and the measurements had to be made manually. The Surfsat downlink tone was detected in a phase locking loop circuit. The downlink tone was amplified by the cooled (20 K) front end of the GBES and then down converted into the GBES IF range, 0.5 to 1 GHz. The downlink IF frequency of Surfsat was measured periodically at the GBES using a frequency counter referenced to a hydrogen maser standard. The frequency counter counts the locked oscillator of a tracking phase locked loop that is locked to the IF signal from the Surfsat spacecraft. The measured IF frequency is related to the observed downlink frequency of Surfsat via the following equation:

$$\nu = 9.1 \times 10^9 - \text{IF Hz.} \quad (1)$$

The flux of the signal from Surfsat, after down conversion, was displayed on a spectrum analyzer. The signal level was visually read from the display (see Figure 1). The spectrum analyzer was set to a 10 KHz resolution bandwidth in the IF frequency range of 621.25 MHz to 621.75 MHz. At the same time that the IF frequency was measured, the signal strength was measured in dB above the noise level (SNR). The system temperature ( $T_{\text{sys}}$ ) of the GBES was measured occasionally and was used for the conversion of the SNR to a flux. The flux of the SurfSat signal is calculated via the equation

$$S = \frac{\text{SNR} * T_{\text{sys}} * k * B}{A_{\text{eff}}} \quad (2)$$

where  $k = 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}}$  is Boltzmann's constant,  $B = 10 \text{ KHz}$  is the resolution bandwidth of the oscilloscope and  $A_{\text{eff}} \sim 59.1 \text{ m}^2$  is the effective collecting area of the GBES.

**THE TRACKING PASSES**

In this section we will discuss each tracking pass of Surfsat with the GBES separately. For several days after the launch of Surfsat a strong signal was detected at the GBES. However,

after several days the signal became weaker. Eventually the signal degraded to the point that during parts of a tracking pass or even during an entire tracking pass no signal would be detected from Surfsat. In Table 1, we have tabulated all of the observed frequency and flux measurements of the Surfsat signal observed with the GBES.

*1995, November 05, 0<sup>h</sup> UTC, MJD=50026*

Surfsat was observed for the first time from the NRAO station at Green Bank on 5 Nov 1995 at 00:41 UTC (Sat 4 Nov, 19:41 EST), within minutes of its being turned on by a command transmission from Goldstone. It turned out that this pass was simultaneously visible from both stations. We had only a rough predicted orbit, based on the first Space Command (radar tracking) vector after the depletion burn; the signal was rather weak, probably because of the resulting pointing error.

*1995, November 05, 12<sup>h</sup> and 13<sup>h</sup> UTC*

On Sunday morning Nov 5, we received a very strong signal on three successive passes. By then we had an updated orbit based on three Space Command vectors. Our (newly implemented) tracking phase locked loop maintained lock throughout all passes (except for a brief time in our zenith keyhole on the second pass), for all elevations above about 4.5 deg. The peak signal level was  $> 30$  dB in a 10 KHz bandwidth. A plot of the observed signal strength for the 13<sup>h</sup> tracking pass of November 5, 1995 is shown in Figure 1.

*1995, November 05, 20<sup>h</sup>, 22<sup>h</sup> and 1995, November 06 0<sup>h</sup> UTC*

During these three tracking passes a strong signal was also received from Surfsat at the GBES. However, for these three tracking passes a large offset from the predicted Surfsat frequency was observed.

*1995, November 06, 12<sup>h</sup> UTC, MJD=50027*

During this tracking pass a frequency difference of  $\sim 0$  KHz (observed - predicted) for the Surfsat downlink frequency was measured. A strong signal from Surfsat was also seen.

*1995, November 06, 13<sup>h</sup> UTC*

During this tracking pass a frequency difference of +42 KHz (observed - predicted) for the Surfsat downlink frequency was measured at 13:38 UTC and +25 KHz was measured at 13:49 UTC. A strong signal ( $> 40$  dB in 10 KHz bandwidth) from Surfsat was also seen during this tracking pass.

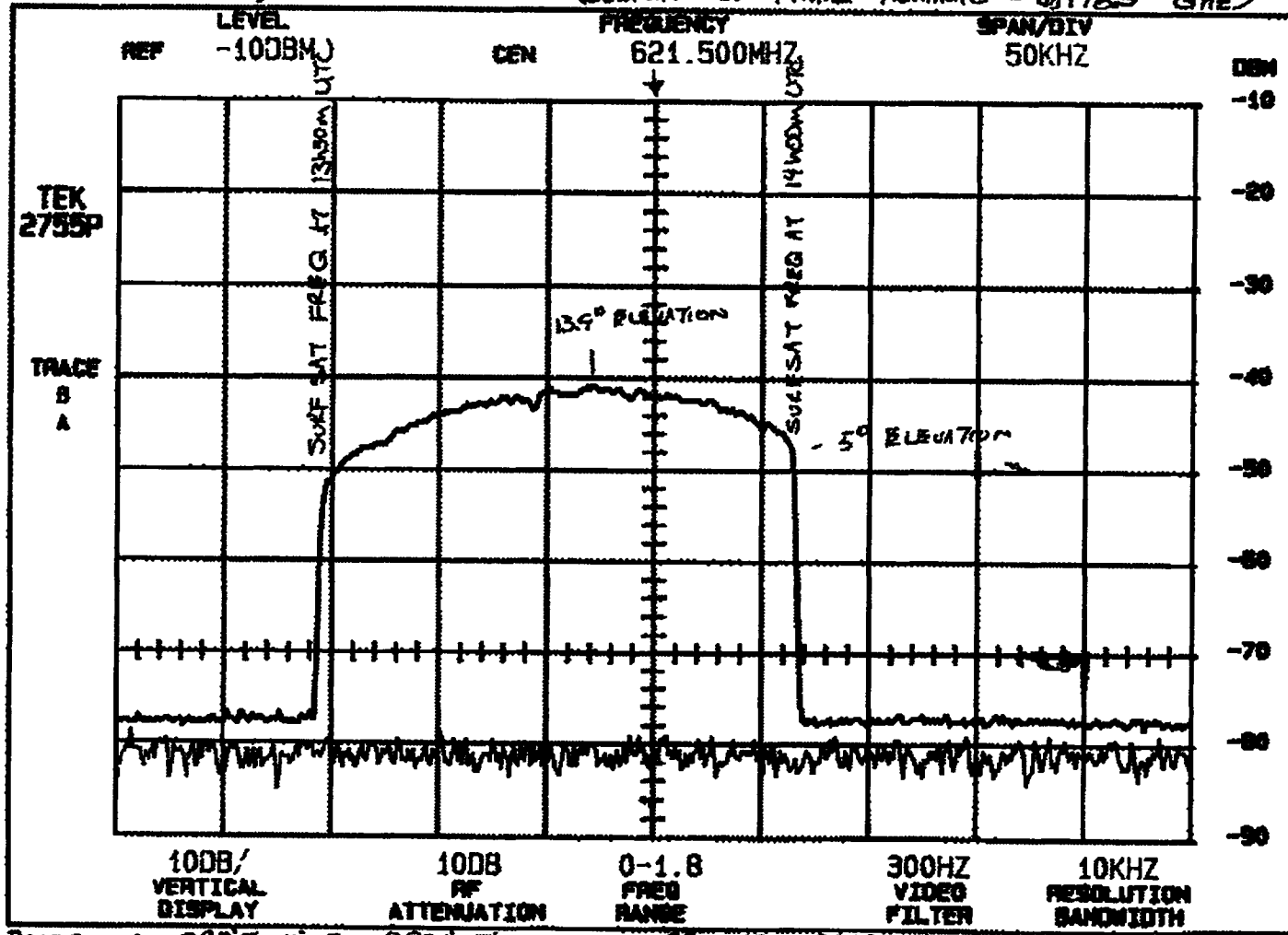
*1995, November 06, 22<sup>h</sup> UTC*

During this tracking pass a frequency difference of +55 KHz (observed - predicted) for the Surfsat downlink frequency was measured at 22:18 UTC and +64 KHz was measured at 22:34 UTC. The signal strength during this tracking pass was  $\sim 30$  dB in a 10 KHz bandwidth.

*1995, November 07, 11<sup>h</sup> UTC, MJD=50028*

During this tracking pass the signal strength of Surfsat was much weaker ( $< 10$  db in a

MAX HOLD SURFSAT SPECTRUM 95 NOV 05 13h49m TO 14h00m UTC  
 SKY FREQ = 9,1000 - IFREQ (SURFSAT REST FRAME NOMINAL = 8,478.5 GHz)



BASED ON ORBIT FILE PREDICTIONS TO REMOVE DOPPLER EFFECTS  
 SURFSAT IS RADIATING AT 8478.50 MHz ± 0.02 MHz

Figure 1: A plot showing the observed maximum signal strength versus IF frequency for Surfsat on 1995, November 5 during the 13th UTC tracking pass.

10 KHz bandwidth) and we were only able to intermittently lock to the downlink signal. At 11:35 UTC the observed minus predicted Surfsat downlink frequency was -20 KHz and at 11:52 UTC the difference was -28 KHz.

*1995, November 07, 13<sup>h</sup> and 20<sup>h</sup> UTC*

During these two tracking passes the signal from Surfsat was nearly continuously present, but at very low levels (< 10 dB in a 10 KHz bandwidth). No lock with the downlink signal was achieved for these tracking passes.

*1995, November 07, 22<sup>h</sup> UTC*

During this tracking pass an intermittent signal from Surfsat was observed. At 22:02 UTC the frequency offset was observed to be -33 KHz (observed - predicted) and at 22:20 UTC it was observed to be -23 KHz.

*1995, November 07, 23<sup>h</sup> UTC*

The signal strength of Surfsat was about 25 db in a 10 KHz bandwidth at the beginning of the tracking pass, but fell as the satellite rose to higher elevations. The signal level fell to about 2-5 dB in a 10 KHz bandwidth near Surfsat maximum elevation of  $\sim 30^\circ$ .

Near the end of this tracking pass, we decided to try entering pointing offsets manually in an attempt to 'peak up' on the Surfsat signal. This had the unintended effect of stopping all antenna motion. After a second, the signal increased from 3db to 15db in a 10 KHz bandwidth and lock was indicated. We were able to measure the frequency and then we lost lock again. By the time we were able to get the antenna tracking again, the satellite had set.

We attempted to transmit a signal to Surfsat from 23:54:00 UTC until 23:59:00 UTC.

During the previous days, it was possible to wait for even time intervals to record the frequency of Surfsat's downlink signal. During all the tracking passes on 1995, November 07, it was necessary to constantly watch the "Demodulator" lock indicator, and record frequencies whenever lock was indicated.

*1995, November 08, 20<sup>h</sup> UTC, MJD=50029*

During the first five minutes of this tracking pass, an intermittent signal from Surfsat was seen by the GBES. Occasionally, the demodulator locked to the downlink signal and it was possible to measure the frequency. However, we were not able to measure the signal strength during this part of the tracking pass. After 20:17 UTC a stronger signal ( $\sim 10$  dB in a 10 KHz bandwidth) was received from Surfsat and we were able to remain locked to the signal for the remainder of the tracking pass.

*1995, November 08, 21<sup>h</sup> UTC*

An  $\sim 30$  dB signal in a 10 KHz bandwidth was observed for most of this tracking pass. The signal during the first few minutes of this tracking pass was about half as strong as in the latter part of the tracking pass.

*1995, November 09, 12<sup>h</sup> UTC, MJD=50090*

We saw some interesting phenomena for this tracking pass. The tracking pass started around 12h59m (UTC). We received no detectable signal from Surfsat for the first nine minutes of the tracking pass. At roughly 13h08m0s, Surfsat suddenly appeared with a weak signal. We were able to lock to the downlink signal intermittently for the next 30 seconds. At roughly 13h08m30s, a lock with the downlink signal was achieved which lasted until Surfsat passed below the GBES horizon limits. The signal steadily increased in time from 13h08m30s until the end of the tracking pass at a few seconds after 13h14m.

*1995, November 09, 19<sup>h</sup> UTC*

During this tracking pass the GBES was able to lock to the Surfsat signal for the entire tracking pass. We were not able, however, to obtain any information on the signal strength due to hardware problems. It was discovered, after this tracking pass, that the station clock was offset six seconds during this tracking pass (GPS-Station = 6.000000 seconds). It is not known how we were able to still see Surfsat with this large time error. During this tracking pass there was a significant variation in the difference between the observed and the predicted downlink frequencies of Surfsat. A plot of this difference versus time is shown in Figure 2.

*1995, November 09, 21<sup>h</sup> UTC*

During this tracking pass a signal from Surfsat was observed for the entire duration of the tracking pass.

*1995, November 10, 14<sup>h</sup> UTC, 50091*

This tracking pass lasted for only four minutes and the satellite reached a peak elevation of only 5 degrees. The signal was seen for only about ten seconds at the start of the pass. Since the satellite was to the west, passing from north to south, it is possible (based on visual inspection) that Cheat Mountain could have blocked the view to the satellite during most of the remainder of the pass.

*1995, November 10, 19<sup>h</sup> UTC*

No signal was seen from Surfsat for the entire duration of this tracking pass.

*1995, November 10, 21<sup>h</sup> UTC*

During the first five minutes of this tracking pass a signal was observed from Surfsat but the GBES was unable to lock to the downlink signal. We attempted to transmit an uplink signal to Surfsat from 21:35:30 UTC until the end of the tracking pass at 21:44:00 UTC. A nearly constant signal strength was observed for the remainder of the tracking pass.

*1995, November 12, 12<sup>h</sup> UTC, MJD=50099*

No signal was seen from Surfsat during this tracking pass. The signal from the satellite was searched for along track up to 3 seconds +/- nominal position. Still no signal was seen.

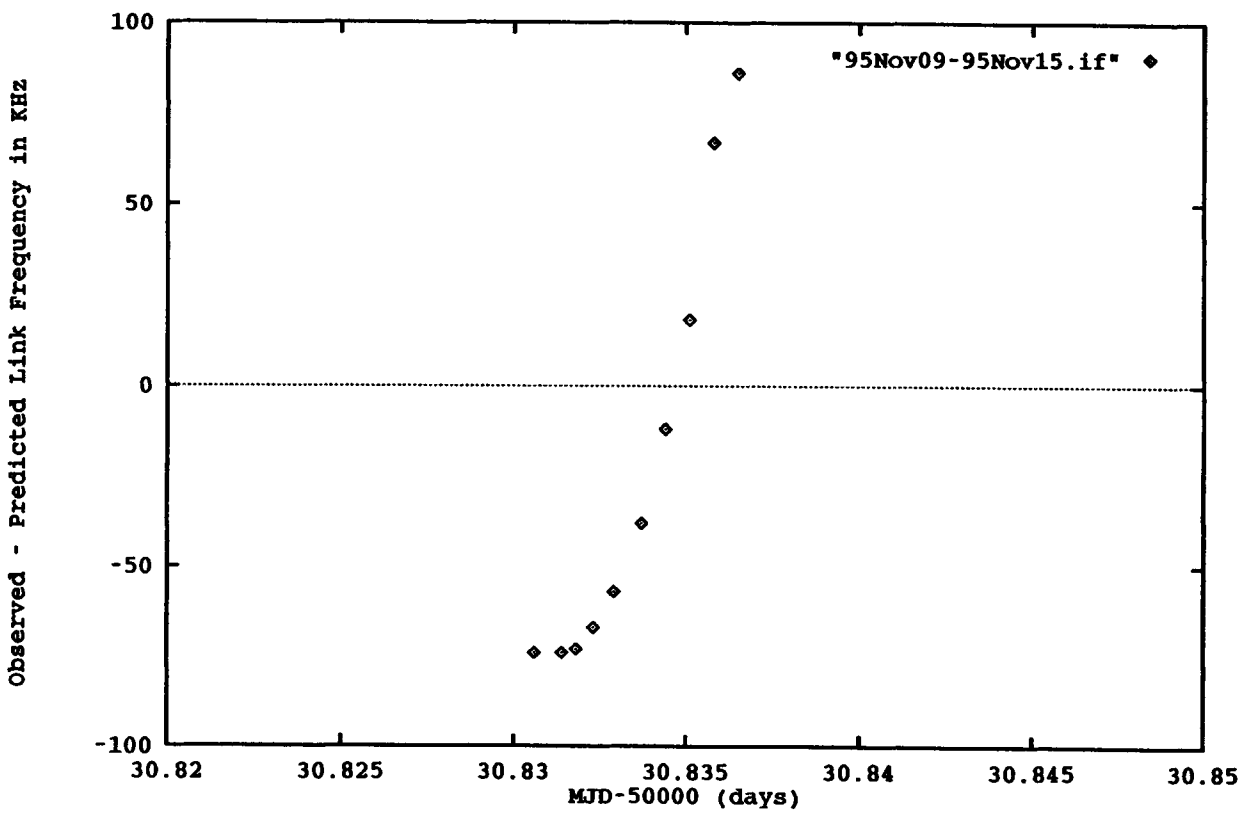


Figure 2: A plot showing the observed difference between the observed and the predicted downlink frequencies of Surfsat on 1995, November 09 during the 19<sup>th</sup> UTC tracking pass.

*1995, November 12, 14<sup>h</sup> UTC*

No signal was detected at the nominal satellite position. However, tracking a position -  $2.0 \pm 0.5$  seconds from the nominal position allowed for the detection of a signal from Surfsat (i.e. the predicted position led the actual position by 2 seconds).

*1995, November 13, 22<sup>h</sup> UTC, MJD=50034*

For the first 15 minutes of the tracking pass no signal from Surfsat was seen. A signal from Surfsat was detected for the last five minutes of the pass. This signal was extremely weak. The signal was typically about 3 to 5 db in a 10 KHz bandwidth and at one time reached 10 db.

*1995, November 14, 20<sup>h</sup> UTC, 50035*

A weak signal from Surfsat (< 10 dB in a 10 KHz bandwidth) was seen for the first five minutes of this tracking pass. During the last portion of the tracking pass a signal strength of 20 dB in a 10 KHz bandwidth was seen. We attempted to transmit an uplink signal to Surfsat during the period 20:50:30 UTC until 20:53:00 UTC.

*1995, November 14, 22<sup>h</sup> UTC*

We had a strong signal for the first half of the tracking pass until the satellite passed through our zenith keyhole where we cannot track the satellite. Once we got back on source (after the satellite passed through the zenith) we never detected any signal for the second half of the tracking pass. We were not able to get frequency measurements because the coarse tuning of our tracking phase locked loop was missed, so it never locked. We attempted to transmit an uplink signal to Surfsat during the period of 22:22:40 UTC until 22:41:50 UTC.

*1995, November 15, 0<sup>h</sup> UTC, MJD=50036*

The GBES had a reasonable signal during all but the initial minute of this tracking pass.

*1995, November 15, 20<sup>h</sup> UTC*

A signal was seen for Surfsat intermittently during this tracking pass. We attempted to transmit an uplink signal to Surfsat during the period 20:26:30 UTC until 20:42:00 UTC.

*1995, November 15, 22<sup>h</sup> UTC*

A moderately strong signal from Surfsat was observed for the duration of this tracking pass except during the period 22:17:20 UTC until 22:23:00 UTC when no signal from Surfsat was observed. We attempted to transmit an uplink signal to Surfsat from 22:09:45 UTC until 22:29:30 UTC.

*1995, November 15, 23<sup>h</sup> UTC*

The GBES had a reasonable signal at the start of the tracking pass but the signal was lost after the first six minutes of the tracking pass. During this tracking pass there was a significant variation in the difference between the observed and the predicted downlink

frequencies of Surfsat. A plot of this difference versus time is shown in Figure 3.

*1995, November 17, 20<sup>h</sup> UTC*

A moderately strong signal from Surfsat was observed for the duration of the tracking pass. We attempted to transmit an uplink signal to Surfsat from 20:03:00 UTC until 20:14:30 UTC. There was no evidence that Surfsat locked to the uplink tone.

*1995, November 17, 21<sup>h</sup> UTC*

A signal from Surfsat was only seen for the first eight minutes of the tracking pass. The observed signal strength was less than 10 dB in a 10 KHz bandwidth.

*1995, November 20, 21<sup>h</sup> UTC, MJD=50041*

During this tracking pass the signal from Surfsat was strongest during the first part of the tracking pass. The signal gradually faded until no signal was seen from Surfsat after 21:26:00 UTC. In Figure 4, we plot the observed signal strength of Surfsat during this tracking pass.

*1995, November 24, 13<sup>h</sup> UTC, MJD=50044*

Transmitter was always off. Signal level was always strong. Tracking was based on prediction file 951122a.bsp The system temperature was  $T_{\text{sys}} = 70\text{K}$ .

## DATA LOG

In Table 1, we present all of the data collected with the GBES for Surfsat tracking passes. The five columns of Table 1 are 1) date of the measurements (Modified Julian Day - 50000), 2) observed Surfsat IF frequency (MHz), 3) measured Surfsat IF frequency, (MHz), 4) the difference between the observed and predicted Surfsat Link frequencies (KHz) and 5) Surfsat's flux  $W m^2$ ). In Figure 5 we present a plot of the difference between the observed and predicted Surfsat link frequencies versus time. In Figure 6 we present a plot the observed Surfsat signal flux versus time.

## INTERPRETATION

The GBES data are consistent with a model for the satellite motion described by Robert Clauss, in which the Delta Rocket 3rd Stage is oscillating/rotating about its nominal, gravity gradient, orientation. In this model, the satellite antenna beam is sweeping out a cone around its nominal pointing direction. The period of this oscillation is roughly equal to the orbital period, 1.8286 hours = 6,583 seconds (Mark Ryne, private communication). The near equality of the orbital and oscillating period explains the correlation between the Surfsat signal on successive tracking passes. The GBES sampling of the signal level is "beating" with the oscillation period. During a tracking pass, the average satellite antenna orientation is only slightly offset from its position on the previous pass.

The longest tracking pass in Green Bank has a duration of 20 minutes, so that Surfsat will sweep out only 66° of its oscillation period during any one pass. Since Surfsat has an hemispherical antenna beam, the signal level changes only by a few db during the tracking



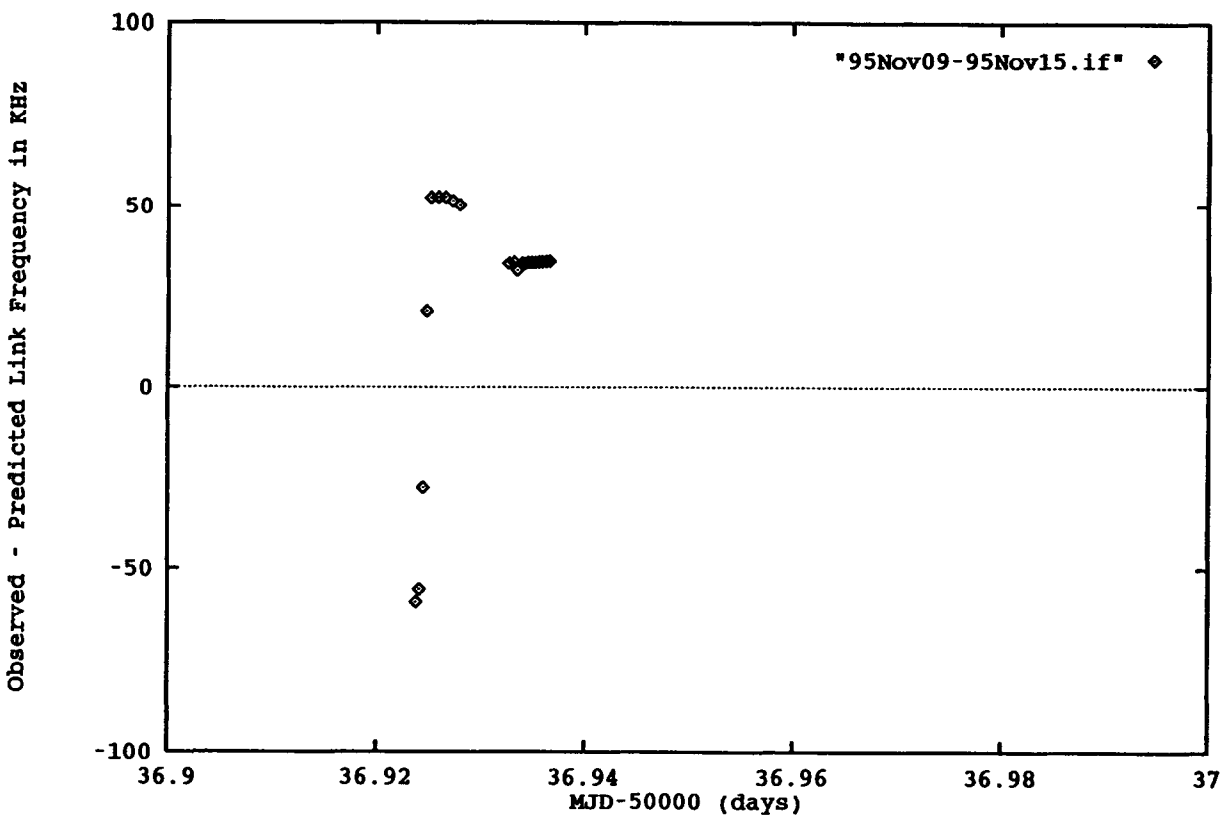


Figure 3: A plot showing the observed difference between the observed and the predicted downlink frequencies of Surfsat on 1995, November 17 during the 23<sup>rd</sup> UTC tracking pass.

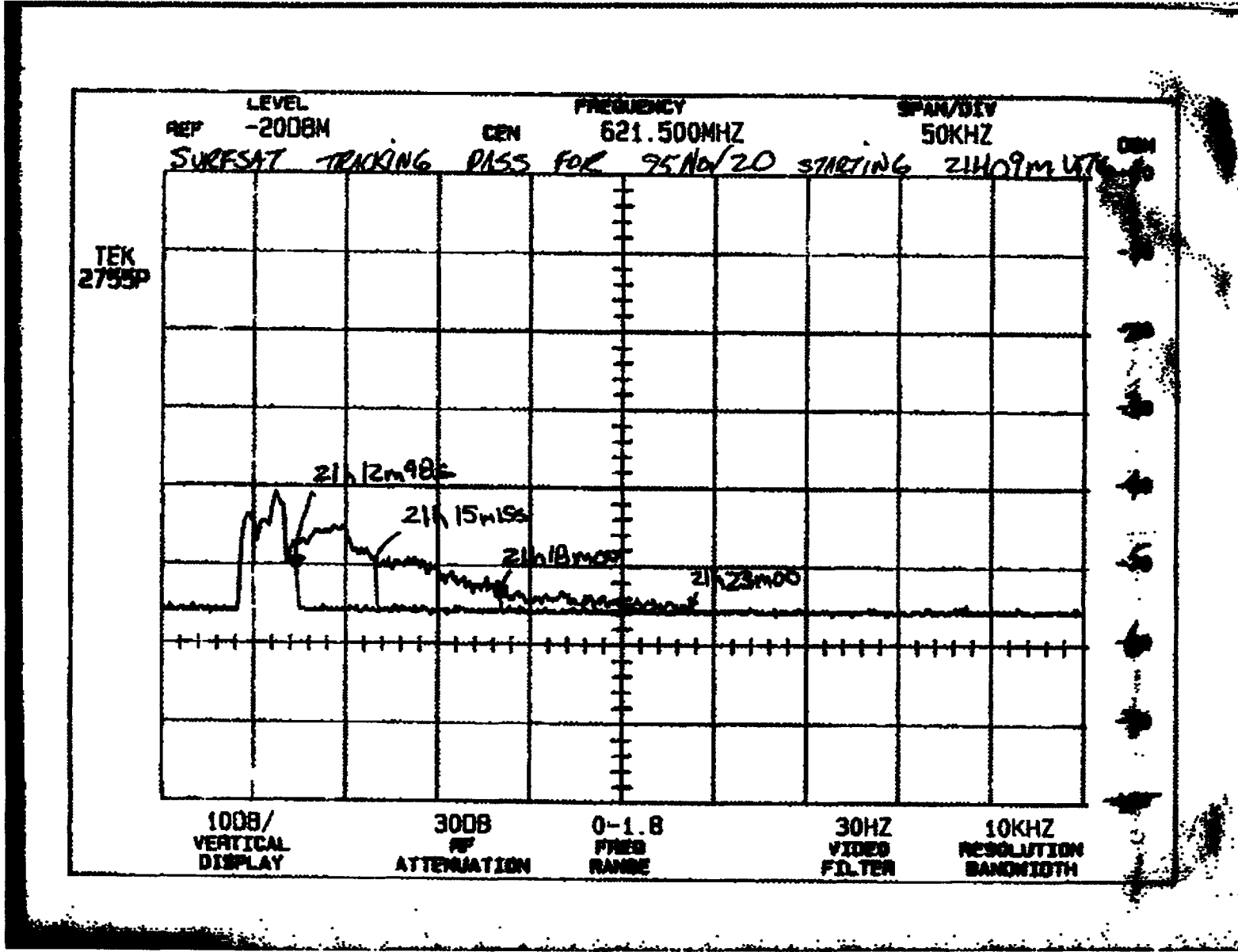


Figure 4: A plot showing the observed maximum signal strength versus IF frequency for Surfsat on 1995, November 20 during the 21<sup>st</sup> UTC tracking pass.

passes with good alignment.

In this model, on some days the antenna is pointed towards the tracking station (ie. 95 Nov. 5,6), latter partially offset (ie. 95 Nov. 7, 8), then away from the tracking station (95 Nov. 9, 10). Other dates when strong continuous signals were detected include 95 Nov. 15 and 95 Nov. 24.

There are too few samples in the GBES data to allow conclusive measurement of the "beat" period of the signal level. Hence it is difficult to predict the next dates when the Surfsat signal will be strong. It appears that the period between sets of tracking passes with strong signals is longer than 4 days.

Usually, the prediction of the satellite location has been accurate, within a fraction of a second. However, occasionally, the accuracy of the orbit prediction was a problem. On 95 Nov 12, 14h UTC, the satellite position was found to be roughly "on track", but  $2.0 \pm 0.5$  seconds behind the predicted position. Since then, when Surfsat has been detected, it has been found near its predicted position.

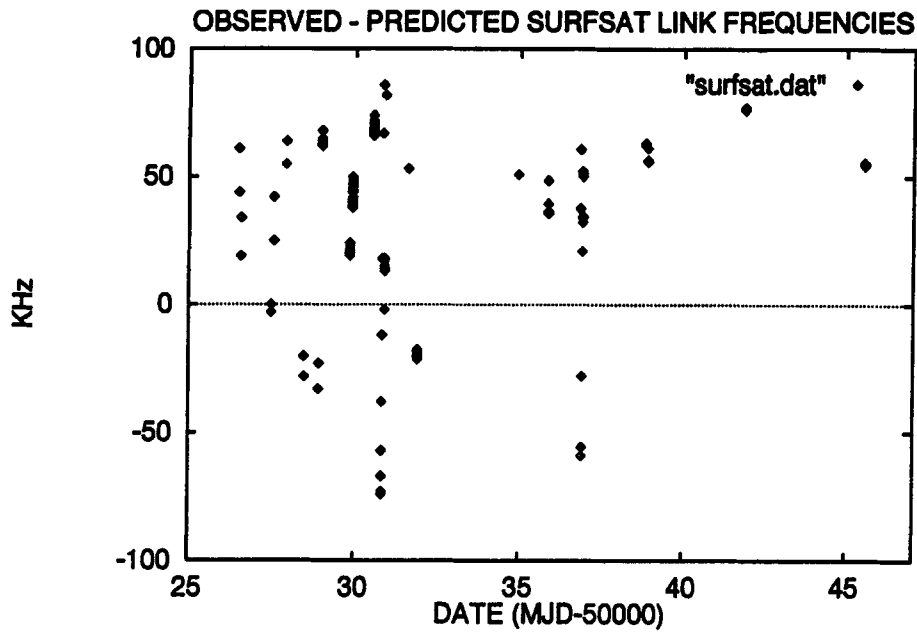


Figure 5: A plot showing the observed difference between the observed and the predicted Surfsat link frequency versus time.

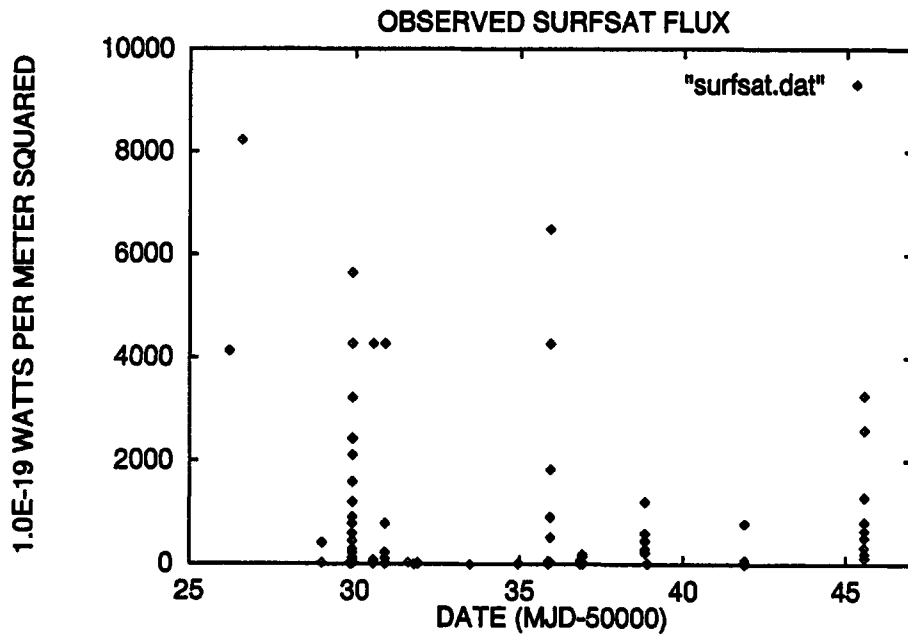


Figure 6: A plot showing the observed maximum signal strength versus time for Surfsat.

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 26.5042           |                       |                      | +61  | 4.2×10 <sup>-18</sup>     |
| 26.5118           |                       |                      | +44.0  |                           |
| 26.5792           |                       |                      | +34.0  | 8.22×10 <sup>-18</sup>    |
| 26.5840           |                       |                      | +19.0  |                           |
| 26.8667           |                       |                      | +214.0   |                           |
| 26.8722           |                       |                      | +218.0   |                           |
| 26.9382           |                       |                      | +208.0   |                           |
| 26.9479           |                       |                      | +217.0   |                           |
| 27.0146           |                       |                      | +191.0   |                           |
| 27.0208           |                       |                      | +199.0   |                           |
| 27.5007           |                       |                      | -3.0   |                           |
| 27.5028           |                       |                      | 0.0  |                           |
| 27.5681           |                       |                      | +42.0  |                           |
| 27.5757           |                       |                      | +25.0  |                           |
| 27.9292           |                       |                      | +55.0  |                           |
| 27.9403           |                       |                      | +64.0  |                           |
| 28.4826           |                       |                      | -20.0  |                           |
| 28.4944           |                       |                      | -28.0  |                           |
| 28.9181           |                       |                      | -33.0  |                           |
| 28.9306           |                       |                      | -23.0  |                           |
| 28.9935           | 621.352               | 621.288              | +64.0  | 4.12×10 <sup>-17</sup>    |
| 28.9942           | 621.355               | 621.293              | +62.0  |                           |
| 28.9944           | 621.358               | 621.295              | +63.0  |                           |
| 28.9948           | 621.361               | 621.298              | +63.0  |                           |
| 28.9951           | 621.365               | 621.302              | +63.0  |                           |
| 28.9955           | 621.369               | 621.307              | +62.0  |                           |
| 28.9962           | 621.381               | 621.318              | +63.0  |                           |
| 28.9965           | 621.388               | 621.325              | +63.0  |                           |
| 28.9972           | 621.405               | 621.340              | +65.0  |                           |
| 28.9998           | 621.495               | 621.427              | +68.0  | 2.60×10 <sup>-18</sup>    |
| 29.8423           | 621.499               | 621.479              | +20.0  |                           |
| 29.8438           | 621.538               | 621.517              | +19.0  |                           |
| 29.8440           | 621.542               | 621.522              | +20.0  |                           |
| 29.8442           | 621.548               | 621.528              | +20.0  |                           |
| 29.8445           | 621.554               | 621.533              | +21.0  |                           |
| 29.8447           | 621.559               | 621.539              | +20.0  |                           |
| 29.8450           | 621.565               | 621.543              | +22.0  | 3.13×10 <sup>-18</sup>    |
| 29.8452           | 621.571               | 621.549              | +22.0  | 3.13×10 <sup>-18</sup>    |
| 29.8455           | 621.576               | 621.554              | +22.0  | 3.13×10 <sup>-18</sup>    |
| 29.8458           | 621.581               | 621.559              | +24.0  | 2.36×10 <sup>-18</sup>    |
| 29.8460           | 621.586               | 621.554              | +22.0  | 2.36×10 <sup>-18</sup>    |
| 29.8464           | 621.592               | 621.569              | +23.0  | 6.68×10 <sup>-19</sup>    |

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 29.9100           | 621.345               | 621.305              | +40.0  | 8.84×10 <sup>-19</sup>    |
| 29.9102           | 621.346               | 621.308              | +38.0  | 2.36×10 <sup>-18</sup>    |
| 29.9106           | 621.348               | 621.310              | +38.0  | 1.55×10 <sup>-18</sup>    |
| 29.9109           | 621.351               | 621.312              | +39.0  | 8.84×10 <sup>-19</sup>    |
| 29.9112           | 621.353               | 621.315              | +38.0  | 2.36×10 <sup>-18</sup>    |
| 29.9116           | 621.357               | 621.318              | +39.0  | 3.13×10 <sup>-18</sup>    |
| 29.9119           | 621.361               | 621.322              | +39.0  | 6.31×10 <sup>-18</sup>    |
| 29.9123           | 621.366               | 621.327              | +39.0  | 1.27×10 <sup>-17</sup>    |
| 29.9126           | 621.372               | 621.333              | +39.0  | 2.23×10 <sup>-17</sup>    |
| 29.9130           | 621.380               | 621.340              | +40.0  | 2.96×10 <sup>-17</sup>    |
| 29.9133           | 621.387               | 621.348              | +39.0  | 4.51×10 <sup>-17</sup>    |
| 29.9137           | 621.399               | 621.358              | +41.0  | 4.51×10 <sup>-17</sup>    |
| 29.9140           | 621.409               | 621.370              | +39.0  | 4.51×10 <sup>-17</sup>    |
| 29.9144           | 621.423               | 621.383              | +40.0  | 9.09×10 <sup>-17</sup>    |
| 29.9147           | 621.438               | 621.400              | +38.0  | 7.90×10 <sup>-17</sup>    |
| 29.9150           | 621.456               | 621.414              | +42.0  | 5.97×10 <sup>-17</sup>    |
| 29.9154           | 621.473               | 621.433              | +40.0  | 1.20×10 <sup>-16</sup>    |
| 29.9157           | 621.492               | 621.451              | +41.0  | 1.59×10 <sup>-16</sup>    |
| 29.9161           | 621.511               | 621.470              | +41.0  | 2.11×10 <sup>-16</sup>    |
| 29.9164           | 621.530               | 621.490              | +40.0  | 2.43×10 <sup>-16</sup>    |
| 29.9168           | 621.548               | 621.506              | +42.0  | 3.22×10 <sup>-16</sup>    |
| 29.9171           | 621.564               | 621.522              | +42.0  | 3.22×10 <sup>-16</sup>    |
| 29.9175           | 621.580               | 621.536              | +44.0  | 3.22×10 <sup>-16</sup>    |
| 29.9178           | 621.593               | 621.549              | +44.0  | 3.22×10 <sup>-16</sup>    |
| 29.9182           | 621.605               | 621.560              | +45.0  | 4.26×10 <sup>-16</sup>    |
| 29.9185           | 621.614               | 621.570              | +44.0  | 4.26×10 <sup>-16</sup>    |
| 29.9189           | 621.623               | 621.577              | +46.0  | 5.64×10 <sup>-16</sup>    |
| 29.9192           | 621.630               | 621.584              | +46.0  | 4.26×10 <sup>-16</sup>    |
| 29.9196           | 621.637               | 621.591              | +46.0  | 4.26×10 <sup>-16</sup>    |
| 29.9199           | 621.641               | 621.594              | +47.0  | 5.64×10 <sup>-16</sup>    |
| 29.9203           | 621.645               | 621.598              | +47.0  | 5.64×10 <sup>-16</sup>    |
| 29.9206           | 621.649               | 621.602              | +47.0  | 3.22×10 <sup>-16</sup>    |
| 29.9209           | 621.652               | 621.604              | +48.0  | 2.43×10 <sup>-16</sup>    |
| 29.9213           | 621.654               | 621.607              | +47.0  | 2.43×10 <sup>-16</sup>    |
| 29.9216           | 621.656               | 621.609              | +47.0  | 2.11×10 <sup>-16</sup>    |
| 29.9220           | 621.658               | 621.610              | +48.0  | 2.11×10 <sup>-16</sup>    |
| 29.9223           | 621.660               | 621.611              | +49.0  | 1.59×10 <sup>-16</sup>    |
| 29.9227           | 621.662               | 621.612              | +50.0  | 1.20×10 <sup>-16</sup>    |

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 30.5476           | 621.534               | 621.468              | +66.0  |                           |
| 30.5478           | 621.544               | 621.476              | +68.0  |                           |
| 30.5483           | 621.562               | 621.495              | +67.0  | $3.60 \times 10^{-19}$    |
| 30.5487           | 621.574               | 621.507              | +67.0  | $7.68 \times 10^{-19}$    |
| 30.5489           | 621.581               | 621.513              | +68.0  | $7.68 \times 10^{-19}$    |
| 30.5491           | 621.588               | 621.519              | +69.0  | $2.05 \times 10^{-18}$    |
| 30.5493           | 621.594               | 621.525              | +69.0  | $2.05 \times 10^{-18}$    |
| 30.5495           | 621.600               | 621.531              | +69.0  | $3.60 \times 10^{-18}$    |
| 30.5498           | 621.606               | 621.536              | +70.0  | $3.60 \times 10^{-18}$    |
| 30.5500           | 621.610               | 621.540              | +70.0  | $8.36 \times 10^{-18}$    |
| 30.5502           | 621.615               | 621.544              | +71.0  | $8.36 \times 10^{-18}$    |
| 30.5505           | 621.619               | 621.548              | +71.0  | $8.36 \times 10^{-18}$    |
| 30.5507           | 621.622               | 621.551              | +71.0  | $8.36 \times 10^{-18}$    |
| 30.5510           | 621.627               | 621.555              | +72.0  | $8.36 \times 10^{-18}$    |
| 30.5514           | 621.632               | 621.558              | +74.0  | $4.26 \times 10^{-16}$    |
| 30.8306           | 621.436               | 621.510              | -74.0  |                           |
| 30.8314           | 621.441               | 621.515              | -74.0  |                           |
| 30.8318           | 621.448               | 621.521              | -73.0  |                           |
| 30.8323           | 621.460               | 621.527              | -67.0  |                           |
| 30.8329           | 621.475               | 621.532              | -57.0  |                           |
| 30.8337           | 621.493               | 621.531              | -38.0  |                           |
| 30.8344           | 621.512               | 621.524              | -12.0  |                           |
| 30.8351           | 621.527               | 621.509              | +18.0  |                           |
| 30.8358           | 621.543               | 621.476              | +67.0  |                           |
| 30.8365           | 621.558               | 621.472              | +86.0  |                           |
| 30.9009           | 621.348               | 621.205              | -143.0   | $2.23 \times 10^{-17}$    |
| 30.9014           | 621.349               | 621.332              | +17.0  | $2.23 \times 10^{-17}$    |
| 30.9027           | 621.359               | 621.361              | -2.0   | $1.11 \times 10^{-17}$    |
| 30.9030           | 621.427               | 621.345              | +82.0  | $2.23 \times 10^{-17}$    |
| 30.9052           | 621.411               | 621.394              | +18.0  | $2.23 \times 10^{-17}$    |
| 30.9059           | 621.434               | 621.419              | +15.0  | $2.05 \times 10^{-18}$    |
| 30.9063           | 621.448               | 621.434              | +14.0  | $1.17 \times 10^{-18}$    |
| 30.9066           | 621.465               | 621.451              | +14.0  | $7.68 \times 10^{-19}$    |
| 30.9073           | 621.499               | 621.485              | +14.0  | $4.26 \times 10^{-16}$    |
| 30.9078           | 621.525               | 621.512              | +13.0  |                           |
| 30.9087           | 621.565               | 621.552              | +13.0  |                           |
| 30.9093           | 621.589               | 621.575              | +14.0  | $7.90 \times 10^{-17}$    |
| 30.9099           | 621.606               | 621.593              | +13.0  | $4.26 \times 10^{-16}$    |
| 30.9104           | 621.619               | 621.606              | +13.0  | $7.90 \times 10^{-17}$    |
| 30.9106           | 621.623               | 621.610              | +13.0  | $4.26 \times 10^{-16}$    |
| 30.9109           | 621.629               | 621.616              | +13.0  | $7.90 \times 10^{-17}$    |
| 30.9114           | 621.636               | 621.623              | +13.0  | $4.26 \times 10^{-16}$    |
| 30.9118           | 621.642               | 621.628              | +14.0  | $7.90 \times 10^{-17}$    |
| 30.9123           | 621.647               | 621.633              | +14.0  | $2.05 \times 10^{-18}$    |

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 31.6095           | 621.4382              | 621.385              | +53.2  | $3.13 \times 10^{-18}$    |
| 31.8924           | 621.3513              |                      |  | $1.55 \times 10^{-18}$    |
| 31.8928           | 621.3530              |                      |  | $1.55 \times 10^{-18}$    |
| 31.8931           | 621.3552              |                      |  | $1.02 \times 10^{-18}$    |
| 31.8934           | 621.3577              |                      |  | $1.17 \times 10^{-18}$    |
| 31.8944           | 621.3682              |                      |  | $2.27 \times 10^{-18}$    |
| 31.8958           | 621.3921              |                      |  | $2.27 \times 10^{-18}$    |
| 31.8970           | 621.4210              | 621.4424             | -21.4  | $1.55 \times 10^{-18}$    |
| 31.8972           | 621.4331              | 621.4532             | -20.1  | $2.05 \times 10^{-18}$    |
| 31.8976           | 621.4465              | 621.4667             | -20.2  | $2.27 \times 10^{-18}$    |
| 31.8979           | 621.4609              | 621.4814             | -20.5  |                           |
| 31.8984           | 621.4841              | 621.5043             | -20.2  | $1.55 \times 10^{-18}$    |
| 31.8986           | 621.4920              | 621.5124             | -20.4  | $1.55 \times 10^{-18}$    |
| 31.8990           | 621.5080              | 621.5283             | -20.3  | $1.78 \times 10^{-18}$    |
| 31.8994           | 621.5290              | 621.5491             | -20.0  | $1.55 \times 10^{-18}$    |
| 31.9000           | 621.5538              | 621.5736             | -19.8  | $2.05 \times 10^{-18}$    |
| 31.9003           | 621.5674              | 621.5889             | -19.4  | $8.84 \times 10^{-19}$    |
| 31.9007           | 621.5797              | 621.5989             | -19.2  | $1.17 \times 10^{-18}$    |
| 31.9010           | 621.5908              | 621.6099             | -19.1  | $1.78 \times 10^{-18}$    |
| 31.9014           | 621.6007              | 621.6192             | -18.5  | $5.97 \times 10^{-19}$    |
| 31.9017           | 621.6094              |                      |  | $5.97 \times 10^{-19}$    |
| 31.9021           | 621.6170              | 621.6355             | -18.5  | $5.97 \times 10^{-19}$    |
| 31.9024           | 621.6236              | 621.6419             | -18.3  | $7.68 \times 10^{-19}$    |
| 31.9028           | 621.6294              | 621.6476             | -18.2  | $1.55 \times 10^{-18}$    |
| 31.9031           | 621.6344              | 621.6526             | -18.2  | $1.02 \times 10^{-18}$    |
| 31.9035           | 621.6387              | 621.6567             | -18.0  | $7.68 \times 10^{-19}$    |
| 31.9038           | 621.6424              | 621.6604             | -18.0  | $7.68 \times 10^{-19}$    |
| 31.9042           | 621.6456              | 621.6634             | -17.8  | $7.68 \times 10^{-19}$    |
| 31.9045           | 621.6484              | 621.6660             | -17.6  | $1.55 \times 10^{-18}$    |
| 31.9049           | 621.6507              | 621.6686             | -17.9  | $8.84 \times 10^{-19}$    |
| 31.9052           | 621.6527              | 621.6702             | -17.5  | $7.68 \times 10^{-19}$    |
| 34.9502           | 621.6281              |                      |  | $6.05 \times 10^{-19}$    |
| 34.9505           | 621.6336              |                      |  | $3.60 \times 10^{-19}$    |
| 34.9506           | 621.6360              |                      |  | $3.60 \times 10^{-19}$    |
| 34.9510           | 621.6422              |                      |  | $2.36 \times 10^{-18}$    |
| 34.9514           | 621.6464              | 621.5872             | +50.9  | $1.78 \times 10^{-18}$    |
| 35.8632           | 621.4501              |                      |  | $2.80 \times 10^{-19}$    |
| 35.8656           | 621.5258              |                      |  | $2.33 \times 10^{-19}$    |
| 35.8661           | 621.5396              | 621.491              | +48.6  | $3.97 \times 10^{-19}$    |
| 35.8666           | 621.5546              | 621.5171             | +39.5  | $5.64 \times 10^{-19}$    |
| 35.8674           | 621.5761              | 621.5394             | +36.7  | $2.05 \times 10^{-18}$    |
| 35.8677           | 621.5824              | 621.5460             | +36.4  | $2.05 \times 10^{-18}$    |
| 35.8681           | 621.5898              | 621.5534             | +36.4  | $4.14 \times 10^{-18}$    |
| 35.8684           | 621.6026              | 621.5670             | +35.6  | $6.31 \times 10^{-18}$    |
| 35.8691           | 621.6081              | 621.5723             | +35.8  | $4.77 \times 10^{-18}$    |



| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 35.8694           | 621.6131              | 621.5774             | +35.7  | $6.31 \times 10^{-18}$    |
| 35.9326           | 621.3403              |                      |  | $3.60 \times 10^{-18}$    |
| 35.9345           | 621.3506              |                      |  | $9.09 \times 10^{-17}$    |
| 35.9347           | 621.3527              |                      |  | $1.83 \times 10^{-16}$    |
| 35.9354           | 621.3616              |                      |  | $4.26 \times 10^{-16}$    |
| 35.9358           | 621.3676              |                      |  | $4.26 \times 10^{-16}$    |
| 35.9361           | 621.3750              |                      |  | $4.26 \times 10^{-16}$    |
| 35.9368           | 621.3947              |                      |  | $6.49 \times 10^{-16}$    |
| 35.9375           | 621.4232              |                      |  | $4.26 \times 10^{-16}$    |
| 35.9382           | 621.4613              |                      |  | $5.19 \times 10^{-17}$    |
| 36.8521           | 621.3984              | 621.3376             | +60.8  |                           |
| 36.8535           | 621.4227              |                      |  | $7.68 \times 10^{-19}$    |
| 36.8545           | 621.4468              |                      |  | $4.64 \times 10^{-19}$    |
| 36.8556           | 621.4754              |                      |  | $4.64 \times 10^{-19}$    |
| 36.8587           | 621.5642              |                      |  | $4.64 \times 10^{-19}$    |
| 36.8597           | 621.5869              |                      |  | $3.60 \times 10^{-18}$    |
| 36.8597           | 621.5934              | 621.5556             | +37.8  | $3.60 \times 10^{-18}$    |
| 36.8604           | 621.5993              | 621.5618             | +37.5  | $8.36 \times 10^{-18}$    |
| 36.9238           | 621.3411              | 621.4001             | -59.0  | $1.94 \times 10^{-17}$    |
| 36.9241           | 621.3421              | 621.3977             | -55.6  |                           |
| 36.9245           | 621.3434              | 621.3712             | -27.8  | $1.94 \times 10^{-17}$    |
| 36.9248           | 621.3450              | 621.3241             | +20.9  | $1.94 \times 10^{-17}$    |
| 36.9252           | 621.3470              | 621.2948             | +52.2  |                           |
| 36.9259           | 621.3524              | 621.3001             | +52.3  | $1.94 \times 10^{-17}$    |
| 36.9266           | 621.3605              | 621.3082             | +52.3  | $1.47 \times 10^{-17}$    |
| 36.9273           | 621.3724              | 621.3212             | +51.3  | $4.77 \times 10^{-18}$    |
| 36.9280           | 621.3898              | 621.3396             | +50.2  | $1.35 \times 10^{-18}$    |
| 36.9327           | 621.6137              | 621.5822             | +34.1  | $6.05 \times 10^{-19}$    |
| 36.9332           | 621.6284              | 621.5940             | +34.4  | $3.13 \times 10^{-18}$    |
| 36.9335           | 621.6349              | 621.6026             | +32.3  | $1.78 \times 10^{-18}$    |
| 36.9340           | 621.6425              | 621.6084             | +34.1  | $1.78 \times 10^{-18}$    |
| 36.9342           | 621.6447              | 621.6107             | +34.0  | $1.35 \times 10^{-18}$    |
| 36.9345           | 621.6484              | 621.6141             | +34.3  | $1.35 \times 10^{-18}$    |
| 36.9349           | 621.6514              | 621.6171             | +34.3  | $7.68 \times 10^{-19}$    |
| 36.9352           | 621.6538              | 621.6195             | +34.3  | $7.68 \times 10^{-19}$    |
| 36.9356           | 621.6559              | 621.6215             | +34.5  | $1.02 \times 10^{-18}$    |
| 36.9359           | 621.6575              | 621.6231             | +34.5  | $7.68 \times 10^{-19}$    |
| 36.9363           | 621.6588              | 621.6242             | +34.6  | $1.35 \times 10^{-18}$    |
| 36.9366           | 621.6599              | 621.6252             | +34.7  | $1.78 \times 10^{-18}$    |

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 38.8360           | 621.418               | 621.356              | +62.5  | 2.96×10 <sup>-17</sup>    |
| 38.8363           | 621.424               | 621.361              | +62.3  | 1.20×10 <sup>-16</sup>    |
| 38.8366           | 621.430               | 621.367              | +62.7  | 2.96×10 <sup>-17</sup>    |
| 38.8370           | 621.437               | 621.375              | +62.5  | 2.96×10 <sup>-17</sup>    |
| 38.8373           | 621.444               | 621.382              | +62.6  | 5.97×10 <sup>-17</sup>    |
| 38.8377           | 621.452               | 621.390              | +62.6  | 2.96×10 <sup>-17</sup>    |
| 38.8380           | 621.460               | 621.397              | +62.8  | 4.51×10 <sup>-17</sup>    |
| 38.8384           | 621.469               | 621.406              | +62.9  | 5.97×10 <sup>-17</sup>    |
| 38.8387           | 621.477               | 621.414              | +63.0  | 5.97×10 <sup>-17</sup>    |
| 38.8391           | 621.486               | 621.423              | +63.1  | 2.96×10 <sup>-17</sup>    |
| 38.8394           | 621.495               | 621.433              | +62.8  | 2.96×10 <sup>-17</sup>    |
| 38.8398           | 621.505               | 621.441              | +63.3  | 4.51×10 <sup>-17</sup>    |
| 38.8401           | 621.514               | 621.451              | +63.2  | 5.97×10 <sup>-17</sup>    |
| 38.8405           | 621.523               | 621.460              | +63.3  | 2.96×10 <sup>-17</sup>    |
| 38.8408           | 621.532               | 621.468              | +63.3  | 2.96×10 <sup>-17</sup>    |
| 38.8411           | 621.540               | 621.477              | +63.2  | 2.23×10 <sup>-17</sup>    |
| 38.8415           | 621.549               | 621.485              | +63.3  | 2.96×10 <sup>-17</sup>    |
| 38.8418           | 621.557               | 621.493              | +63.2  | 4.51×10 <sup>-17</sup>    |
| 38.8422           | 621.564               | 621.501              | +62.7  | 2.96×10 <sup>-17</sup>    |
| 38.8425           | 621.571               | 621.508              | +63.2  | 2.23×10 <sup>-17</sup>    |
| 38.9075           | 621.350               | 621.294              | +56.7  | 1.17×10 <sup>-18</sup>    |
| 38.9078           | 621.358               | 621.302              | +56.4  | 1.17×10 <sup>-18</sup>    |
| 38.9082           | 621.362               | 621.306              | +56.5  | 1.55×10 <sup>-18</sup>    |
| 38.9085           | 621.372               | 621.311              | +61.2  | 1.17×10 <sup>-18</sup>    |
| 38.9092           | 621.433               | 621.382              | +56.4  | 2.36×10 <sup>-18</sup>    |
| 38.9116           | 621.446               | 621.389              | +56.6  | 1.17×10 <sup>-18</sup>    |
| 38.9120           | 621.463               | 621.407              | +55.9  | 6.05×10 <sup>-19</sup>    |
| 41.8814           | 621.3607              |                      |  | 2.00×10 <sup>-19</sup>    |
| 41.8828           | 621.3732              | 621.2970             | +76.2  | 8.36×10 <sup>-18</sup>    |
| 41.8832           | 621.3776              | 621.3009             | +76.7  | 8.36×10 <sup>-18</sup>    |
| 41.8835           | 621.3827              | 621.3061             | +76.6  | 7.90×10 <sup>-17</sup>    |
| 41.8839           | 621.3885              | 621.3122             | +76.3  | 4.38×10 <sup>-19</sup>    |
| 41.8842           | 621.3950              | 621.3182             | +76.8  | 5.72×10 <sup>-19</sup>    |
| 41.8845           | 621.4025              | 621.3264             | +76.1  | 3.60×10 <sup>-18</sup>    |
| 41.8849           | 621.4109              | 621.3344             | +76.5  | 1.17×10 <sup>-18</sup>    |
| 41.8852           | 621.4203              | 621.3434             | +76.9  | 4.38×10 <sup>-19</sup>    |
| 41.8856           | 621.4307              | 621.3538             | +76.9  | 4.38×10 <sup>-19</sup>    |
| 41.8863           | 621.4543              | 621.3775             | +76.8  | 4.38×10 <sup>-19</sup>    |
| 41.8870           | 621.4810              | 621.4038             | +77.2  | 2.68×10 <sup>-19</sup>    |
| 41.8877           | 621.5092              |                      |  | 2.23×10 <sup>-19</sup>    |
| 41.8905           | 621.6013              |                      |  | 2.11×10 <sup>-19</sup>    |
| 41.8911           | 621.6153              |                      |  | 2.11×10 <sup>-19</sup>    |
| 41.8925           | 621.6345              |                      |  | 2.00×10 <sup>-19</sup>    |

| Date<br>MJD-50000 | Predicted<br>IF (MHz) | Observed<br>IF (MHz) | Observed-Predicted<br>Surfsat Link Freq. (KHz) | Flux<br>W M <sup>-2</sup> |
|-------------------|-----------------------|----------------------|--|---------------------------|
| 45.5620           | 621.3713              | 621.3156             | +55.7  | $3.26 \times 10^{-17}$    |
| 45.5623           | 621.3776              | 621.3221             | +55.5  | $8.20 \times 10^{-17}$    |
| 45.5634           | 621.4022              | 621.3467             | +55.5  | $2.59 \times 10^{-16}$    |
| 45.5641           | 621.4244              | 621.3690             | +55.4  | $3.26 \times 10^{-16}$    |
| 45.5648           | 621.4514              | 621.3964             | +55.0  | $1.30 \times 10^{-16}$    |
| 45.5655           | 621.5142              | 621.4586             | +55.6  | $8.20 \times 10^{-17}$    |
| 45.5668           | 621.5454              | 621.4906             | +54.8  | $6.51 \times 10^{-17}$    |
| 45.5675           | 621.5732              | 621.5186             | +54.6  | $5.17 \times 10^{-17}$    |
| 45.5682           | 621.5965              | 621.5421             | +54.4  | $2.06 \times 10^{-17}$    |
| 45.5689           | 621.6151              | 621.5607             | +54.4  | $1.30 \times 10^{-17}$    |

Table 1: Table of observed and predicted Surfsat frequencies and the signal strength of Surfsat observed with the Green Bank Earth Station from November 09, 1995 through November 24, 1995.