2017 Solar Eclipse Prediction Results
using the Sudden Ionospheric Disturbance Radio Telescope

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Abstract: This is a follow-up to the paper presented at the July 25, 2017 SARA Annual Conference in Green Bank, W.V., "*Ionospheric Reflection Variation During Sunrise and Sunset and Predictions for the 2017 Total Eclipse*" (1).This paper showed the development of a mathematical model to predict the signal response of the solar eclipse on the SuperSID radio telescope. The data of five SuperSID observers who measured data during the eclipse was obtained and analyzed. The model was applied to each observers' data to determine its predictive properties.

Background Science

The sudden ionospheric disturbance (SID) monitor measures the signal strength of a very low frequency (VLF) broadcast station after its signal is reflected off of the ionosphere. The characteristics of the signal strength is highly dependent on the local night and day.

The Sun's energy ionizes the Earth's atmosphere during the day. This produces different ionization layers defined as layers D, E, F. At night, there is only ionization from cosmic waves, and therefore there is only an F layer (2).

VLF radio waves reflect off the free electrons in the different ionosphere layers. The signal strength of this reflected signal can be detected by a SID small radio telescope. The normal use of the SID radio telescope is to detect solar flares which appear as short term signal strength increases during the daytime monitoring. The author will use the SID telescope's capability to measure and analyze the VLF signal strength variations and the effect of the solar eclipse on the ionosphere.

The total solar eclipse on August 21, 2017 in North America provided an opportunity to analyze the differences between the eclipse and normal daily ionospheric reflections.

The author has been using the SID radio telescope for over a year as an official observer for the American Association of Variable Star Observers (AAVSO) (3). By chance, the eclipse umbra passed between the VLF transmitter station and the author's SID radio telescope. This provided a unique opportunity to compare over a year's historic data with the eclipse data. In order to gain insight into the possible effects of the eclipse, the author developed two predictive models using historic data and eclipse times.

The eclipse prediction paper: "*Ionospheric Reflection Variation During Sunrise and Sunset and Predictions for the 2017 Total Eclipse*" (1) was presented on July 25, 2017 to the SARA Annual Conference in Green Bank, W.V. The paper is documented in the 2017 SARA Annual Conference Proceedings.

SuperSID Monitor Measurements

The author's Deep Space Exploration Society(DSES) (4) SuperSID station was set up in Colorado Springs, CO. It consisted of a VLF antenna, a preamp and a software program (2) as shown in figure 1.

Figure 1: Colorado Springs SuperSID Monitoring Station

Eclipse and VLF Signal Geometry

The solar eclipse forms when the Moon crosses between the Sun and the Earth. A total eclipse forms the umbra and a partial eclipse forms the penumbra. (figure 2)

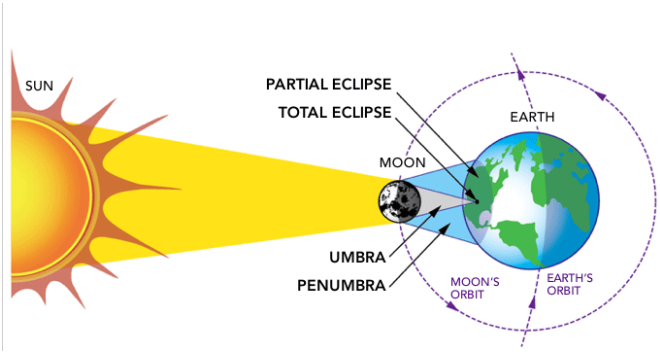


Figure 2: Eclipse Basics (Curtesy of NASA)

NASA had plotted the umbra and penumbra for the August 21 path through North America. The umbra and penumbra happened to cross through the line between the LaMoore, North Dakota VLF station and the author's SID radio telescope in Colorado Springs, Colorado. (figure 3).

Four other AAVSO observers also contributed their data. They were located at the following cities (table 1):

Table 1: AAVSO Observers and Range from NML

Observer ID	Observer Location	Distance from NML (km)
A94	St Cloud, MN	333 km
A121	Ft. Collins, CO	844 km
A125	Partridge, KS	933 km
A147 (author's)	Colorado Springs, CO	993 km
A138	Hermosillo, MX	2217 km

The geometry of the observers compared to the NML transmitter and the eclipse path is shown in figures 3 and 4.

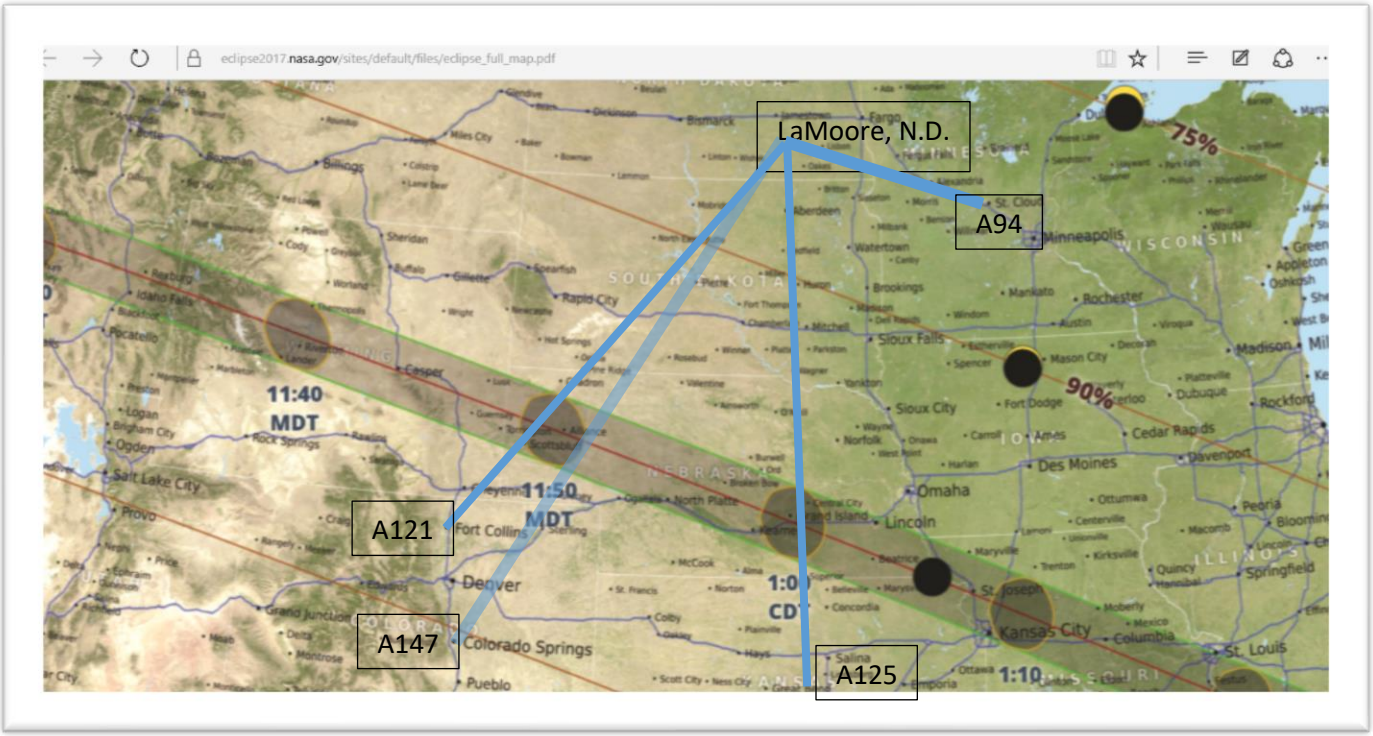


Figure 3: Eclipse Path (Curtesy of NASA) (5) (6)

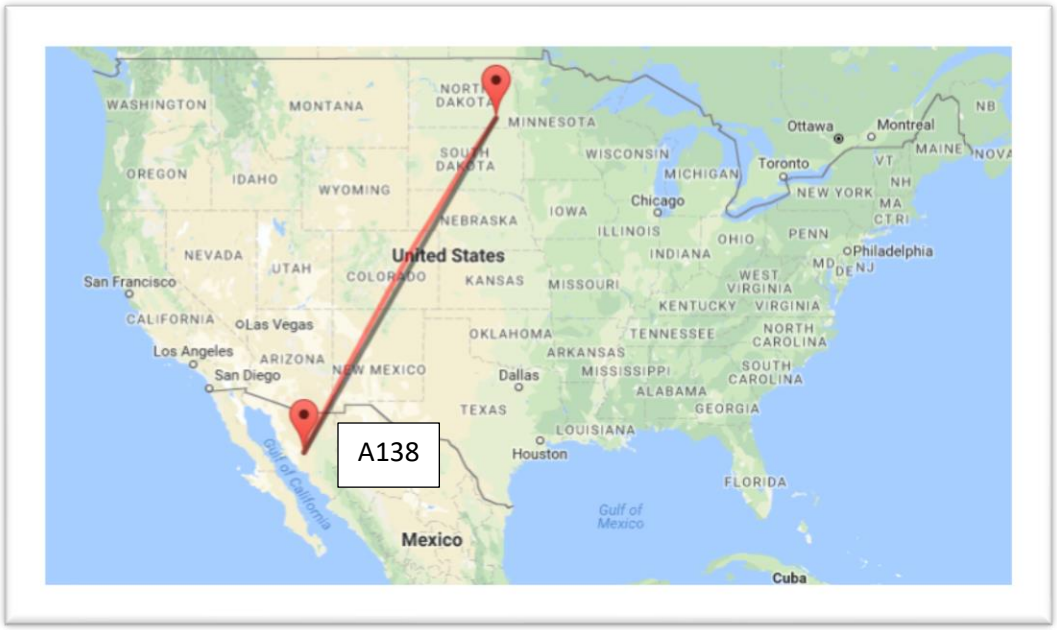


Figure 4: LaMoore, N.D. to Hermosilla, Mexico (A138) (7)

NASA also published the times for the eclipse for major cities along the path. (figure 4)

	Eclipse Begins	Totality Begins	Totality Ends	Eclipse Ends	
Madras, OR	09:06 a.m.	10:19 a.m.	10:21 a.m.	11:41 a.m.	PDT
Idaho Falls, ID	10:15 a.m.	11:33 a.m.	11:34 a.m.	12:58 p.m.	MDT
Casper, WY	10:22 a.m.	11:42 a.m.	11:45 a.m.	01:09 p.m.	MDT
Lincoln, NE	11:37 a.m.	01:02 p.m.	01:04 p.m.	02:29 p.m.	CDT

Figure 4: Eclipse Schedule (Courtesy of NASA) (5)

One of the key predictions was to determine when the start, totality and end of the eclipse would appear for the SID radio telescope. The VLF path line crosses the full totality point at the 11:50 AM point. Using the Casper, WY schedule in figure 4, the rough estimate is that the times should be adjusted by + 8 minutes. Add 6 hours to convert from Mountain Daylight time gives:

Eclipse Begins: 1630 UTC
Totality Begins: 1750 UTC
Totality Ends: 1753 UTC
Eclipse Ends: 1917 UTC

For the author's SuperSID station (A147), the result was early by about 10 minutes for the actual eclipse. The error could have been reduced by using a more accurate chart and deriving the eclipse crossing using a great circle projection chart.

Calculating the Eclipse Area over Time

As the Moon passed in front of the Sun, it subscribes an arc *abc*. The total area eclipsed is therefore areas (A1+A2). (figure 5).

Note: the full derivation is shown in (1).

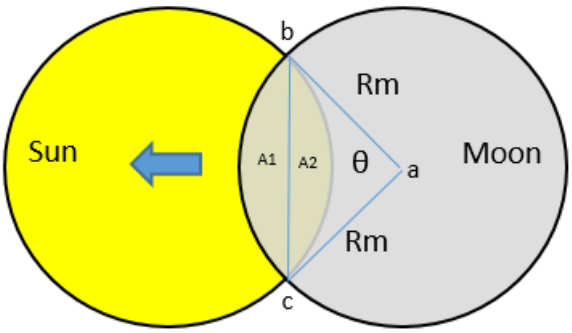


Figure 5: Sun and Moon Eclipse Geometry

$$Percent\ Sun\ Eclipsed = \frac{\theta}{180} - \frac{2}{\pi}\boldsymbol{cos}\left(\frac{\boldsymbol{\theta}}{\mathbf{2}}\right)\boldsymbol{sin}\left(\frac{\boldsymbol{\theta}}{\mathbf{2}}\right) \qquad (1)$$

Equation 1 allows for the calculation of the percentage of the Sun that is being eclipsed without knowing the apparent radius of either the Sun or the Moon. The eclipse area calculation is shown in figure 6.

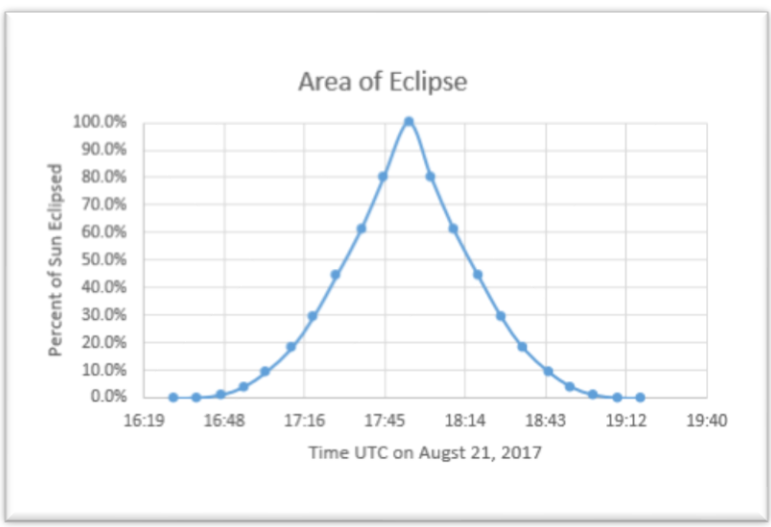


Figure 6: Calculations and Plot for % Sun Eclipsed over Time

The prediction for the effects of the eclipse on the A147 SuperSID monitor data is shown in figure 7.

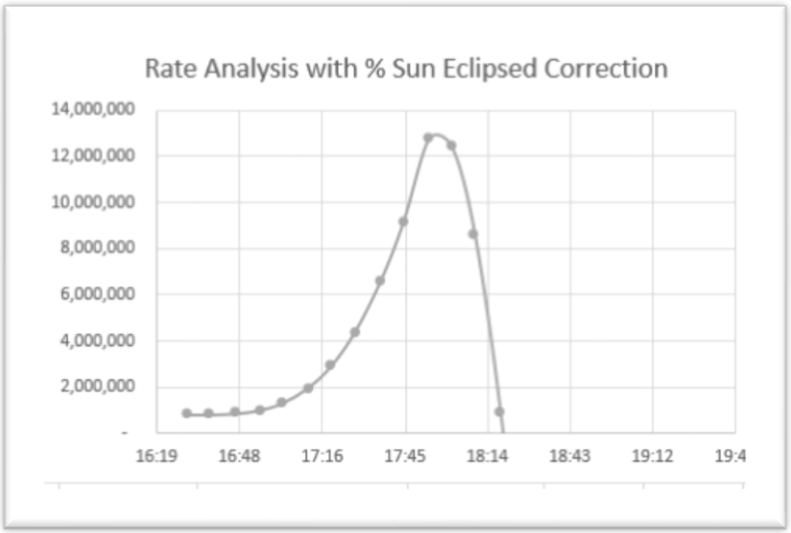


Figure 7: Prediction for A147

Actual Eclipse Measurement

The data from the A147 DSES SuperSID was analyzed using the SIDGRABBER (8) software.

A signal was detected during the time of the eclipse (figure 8).

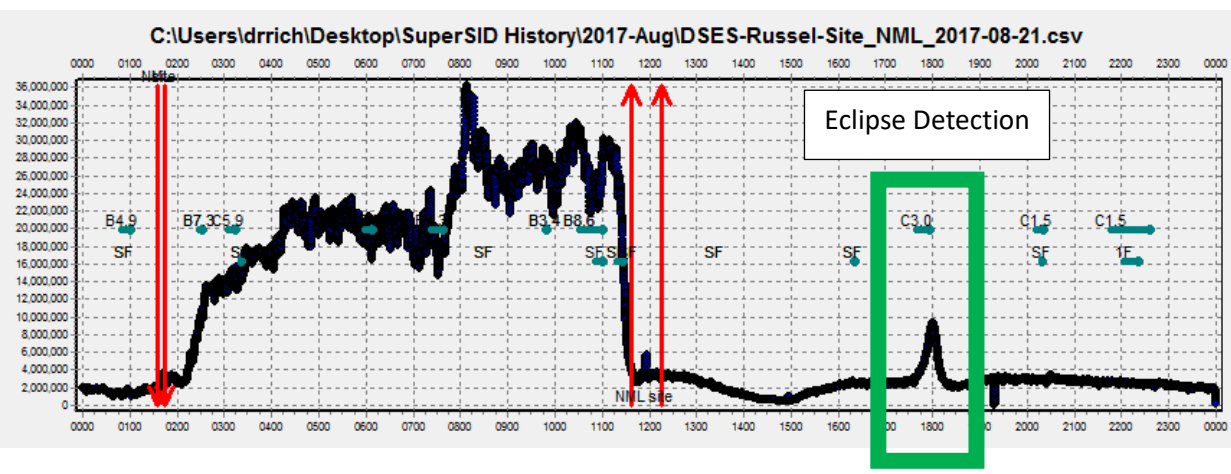


Figure 8: August 21, 2017 Eclipse data

Zooming in on the eclipse time shows that the predicted and the actual eclipse signal was similar. Figure 9 shows the predicted and the actual side by side. Note that there is also a C3.0 flare during the eclipse time. There does not appear to a clear effect of the C3.0 flare. It is possible that any effect was masked by the solar eclipse signal.

By plotting the entire predicted chart, which was based on May 2017, with the actual eclipse day results of August 21, 2017 the scale of the signal against normal night time conditions can be seen.

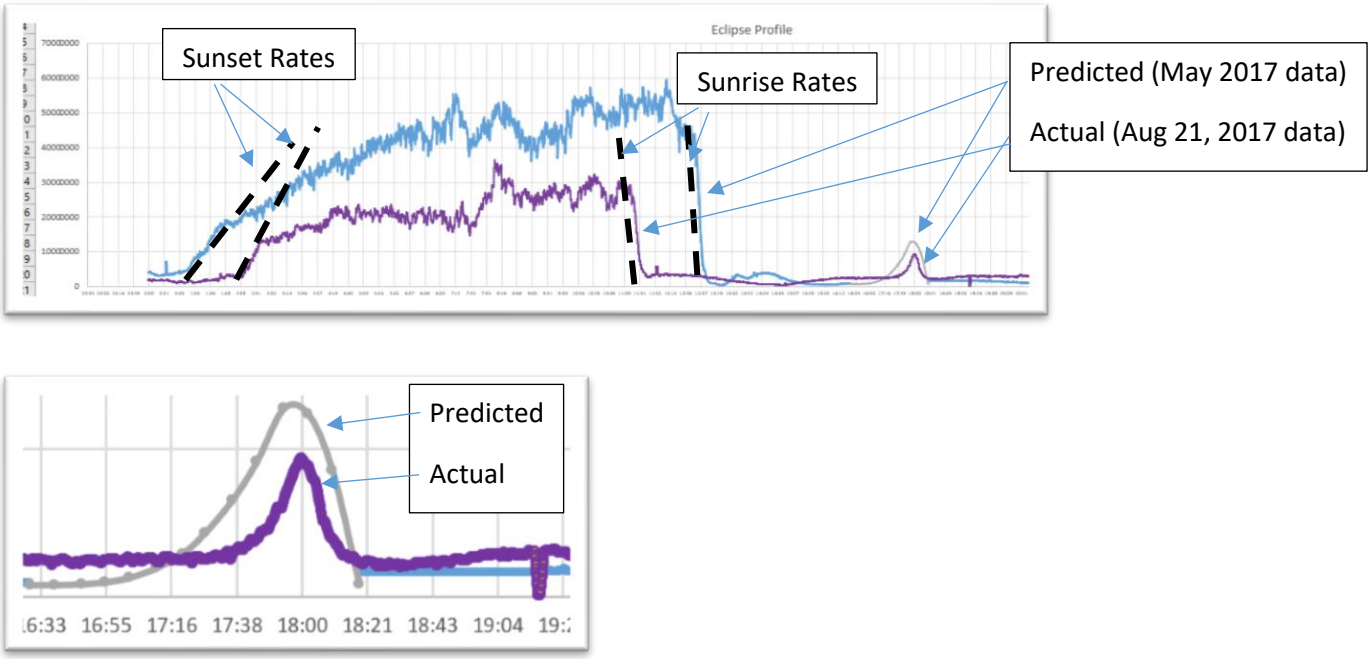


Figure 9: Actual Results vs Prediction for A147

Updated Model based on Eclipse Day Environment

The original prediction used the average sunrise and sunset data for the last year for A147. The updated model (figure 10) used the August 21, 2017 sunset/sunrise rates. The time was also adjusted so that the maximum peak of the updated model corresponded with the actual eclipse data.

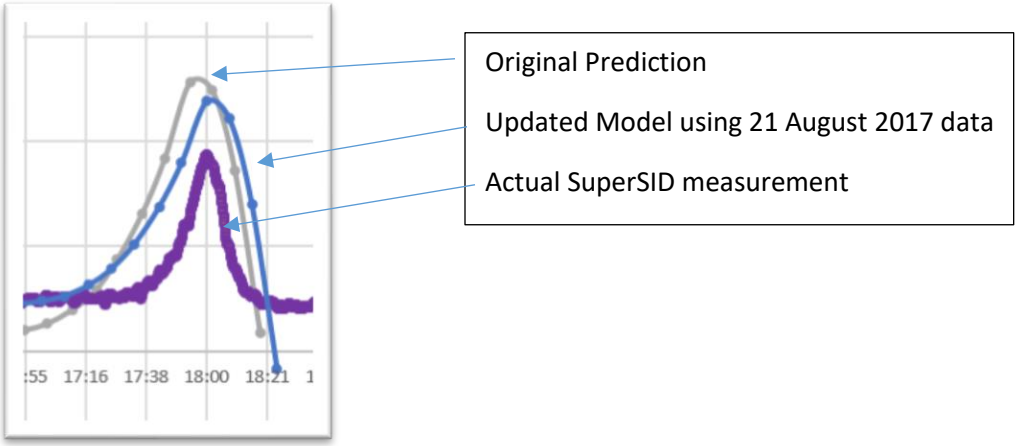


Figure 10: Updated Eclipse Model Using 21 August 2017 Data

The actual eclipse shape appears more symmetrical than the prediction model. This may indicate that the sunrise and sunset rates used may be affected by the Earth's terrain while the actual eclipse signal was not. Note that the SuperSIDS system for A147 is located on the eastern side of Pike's Peak, a 14,115 ft. mountain. It has also been noted (1) that the sunset rates change throughout the year. This might be caused by the location along the mountain where the sunset occurs. Some parts of the mountain range, during the sunsets, are low while Pike's

Peak is the highest point to the west. Further investigation is warranted on the effects of the local horizons on the sunset and sunrise rates.

In order to determine if the model works for other SuperSID radio telescopes, observation of the eclipse were obtained from four other AAVSO observers. All of the observations indicated an increase in signal during the eclipse period. Based on research, distance from the transmitter site may cause a different signal characteristics. (9) This research analyzed VLF signals from the 2001 eclipse and showed that at certain distances from the transmitter the signal was actually inverted below the normal average levels. This was normally found greater than 2000 km from the transmitter, while negative signals were noted greater than 10,000 km. The AAVSO observers were all within 2300 km, and were also all positive signals, which correlates with the 2001 eclipse results.

The stacked plots of the five eclipse observations are shown in figure 11.

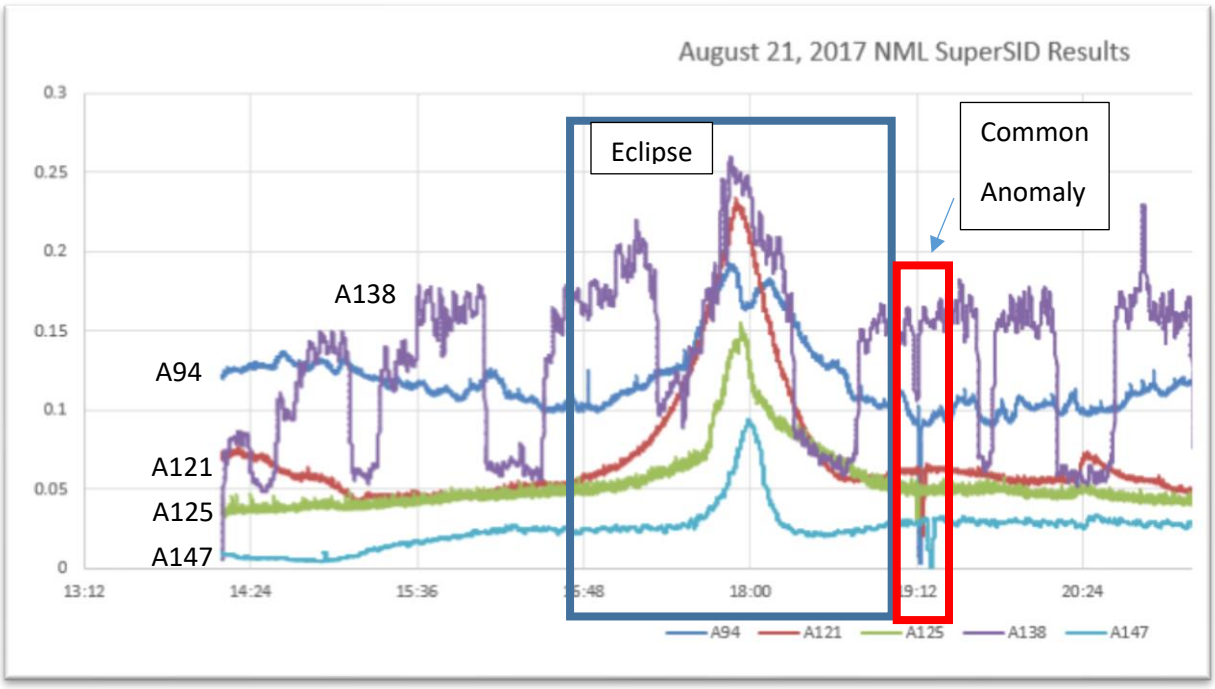


Figure 11: Multiple Observer Eclipse Results

Analysis of multiple observations

1) Almost all have the single peak characteristic except A94 which exhibits a double hump. This was also observed in some of the 2001 eclipse results (9).

2) A common drop in signal is common in all observer's data at approximately 1912Z. This will be referred to as the common anomaly. The author has not been able to determine a hypothesis for this anomaly, however, it occurred at the end of the predicted eclipse time.

3) The width of the base of each signal varies between observations.

4) The eclipse crossing geometry and the range to NML would provide more insight into the eclipse effect.

The raw data for each of the four other AAVSO observers is shown in figures 12 to 15. The internal table on each figure shows the measured sunset and sunrise times measured for each observer.

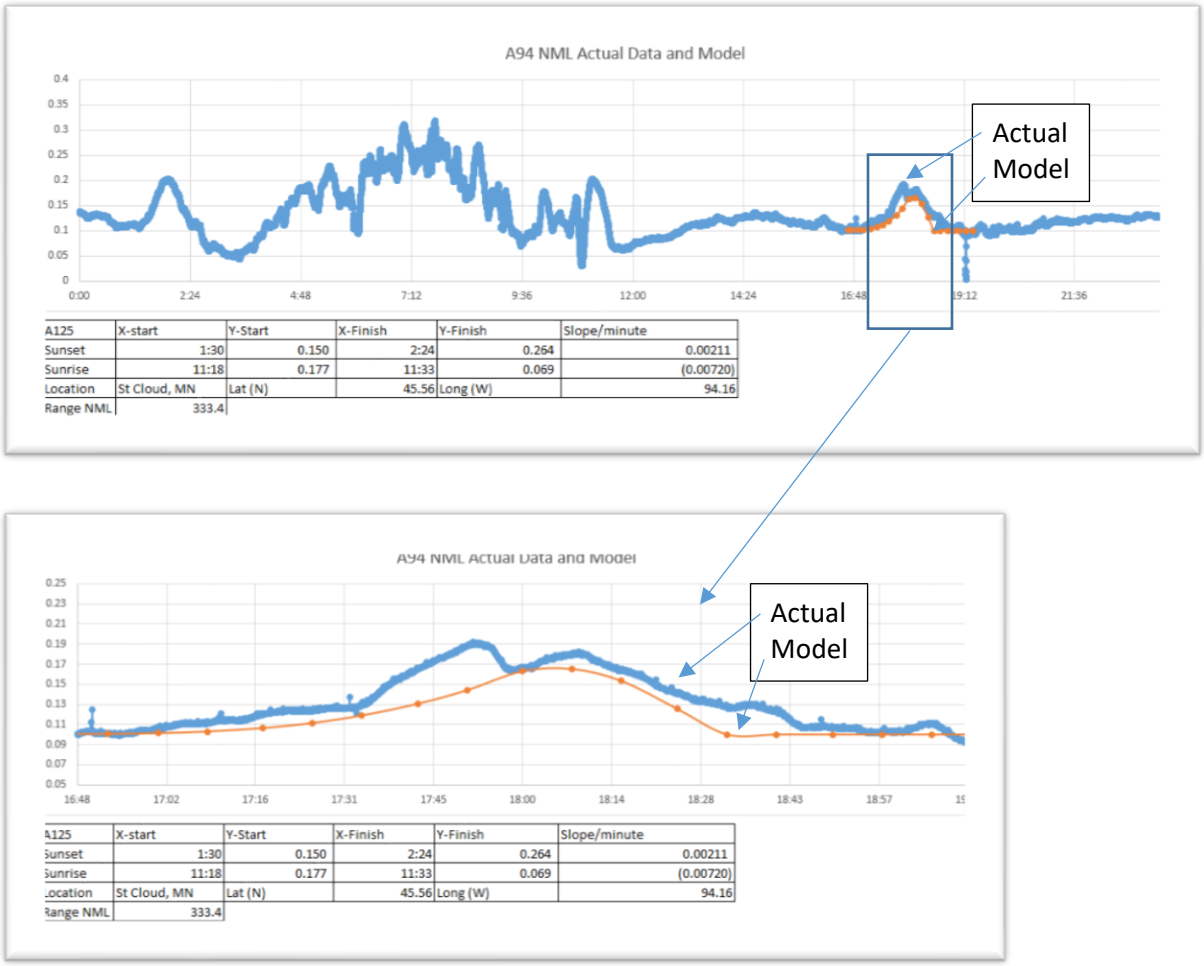
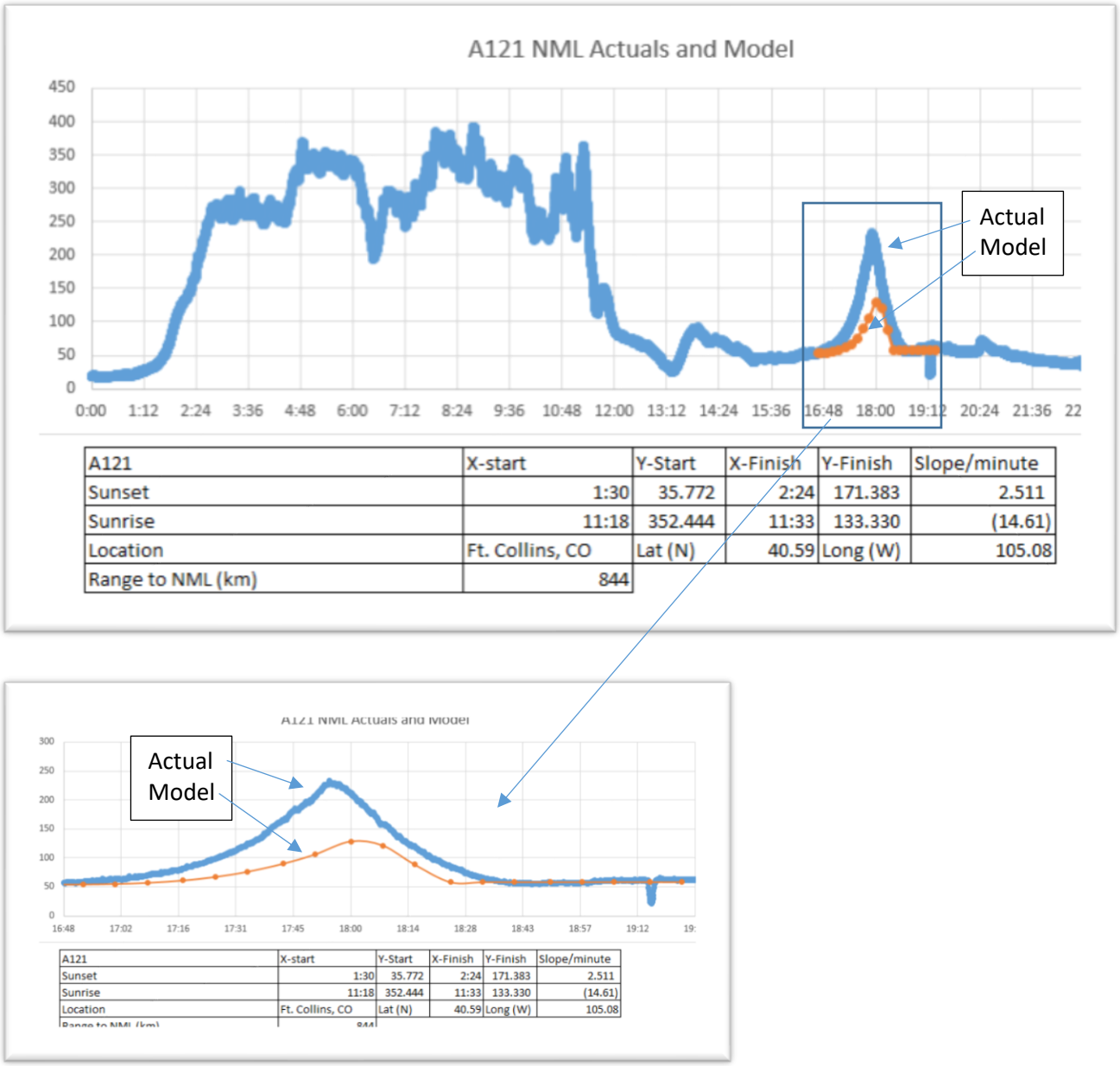
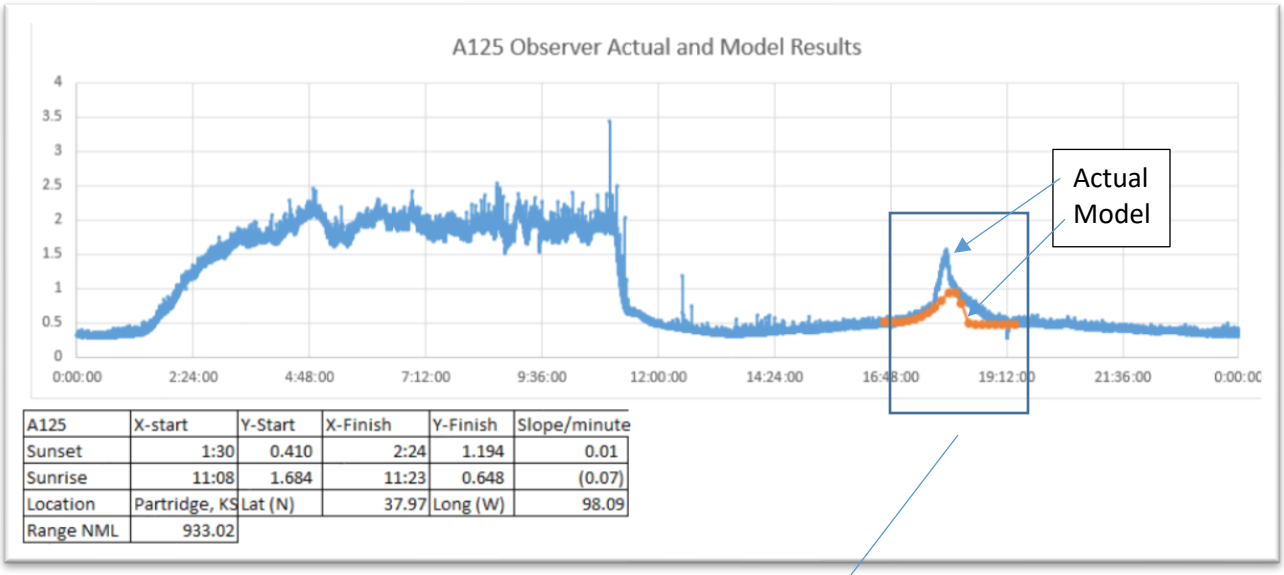


Figure 12: A94 NML Actual and Model Data for August 21, 2017



A121	X-start	Y-Start	X-Finish	Y-Finish	Slope/minute
Sunset	1:30	35.772	2:24	171.383	2.511
Sunrise	11:18	352.444	11:33	133.330	(14.61)
Location	Ft. Collins, CO	Lat (N)	40.59	Long (W)	105.08
Range to NML (km)	844				

Figure 13: A121 NML Actual and Model Data for August 21, 2017



A125	X-start	Y-Start	X-Finish	Y-Finish	Slope/minute
Sunset	1:30	0.410	2:24	1.194	0.01
Sunrise	11:08	1.684	11:23	0.648	(0.07)
Location	Partridge, KS	Lat (N)	37.97	Long (W)	98.09
Range NML	933.02				

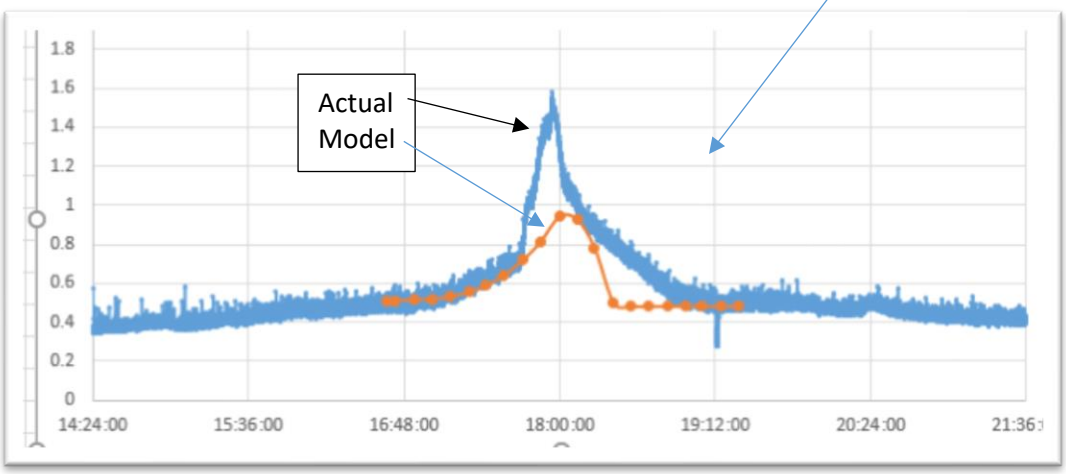


Figure 14: A125 NML Actual and Model Data for August 21, 2017

A138	X-start	Y-Start	X-Finish	Y-Finish	Slope/minute
Sunset	Bad Data			-	-
Sunrise	Bad Data			-	-
Location	Hermosilla, Mexico	Lat (N)	29.095N	Long (W)	110.95W
Range to NML (km)	2217				

Figure 15: A138 NML Actual and Model Data for August 21, 2017

Note that A138 had a problem with its data for August 21, however, it still shows an eclipse signal. The sunset and sunrise rates could not be derived from the signal. The A138 observation is shown because of its range from NML (2217 km).

Follow-On Analysis

Detailed follow-on study of the results are needed to evaluate the difference of the eclipse results and normal sunset and sunrise results. Some areas of future research include:

- Analysis of the increase and decrease rates to see if there is terrain variations in the normal data
- Development of an accurate model for predicting eclipse crossing time using great circle routes

- Analysis of the other VLF transmitter frequency results using the Stanford Database
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Summary

The 2017 Annual SARA Conference paper provided an approximation to predicting the eclipse signal response on the SuperSID radio telescope. This analysis used mathematical models and historic datasets to provide this prediction of the eclipse response. Further analysis is warranted to determine the slight variations of predicted and actual data. This analysis could add value to the overall SuperSID signal model for solar flares in the future.

Further work is also required to refine the model to provide for the more input and output variables including:

a) Range from the transmitter

b) amplitude of the received signal

c) width of the received signal

The model successfully predicted the eclipse signal. The follow-on work will help refine the amplitude and shape of the model to improve the signal characteristic predictions.

Online Videos of the SARA Conference

During the July 25, 2017 SARA Annual Conference in Green Bank, W.V., Richard Russel in his paper, "*Ionospheric Reflection Variation During Sunrise and Sunset and Predictions for the 2017 Total Eclipse*". Video is at time 1:27 https://www.youtube.com/watch?v=zOOuiirE1L4

Dr. Russel also presented a paper on the use of Monte-Carlos analysis: *"The Use of Monte-Carlo Analysis to Evaluate Radio Astronomy Source Detection"***.** The video is at time: 1:46:

https://www.youtube.com/watch?v=QQL1sarelQs

Works Cited

1. *Ionospheric Variation During Sunrise and Sunset and Predictions for the 2017 Total Eclipse.* Russel, Richard. Green Bank, W.V. : Society of Amateur Radio Astronomers, 2017. SARA 2017 Annual Conference.

2. Stanford Solar . *SuperSID Manual: Space Weather Monitors.* s.l. : Stanford Solar Center, Stanford University, 2009.

3. American Association of Variable Star Observers. *AAVSO.org.* [Online]

4. Deep Space Exploration Society. [Online] DSES.Science.

5. NASA. https://eclipse2017.nasa.gov/eclipse-who-what-where-when-and-. [Online]

6. —. https://eclipse2017.nasa.gov/sites/default/files/eclipse_full_map.pd. [Online]

7. DistanceFromTo. [Online] http://www.distancefromto.net/.

8. American Association of Variable Star Observers - SID Data Grabber. *Sudden Ionospheric Disturbances (SIDs).* [Online] https://www.aavso.org/category/tags/sid-section.

9. *Total Solar Eclipse Effects on VLF Signals> Observations and Models.* Mark Clilverd, Craig Rodger, Neil Thomson, Janos Lichtenberger, Peter Steinbach, Paul Cannon, Matthew Angling. July/August 2001, Radio Science, Vol. Volume 36 Number 4, pp. 773-778.

10. https://en.wikipedia.org/wiki/Snell%27s_law. *w.* [Online]