Planning for the 2017 Solar Eclipse at VLF and LF

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1. Introduction

Solar eclipses of all types (partial, annular, total) are not particularly rare worldwide (for example, see {Solar}). Total solar eclipses (TSE) occur somewhere around the world annually but for most of us the opportunity to view a TSE happens only a few times in our lifetime. This brief article provides information to help you plan for the solar eclipse in 2017 and observe its effects on propagation of terrestrial radio waves at very low frequencies (VLF, 3 to 30 kHz) and low frequencies (LF, 30 to 300 kHz).

On 21 August 2017, a total solar eclipse will be visible in the United States (figure 1). The path of totality – the path where the Moon totally obscures the Sun as viewed from Earth's surface – starts in Oregon about 1715 UTC and ends in South Carolina about 1850 UTC. The duration of total eclipse will be about 2.5 min at any given location along the totality path. The Moon will cast a shadow up to 115 km wide as it moves across the contiguous states, taking about 4 hours from start to finish (longer if you consider the two non-contiguous states Alaska and Hawaii). See {Path} for more detail.

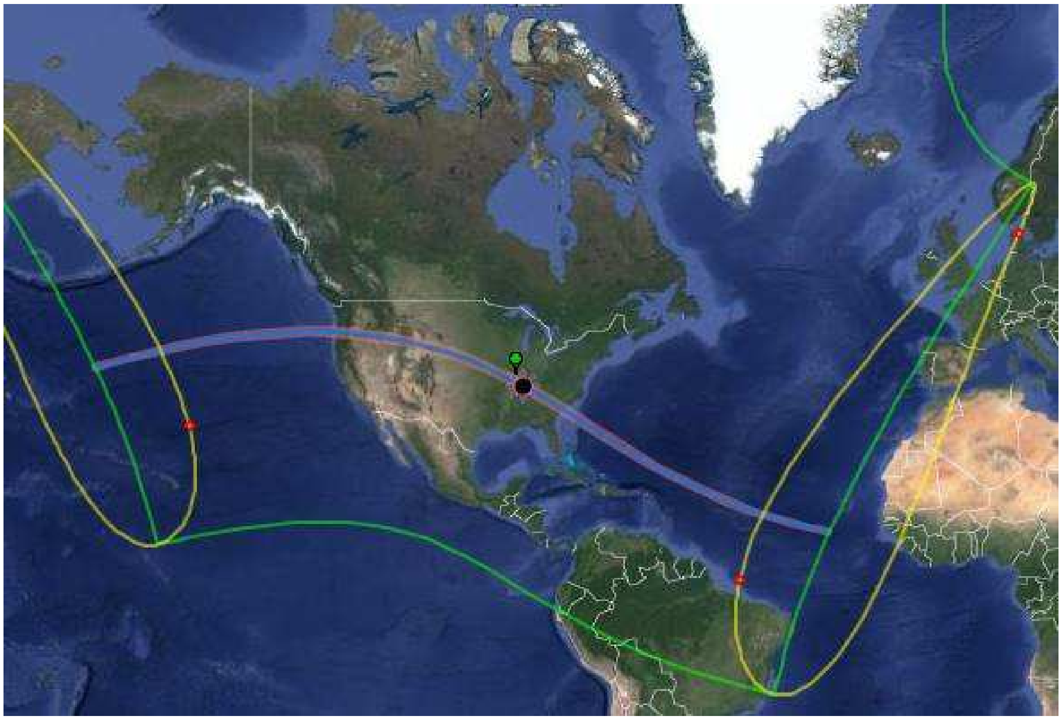

Figure 1 ~ Path of the 2017 solar eclipse across Earth's surface. It will be at least partially visible within the area outlined in green. The northern and southern limits of totality are shown by the thick purple-pink line with blue center. The location of longest duration, 2 min 41.0 s in southern Illinois, is indicated by the green pin. Image source: Google Earth at {GE-Eclipse}. For a similar map, see {NASA}.

All states in the USA will be able to view at least a partial eclipse. Two extremes are Barrow, Alaska with 22% maximum obscuration and South Point on the big island of Hawaii with 19% maximum obscuration. I will be able to view more obscuration, 48%, at my Cohoe Radio Observatory in southcentral Alaska (60.4°N, 151.3°W).

Now is the best time to start planning your radio observations. Do not wait until the last minute next August. If you are involved with schools, remember that you need to be prepared for the eclipse as well as for the chaos that ensues when school starts about the same time in late August and early September. Even if you are not along the totality path, it will be fun planning, participating and observing. Be sure to pretest your receiving or monitoring system long before 21 August so that you have plenty of time to familiarize yourself with it and correct any problems.

2. Propagation

The primary modes of propagation for terrestrial VLF and LF radio waves during daytime are groundwave and Earth-D-region ionosphere waveguide mode [Hunsucker]. Due to Earth losses, the groundwave dissipates over fairly short distances, but the waveguide mode supports a spacewave that can propagate much farther (figure 2).

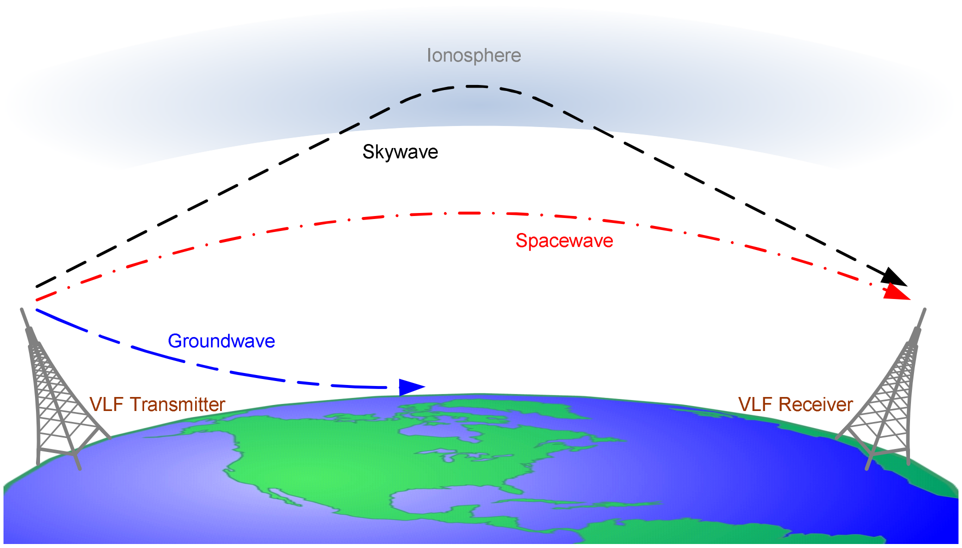

Figure 2 ~ Propagation at VLF and LF consists mainly of groundwaves and spacewaves. The groundwaves dissipate over relatively short distances, but the spacewaves use an Earth-Ionosphere waveguide mode that supports propagation over thousands of km. The skywave is important at higher frequencies but generally not used by VLF and LF radio waves. Image ©2010 W. Reeve.

The D-region is the lower portion of the ionosphere that extends from about 60 to 90 km altitude. The atmospheric pressure at 60 km altitude is only 0.02% of the pressure at Earth's surface (on the order of 0.02 kPa compared to 100 kPa, see {Atmos}), and the temperature is around –30° C. The atoms and molecules in the rarefied atmosphere are ionized by the Sun's ultraviolet (UV) and X-ray radiation, resulting in electron densities in the range 10^7 to 10^{10} electrons-m^{-3}. The free electrons provide a conductive layer that is the upper part of an Earth-Ionosphere waveguide. The D-region quickly disappears at sunset when the positive ions and electrons readily recombine.

As a first order approximation, VLF and LF radio waves propagating at a low angle during the day are refracted at the sharp boundary in the D-region because the electron density and, thus, the refractive index changes significantly within a few tens of km, or about one wavelength (the wavelength of a 20 kHz radio wave is 15 km). The refraction altitude falls sharply perhaps 15 km before ground sunrise, remains almost constant during the day, and rises sharply after ground sunset. These altitude changes at sunrise and sunset affect propagation and are most apparent on east-west propagation paths.

Since the D-region remains almost constant during the day, the received signal strength also remains almost constant. However, the signal strength is relatively low during the day because the radio waves penetrate the D-region on the way in and out and lose some energy by absorption. At night, the D-region disappears so the radio waves experience less loss as they are reflected by the higher ionosphere regions that remain on the Earth's night-side, specifically the sporadic E-region and F-region. However, the reduction of ionization in the E- and F-regions at night causes significant variations in received signal levels (Fig. 3).

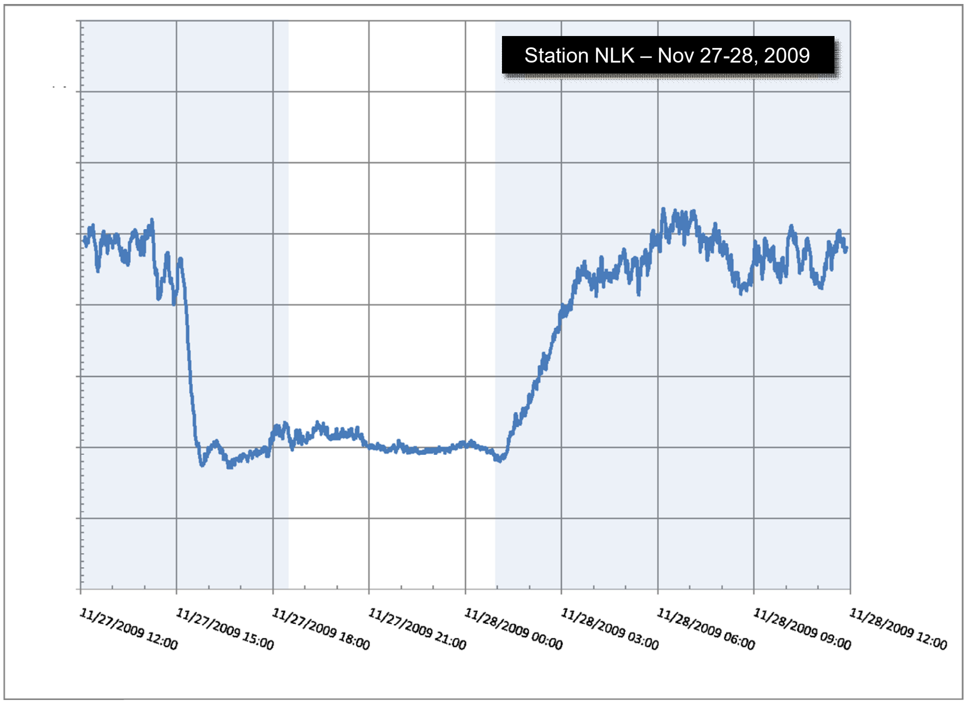

Figure 3 ~ Relative received signal level versus time at Anchorage, Alaska from transmitting station NLK located at Jim Creek, Washington about 2300 km away. Frequency is 24.8 kHz. The shaded areas indicate before sunrise (left) and after sunset (right). The plot illustrates two characteristics of VLF propagation – the relatively lower but constant level during the day and higher but more variable level during the night. Note that the signal level sharply dips 3 h before sunrise but starts rising almost immediately after sunset. Image ©2009 W. Reeve.

The onset of a solar eclipse at a given location will be like a sunset and the reappearance of the Sun a few minutes later will be like a sunrise. The Sun's radiation reaching the D-region will be reduced in the eclipse shadow. This in turn allows the ions and electrons to recombine, reducing the amount of ionization and changing the characteristics of the Earth-Ionosphere waveguide through which the VLF and LF radio waves propagate. Based on this comparison to sunset and sunrise, we would think that a plot of the received signal level will show a momentary increase during the eclipse. However, the daytime E- and F-regions will be considerably different than at night, so it remains to be seen what will be observed at any given location. Observed propagation phenomena from past eclipses are listed in the next section.

As the eclipse sweeps across the USA, the changes in the ionosphere will correspondingly vary with time and position above Earth's surface. Winds and turbulence at D-region altitudes can induce additional variability in VLF and LF propagation during the eclipse. Earth's magnetic field also influences propagation and different magnetic field inclinations at the receiver and transmitter stations may have some effect during the eclipse.

Ionospheric variations affect a wide range of frequencies but we are particularly interested in frequencies in the range 15 kHz to above 60 kHz used for submarine communications and navigation and time signals. In 1952, Robert Bracewell was the first investigator to report the radio phenomenon when he observed a 1949 partial eclipse while he was with the Division of Radiophysics, Commonwealth Scientific and Industrial Research Organization in Australia [Bracewell].

3. Observed Phenomena

To give you an idea of some of the VLF and LF radio phenomena that might be observed during the 2017 TSE, here is a brief list from scientific work dating from the present back to 1952 (these are described in slightly more detail in [Silber]).

1) Phase changes in the received signal due to apparent change in the D-region reflection height of up to 11 km and a corresponding change to the radio wave's path length
2) Amplitude changes of up to 3 dB with polarities (increase or decrease) that depend on the length of the TRGCP traversed by the TSE
3) Turbulence, wave-like structures and oscillations in the D-region as the TSE passes through the transmitter-receiver great circle path (TRGCP), lasting up to 80 min
4) Delays between the TSE maximum and signal reception response of up to 4 min
5) Ionosphere changes that are not linearly dependent on the solar obscuration percentage (although some studies noted linearity)
6) Gravity waves. Gravity Waves are the physical responses driven by gravity's restoring force after a disturbance in the atmosphere and bodies of water. Ocean and atmospheric waves are examples. Gravity waves that reach the altitude of the D-region are detected by their effect on propagation.

4. Detecting and Monitoring

Monitoring solar effects on VLF and LF transmissions is a popular activity with SARA members who use the SuperSID monitor (figure 4). If you do not already have a SuperSID, you can order one from SARA at {SuperSID}; however, an antenna is not included (see below). The SARA website also has weblinks that will help you get setup. Other receiver and monitor configurations may be used including the single-frequency receiver available from {UKRAA}, but the SuperSID is unique for packaged systems in that it can simultaneously monitor multiple transmitting stations.

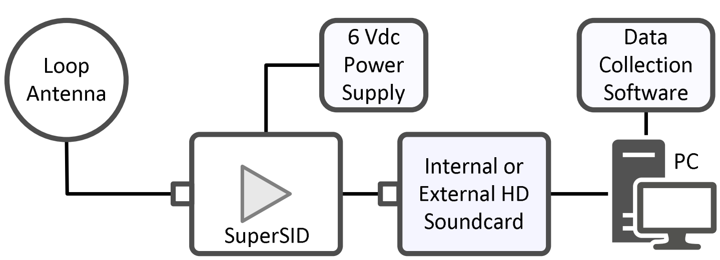

Figure 4 ~ Block diagram showing the SuperSID VLF monitor. The SuperSID includes a 6 Vdc power adapter and necessary software. It works best with a high definition (HD) internal or external soundcard that supports at least 96 kHz sampling rate, in which case the SuperSID can monitor a range of frequencies up to about 48 kHz. Image ©2016 W. Reeve.

Generally, a loop antenna is recommended for the low frequencies involved, and loops are easy to build. A loop with diameter larger than 1 m (0.8 m^2 area) and possibly a preamplifier may be needed if you are located more than a couple thousand km from a transmitting station. Information on building a suitable loop antenna can be found at the Stanford Solar Center {SSC}. For a description of the construction of a large octagon loop with a flat-to-flat distance of 1.7 m (2.3 m^2 area) go to {Loop}.

Depending on your receiver and antenna, you can receive one or more transmitting stations and observe propagation anomalies on different transmitter-receiver great circle paths (TRGCP) during the eclipse. The TRGCP is the path over the ground followed by the VLF and LF radio waves as they propagate from a transmitter to a receiver. It will be well worth your effort planning the paths to be monitored and working out the transmitter-receiver location relationships beforehand. For example, your station location may allow reception on a TRGCP parallel to the totality path, at a right-angle to it or at some other angle. The TSE effects and their timing likely will be different for different orientations and locations.

A list of VLF and LF stations worldwide that may be suitable for receiving during the TSE can be found at {StaList}. It is possible that not all stations listed are active or can be received at your location but it will give you a place to start.

If you would like to know the great circle distance and bearing between your location and a particular transmitter, use the distance and bearing calculator for cities at {Cities} or for geographical coordinates at (Coord1} or {Coord2}. If you like to do great circle calculations by hand or with a programmable calculator, see {Calc}. You also can download a map image that is centered on your station or any other location and then project a line to a transmitting station (figure 5); see {Map1} or {Map2}. Great circle calculations and maps are important aids for pointing a directional antenna such as a loop.

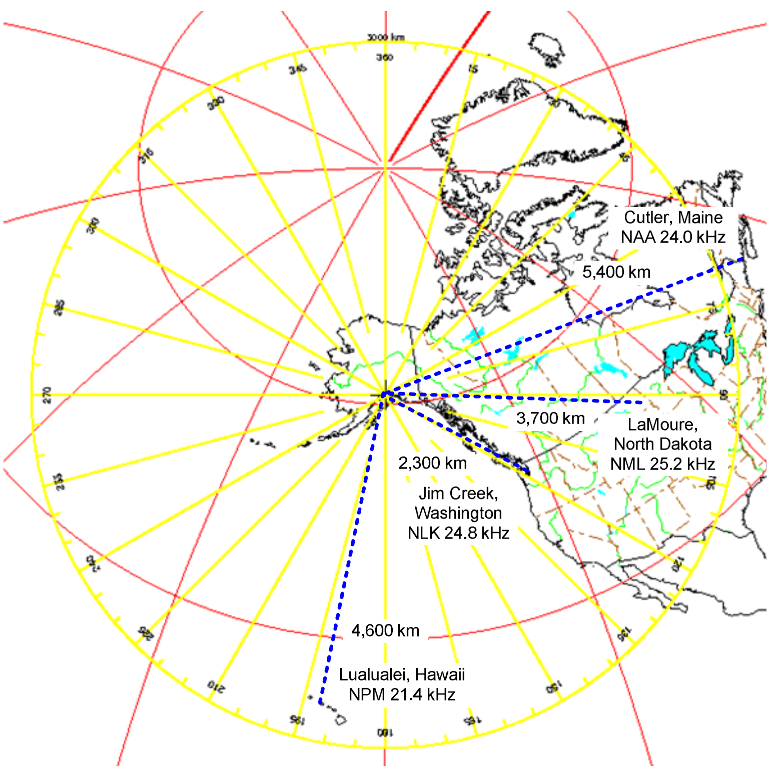

Figure 5 ~ Azimuth map centered on Anchorage, Alaska. For this image I pasted the map image into Microsoft Visio (other drawing programs will work, too) and drew dotted lines between my Anchorage observatory and three VLF transmitting stations in the USA. I also added annotations to indicate location, call sign, distance and frequency. The red lines are part of the original map and are latitude and longitude based on geographical coordinates. The yellow lines also are part of the original map and are true north compass rose lines from Anchorage. Image ©2010 W. Reeve.

5. Conclusions

The total solar eclipse on 21 August 2017 provides a great opportunity for VLF and LF enthusiasts in the United States to measure propagation anomalies as the Moon's shadow alters the amounts of D-region ionization and perturbs propagation. These effects likely will be observable even outside the path of totality. To be most successful observers should start planning now for the event.

6. Weblinks and References

{Atmos}	http://www.braeunig.us/space/atmos.htm
{Calc}	http://www.reeve.com/Documents/Articles%20Papers/Reeve_PosDistBrngCalcs.pdf
{Cities}	http://www.timeanddate.com/worldclock/distance.html
(Coord1}	http://williams.best.vwh.net/gccalc.htm
{Coord2}	http://www.chemical-ecology.net/java/lat-long.htm
{GE-Eclipse}	http://xjubier.free.fr/en/site_pages/solar_eclipses/TSE_2017_GoogleMapFull.html
{Loop}	http://www.reeve.com/Documents/Articles%20Papers/Reeve_OctagaonLoopAntennaConstruction.pdf
{Map1}	http://ns6t.net/azimuth/azimuth.html
{Map2}	http://www.wm7d.net/az_proj/az_html/azproj.shtml#make_map
{NASA}	http://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2017Aug21Tgoogle.html
{Path}	https://eclipse.gsfc.nasa.gov/SEpath/SEpath2001/SE2017Aug21Tpath.html
{Solar}	http://www.timeanddate.com/eclipse/list.html%3Fstarty%3D1950
{SSC}	http://solar-center.stanford.edu/SID/sidmonitor/
{StaList}	http://www.reeve.com/Documents/Articles%20Papers/Reeve_VLF-LFStationList.pdf
{SuperSID}	http://radio-astronomy.org/node/210

[Bracewell] Bracewell, R., Theory of Formation of an Ionospheric Layer Below E Layer Base on Eclipse and Solar Flare Effects at 16 kc/sec, Journal of Atmospheric and Terrestrial Physics, Vol. 2, Iss. 4, pg 226-235

[Hunsucker] Hunsucker, R. and Hargreaves, J., The High-Latitude Ionosphere and its Effects on Radio Propagation, Cambridge University Press, 2003

[Silber] Silber, I. and Price, C., On the Use of VLF Narrowband Measurements to Study the Lower Ionosphere and the Mesosphere-Lower Thermosphere, Survey of Geophysics, DOI: 10.1007/s10712-016-9396-9, 2016

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