NVIS COMMUNICATIONS DURING THE SOLAR MINIMUM

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ABSTRACT

A popular technique for providing non line-of-sight coverage in mountainous or urban terrain is high frequency (HF) radio near-vertical incidence skywave (NVIS) mode. In NVIS operation, HF energy is directed vertically, and is refracted from the ionosphere to return nearly vertically to the area surrounding the transmitter; this nicely avoids nearly all obstacles. Direction finding versus a NVIS transmitter is also made difficult to the extent that the energy is directed vertically and groundwave is suppressed.

However, NVIS operation requires the presence of substantial ionization in the ionosphere directly overhead the transmitter, so some concern is warranted about the effectiveness of NVIS operation during a solar minimum. In this paper, we present measurements and analysis of a multi-year NVIS experiment conducted during the current minimum of the sunspot cycle, including the effectiveness of the NVIS mode of operation, and evaluation of the accuracy of standard HF propagation programs in predicting usable operating frequencies.

INTRODUCTION

When line-of-sight communications is blocked by mountainous or urban terrain, high frequency (HF) radio in near-vertical incidence skywave (NVIS) mode provides a useful solution [1]. NVIS operation is a special case of skywave operation that launches HF energy nearly vertically, with reflected energy coming back to the Earth's surface with a nearly vertical angle of arrival throughout the region surrounding the transmitter (Figure 1). This popular mode overcomes nearby terrain obstacles without a skip zone, but requires careful selection of antennas and operating frequency. Direction finding versus a NVIS transmitter is also made difficult to the extent that the energy is directed vertically and groundwave is suppressed.

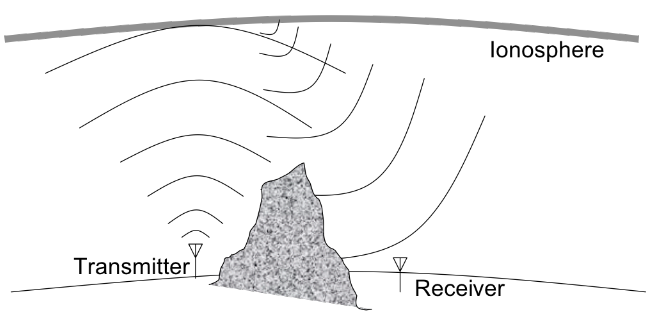

Figure 1: NVIS Operation

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One of the peculiar characteristics of HF radio skywave (including NVIS) propagation is a strong dependence of path loss on operating frequency. In particular, the highest useful frequency on a given point-to-point link is determined by the current ionization of the region(s) of the ionosphere where the propagating wave is refracted. Frequencies above the critical frequency are not "bent" sufficiently to return to Earth, and so cannot be used for communication *over that path* and *at that time*. The amount of bending required, and therefore the required free electron density, increases with the angle of arrival of the signal. This angle is at its maximum for NVIS operation.

Thus, NVIS operation requires the presence of substantial ionization in the ionosphere overhead the transmitter. This ionization is produced by solar radiation, so some concern is warranted about the effectiveness of NVIS operation during a minimum in the cycle of solar activity. Figure 2 depicts the progression of the current solar cycle (in terms of sunspot number, which is strongly correlated with peak free electron density in the Earth's ionosphere).

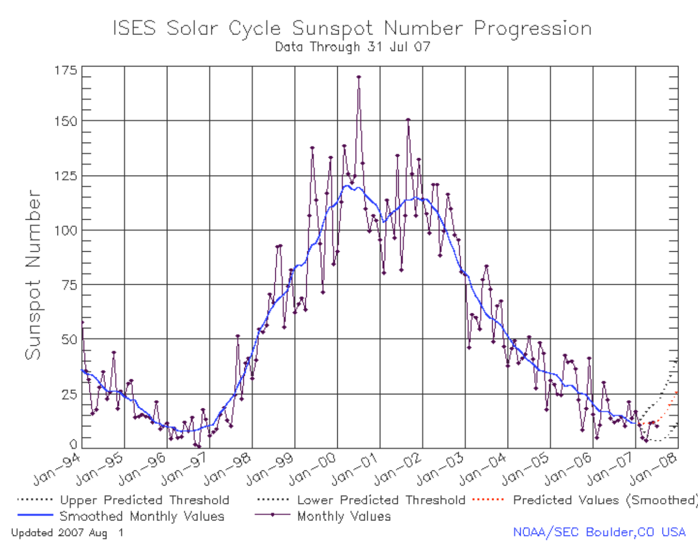

Figure 2: Current Solar Cycle

In this paper, we present measurements and an initial analysis from a multi-year NVIS experiment conducted during the current minimum of the sunspot cycle, including the effectiveness of Automatic Link Establishment (ALE) in supporting the NVIS mode of operation, and evaluation of the accuracy of standard HF propagation programs in predicting usable operating frequencies.

MEASUREMENT SETUP

The measurement program uses ALE systems [2] located at three points in the Southwest US: Ft Huachuca, AZ; Las Cruces, NM; and Albuquerque, NM (see Figure 3). The separations among the sites are all greater than 300 km, so these measurements are taken at somewhat greater range than is normally considered NVIS (e.g., 50 km [3]). The radios are nominal 100 W units; measured power into the antennas is about 50 W. Broadband horizontal dipole antennas (flat and inverted V) were used.

Measurement Approach

Propagation is measured using the automated sounding capability of the ALE systems:

- One ALE transmission is sent each hour on each of five frequencies, one each in the 3, 4, 6, 7, and 9 MHz bands
- The signal to noise ratio (SNR) of the signals received at Arizona is recorded by the ALE radio there.
- Monthly averages of these measurements are compared to VOACAP predictions using *ex post* sunspot numbers.

In this paper, we present and analyze measurements of propagation from Las Cruces to Arizona during the period July through December 2006 as the solar activity was dropping into the minimum of the current cycle.

VOACAP PREDICTIONS

We begin by presenting the SNR predicted by the Voice of America Coverage Analysis Program VOACAP [4] during the months of interest. The smoothed sunspot numbers required by VOACAP are computed using the measured sunspot numbers from six months before through six months after the month of interest.

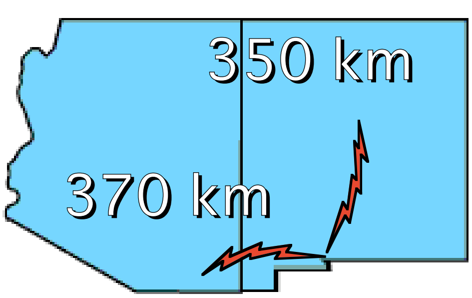

Figure 3: NVIS Experiment Sites

The charts below show color-coded SNR vs. hour (horizontal axis) and frequency (vertical axis).

- The times shown are Coordinated Universal Time (UT); subtract 7 hours for local (Mountain Standard) time.
- The SNR contours are labeled in SNR density; reduce by 35 dB to obtain SNR in a 3 kHz channel.
- The heavy line indicates the predicted Maximum Usable Frequency (MUF).
- These graphs were produced using the default horizontal dipole antenna model built in to VOACAP, with added loss to approximate the antennas actually used in this project. The graphs would change somewhat if more accurate antenna models were used.

As expected, lower frequencies have higher SNR at night (left side) with a pronounced change in the daytime (right side).

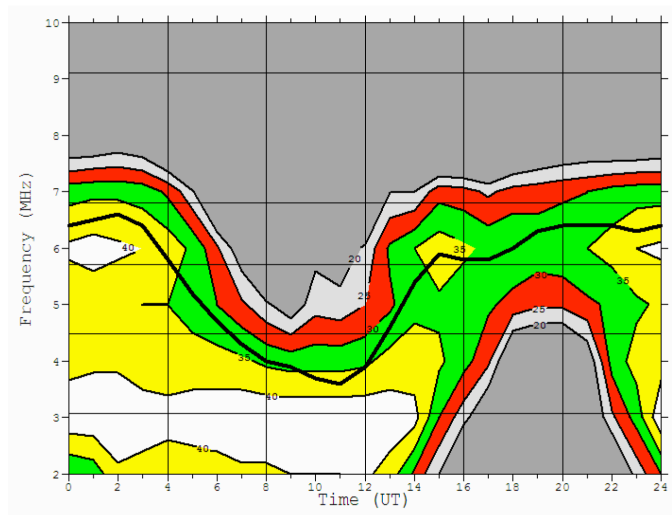

Figure 4: VOACAP Prediction July 2006

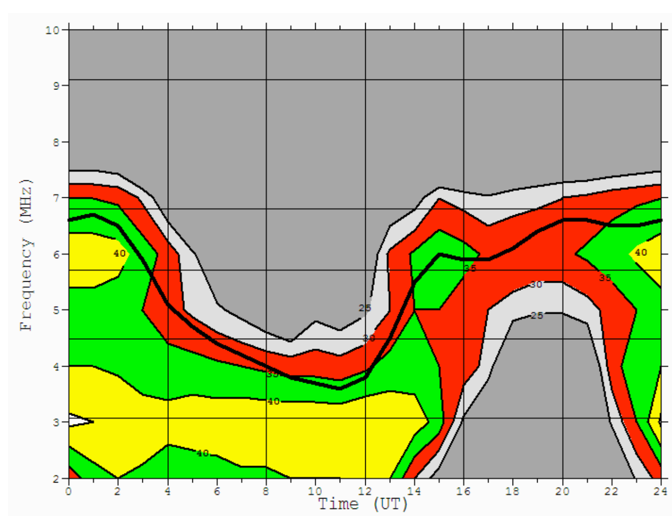

Figure 5: VOACAP Prediction August 2006

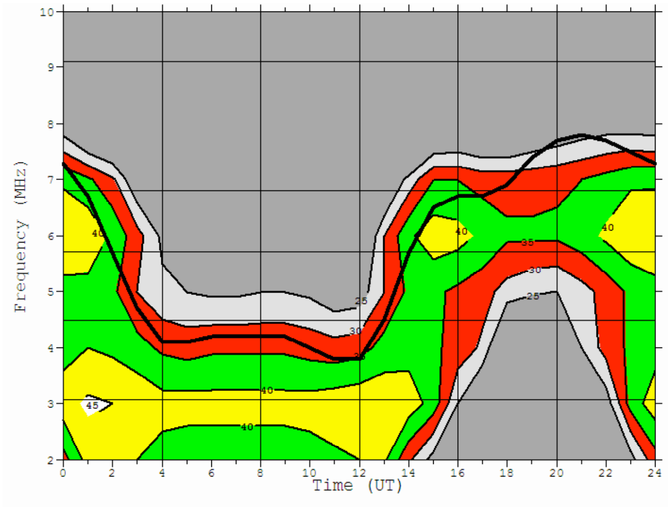

Figure 6: VOACAP Prediction September 2006

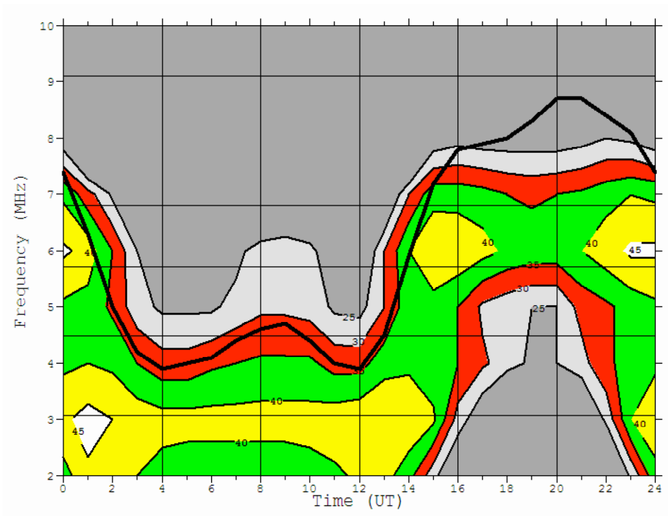

Figure 7: VOACAP Prediction October 2006

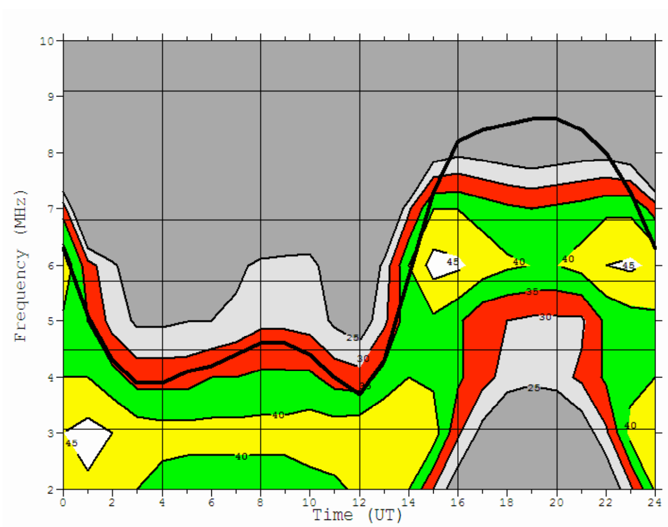

Figure 8: VOACAP Prediction November 2006

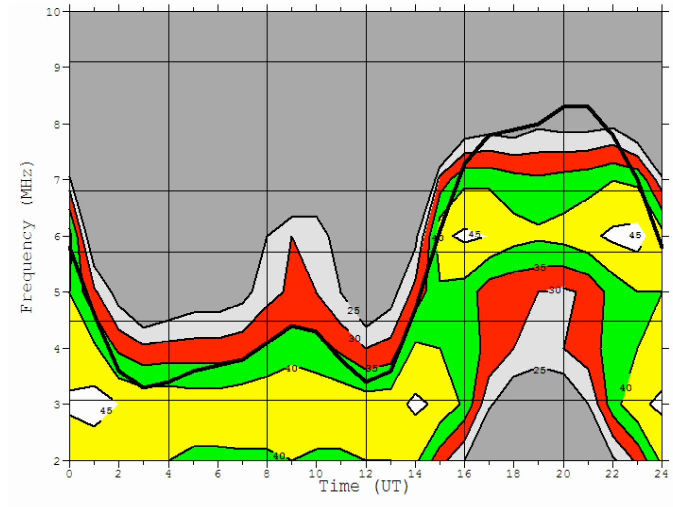

Figure 9: VOACAP Prediction December 2006

MEASUREMENTS

In this section, the measured SNR values for selected frequencies are plotted after averaging over an entire month, and compared to the VOACAP predictions, adjusted for shortcomings in the antenna model as described below.

As noted in the previous section, the VOACAP predictions were obtained using a rough approximation to the actual antennas (default dipole with 10 dB extra loss). The SNR predictions were found to be systematically lower than our measurements, probably due to the poor antenna models. As a crude correction, the predicted SNR values were adjusted upward by the following amounts, based on our measurements:

Frequency	Adjustment
3 MHz	0 dB
4 MHz	12 dB
6 MHz	18 dB
7 MHz	18 dB

The adjusted values are plotted in the charts in this section, labeled with the SSN used in the prediction.

During July and August, thunderstorms are common in the Southwest, and 2006 was no exception. These storms generally start in the afternoon and may continue into the evening. These storms can be expected to degrade the SNR of the lower frequencies in the HF band, and in Figures 10 and 11 we see this effect in the SNR values measured at 3 and 6 MHz. Otherwise, the measurements and the predictions are in qualitatively good agreement.

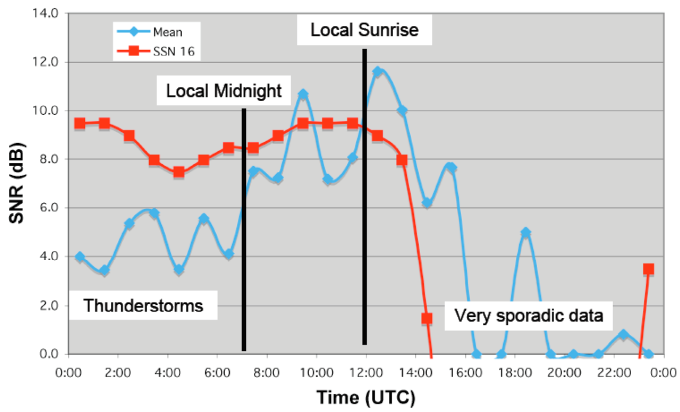

Figure 10: LRU to FTH, July 2006, 3 MHz

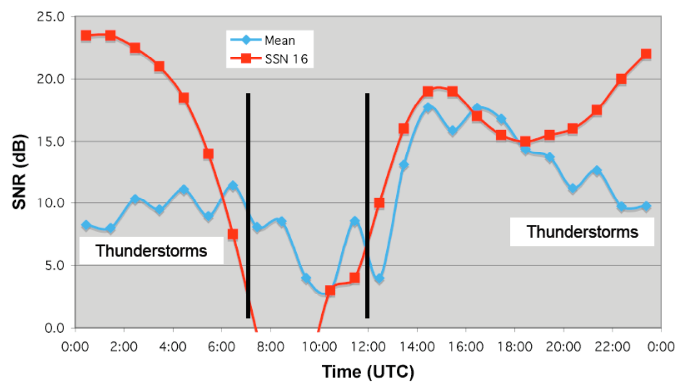

Figure 11: LRU to FTH, July 2006, 6 MHz

In September, 3 MHz was found to be unreliable. Measurements and predictions at 4 and 6 MHz agree fairly well, but with a couple of anomalies: overnight performance at 4 MHz fell short of the VOACAP prediction, and the midday "sag" in SNR expected at 6 MHz (due to D layer absorption) was not apparent in our measurements.

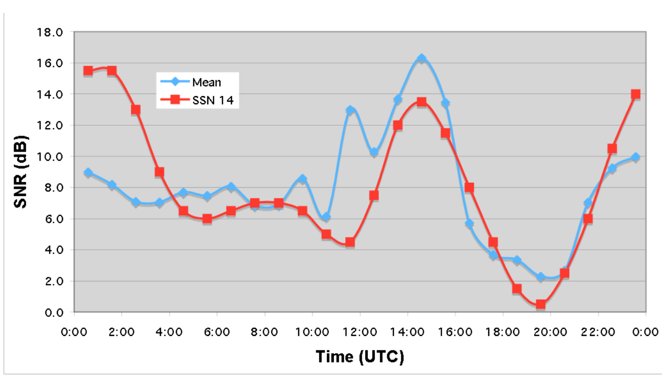

Figure 12: LRU to FTH, September 2006, 4 MHz

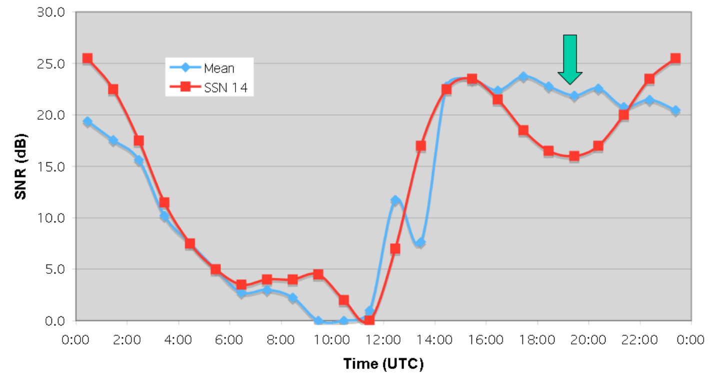

Figure 13: LRU to FTH, September 2006, 6 MHz

At 7 MHz, the opposite anomaly was observed: the SNR in late morning inexplicably dropped, but recovered in the afternoon. Further investigation is needed to determine whether there was systematic interference on that frequency (i.e., daily at the same hour).

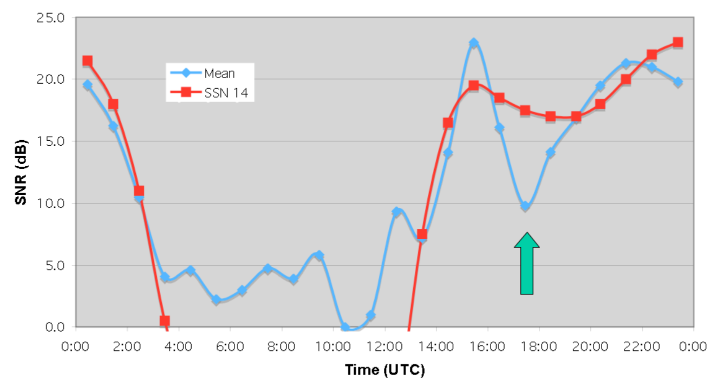

Figure 14: LRU to FTH, September 2006, 7 MHz

By November, the SSN had dropped further (to 11). As a result of the low SNR and low angle of the daytime sun relative to our path, ionization overnight apparently fell too low to support night-time communications on the frequencies used in our project. Measurements at 6 MHz show good agreement with VOACAP predictions (Figure 15).

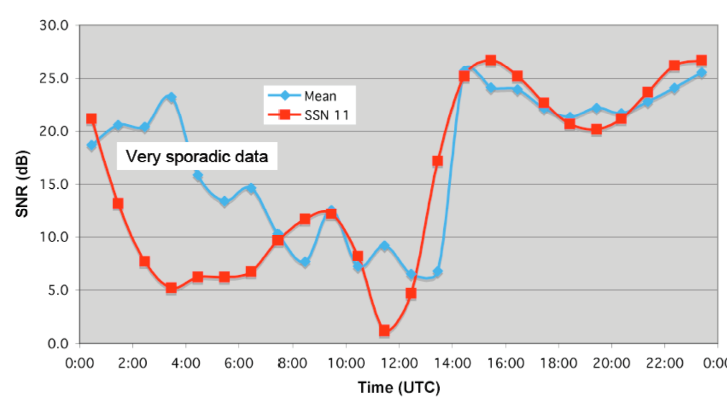

Figure 15: LRU to FTH, November 2006, 6 MHz

However, at 9 MHz, we measured much higher SNR than was predicted. The predictions and measurements are in agreement for the time of day in which the channel propagates, but the predictions were about 40 dB lower than our measurements. It should be noted that the measured SNR values were not flukes, but reflect measured propagation for a majority of the days in November.

The result of adjusting the predictions upward by 40 dB is shown in Figure 16 for comparison of the temporal behavior of the channel, but there is clearly a significant disagreement between VOACAP and our measurements.

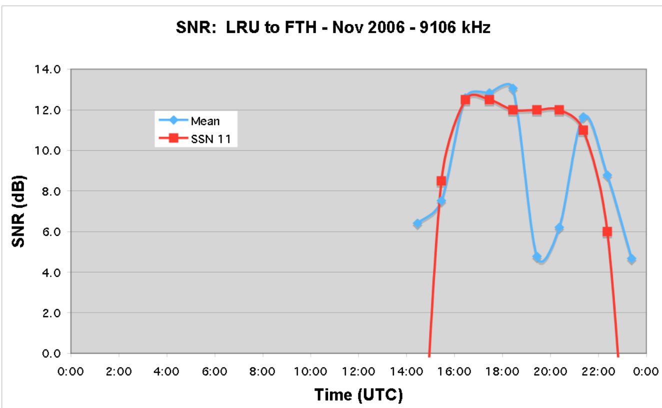

Figure 16: LRU to FTH, November 2006, 9 MHz (VOACAP adjusted by 40 dB!)

CONCLUSIONS AND FUTURE WORK

A. Conclusions

Our low-power ALE system is able to provide NVIS connectivity during the daytime even near solar minimum in the winter. During the summer, with solar activity nearly as low, 24-hour connectivity was available. However, the low power and low ionization left the system vulnerable to outages in the presence of thunderstorms.

VOACAP is generally accurate, but we found some curious discrepancies between predictions and measurements, such as the absence of a mid-day drop in SNR at some frequencies that one would expect to suffer D-lay absorption.

B. Future Work

Several aspects of this work merit further study:

- Investigation of the absence of a daytime D-layer dip in SNR.
- Investigation of the large disagreement in propagation at 9 MHz.
- Measurement of shorter paths that are nearer vertical incidence, for example on opposite sides of a mountain range (as seen in Figure 1).

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REFERENCES

[1] J. Goodman, *HF Communications Science and Technology*, Van Nostrand Reinhold, New York, NY, 1992.

[2] MIL-STD-188-141B *Interoperability and Performance Standards for Medium and High Frequency Radio Systems,* Appendix A, "Second Generation Automatic Link Establishment," 2001.

[3] E.E. Johnson, *et al*, *Advanced High-Frequency Radio Communications*, R. Desourdis ed., Artech House, Boston, 1997.

[4] Sweeney, Rhoads, DeBlasio, and Lane, "Voice of America Coverage Analysis Program, A User's Guide for VOACAP," US Dept of Commerce, 1993.