EARLY SKYWAVE EXAMPLES FROM U.S. COAST GUARD PRIMARY CONTROL MONITOR SET DATA

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BIOGRAPHY

Mr. Wenzel has been supporting the FAA's project to examine the potential of Loran-C since May 2000. Prior to joining Booz Allen, Mr. Wenzel served in a variety of radio navigation, electronics, and R&D positions in the U.S. Coast Guard. These involved the Loran-C and Omega radio navigation systems and the Differential GPS development project.

LT Montgomery has been on active duty with the US Coast Guard since 1981. While on active duty he has served on 4 Loran Transmitting Stations, 3 Control Monitor Stations, the Electronics Engineering Center, and two tours at the Navigation Center. During this time he has worked on three generations of the Coast Guard's LORAN Monitor Receivers.

ABSTRACT

As part of the FAA's ongoing studies to assess the ability of Loran-C to meet the evolving requirements for area navigation, the classical loran issue of early skywave interference must be re-examined. The problems, which are most severe at high latitudes, were examined early in the last decade by the Coast Guard. The work resulted in a series of papers by Peterson et al, Arsenault, and Watkins. Since that time there has been a change in the Coast Guard's monitor receivers but indications of early skywave persist. For the Port Clarence baseline in the Gulf of Alaska chain, for example, such effects still lead to station blink on the order of 2 to 3% of the time. This paper illustrates the effects by showing how the monitor receivers are affected in a handful of incidents. Where possible, we examine the correlation of the incident times with available indications of unusual solar activity.

INTRODUCTION

Background

The ongoing assessment of the Loran-C system by the FAA and Coast Guard seeks to exploit the full potential of the system in a variety of ways. One of the major hoped-for improvements comes from so-called "all-in-view" operation. This term seems to have been adopted by Loran-C advocates as a way to establish common ground with policy makers who have become familiar with GPS jargon. It would incorporate such availability enhancing concepts as "master independent" and "cross-chain operations" that were being considered in the 1970's and early 1980's. It also implies the use of signals which would traditionally be considered out of range.

Initial efforts directed at achieving the FAA's requirements established signal range limits based only on signal-to-noise ratio (SNR). The main performance parameter affected by SNR was the time-to-alarm criteria of 10 seconds. Even if "blink" is changed to taking the station off air, we've established this requires the SNR be not much worse than –10 db. Even at this level, of course, the signal time of arrival or ECD estimates produced by aviation receivers with practical averaging times may have to be too large to meet the accuracy or integrity requirements, depending on geometry and other error sources. If established accuracy limits are not exceeded based solely on SNR considerations, there remains a serious potential source of error – interference from skywaves with extremely short delay times.

Table 1 shows various receiver early skywave specifications. They show the size and timing of the skywave, relative to the groundwave, that a receiver must be able to tolerate with a minimal phase estimation error (e.g., 100 nanoseconds) and an ECD estimation error small enough so that confident correct cycle selection is maintained. These requirements, most notably those of Transport Canada, are not trivial. However, practical receivers designed and brought to market over the past 25 years have proven capable of meeting them. These characteristics conform with what might be called "classic" notions of early skywave interference that we expect to encounter at about sunset and consider ourselves free from shortly after sunrise.

Source	**Mode**	**Min. SW Delay (usec)**	**SW/GW Ratio**
RTCA/FAA	Aviation	35	+ 6 db
		37.5	+ 10db
		42.5	+ 15 db
		45	+ 20 db
		55	+ 25 db
RTCM/USCG	Maritime	37.5	+ 12 db
		60	+26 db
Transport Canada	Maritime	32.5	+12 db
		45	+26 db

Table 1. Various Specifications for Early Skywave Receiver Immunity

However, operation at northern latitudes seems to entail early skywave effects that are considerably more challenging.

Experience in Alaska

The series of papers comprising references 1 through 3 describe problems with the Port Clarence signal (7960-Z) observed at Fairbanks that have the appearance of early skywave interference. In our opinion, it is not possible to exclude at least some cross-rate interference effects from those operational observations because the Coast Guard monitor receiver of the time did not employ any cross-rate blanking. However, the effects appear as offsets with sufficient stability to indicate the largest component is not cross-rate interference. Regarding the earlier reports, we have examined the early skywave characteristics of the Austron 5000 receiver and found it is nearly as good as those of the newer monitor receivers produced by Locus, Inc. To the extent the problems reported in references 2 and 3 were due to early skywaves, those skywaves had to be received at delays well below 30 usec for the Austron 5000 monitor receiver to see such effects.

In reference 1, Ben Peterson described the results of deploying a receiver with sophisticated signal processing capabilities that allowed him to estimate skywave amplitude and delay. In one case, he concluded the skywave was 6 db greater than the groundwave with a delay less than 30 usec. He had two ways of measuring the delay – one from the envelope, which produced an estimate of about 28.5 usec, and one from the phase, which produced an estimate of about 23.5 usec. We have recently come to suspect there is a phase reversal associated with the "reflection" of the skywave in the ionosphere. Ben indicates this would explain the 5 usec difference between the envelope and phase measurements. The question is: which is it, 23.5 or 28.5 usec?

As Ben reported in reference 1, at the time of the early skywave event, the Austron 5000 ECD estimate moved about –3.4 usec from the nominal. Examination of Austron 5000 receiver characteristics shows this is not possible for a 28.5 usec +6 db skywave, but is about what should be expected for a delay of 23.5 usec.

Scope

In this session of this conference, Dr. Peter Morris will describe the physics that can cause the early skywave effects of the type reported in references 1 through 3 and herein. Later in this same session, Dr. Peterson will describe a range of receiver design considerations that show how the effects on availability can be minimized. In this paper, we will show concrete evidence that the effects do exist in Alaska. We will also show evidence of similar effects, to a much smaller degree, in "the lower 48."

OBSERVATIONS

The Propagation Paths and The Equipment

Figure 1 shows the propagation path from Port Clarence to Fairbanks for the 7960-Z signal. This signal was not part of the original Gulf of Alaska chain. It was created in the mid-1980's, as part of the "mid-continent expansion" of Loran-C by double-rating the North Pacific chain station at Port Clarence . The receiving station at Fairbanks is the so-called A1, or system area monitor. The path is nearly east-west in orientation with an average latitude of about 65 degrees North. It is about 480 nm in length, just under 900 km. Per Dr. Morris' description, this would be a prime candidate for having anomalous early skywave effects.

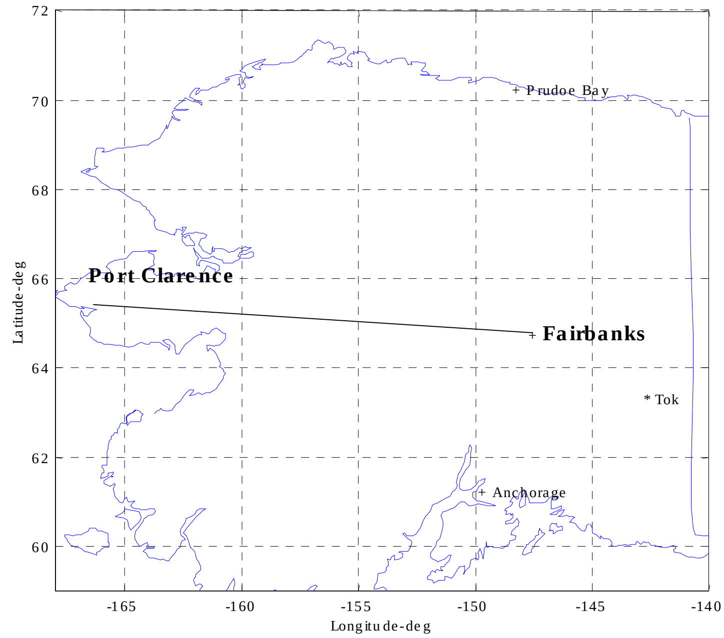
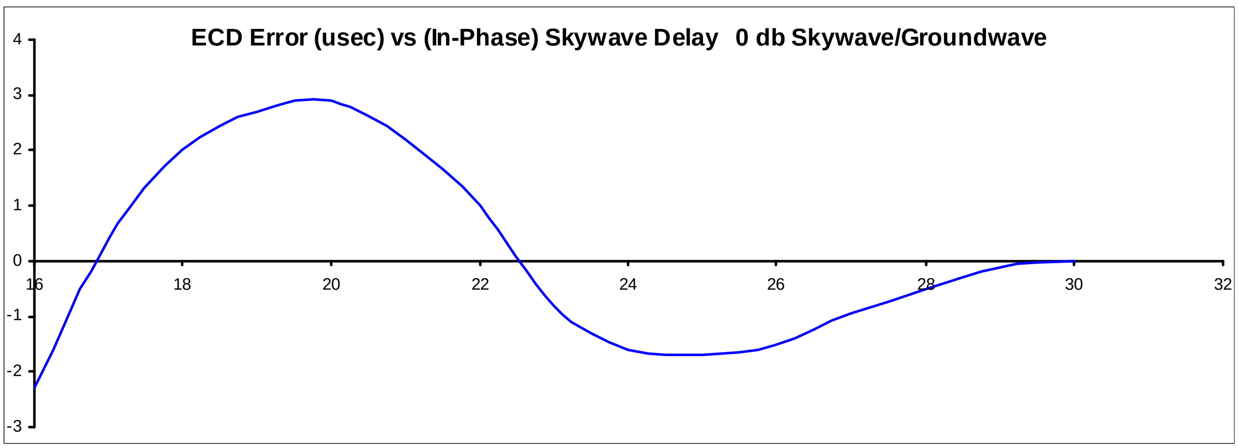


Figure 1. The Port Clarence-Fairbanks Propagation Path

From its inception in 1977, the Gulf of Alaska chain had occasional problems controlling ECD via methods that were effective at lower latitudes. For the most part, the problems were manifested in the observations of the Tok signal by the Kodiak monitor. However, these problems have proven to be very minimal, when compared to the severity and frequency of problems on the 7960-Z (Port Clarence) signal.

To appreciate the magnitude of the problem, it is important to know the characteristics of the receiver used to make the measurements. For the plots shown in this paper, the receiver is the Locus LRSIIID receiver. Figure 2 shows the results of simulator tests to measure the ECD and Phase errors created by the presence of a 0 db skywave, at various delays. The notation “In-Phase” in the title indicates that this simulation assumed there was no phase reversal upon “reflection” of the interfering skywave. The authors confess to not knowing if there is a reversal. If, indeed, there is a reversal, the offsets shown in the plots would be of the opposite sign. Note that the effects are 90 degrees out between the ECD and phase. For example, at about 25 usec, the phase offset is zero while the ECD offset is peaking.



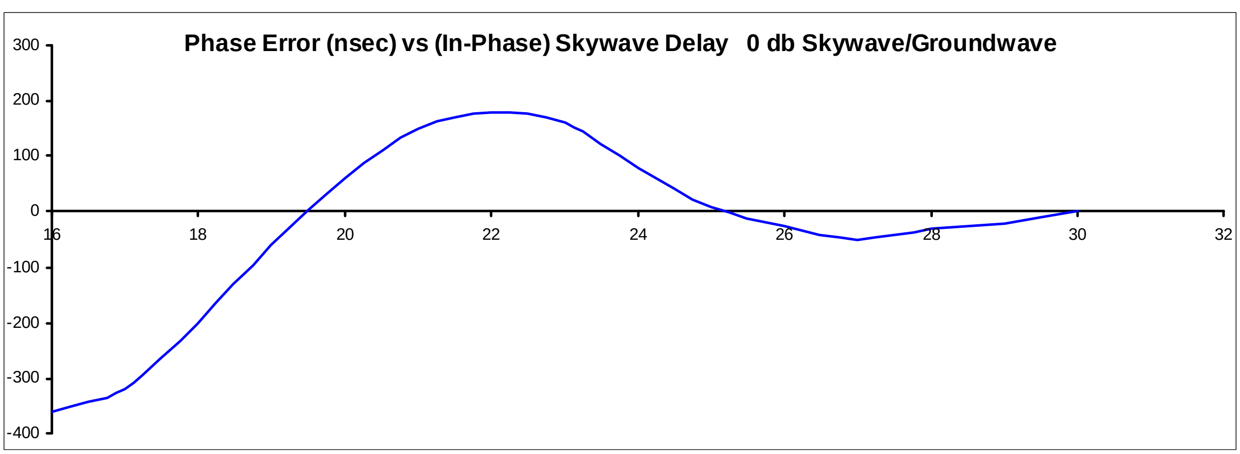


Figure 2. Early Skywave Interference Tests With Locus LRS IIID Receiver

January 2002 Observations.

We began looking for representative events by considering the data archived by the Coast Guard from its Fairbanks monitor site beginning in the year 2002. As shown on the next page, there were 6 periods of blink during January 2002. In the plot, the value “1” is assigned to the periods of blink; otherwise, the plotted value is zero. These incidents are significant in that they average about 3 hours. This represents an availability of 97.6% over a 1-month period. This is nearly 1-1/2 orders of magnitude below what the Coast Guard typically requires to meet its historically-advertised availability of 99.7% per triad.

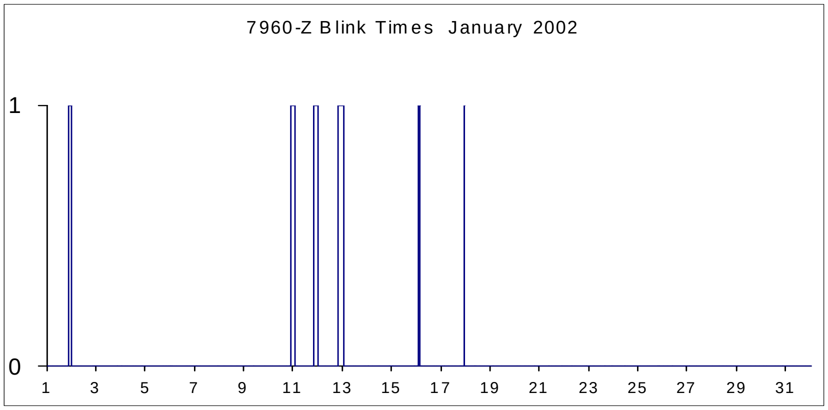
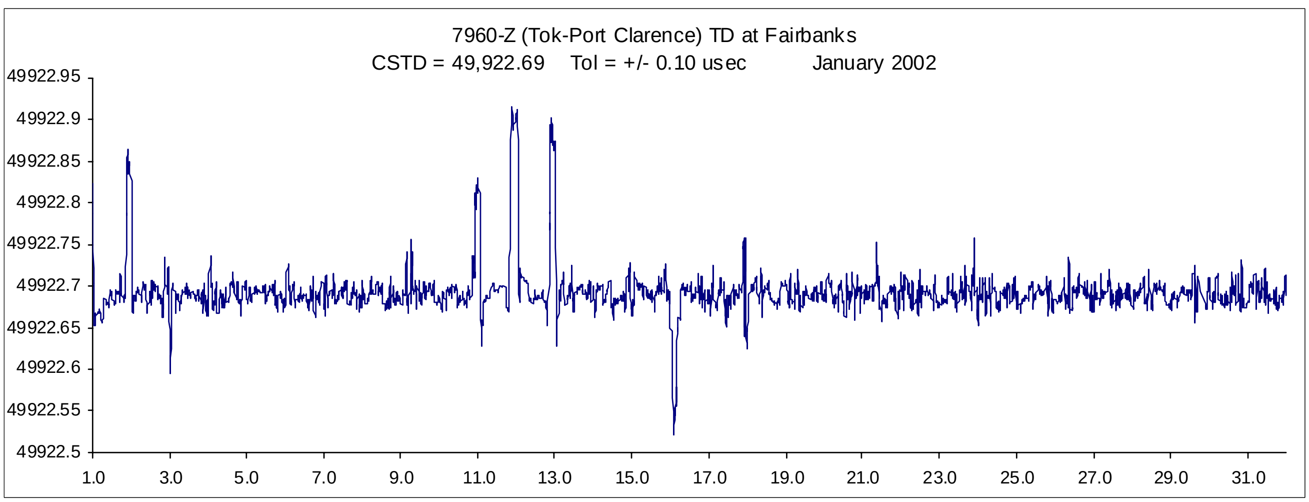


Figure 3. Times of “Blink: for the 7960-Z Baseline in January 2002

Figure 4 shows the time difference (TD) and ECD plots for January 2002. There are more “glitches” than there are blink incidents, since only a variation greater than 100 nsec for the TD, or 1.5 usec for the ECD, will cause blink.



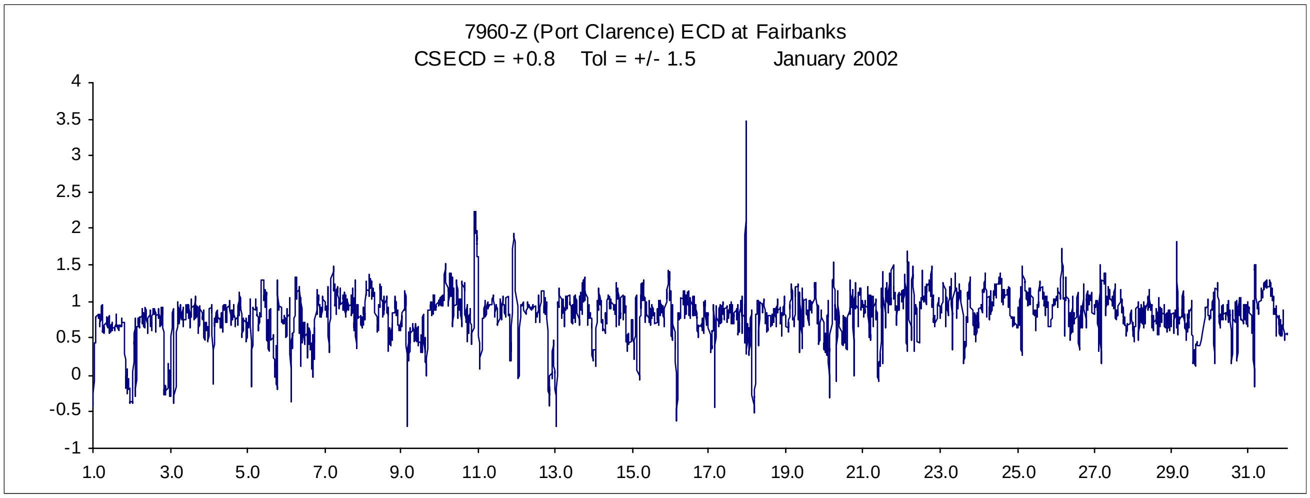
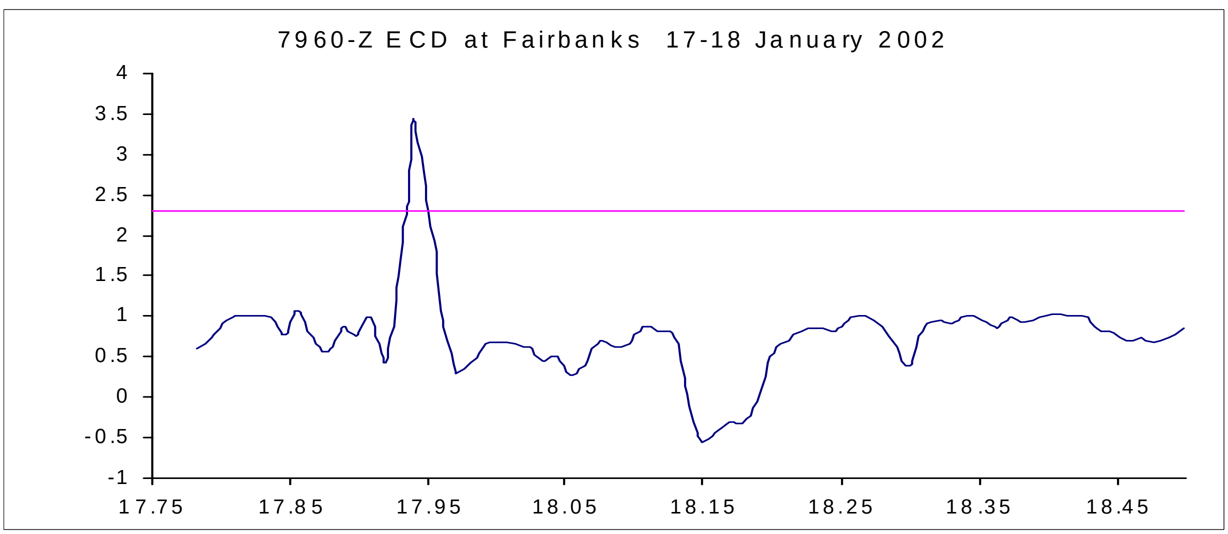


Figure 4. ECD and TD Plots for 7960-Z at Fairbanks in January 2002

The first three annotated points show the receiver sees three of the four possible polarity combinations of the TD/ECD pairs. Incident 1 indicates positive phase, negative ECD. Incident 2 is positive, positive, and incident 3 is positive, negative. Referral back to figure 2 indicates these three conditions are consistent with skywaves close in amplitude to the groundwave, and with delays in about the 20-28 usec range. Incident 4 seems to suggest a positive/negative TD/ECD pair and is worth closer scrutiny.



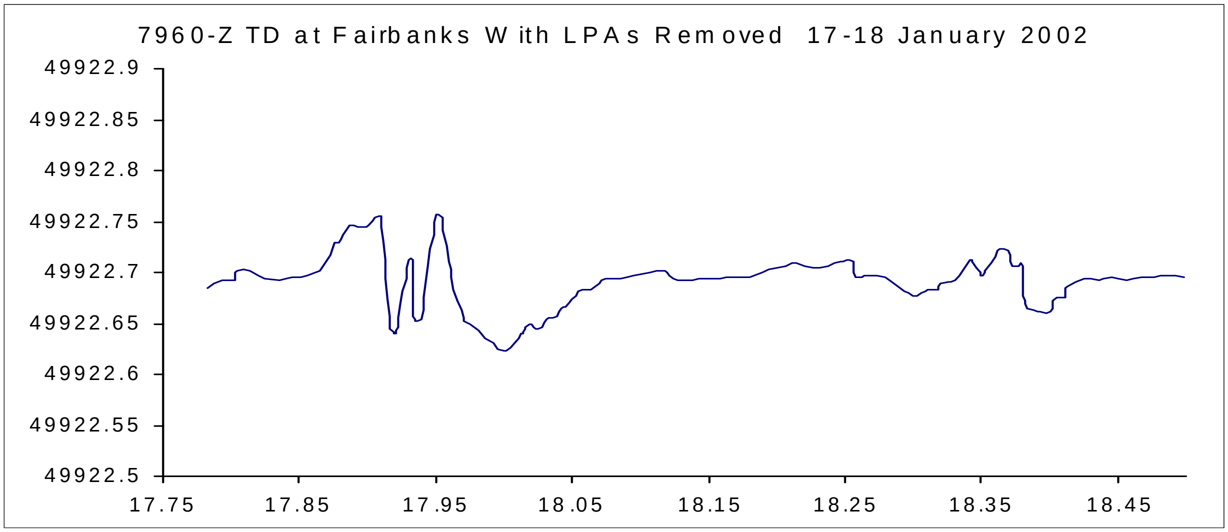
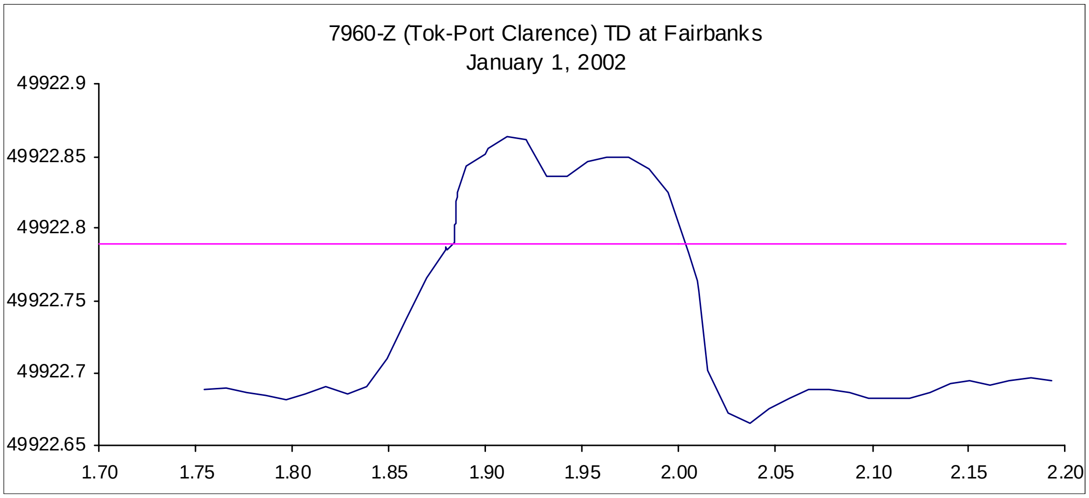


Figure 5. ECD and TD Plots for 7960-Z at Fairbanks, 17-18 January 2002

The times plotted on the horizontal axis have units of days. Hence, the time 17.75 is 3/4^{ths} of the way between the beginning and end of day 17. It, thus, corresponds to 1800 UT on the 17th. The horizontal line in the top plot represents the blink tolerance limits. This is the only incident in January 2002 in which the blink was caused by the ECD, rather than the phase. We can see that the phase goes positive before the ECD moves very positive. The phase then fluctuates back and forth about the expected value of 49922.69. These conditions seem to correspond to receiver characteristics found, in figure 2, for a 0 db skywave with delays in the range 18 to 19 usec.

On the other hand, and as previously noted, if there is a phase reversal as the skywave is reflected, the characteristics shown in figure 2 would be reversed. In that case, the positive ECD/negative TD combination would correspond to a delay in the 23 to 24 usec range. Notice, however, that the 18 to 19 usec delay range would then feature a negative ECD error and a positive TD error if there is a phase reversal. That's what we see in incident 1 of figure 4.

Backing up a few days, we can look at the first incident in January in more detail. This is incident 1 of figure 4 and is an instance of the TD going positive while the ECD goes negative. In this case, it is the TD that goes out of tolerance. Blink is started as soon as the out-of-tolerance condition is achieved.



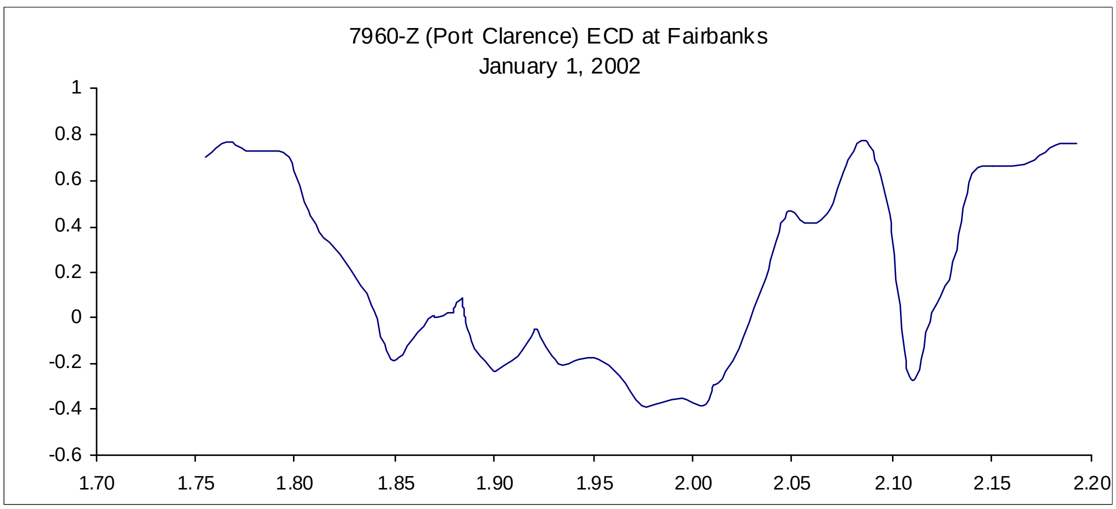


Figure 6. ECD and TD Plots for 7960-Z at Fairbanks, 17-18 January 2002

Here is the sequence illustrated in the above plots. Effects are first seen in the ECD, starting just before "day (or time) 1.80." It happens that civil twilight began at Fairbanks at 1832Z on this day. That would correspond to time 1.77 in the plots. Sunrise occurs at time 1.83 (1954Z). It is about at that time that we begin to see some movement in the TD. At Port Clarence, sunrise doesn't happen until about day 1.89 (2118Z). At that point, the path is fully illuminated. This is about when the TD excursion "reaches the top of the plateau."

On January 1, the day is very short at these latitudes. Sunset happens about 4 hours after sunrise at Fairbanks – i.e., at 2356Z, or day 2.00. This is about the time we see the TD start to come down and the ECD start to rise. Sunset at Port Clarence is at about day 2.04 and twilight ends at about day 2.10.

The lesson from this set of plots is that these effects are daytime phenomena. As later data will show, it's likely that the physical phenomenon that caused the incident happened at night and was only visible during the day.

Whereas these effects are most pronounced in Alaska, we can see evidence of the same in data from the northeast portion of "the lower 48." The Coast Guard "A2" (backup control) monitor for the Caribou (W) signal of chain 9960 is at Sandy Hook, N.J. This path has a length of about 860 km, slightly shorter than the Port Clarence-Fairbanks path. TD plots are not shown because there were no TD effects at Sandy Hook.

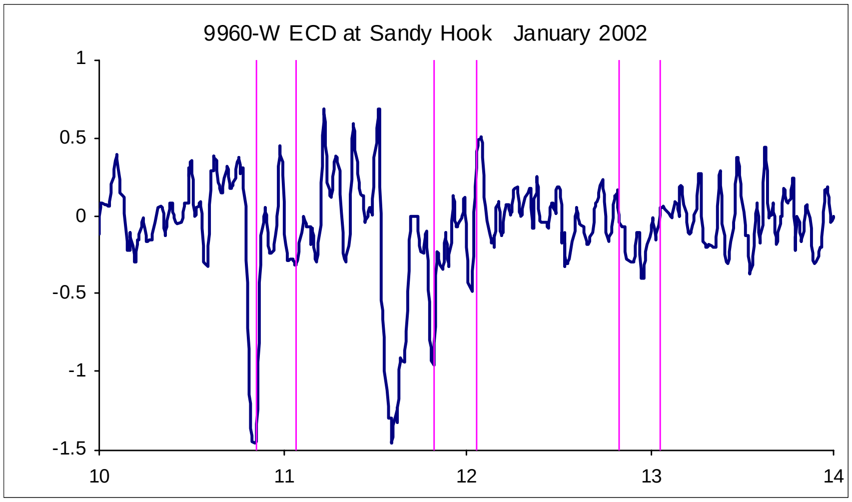
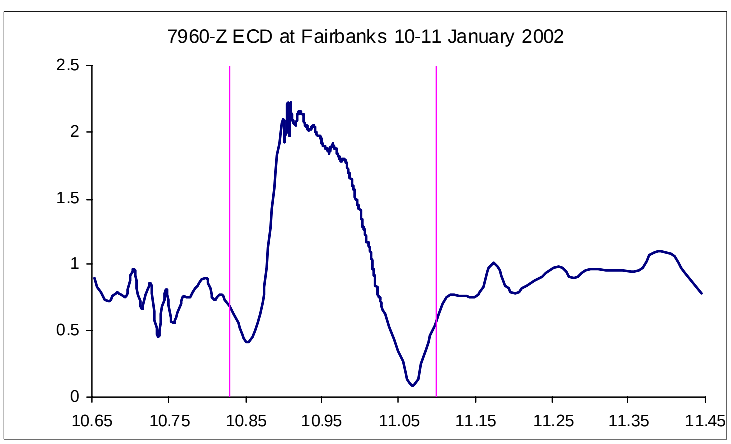


Figure 7. Annotated ECD Plot for 9960-W at Sandy Hook, 10-14 January 2002

The plot of figure 6 is annotated with vertical lines which indicate the times of out-of-tolerance conditions for the 7960-Z baseline during the Alaska day. There is some notable negative ECD activity during the first two of these incidents, but the times don't align with those of the Alaskan incidents. The plot below takes a closer look at the activity on the 10th and 11th.



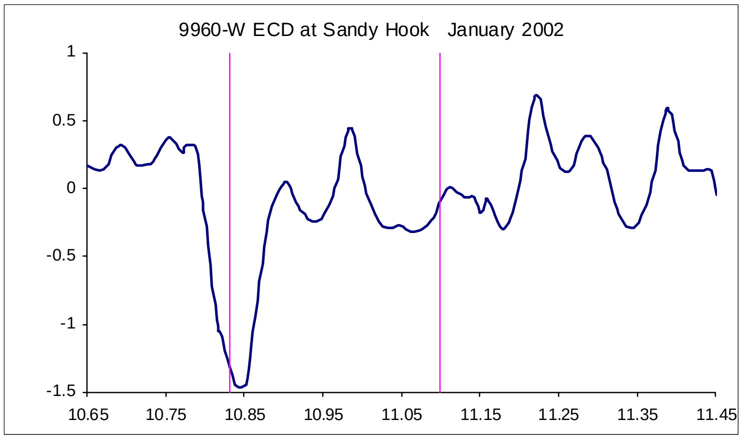
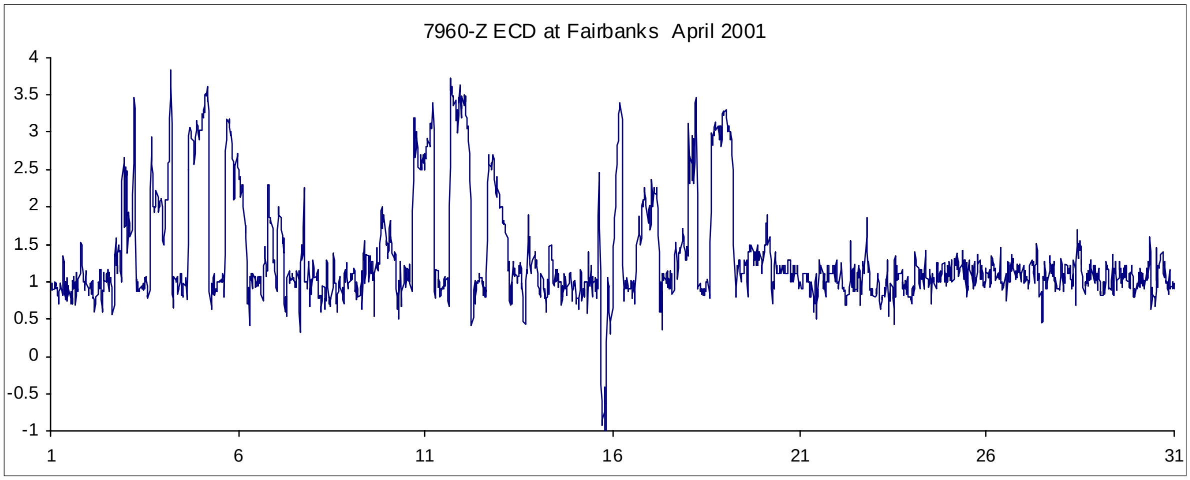


Figure 8. ECD Plots for 9960-W at Sandy Hook and 7960-Z at Fairbanks, 10-11 January 2002

More Pronounced Observations



A quick check of the Space Environmental Center's data, searching for very energetic events directed our attention to April 2001. The effects are most pronounced in the ECD, as shown in figure 9.

Figure 9. 7960-Z ECD at Fairbanks, April 2001

Scrutinizing the plot indicates there appear to be three incidents in the first 2/3rds of the month, each lasting 4 or 5 days. The first event is examined in more detail via the next plots.

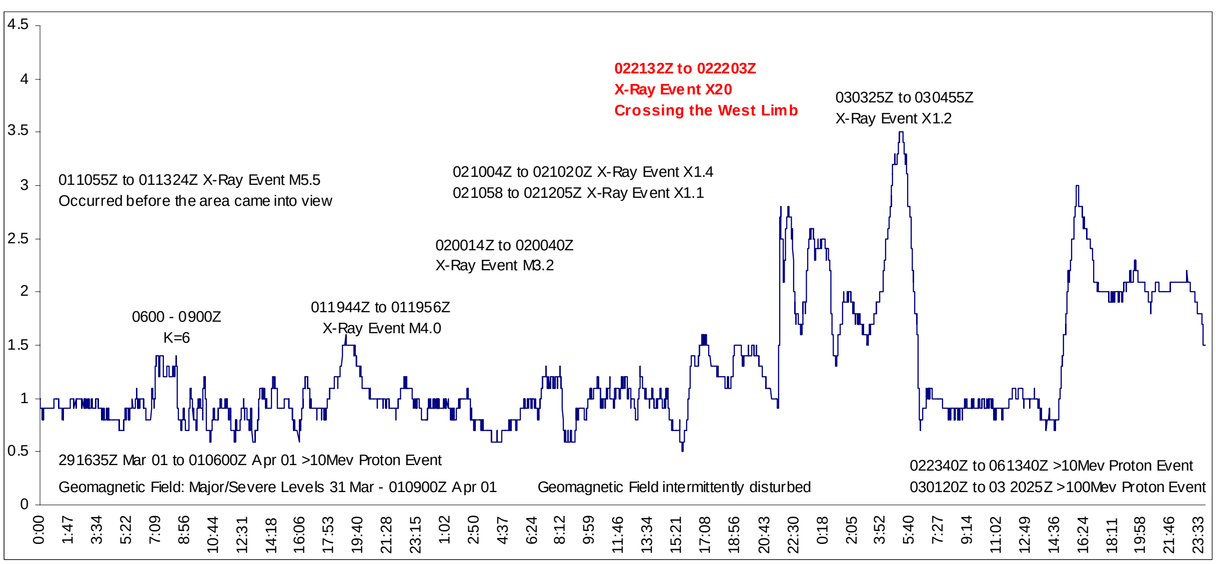
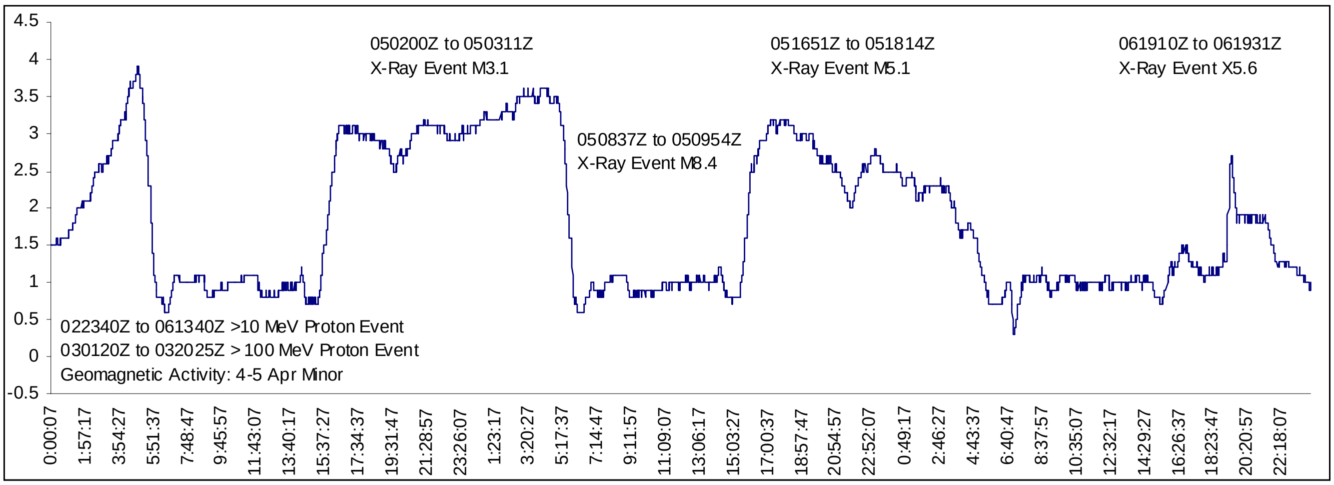


Figure 10. 7960-Z ECD at Fairbanks, April 1-3, 2001

The 7960-Z ECD shows some instability on April 1 caused by a ">10MeV" Proton Event that began on March 29 and finally decayed on April 1. There is also a period where the

K Index for College, Alaska reached a level of 6 causing a shift in the ECD. The major problem during this period was the X20 flare that erupted late on April 2: the notation "022132Z" means 2132 UT on the 2nd. This is about midway between sunrise and sunset on this propagation path and the X-Ray and proton effects were noticed immediately. Close scrutiny of the data (not shown here) indicates both the ECD and the TD moved out of tolerance over a period of about 7 minutes, leaving plenty of time for monitors to warn users. The event seems to end, at least temporarily, over the period from 0517Z to 0624Z on the 3rd. This runs from about 30 minutes after sunset at Fairbanks, to about 25 minutes after sunset at Port Clarence. The effects become visible again over the period from 1451Z to 1557Z. This is about 20 minutes before sunrise at Fairbanks to about 25 minutes before sunrise at Port Clarence.



This period featured significant out of tolerance conditions because of the X20 event on April 2nd. The proton event lasted 3-1/2 days finally decaying on 6 Apr. During this period the A-1 ECD was out of tolerance during the daylight hours and returned to normal during the nighttime hours. In the plot below, the ECD steadied out at about 0.9 usec between about 0600Z at 1530Z (nighttime) and moved positive out of tolerance between about 1630Z and 0515Z (daytime). The transitions between the two states took 60 to 90 minutes. The effects continue to "die out" over the course of days 7-9.

Figure 11. 7960-Z ECD at Fairbanks, April 4-6, 2001 On April 10th, there is another incident "trigger," as illustrated below.

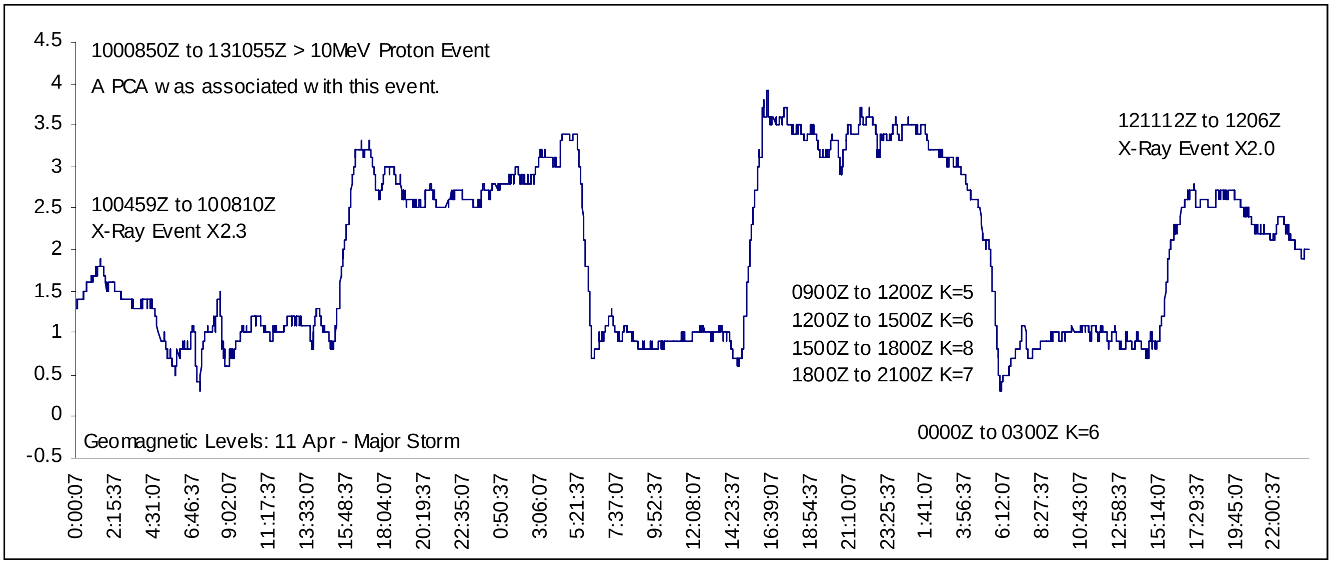


Figure 12. 7960-Z ECD at Fairbanks, April 10-12, 2001 The abnormalities during this period appear to have been caused by the X2.3 event on April 10th. This event appears to have been oriented almost directly at the Earth because of the 3-day duration of the proton event. The effects can be seen to peak on the second day and the decay has definitely begun by the 12th. Again, the effects are seen during the day, and vanish at night.

CONCLUSIONS

The examples selected for and presented in this paper compose strong evidence of very early skywave interference along the most difficult of the Loran-C propagation paths routinely monitored by the Coast Guard in Alaska. These events seem to be initiated by high energy solar activity. Unlike “classical skywave,” the effects are visible during the day and disappear at night.

High performance monitor receivers like the Austron 5000 and the Locus LRSIIID easily meet existing RTCA and RTCM minimum operating standards regarding early skywave interference protection. However, the Alaska anomalies shown here feature delays which are 10 usec – or more – less than previously specified. Even these stationary, “monitor grade” receivers produce unusable measurements when faced with the interference seen in the 7960-Z baseline at Fairbanks.

We will have to deploy special monitor equipment to nail down the exact delays and amplitudes of these skywaves. Even without knowing the extreme values, however, we can note that these events materialize over a period of time that appears very adequate for meeting system integrity requirements. However, the current system of “blinking” the baseline, will result in excessive losses of system availability. This suggests another system of user notification, such as the Loran-C communications system to be discussed by Ben Peterson in this same conference, must be used.

Effects similar to those seen in the Alaska data, though somewhat attenuated, can be seen in long baselines in the Northeast U.S. chain. For the baselines examined, these effects were visible only in the ECD records, not the TD records.

REFERENCES

[1] Benjamin Peterson, Keith Gross, Eric Chamberlin, and Edward Sheppard, “Port Clarence Skywave Interference Study,” Proceedings of the Twenty-Second Annual Wild Goose Association Technical Symposium, Santa Barbara, October, 1993.
[2] David C. Watkins, Analysis of High Latitude Loran-C Abnormalities in Alaska,” Proceedings of the Twenty-Third Annual Wild Goose Association Technical Symposium, Newport, November, 1993.
[3] Arsenault, Alan, The Effects of Geomagnetic Activity on Skywave Interference and the Quality of the Port Clarence Loran-C Radio Navigation Signal,” Proceedings of the Twenty-Third Annual Wild Goose Association Technical Symposium, Newport, November, 1993.