Peterson Integrated Geopositioning

Differential LORAN-C

Ben Peterson, Ken Dykstra & Peter Swaszek
Peterson Integrated Geopositioning

Kevin Carroll & Anthony Hawes,
USCG Loran Support Unit

Sherman Lo,
Stanford University

Outline

- Basic approach
- Proposed Modulation & Message Formats
- dLoran for precise time and frequency
- Underway tests on USACE S/V Shuman
  - Real time fixes using differential corrections from LSU
  - E field vs H field
- Coverage analysis & design software tools
  - Comparison to actual data

1 - Note that modulation and message formats are presented as "proposed" versus final.

2 – "E fieldvs H field" refers to the two types of antennas that were used to receive the differential Loran signal: electric field (e-field) and magnetic field (h-field). The difference in results obtained while using these antennas is caused by coupling in the h-field antenna loops which results in a heading-dependent phase error which adversely affects accuracy. (This can be mitigated, however the phenomenon will be covered)

3 – Coverage Analysis: will compare predictions based on PIG model to actual data)

Basic Approach

- Receiver calculates ASF's as sum of two terms:
  - Temporal terms measured at a local base station
  - A spatial grid based on survey of ASF's compared to those observed simultaneously at the local base station
  - Differential corrections will be offsets from published nominal values vice absolute to conserve bits/maintain dynamic range
- Effort is to demonstrate that Loran can meet HEA requirements and to determine base station density

1 – In this context, the receiver will calculate ASFtotal = ASFnominal + ASFdiff, where:

ASFnominal is a value obtained from a survey of the local waterway, stored in the receiver memory, and

ASFdiff is the term that accounts for the seasonal change in conductivity along the path from the transmitter to receiver, and all other timing errors. This is the "differential" part of differential LORAN.

For more information, refer to USCGA "A Demonstration of High Accuracy Loran-C for Harbor Entrance and Approach Areas" (ION June 2003)

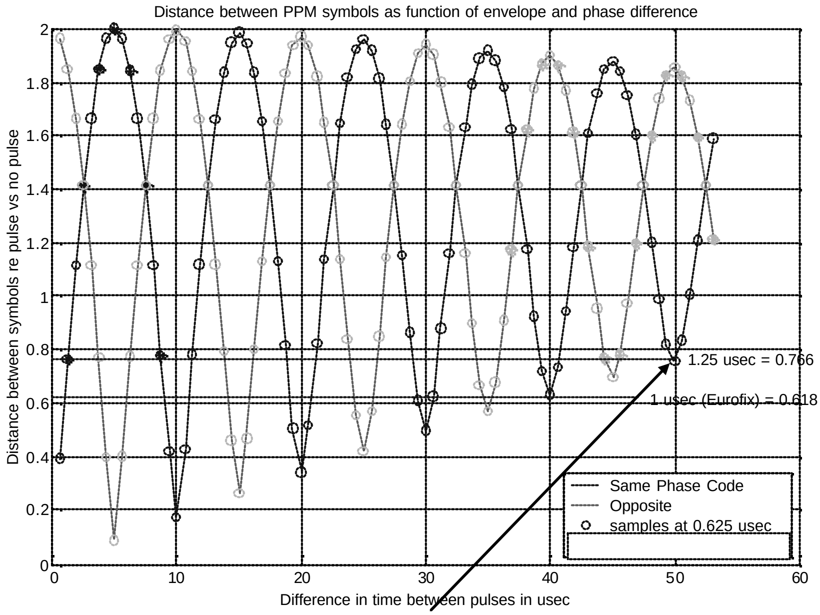
Proposed Modulation Scheme

- 9th pulse Pulse Position Modulation (PPM)
- 32 state PPM, 5 bits/GRI
  - 3 bits phase, 2 bits envelope & phase
- Averages to zero in legacy receivers, CRI increases 0.5dB
- Message length is 24 GRI or max of 2.38 seconds
- PPM vice IFM means no transmitter modifications, modulation done in software in TFE
- 9th pulse in cross rate would be blanked, other 8 could be cancelled if desired.

1 – Using 9th pulse pulse position modulation (PPM) vice Intra-frequency Modulation (IFM) avoids a change in spectrum allocation (which might prove difficult).

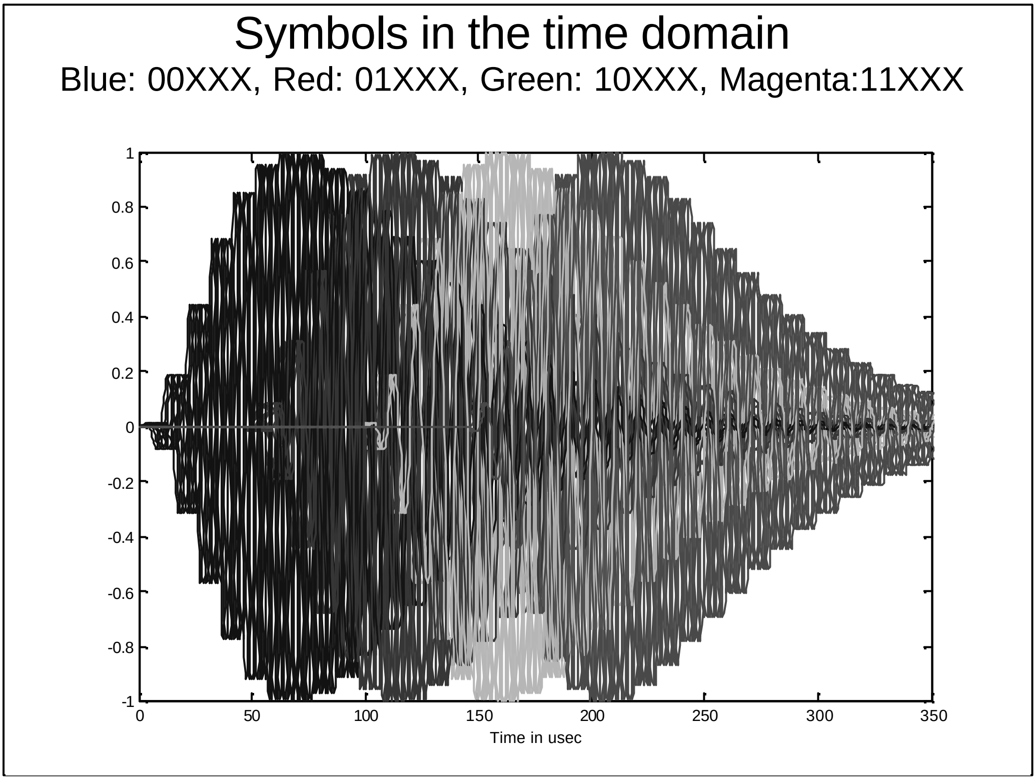
BBP. It does mean no change in spectrum, but IFM could have been done within spectrum requirements if necessary.

Determination of minimum envelope delay between groups of 8 symbols



To get same distance as 1.25 usec phase shift need to delay envelope 50 usec

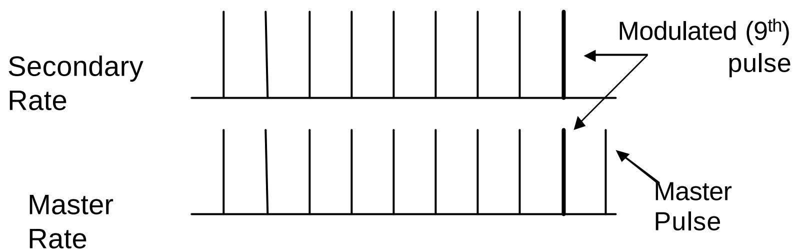
(Earlier version had negative phase codes and 45.625 usec between groups, changed to make SSX modulator easier)


Symbols in the time domain
Blue: 00XXX, Red: 01XXX, Green: 10XXX, Magenta:11XXX
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
Time in usec

Modulated 9th Pulse Location and Phase

Group	Master	Secondary
A	+ + - - + - + - - +	+ + + + + - - + +
B	+ - - + + + + + + -	+ - + - + + - - -

Phase of Modulated (9th) pulse

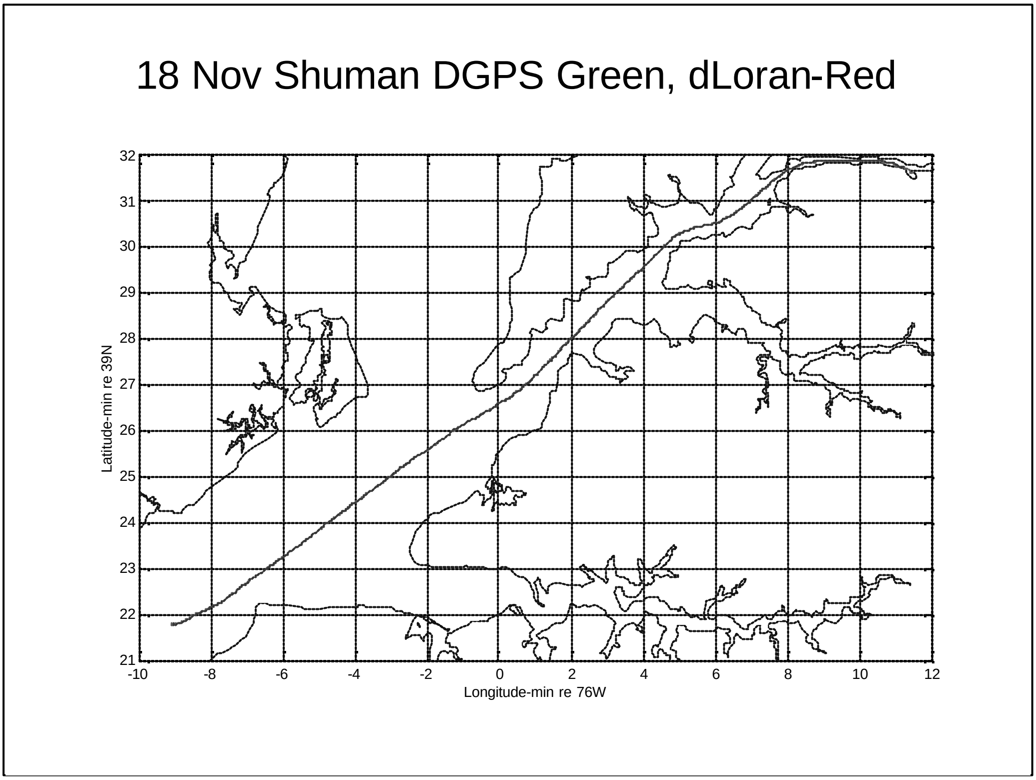


Message types

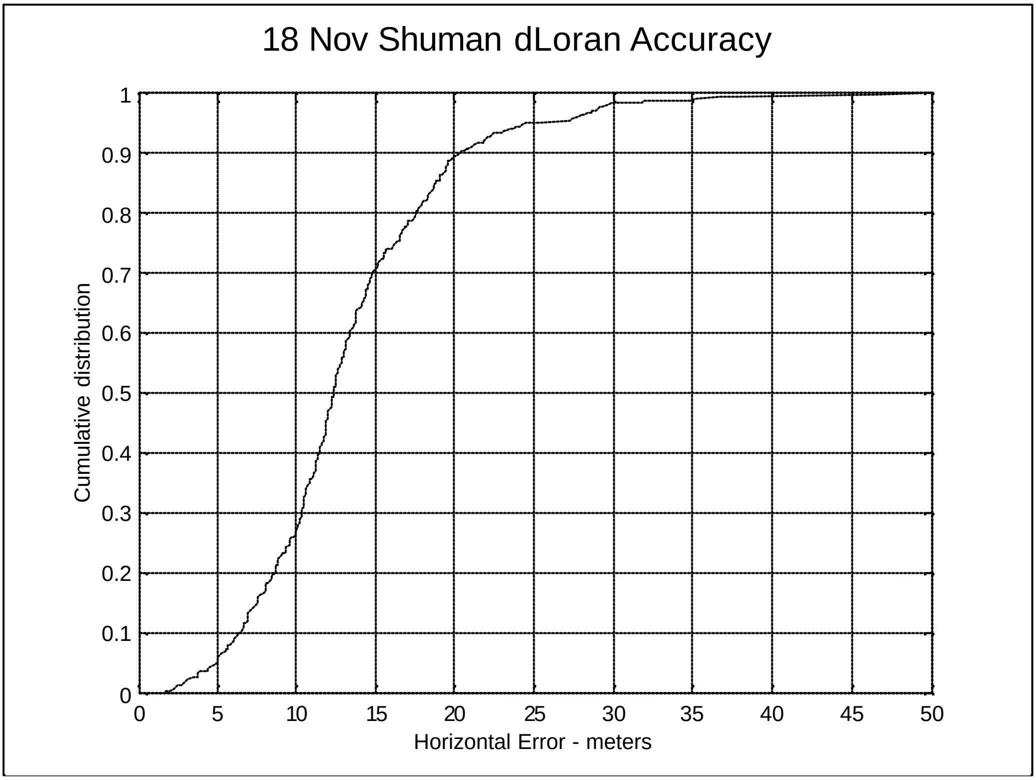
- Absolute time and station ID
  - Also fields for leap seconds and leap second warnings
- Differential Loran
  - Two corrections/message
  - Fields for time base quality & correction age
  - Each LORSTA transmits corrections for base stations in it’s area, not corrections for it’s signal
- Early skywave warning for aviation
- Others TBD (16 possible message types)

Real-time test of maritime corrections on 18 NOV

- ASF spatial grid was based previous trip in same general area, not really a survey
- Base station @ LSU transmitted corrections via LAN to PC modulating TTX on 9960T
- Real time fixes generated using corrections and grid
  - NMEA messages sent via RS-232 to another PC along with DGPS NMEA messages & both stored
  - Plots generated from these files

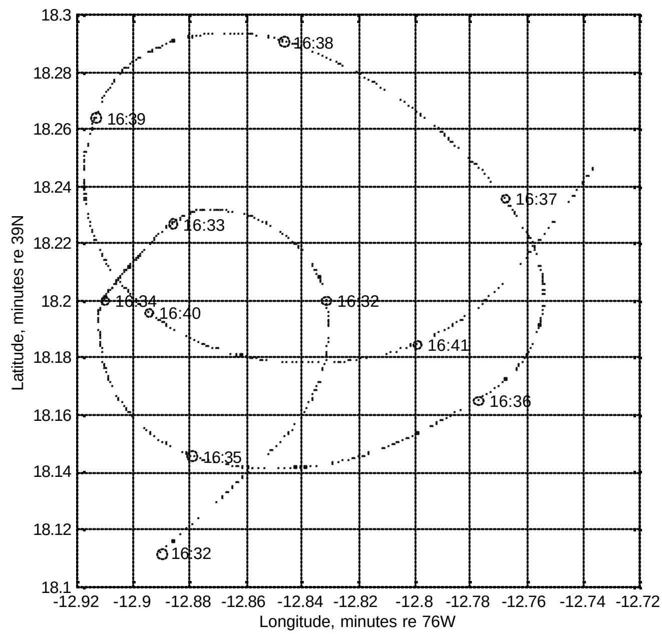


Upper Chesapeake Bay: The reed and green lines are virtually on top of each other in this plot. Zooming in reveals the two separate lines.

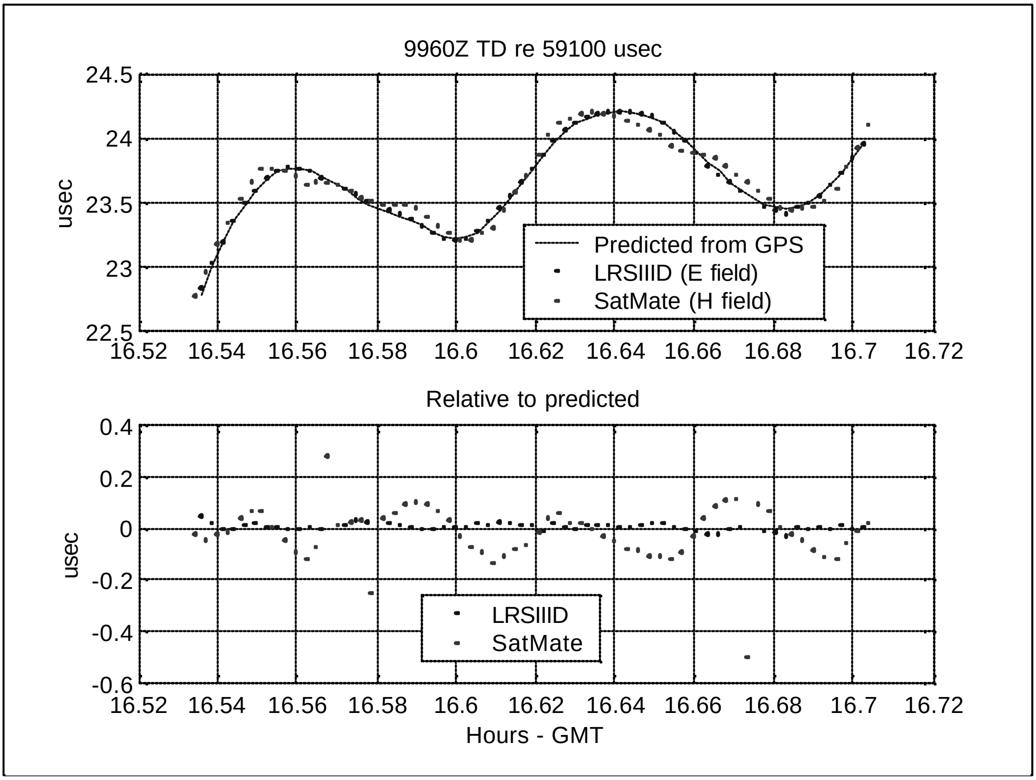


This slide indicates the position **during this 18 NOV 2003 test** was accurate to within **25 meters, 95% of the time**.

Test of directional dependence of H field antenna



This is a position plot for the S/V SHUMAN making turns to collect data on the directional dependence of the magnetic loop (h-field antennas)

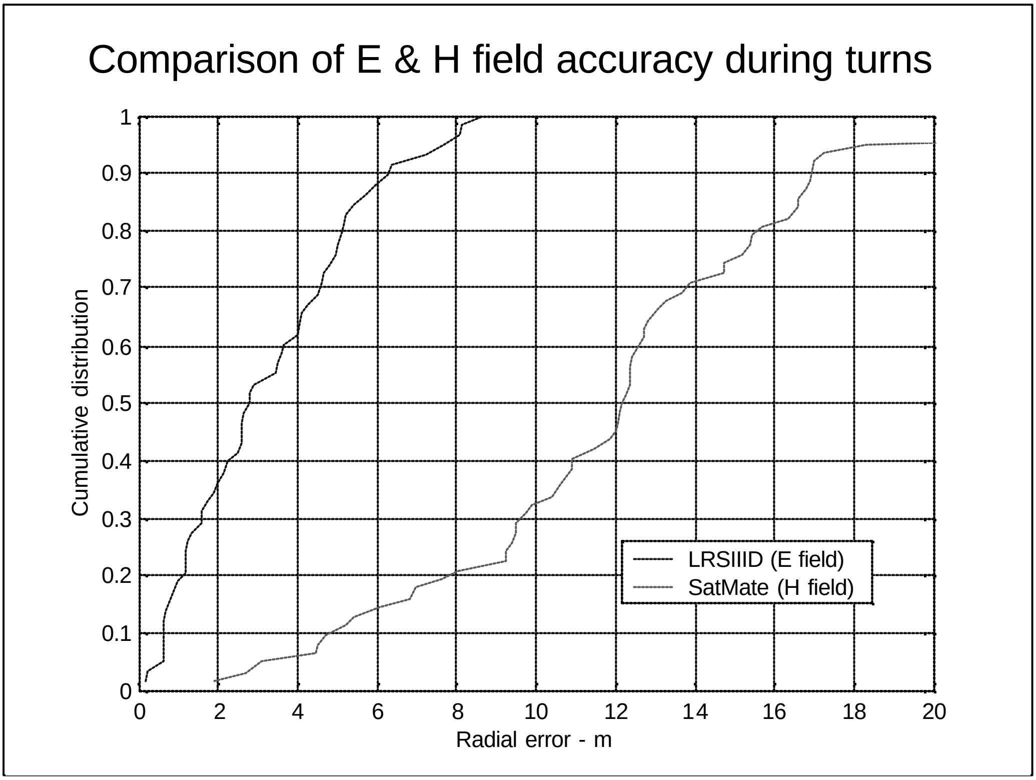


This slide illustrates the coupling effect in the h-field antennas.

1 – Setup: the LOCUS LRSIIID receiver used an e-field antenna, while the LOCUS SatMate used an h-field antenna. Note this when looking at the legends on the plots.

2 – The upper plot is total ASF. Note that the measurements using the e-field antenna closely follows that predicted from GPS, while the ones obtained using the h-field antenna deviate fro the predicted values.

3 – The lower plot is normalized by removing the predicted bias. It shows more clearly the timing errors introduced when using an un-calibrated h-field antenna.

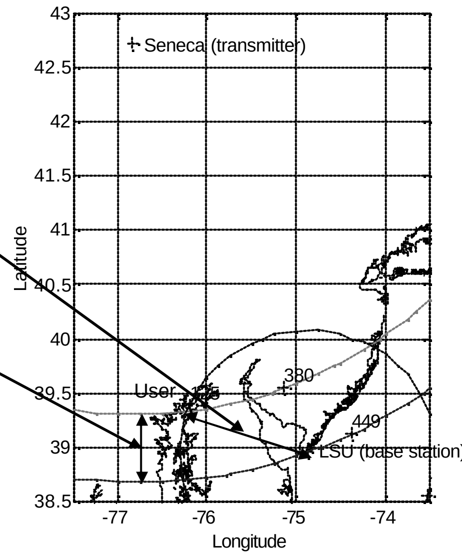


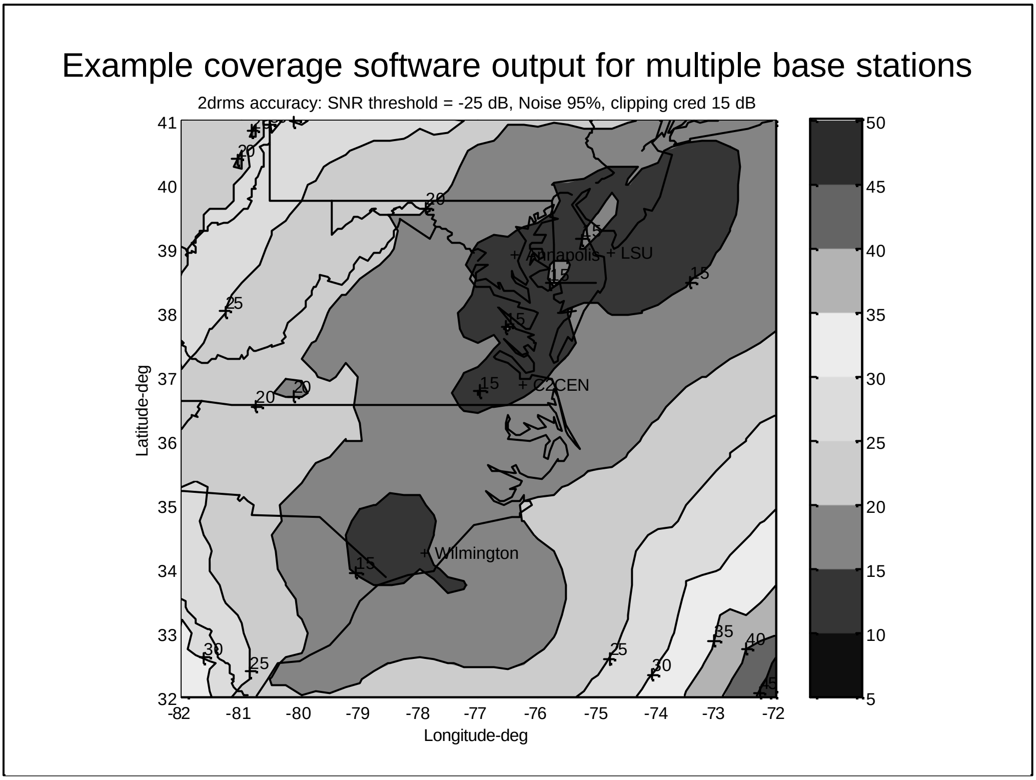
A Cumulative Distribution (CD) plot illustrating the loss of accuracy when using an uncalibrated h-field antenna vice an e-field antenna **during a turn.** From this plot we see that for this transit, **at the 95% level**, there was a **loss of accuracy of at least 11 meters** using the h-field antenna vice the E-field antenna.

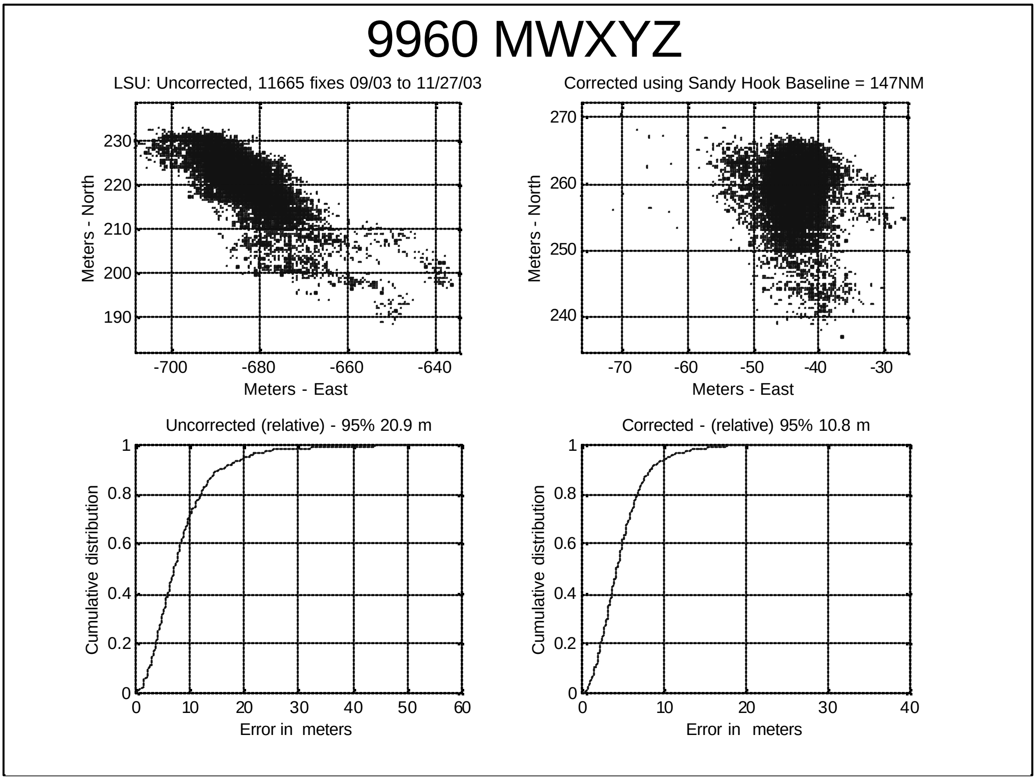
Basic dLoran Pseudorange Accuracy Model

$$\sigma^2 = k_1 + 337^2/(\text{Npulses} * \text{SNR}) + k_2 * r_{bs}^2 + k_3 * dr_{tr}^2$$

- $k_1 = \Sigma$ constants independent of position (transmitter jitter, base station noise, grid accuracy, etc.) Assumed uncorrelated from transmitter to transmitter.
- r_{bs} = Range from user to base station, Error assumed uncorrelated from transmitter to transmitter.
- dr_{tr} = Difference in range between transmitter & user and transmitter and base station. Error assumed correlated from transmitter to transmitter. Seasonal ASF term that will vary by region. (Regional map used in following examples.)




Example coverage software output for multiple base stations
2drms accuracy: SNR threshold = -25 dB, Noise 95%, clipping cred 15 dB
Latitude-deg
Longitude-deg
+ Annapolis
+ LSU
+ C2CEN
+ Wilmington
41
40
39
38
37
36
35
34
33
32
-82
-81
-80
-79
-78
-77
-76
-75
-74
-73
-72
50
45
40
35
30
25
20
15
10
5



The next three slides are similar and contain the same information for different locations.

Summary/General Idea:

1 – the survey and grid is required for differential LORAN.

2 – the differential corrections offer a significant improvement in accuracy.

3 – there is no significant variation in accuracy with baseline.

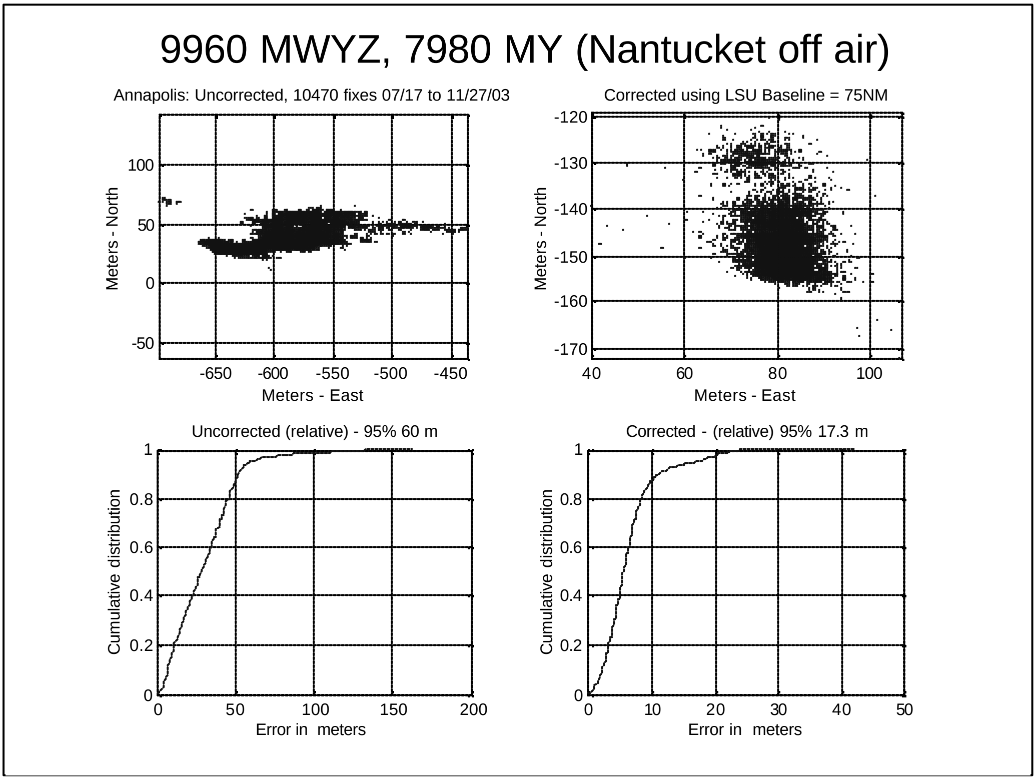
For this slide:

LORAN fixes of the LSU monitor site were taken. This is a fixed position

Top left: (without a grid) a scatter plot of uncorrected LORAN positions (i.e. no differential corrections). Note that the positions are generally 700 meters in error, and spread over roughly 1600 m^2.

Top right: (without a grid) a scatter plot of LORAN positions using differential corrections from Sandy Hook, NJ. Note that the positions are generally 260 meters in error, and spread over 900 m^2.

Bottom Left: (with grid) a CD plot of the accuracy obtained from uncorrected positions. Error < 20.9 m, 95% of the time.


9960 MWYZ, 7980 MY (Nantucket off air)
Annapolis: Uncorrected, 10470 fixes 07/17 to 11/27/03
Corrected using LSU Baseline = 75NM
Meters - North
Meters - East
Uncorrected (relative) - 95% 60 m
Corrected - (relative) 95% 17.3 m
Cumulative distribution
Error in meters

Summary

- Modulation & message format is frozen at least for the proof of concept phase
- Message generator, TTX modulator & LDC/NAV receiver successfully tested in real time, SSX modulator testing soon
- Coverage analysis software written & now being validated
- Differential Loran can meet 20 meter 2drms, HEA requirement throughout most of the US
  - Requires grid survey and differential base station
  - Baseline lengths of 100 NM or more feasible making total number of base stations reasonable (<100)
  - E field better than H field at this point, calibration and/or antennas with less bias may solve problem
  - Some locations (e.g. Miami, San Juan, Honolulu have no coverage.
  - Others, (e.g. Southern California) have marginal geometry and could meet 25-30 meter requirement
  - Others (south Florida, south Texas) depend critically on single station and continuity an issue.

Acknowledgements

Funded by Federal Aviation Administration

Mitch Narins – Program Manager

USCG Loran Support Unit

CDR John Macaluso, LT Kevin Carroll,LT Anthony Hawes, LTJG Ron Wright & Electronics Technician Todd Abraham

USCG Command and Control Center

CDR Gordon Weeks

US Army Corps of Engineers

Joe Scolari, Linn Prince, Joe Nudge, Bill Haynes, & Buzz Etschman

Peterson Integrated Geopositioning

Ken Dykstra & Peter Swaszek

Contact Info/Disclaimer

For additional info:

Dr. Ben Peterson

benjaminpeterson@ieee.org

-Note-

The views expressed herein are those of the author and are not to be construed as official or reflecting the views of the U.S. Coast Guard, the U. S. Federal Aviation Administration, or the U.S. Departments of Transportation and Homeland Security.