Current Status of Ongoing Loran Evaluations

The Road to eLoran in the United States

Mitchell J. Narins

US Federal Aviation Administration

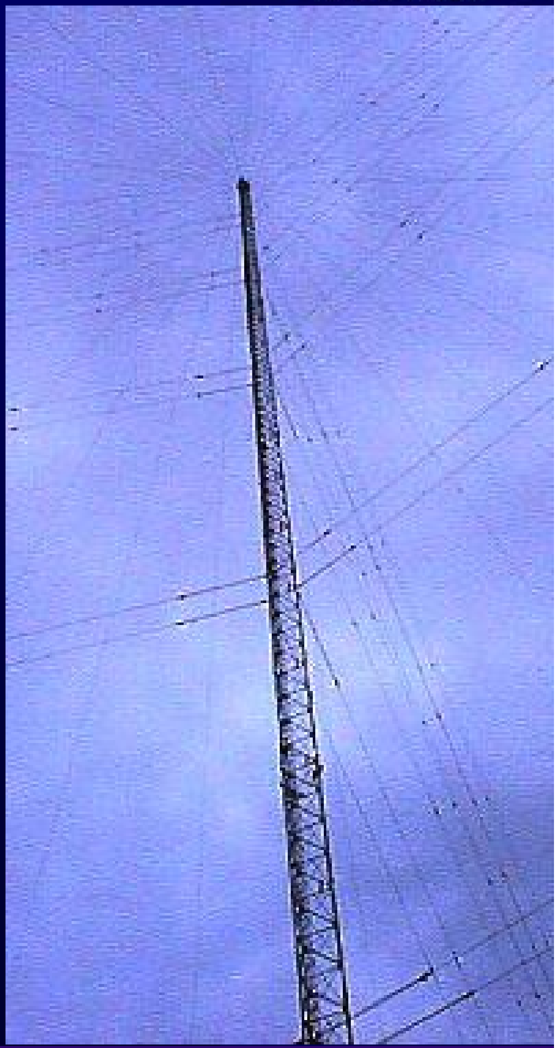
ILA Meeting

Santa Barbara, CA

October 2005

Background

- Loran is currently:
  - A hyperbolic radionavigation system…
    - …operating between 90 kHz and 110 kHz…
    - …that uses a very tall antenna…
    - …that broadcasts primarily a groundwave
    - …at high power…
    - …that provides both lateral position…
    - …and a robust time and frequency standard
  - A supplemental system for enroute navigation in the US National Airspace System (NAS)
  - A system for maritime navigation in the coastal confluence zone (CCZ)
  - A Stratum 1 frequency standard (i.e., 1×10^{-11}) that also provides time within 100 ns of UTC (USNO)



Background

- As a radionavigation system, Loran provides*:
  - A predicted 2drms accuracy of 0.25 nm (460 m) and a repeatable accuracy of 60-300 ft (18-90 m)*
  - An availability of 99.7% (based on triad operation)*
  - A level of Integrity based on exceeding certain operational parameters measured at the transmitters and at system area monitor sites.
  - Continuity no greater than 99.7% (its availability), but potentially worse depending on receiver characteristics and geometry of the triad being used, and…..
- ***If this is all Loran can do, the US will turn it off!***

*US Federal Radionavigation Plan (FRP)

Current US FRP Loran Policy

"The Government is evaluating the ability of an enhanced Loran system to support ***non-precision approach*** for aviation users, ***harbor entrance and approach*** for maritime users, and ***improved performance for time and frequency users***. If the Government concludes as a result of the evaluations that Loran-C *is not needed* or *is not cost effective*, the United States Coast Guard (USCG) will plan to disestablish the system by the end of fiscal year 2008 with appropriate public notice."

US DOT Navigation Task Force Report

"If Loran ***can meet*** requirements for non-precision approach for aviation users, harbor entrance and approach for maritime users, and improved performance for time and frequency users, and is cost effective, ***Loran should be included in the future radionavigation mix***."

The Report:

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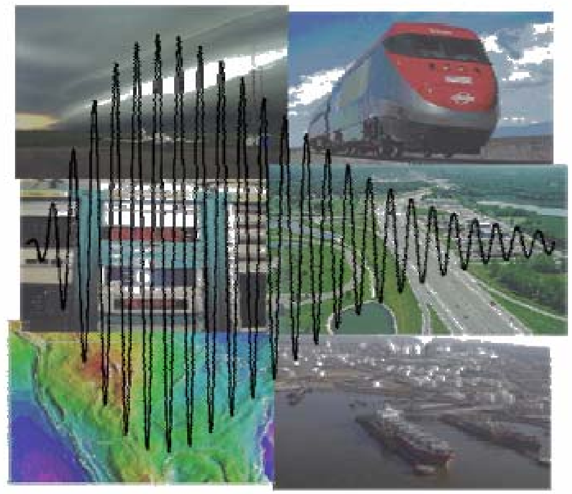
Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications



Prepared for the
FEDERAL AVIATION ADMINISTRATION
VICE PRESIDENT FOR TECHNICAL OPERATIONS
NAVIGATION SERVICES DIRECTORATE

March 2004

FOR OFFICIAL USE ONLY

https://ksn.faa.gov/km/navservices/navservicesIt/tech/Loran_Eval_Report/default.aspx

The Loran Evaluation Specifics

- Determined whether an enhanced Loran could provide the:
  - *Accuracy*
  - *Availability*
  - *Integrity*
  - *Continuity*

  a) to support Lateral Navigation through all phases of flight – including Non-Precision Approach (NPA)

  b) to support Harbor Entrance and Approach (HEA) for maritime users
- Determined what other ancillary benefits could be derived from the continued provision of enhanced Loran services
  - e.g., to support Stratum 1 frequency and timing users
- Determined if providing these services via Loran would be cost-beneficial (i.e., Benefits/Costs >1 and other things considered)*

* Not a part of the Technical Evaluation

The eLoran Technical Challenge
Current Capabilities vs. Future Requirements*

	Accuracy	Availability	Integrity	Continuity
Current Definition of Capability* (US FRP)	0.25 nm (463 m)	0.997	10 second alarm/ 25 m error	0.997
FAA NPA (RNP 0.3)** Requirements	0.16 nm (307 m)	0.999 – 0.9999	0.9999999 (1 x 10-7)	0.999 - 0.9999 over 150 sec
US Coast Guard HEA Requirements	0.004 - 0.01 nm (8 – 20 m)	0.997 - 0.999	10 second alarm/ 25 m error (3×10^{-5})	0.9985 – 0.9997 over 3 hours

* Includes Stratum 1 timing and frequency capability.
** Non-Precision Approach Required Navigation Performance

The Evaluation Team's Conclusion

"The evaluation shows that the modernized Loran system could satisfy the current NPA, HEA, and timing/frequency requirements in the United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the users to retain the benefits they derive from their use of GPS."

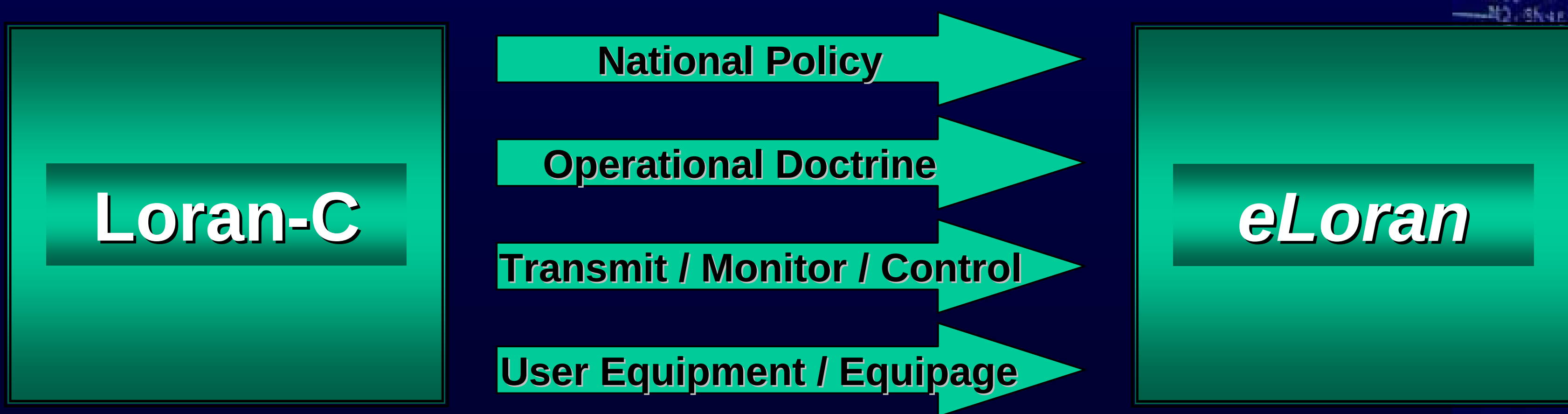
"This conclusion is based on an analysis of the applications' performance requirements; expected modification of radionavigation policies, operating procedures, transmitter, monitor and control processes, and user equipment specifications; completion of the identified Loran-C infrastructure changes; and results from numerous field tests. Collectively, these create the architecture for the modernized Loran system."

The Loran Evaluation --Good News/Bad News

- GPS has been extremely reliable and its use as the primary means of deriving Position Navigation and Time (PNT) is expanding.
- GPS' excellent "track record" may be deterring the implementation of backup systems despite vulnerability concerns.
- The potential safety, security, and economic impacts of a GPS disruption of service may not be fully understood or appreciated.
- **The Loran Evaluation was done for the users of GPS so they would not lose the benefit they derive from using GPS in their applications.**

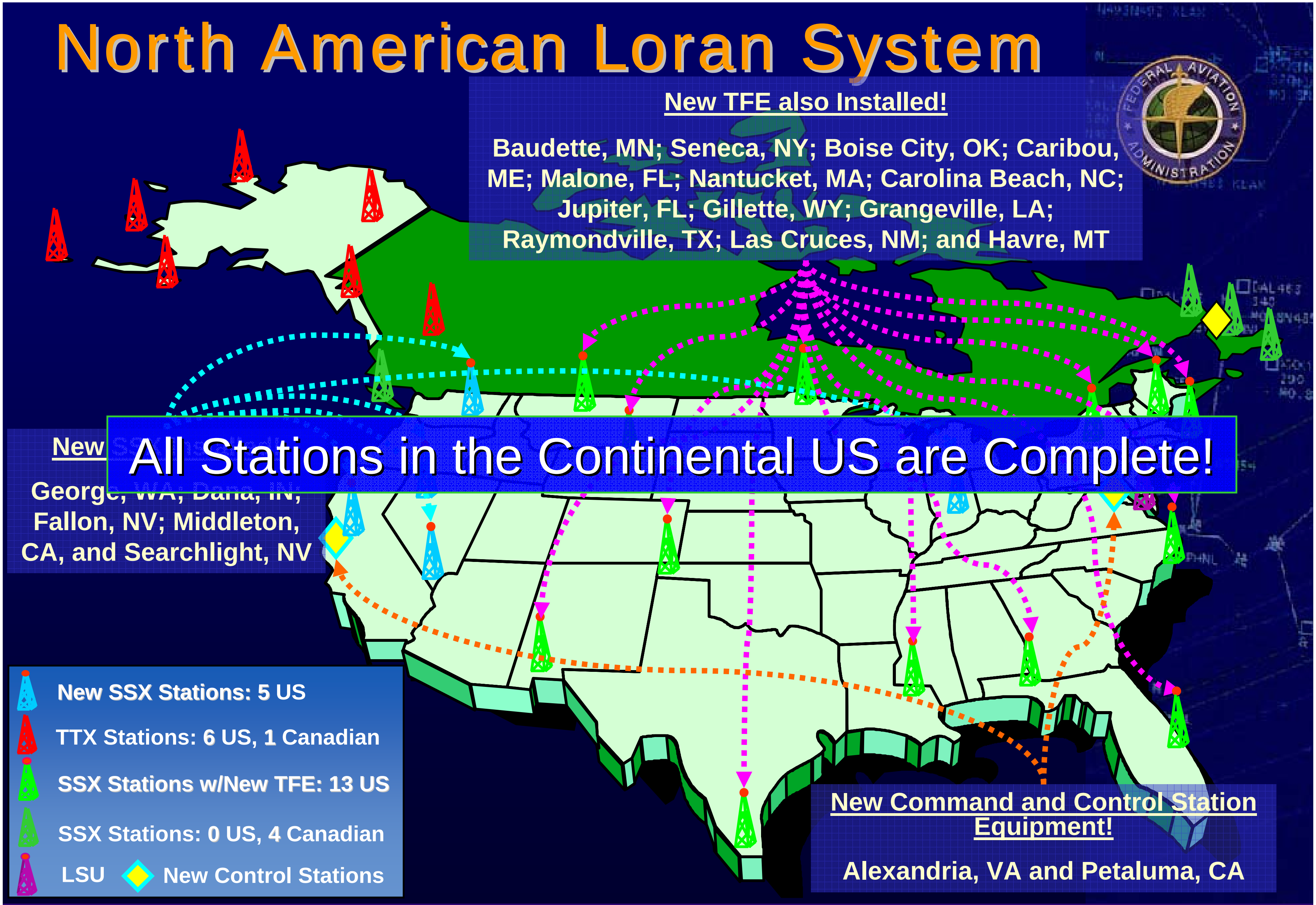
"Enhanced" Loran (eLoran)

"…If the decision is made to retain Loran as one of the federally provided radionavigation systems, the extent to which these modifications are accepted and implemented will define the actual characteristics of the resulting enhanced Loran (*eLoran*) system."



Program Status

- Loran Technical Evaluation Report – March 2004
  - Stated that an enhanced Loran system could technically satisfy aviation, maritime, and timing requirements and allow users to retain most benefits they derive from GPS
  - Report released to the public – December 2004
- No decision has been made on Loran; however, the US Congress continues its budgetary support of the program and work is progressing towards implementation of enhanced Loran (*eLoran*)
  - Loran modernization
  - Loran working groups
  - Loran timing panel
  - Loran user equipment development
  - Loran testing and applications


North American Loran System
New TFE also Installed!
Baudette, MN; Seneca, NY; Boise City, OK; Caribou, ME; Malone, FL; Nantucket, MA; Carolina Beach, NC; Jupiter, FL; Gillette, WY; Grangeville, LA; Raymondville, TX; Las Cruces, NM; and Havre, MT
All Stations in the Continental US are Complete!
New
Fallon, NV; Middleton, CA, and Searchlight, NV
New SSX Stations: 5 US
TTX Stations: 6 US, 1 Canadian
SSX Stations w/New TFE: 13 US
SSX Stations: 0 US, 4 Canadian
LSU
New Control Stations
New Command and Control Station Equipment!
Alexandria, VA and Petaluma, CA

Ongoing Loran Modernization

- The Loran Evaluation Team is also moving forward in support of:
  - US test of Time-of-Transmission (TOT) Operations
  - Implementation of a Loran Enhanced Monitoring System (LEMS)
  - Development of a Loran Information Control and Operations System (LICOS)

The Loran Clock

A Most Important Infrastructure Undertaking

- All US Loran Stations and the Loran Support Unit have three new cesium clocks – ***78*** very high stability clocks ***geographically dispersed*** across North America
- Tests have shown that all 78 clocks could be steered to UTC (USNO) (independently from GPS) with great accuracy
- Current efforts lays the groundwork for the establishment of a robust Loran clock akin to the GPS clock

eLoran Working Groups

- Continuing the assessment and development of *eLoran* for aviation and maritime operations
  - Standards Development: Receiver MOPS and system safety assessment
  - Refinement of hazard models
    - Noise
    - variations in ASF and ECD
    - etc.
  - System infrastructure and design development:
    - Early skywave detection network
    - ninth pulse messages,
    - ASF and differential Loran grid
    - Differential Loran monitors
- ***This work will prepare for the necessary assessments, analyses, and documents needed for certification***

Loran Working Groups (cont)

- Ten Working Groups are currently active:
  - **WG1 Receiver MOPs coordination**
  - **WG2 Model Validation**
  - **WG3 Loran Signal Specification**
  - **WG4 Transmitter Characteristics**
  - **WG5 Propagation I (ASF, ECD)**
  - **WG6 Propagation II (noise, skywave)**
  - **WG7 System Safety Assessment**
  - **WG8 Data Warehouse**
  - **WG9 Time and frequency**
  - **WG10 GPS Integration**

Early Skywave Testing

- Early skywave is a major integrity hazard
  - Interferes with the desired groundwave
  - Is analogous to GPS multipath
- Efforts are ongoing to:
  - Develop monitor receivers & reliable test methodology to determine if an event occurred
  - Develop a network and associated architecture to detect an event and to determine the affected area
  - Develop protocols and message design to warn users of this hazard

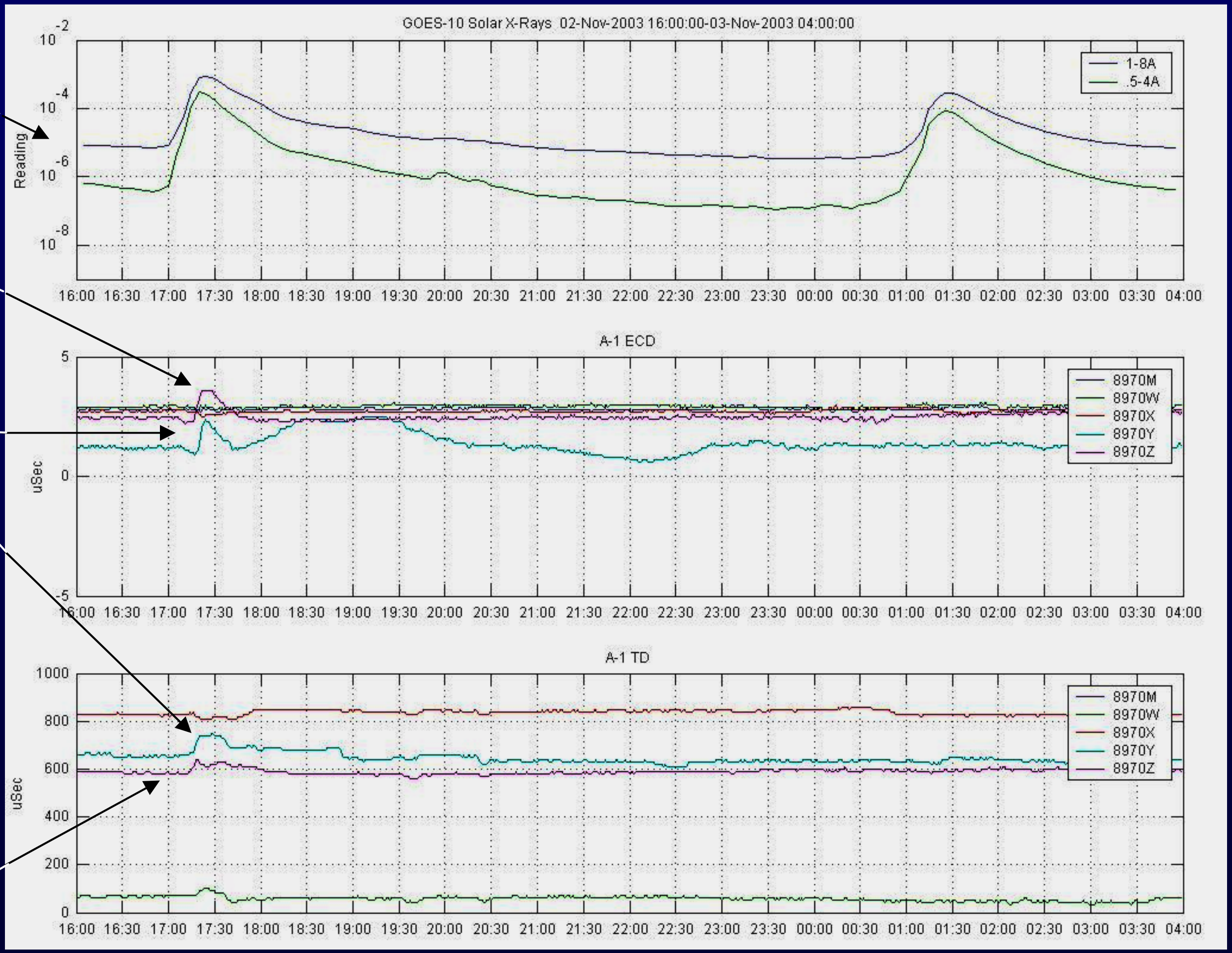
Detecting Early Skywave

GOES Data

Boise City – Little Rock

Baudette – Dunbar Forest

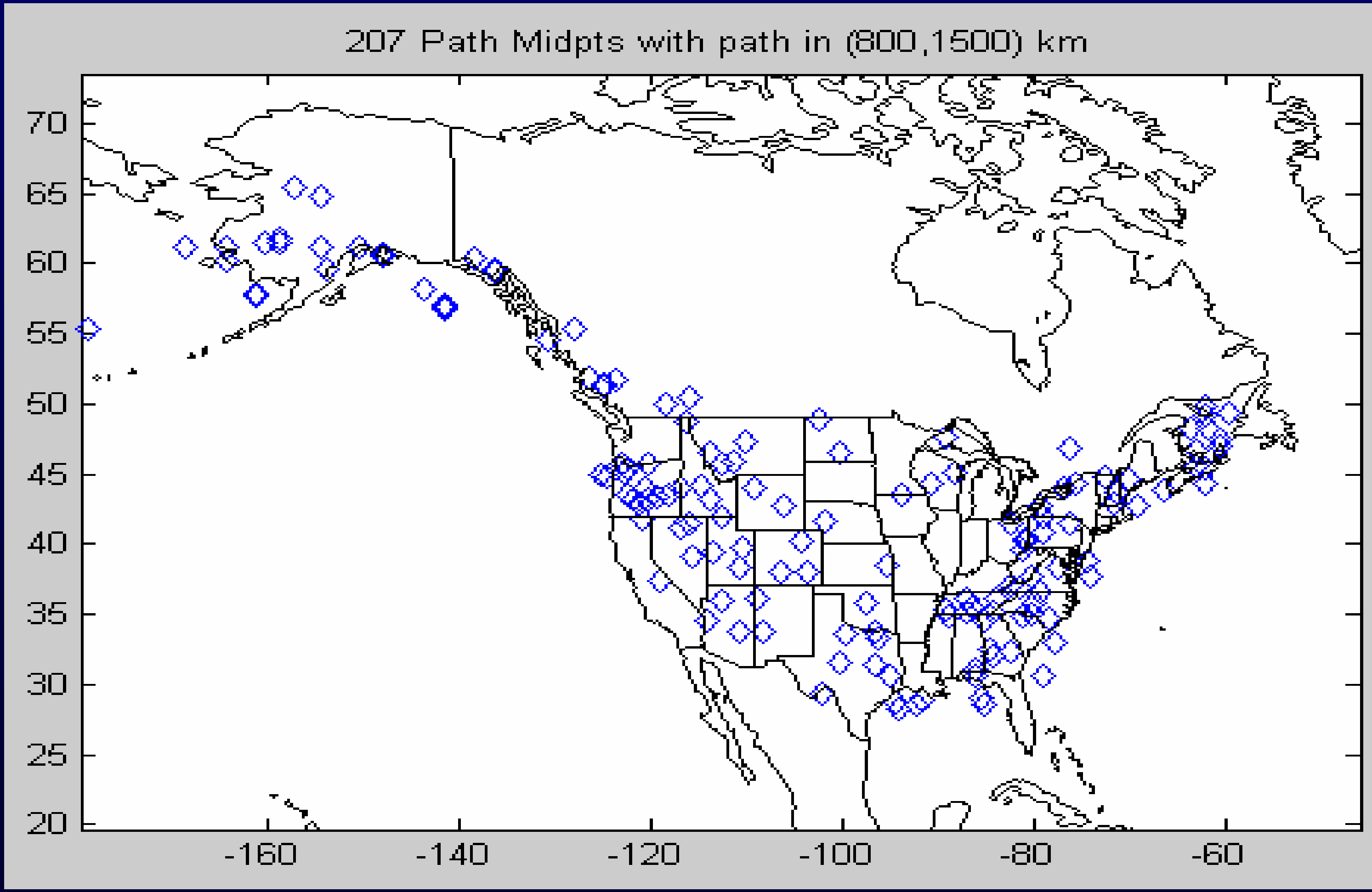
Boise City – Little Rock



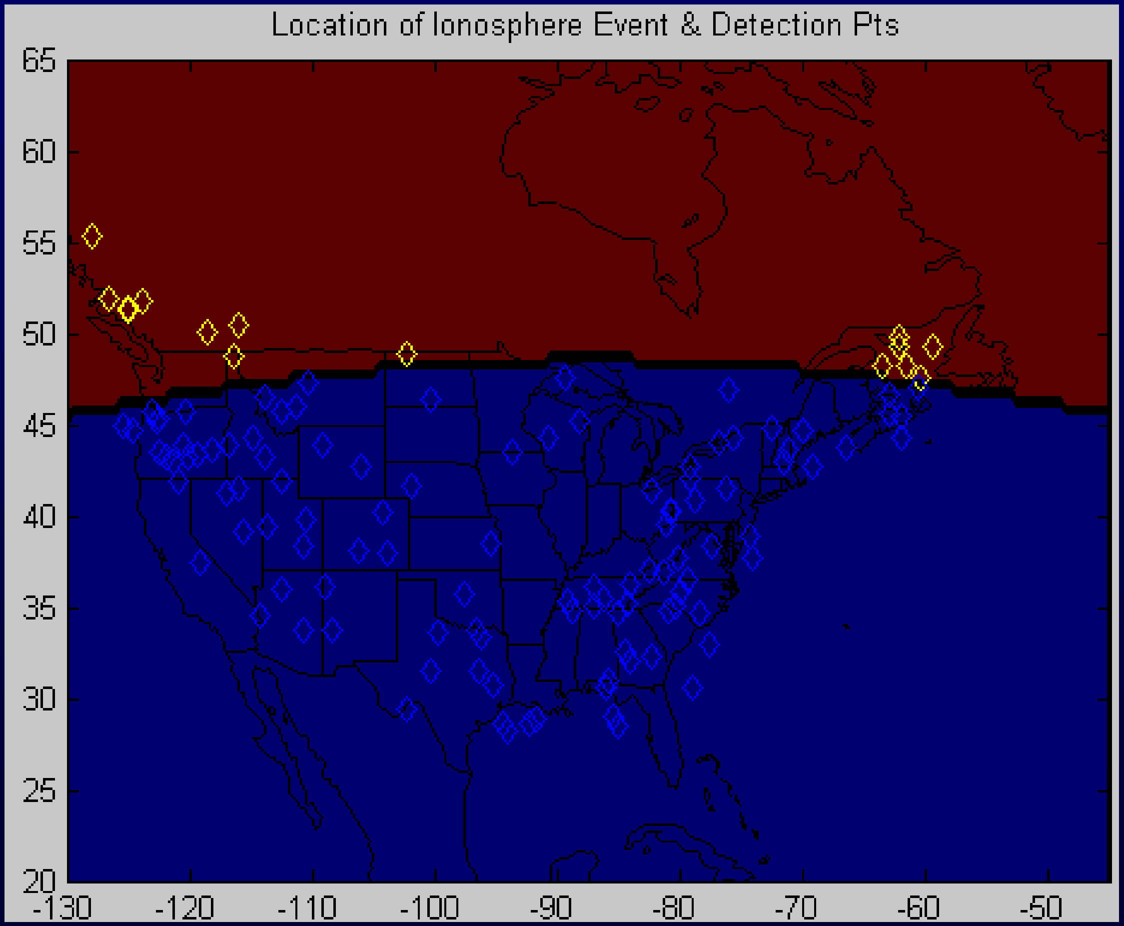
*From Dunbar Forest, MN and Little Rock, AR (8970 Alpha 1 monitors) 02-03 Nov 2003

Early Skywave Detection Network

Path Midpoints for Early Skywave



Early Skywave Network *Simulator*

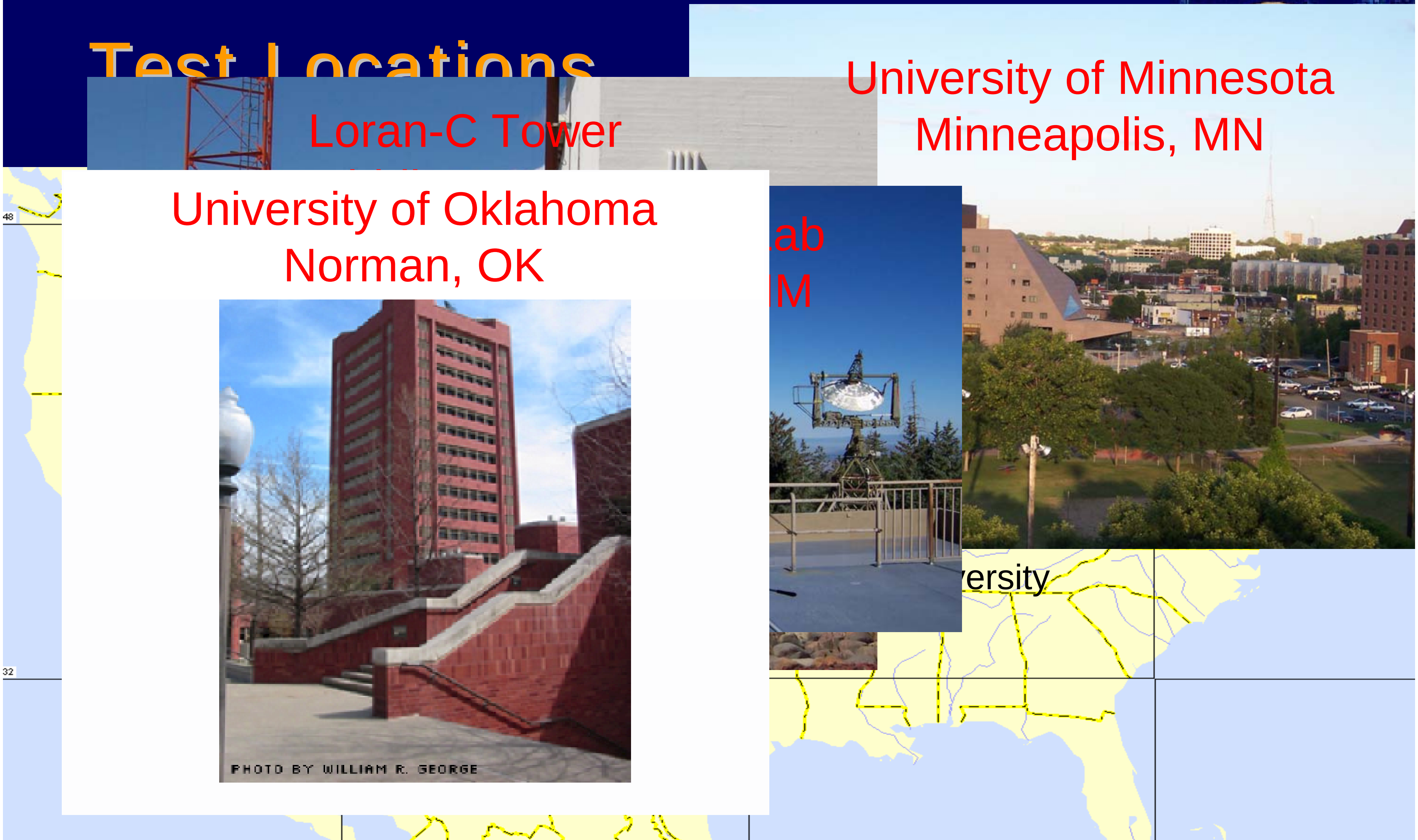


- Simulator being developed tests network design against potential early skywave events
  - Worst case failures
  - False alarms
- Also tests warning algorithms
- Plot shows early skywave detection points if all transmitters and SAM sites are used in monitor network
  - Red areas are where early skywave could exist
  - Highlighted points are detected locations

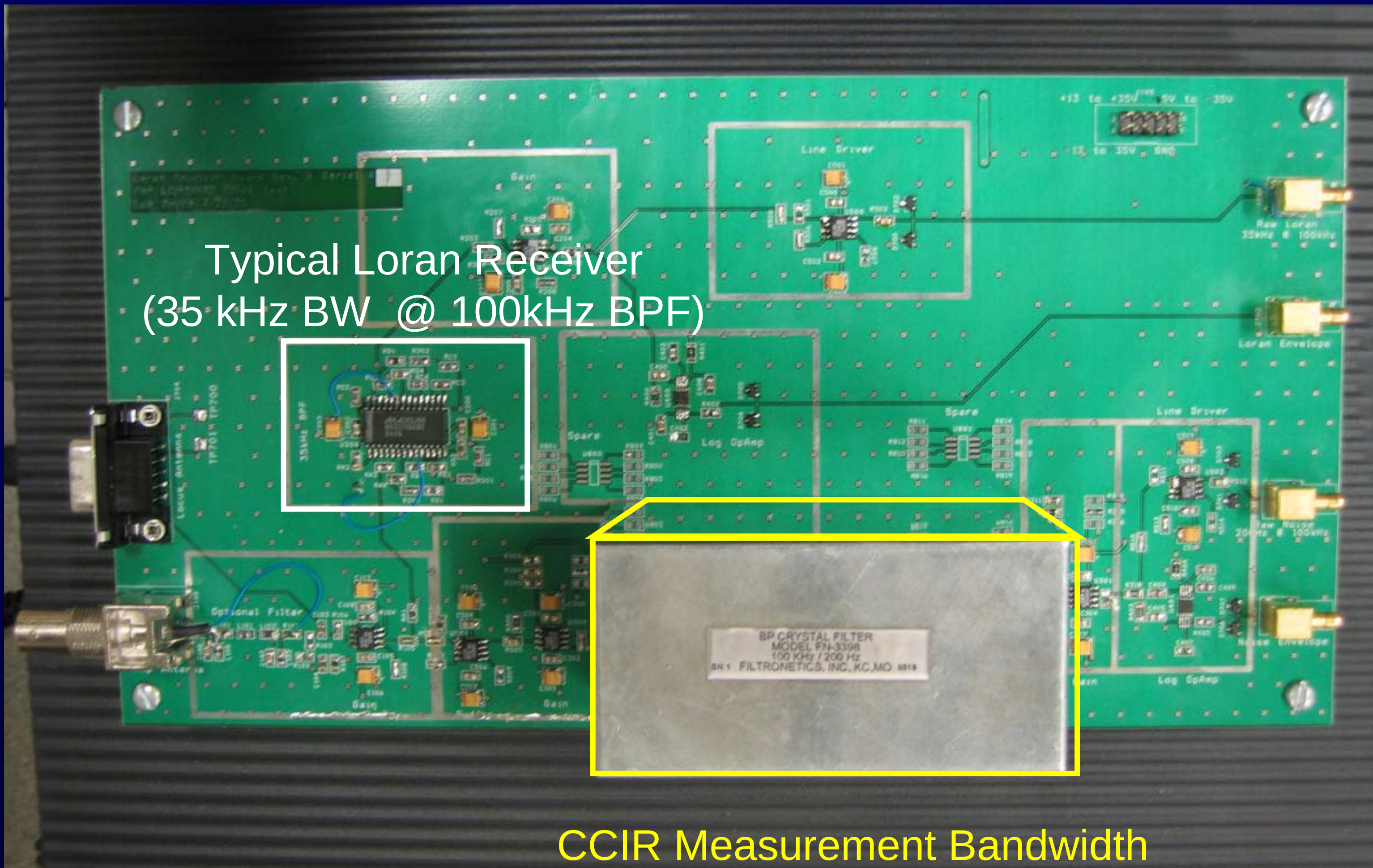
Atmospheric Noise Testing

- Atmospheric noise is the major source of noise in the Loran band
  - CCIR is the standard model
- Validation and refinement of CCIR models is ongoing for use in coverage predictions
- Signal processing is being developed as a means to reduce the effect of noise and to improve coverage

Test Locations



Atmospheric Noise Front End



University of Oklahoma

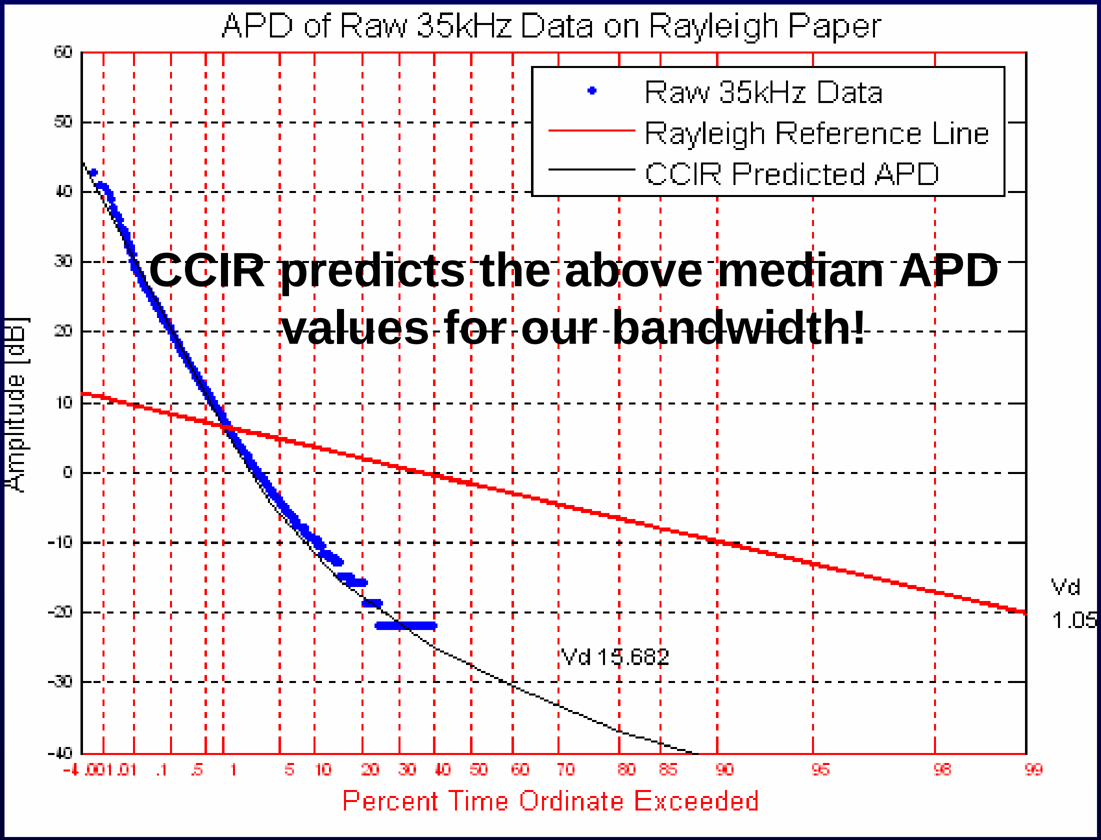
Locus Loran Antenna
35 kHz & 200 Hz

True Time GPS Antenna
(For Signal Timing)

Wide-band Flat Plate Antenna
250 kHz BW

Used to calibrate measurement setup

Our Preliminary Results



- Confirm both the predicted CCIR noise levels and the CCIR amplitude distribution
- The CCIR recommendation for translating their data to the Loran band seems valid
- Suggest that high noise (> 100 dBuV/m) levels are possible for Loran
- ***Suggest that nonlinear processing could produce significant gain!***

Predicted and Actual Amplitude Probability Distribution

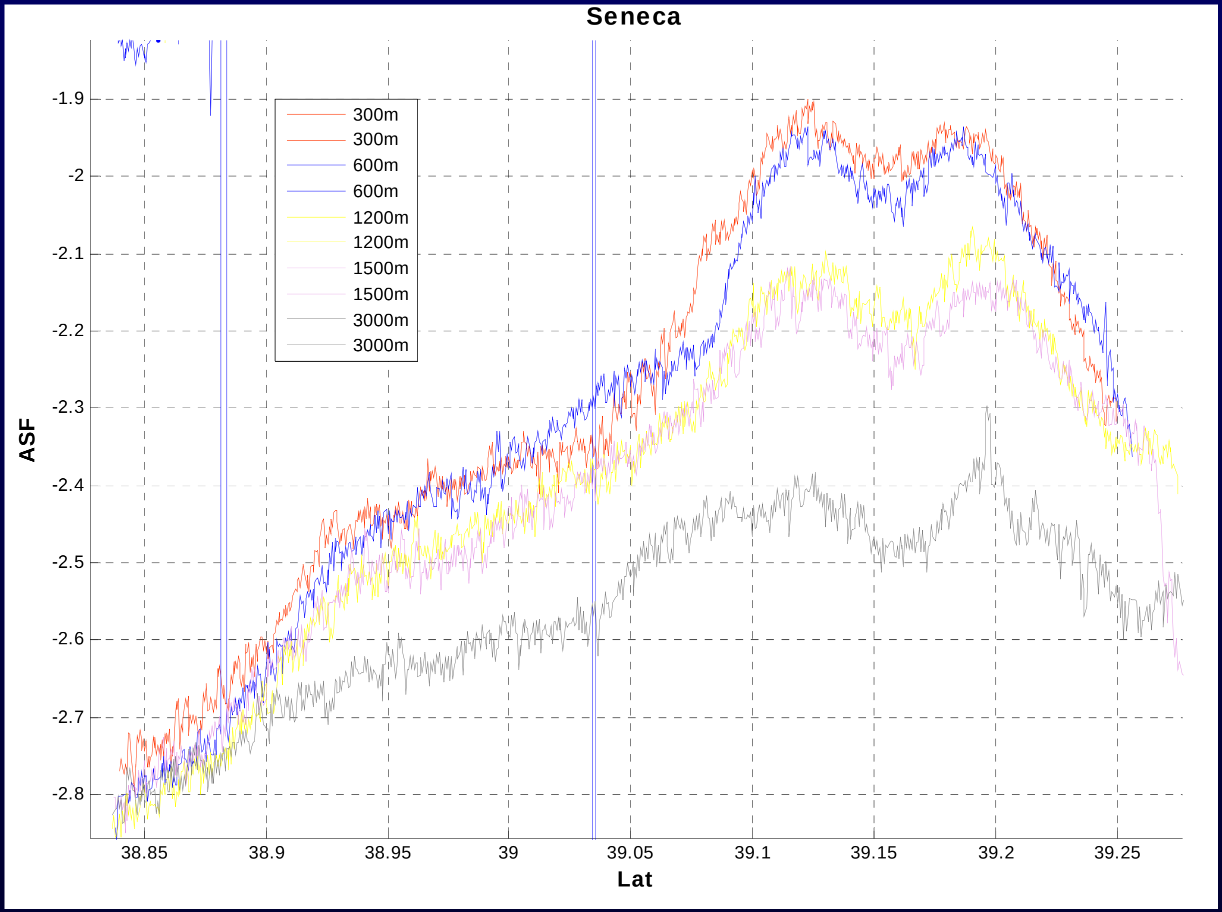
Additional Secondary Factor (ASF) Testing

- ASFs are propagation delays due to terrain – both ground conductivity and topography
- Validation of ASF models is necessary to ensure the integrity of the navigation and time services and the validity of coverage predictions
  - Efforts are underway to develop procedures for airport surveys and the eventual generation of government -approved ASFs for aviation
  - Efforts are also underway to determine the extent and density of ASF monitoring to support HEA

Planned Flights to Validate Our Spatial ASF Models

FAA Van for Collecting ASF Data

Variation of ASF with Altitude



- Plane flew back and forth between 2 points at various altitudes:
  - 300m, 600m, 1200m, 1500m, 3000m
- ASF variation may be due to antenna directionality, measurement error, etc.

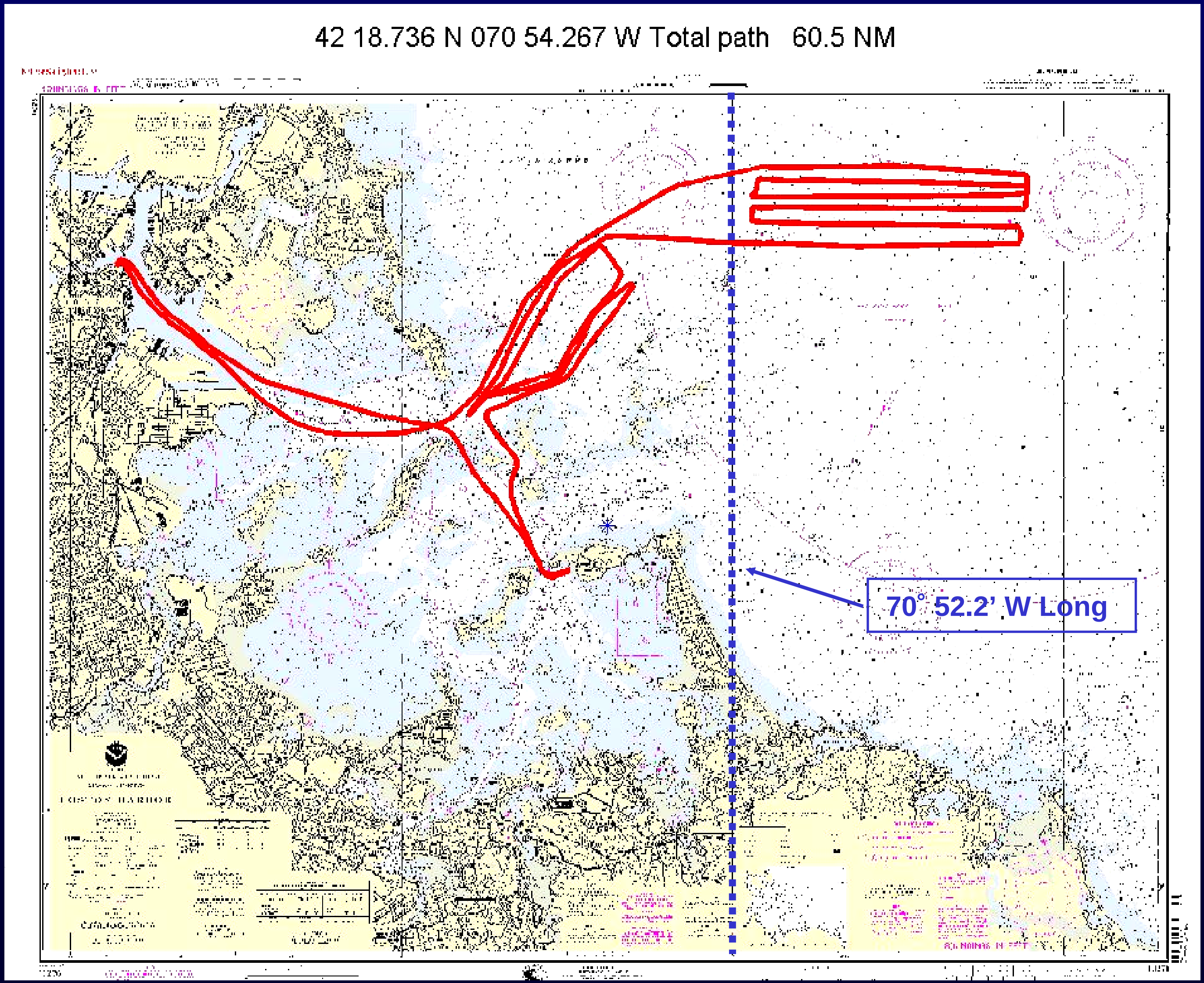
Airship for Testing ASF Variation as a Function of Altitude

Testing scheduled this summer

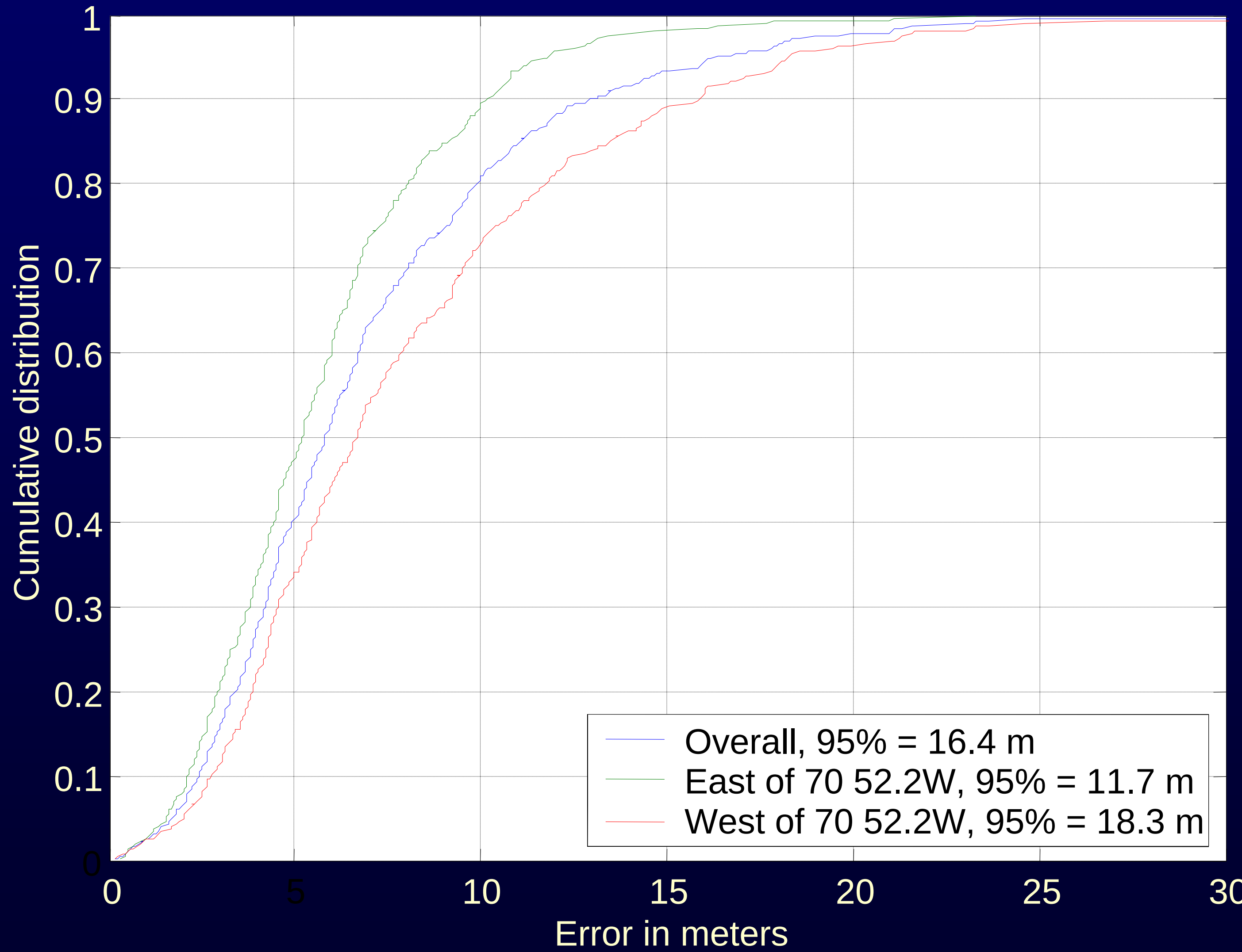
"Special Testing" and Applications

- Boston, MA
  - Harbor Testing by USCG Academy and Loran Support Unit
- New York City
  - "Urban Canyon" Testing by Volpe Center
- White Sands, NM
  - Testing during GPS Jamming by Volpe Center

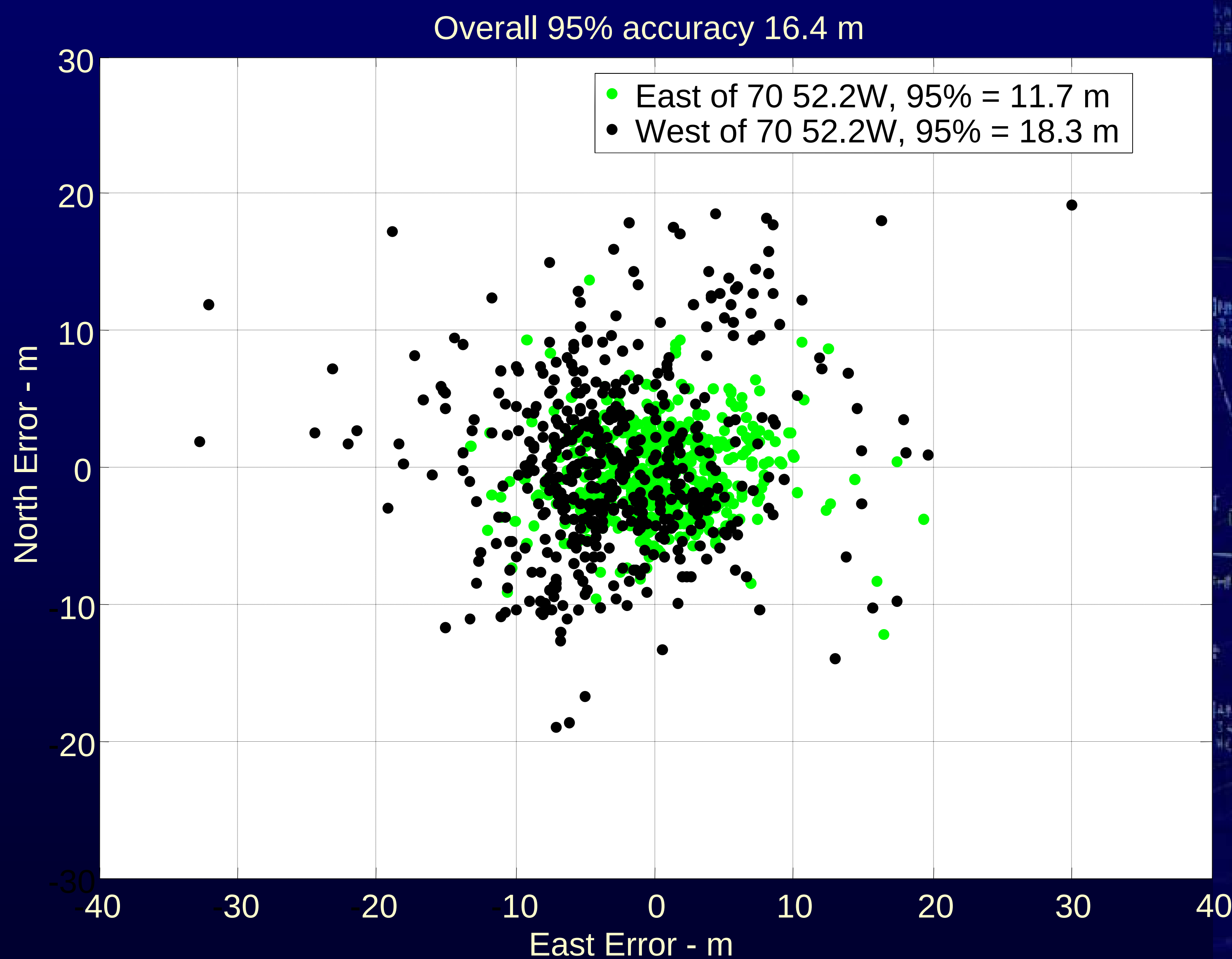
Harbor Testing 2005: Boston



Example Marine Data: Boston Harbor



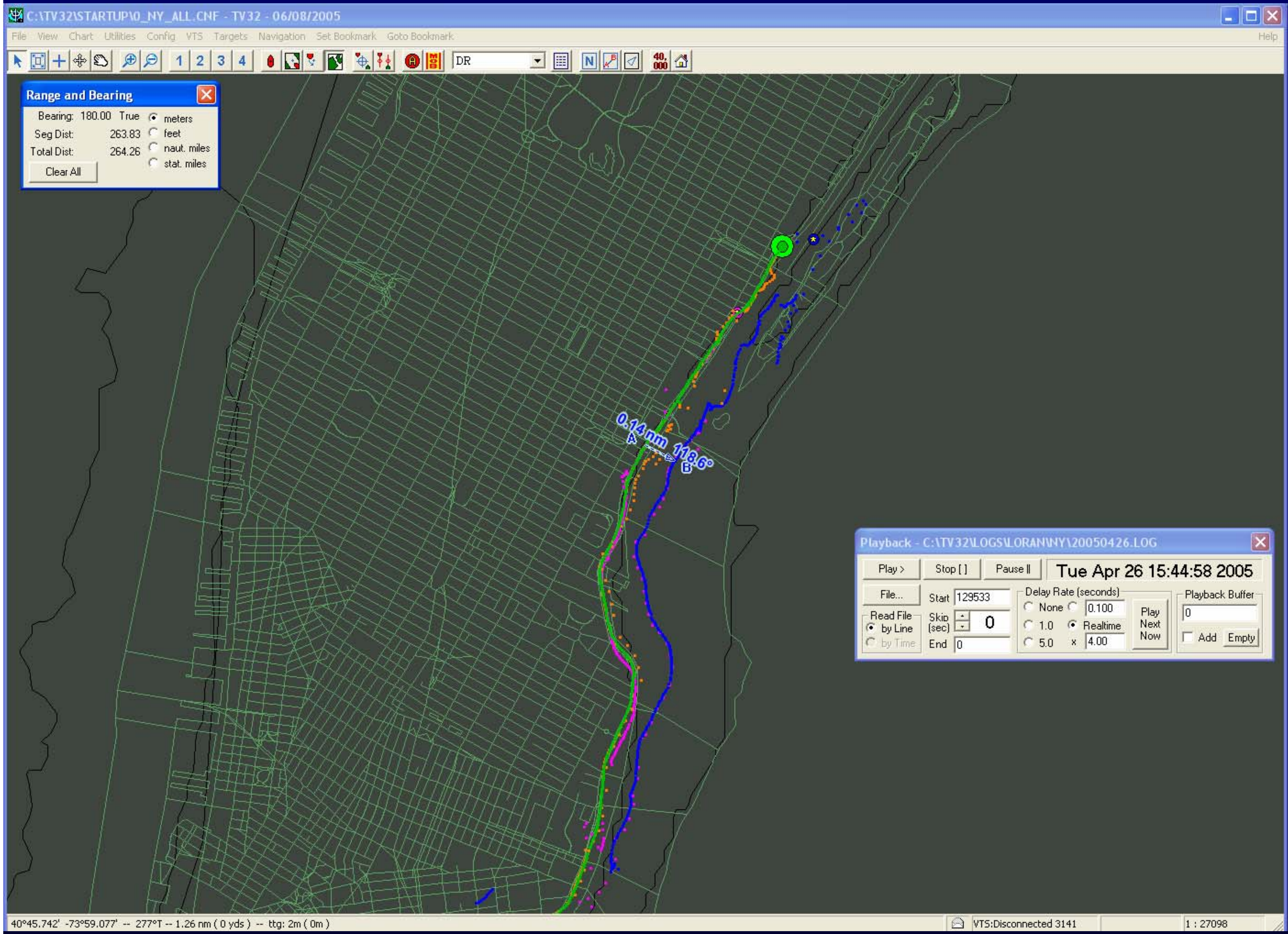
Example Marine Data: Boston Harbor



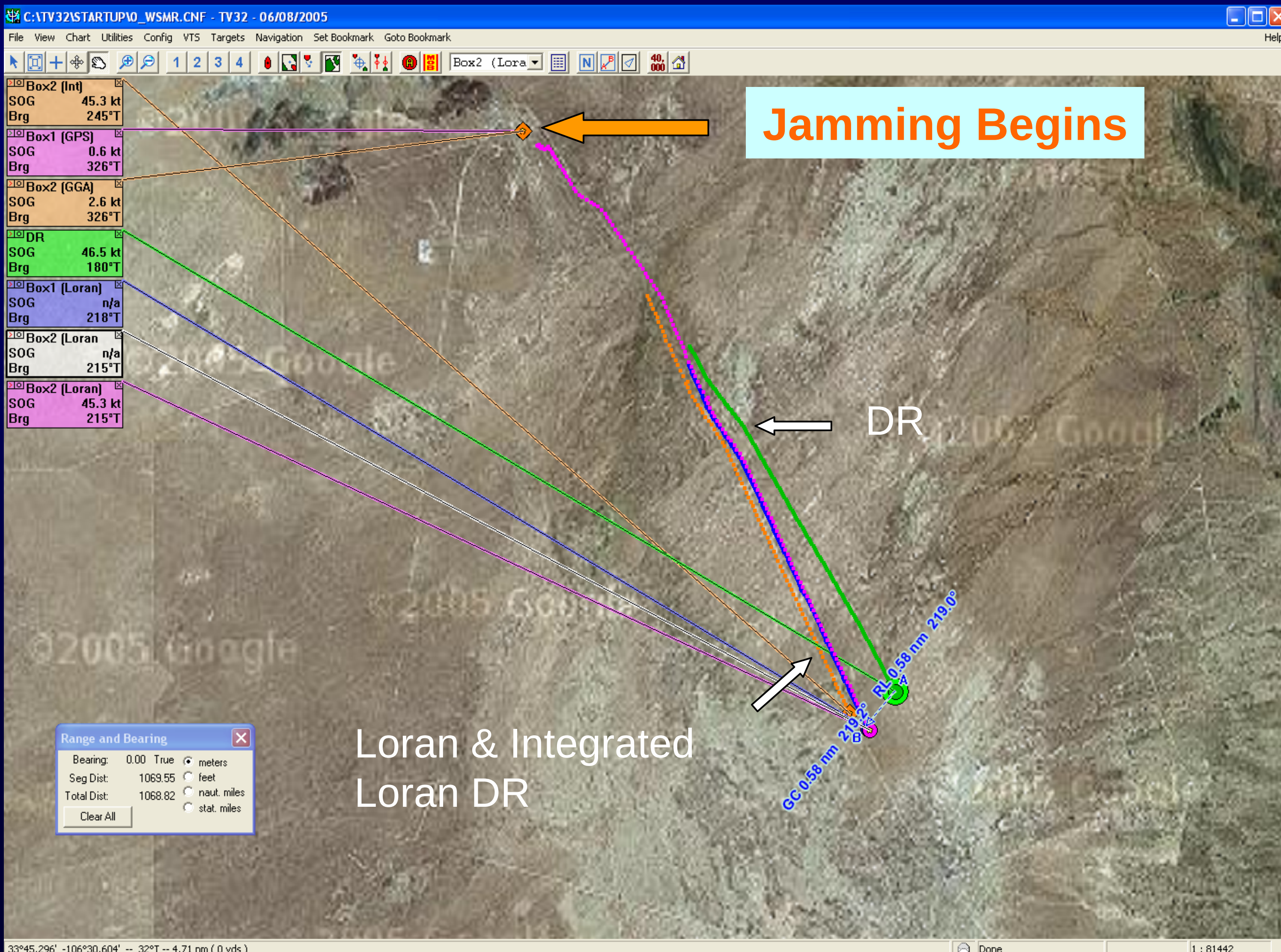
Land Mobile Testing

- How can independent and integrated combinations of Loran, DR, GPS benefit users in challenging “urban canyon” environments
- How is stand-alone and integrated Loran affected by GPS jamming
- Determine when and how Loran should be integrated with other navigational capabilities

Urban Environment Testing



GPS Jamming Environment



Prototype Locus Loran Card in Rockwell Collins Multi-Mode Receiver

- **Rockwell Collins has continued the work *on their own* to incorporate low cost gyros into the integrated receiver solution**

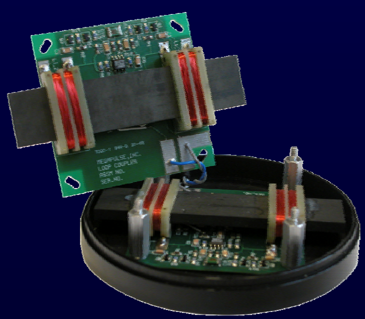
FreeFlight Systems/Locus
GA Multi-Mode Receiver Development

2003

2004

Loran/GPS/WAAS
Megapulse/Reelektronika Receiver

Megapulse/Reelektronika/Si-Tek Multi-Mode Marine Receiver



Signal Processor
77 x 51 mm

Front End & ADC
77 x 47 mm

GPS – WAAS — Loran

Receiver Availability – *Now*!

MSRP: $999

Our Next Steps:

- Continue modernization of Loran infrastructure to support evolving system to *eLoran*
- Support testing to support evolving US Loran System to Time-of-Transmission control
- Continue development and testing of 9th Pulse communications parameters and message set to support delivery of *eLoran* services
- Continue technical analyses of mechanisms that affect Loran performance and present challenges to providing envisioned *eLoran* services
- Continue development of integrated *eLoran* receivers to support multiple user communities
- Await Department of Transportation and Department of Homeland Security Decision

Questions

Backup

Trade Spaces Identified in Report

- **Radionavigation Policy**

  The high-level statements of performance, certification, calibration, funding, etc. These are areas that require agency, multi-agency, or international action or agreements.

- **Operational Doctrine**

  The out-of-tolerance (OOT) limits, control parameters, off-air planning, etc to be employed in daily management of the system. These are areas that the USCG must integrate into their operational control process and procedures to satisfy all users requirements.

- **Transmitter, Monitor, and Control Equipment**

  The equipment used for signal generation, monitoring, and control. This trade space describes the equipment and modifications to the existing Loran-C infrastructure.

- **User Equipment**

  The sensor specification, antenna types, and algorithms used to define and implement user equipment. This trade space describes the parameters and conditions that must be met by the user equipment.

Navigation Must Fail-Soft / Fail-Safe

Navigation is no longer a nicety – it has become a necessity!

- **The FAA's definitions of three levels of fallback in the event of a GPS outage were used in the Loran Evaluation:**
  - **Redundant Capability** – a capability where interference has *no effect on operations* and navigation capabilities are similar to what can be accomplished using SatNav.
  - **Backup Capability** – a capability where SatNav interference *will affect operations* by requiring reliance on other unaffected ground-based Navaids or other radionavigation services and the following of alternative procedures. While carrying a backup capability *may* allow arrivals to or departures from a specific location, it must ensure the ability to reach a safe location.
  - **Operational Contingency** – a capability that relies on specific operational contingency procedures to *ensure safety* at the onset of and during SatNav interference. These procedures may *preclude or limit operations*, including access to or egress from certain locations.
- **The Report had to determine what role(s) Loran could play.**

Evaluation Participants

- **Government**
  - FAA
    - Navigation and Landing Systems Engineering, AND-740
    - Navigation and Landing System Architecture, ASD-140
    - CNS Test and Evaluation, ACB-440
    - Flight Standards, AFS-400
    - Aircraft Certification, AIR-130
    - Special Programs, AVN-5
  - US Coast Guard
    - HQ Aids to Navigation
    - Navigation Center
    - Loran Support Unit
    - Command and Control Center
  - Volpe National Transportation System Center

Evaluation Participants

- **Industry**
  - Booz|Allen|Hamilton
  - FreeFlight Systems
  - Illgen Simulation Technologies, Inc.
  - JJMA
  - Locus, Inc.
  - Megapulse, Inc.
  - Peterson Integrated Geopositioning
  - Reelektronika
  - Rockwell Collins
  - Si-Tex Marine
  - Timing Solutions
  - WR Systems
- **Academia**
  - Ohio University
  - Stanford University
  - US Coast Guard Academy
  - University of Rhode Island
  - University of Alaska
  - University of Wales

Loran Evaluation Activities
Numerous Interrelationships

- To determine Loran *Accuracy* Potential:
  - Loran Accuracy Performance Panel (LORAPP)
  - Receiver/Integrated receiver studies
  - ASF* studies and calibration (for both conductivity and terrain)
  - Differential Loran study
- To determine Loran *Availability* Potential:
  - H-Field Antenna/P-static testing
  - CONUS All-in-view receiver analysis
  - Noise analysis
  - SSX and TFE modification evaluations
- To determine Loran *Integrity* Potential:
  - Loran Integrity Performance Panel (LORIPP)
  - Time of Transmission/ASF studies
- To determine Loran *Continuity* Potential:
  - Receiver/Integrated receiver/antenna studies

*additional secondary factors

Loran Issue 1: Accuracy

- **Current Accuracy:** **0.25 nm, 2drms, 95%**
- **Target Accuracy (NPA):** **0.16 nm (307 m) - RNP 0.3**
  0.43 nm (802 m) - RNP 0.5
- **Target Accuracy (HEA):** **8 – 20 m, 2drms, 95%**

Issues	Potential Mitigations
– Old timing sources	☑ New cesium clocks
– Old timing equipment	☑ New timing suite
– Tube technology	☑ Solid State Transmitter (SSX) technology
– Simple prop. model	☐ New ASF* tables/algorithms
– No real-time corrections	☑ LORAPP (Differential Loran)

*Additional Secondary Factors

Loran Issue 2: Availability

- **Current Availability: 0.997**
- **Target Availability (NPA): 0.999 - 0.9999**
- **Target Availability (HEA): 0.997 – 0.999 ☑**

Issues	**Potential Mitigations**
– Precipitation Static	☑ H-Field Antenna
– Atmospheric Noise	☑ H-Field, All-in View receiver
– Loss of Station Power	☑ UPS
– Lightning	☑ New Lightning Protection
– Chain/Stick Availability	☑ All-in-view (AIV) receivers
– Tube overloads	☑ Solid State Transmitters

Loran Issue 3: Integrity

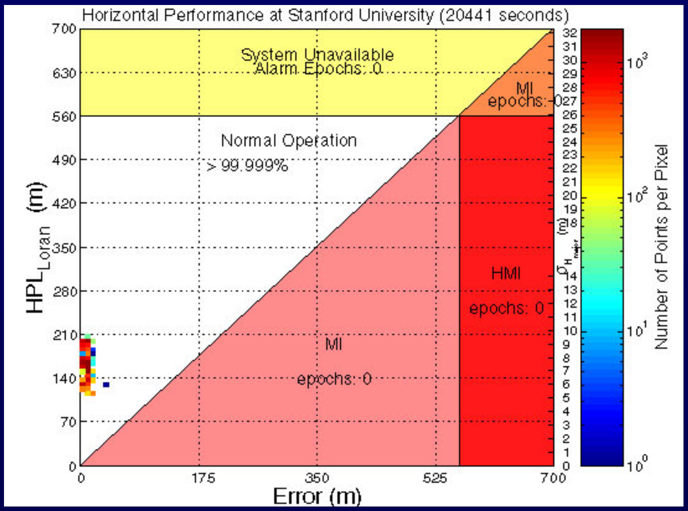
- **Current Integrity:** **10 sec. alert @ ± 100ns or other specified error conditions**
- **Target Integrity (NPA):** **0.9999999* 556m HPL, 10 sec. alert**
- **Target Integrity (HEA):** **0.99997****

Issues	**Potential Mitigations**
– Presumed Integrity/ Auto Blink System	☑ Loran Integrity Panel (LORIPP)
	☑ Loran Accuracy Panel (LORAPP)

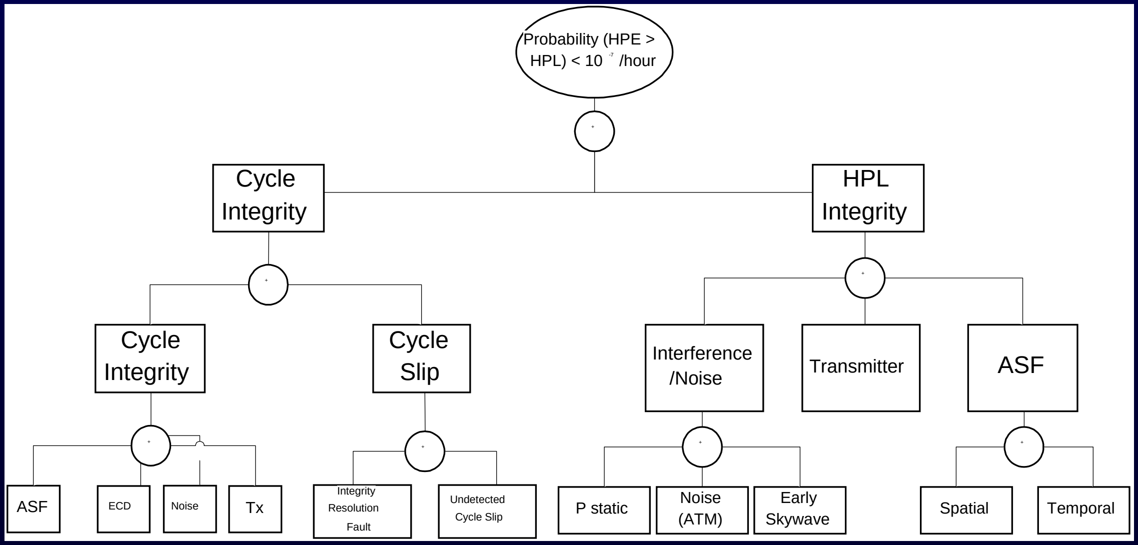
***For Aviation: The probability of providing Hazardous or Misleading Information (HMI) is 1×10^{-7}**

****For Maritime: The probability of providing Hazardous or Misleading Information (HMI) is 3×10^{-5}**

Integrity



Horizontal Performance at Stanford University (20441 seconds)
System Unavailable
Alarm Epochs: 0
MI
epochs: 0
Normal Operation
> 99.999%
HMI
epochs: 0
MI
epochs: 0
HPL_Loran (m)
Error (m)
Number of Points per Pixel



Probability (HPE > HPL) < 10⁻⁷ /hour
Cycle Integrity
HPL Integrity
Cycle Integrity
Cycle Slip
Interference /Noise
Transmitter
ASF
ASF
ECD
Noise
Tx
Integrity Resolution Fault
Undetected Cycle Slip
P static
Noise (ATM)
Early Skywave
Spatial
Temporal

Loran Issue 4: Continuity

- **Current Continuity:** **0.997**
- **Target Continuity (NPA):** **0.999 - 0.9999**
- **Target Continuity (HEA):** **0.9985 – 0.9997**

Issues

Same as **Availability** plus:

– Receiver acquisition time

Potential Mitigations

☑ New DSP technology

☑ New SSX Switch Units

☑ AIV/Integrated Receiver

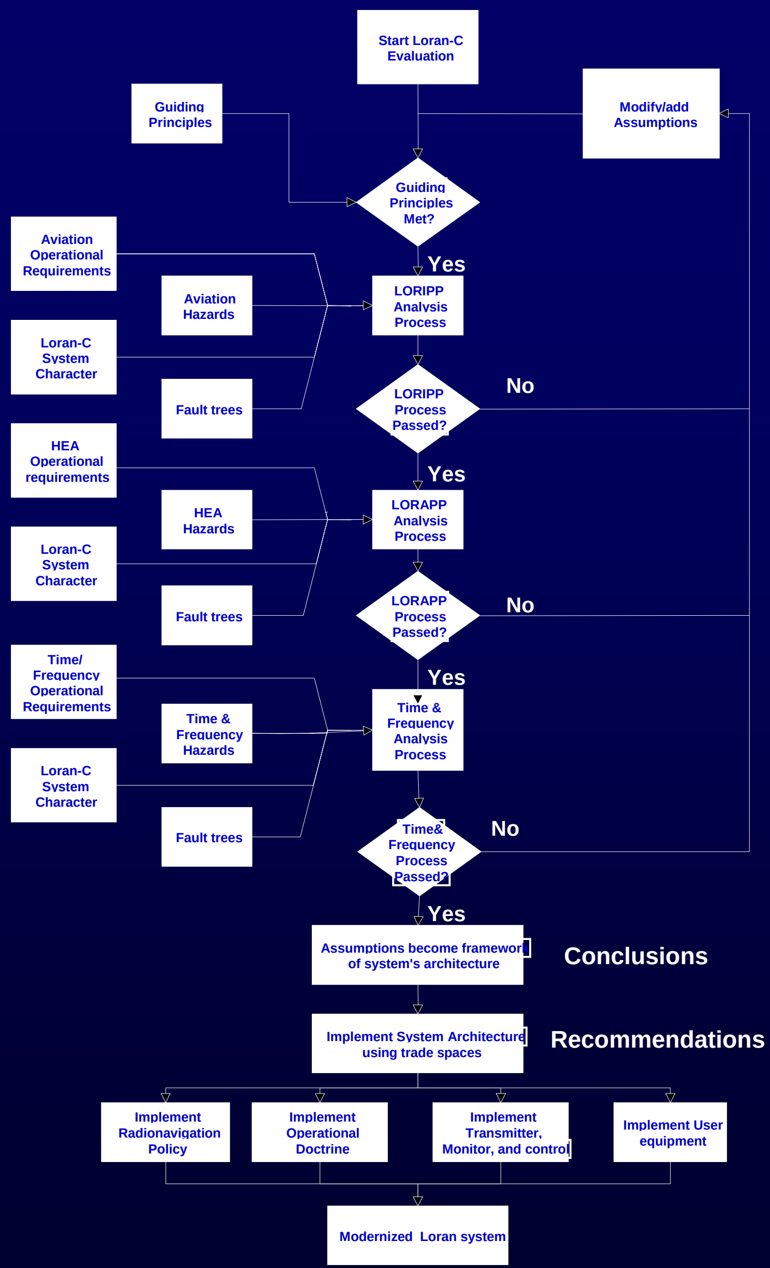
The Loran Evaluation Team Makeup

- A group of internationally recognized navigation experts with direct real-world technical and operational Loran-C experience
  - Transmission
  - Monitoring and control
  - User receiving equipment
  - Operational doctrine
  - Radionavigation policy

- The Loran "Body of Knowledge" has significantly improved as a result of the evaluation

Loran Evaluation Program Logo Collection

FAA Technical Center
the VOLPE center
Megapulse
Loran-C
ASD
LOCUS
NORTHROP GRUMMAN Mission Systems
NORTHROP GRUMMAN Information Technology
Rockwell Collins
Booz | Allen | Hamilton
JJMA An Employee Owned Company
TIMING SOLUTIONS
reelektronika
WR SYSTEMS
SI-TEX MARINE ELECTRONICS
FreeFlight SYSTEMS
PETERSON INTEGRATED GEOPOSITIONING
OHIO UNIVERSITY
• PRIFYSGOL CYMRU • UNIVERSITY OF WALES BANGOR
UNIVERSITY OF Rhode Island
UNIVERSITY of ALASKA

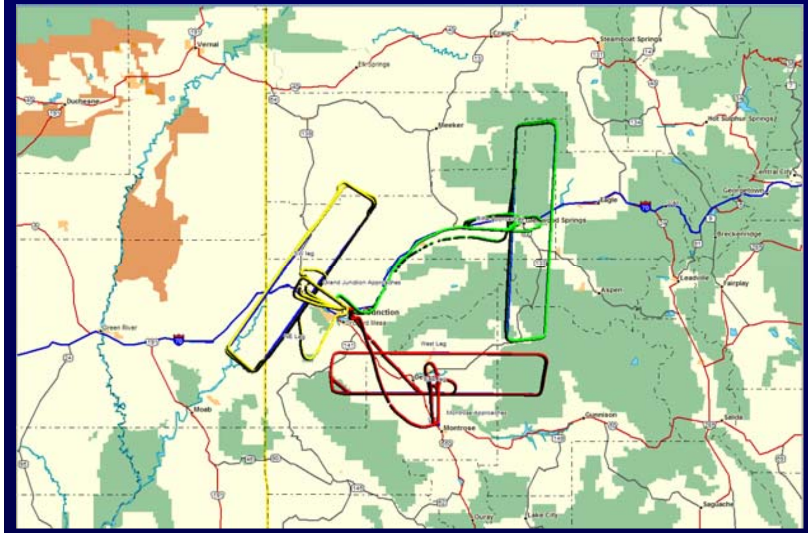


The Evaluation Process

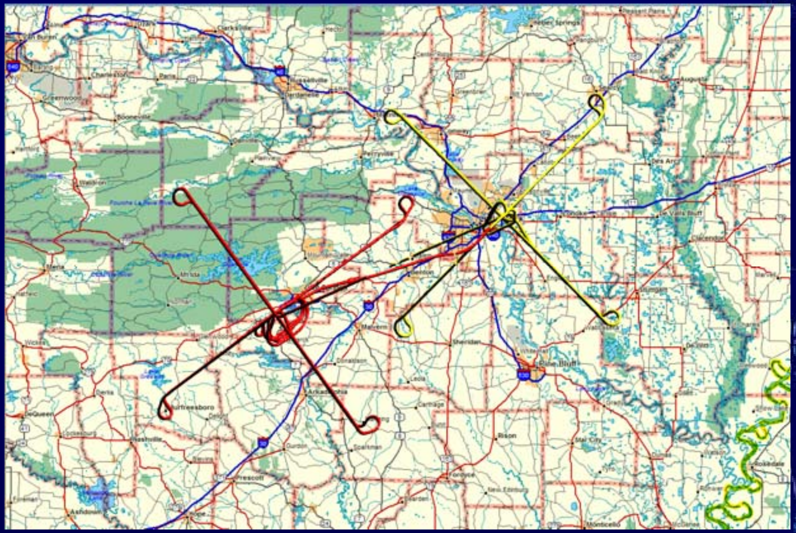
- Assumptions
- Experimentation
- Fault trees
- Analyses
- Thought Experiments
- Discussions
- Problem Resolutions
- Consensus

Utilized lessons from the WAAS Program

Loran Measurement Campaign
Lots of Miles – Lots of Data

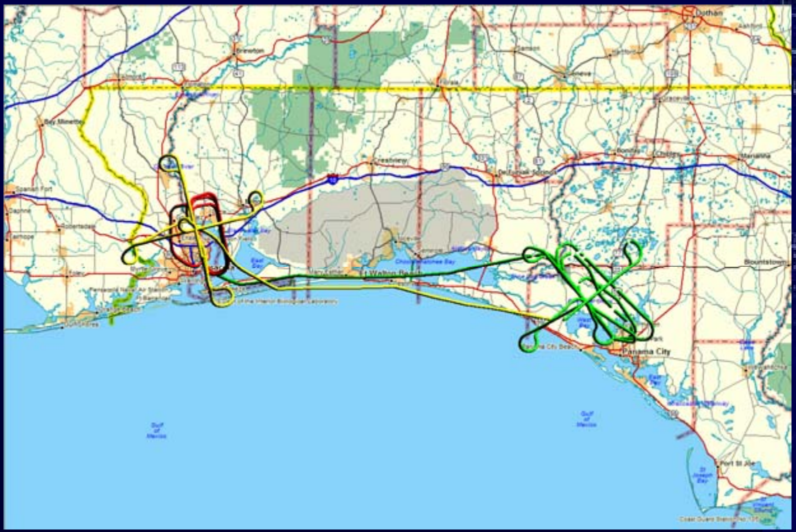


Grand Junction, Colorado



Little Rock, Arkansas

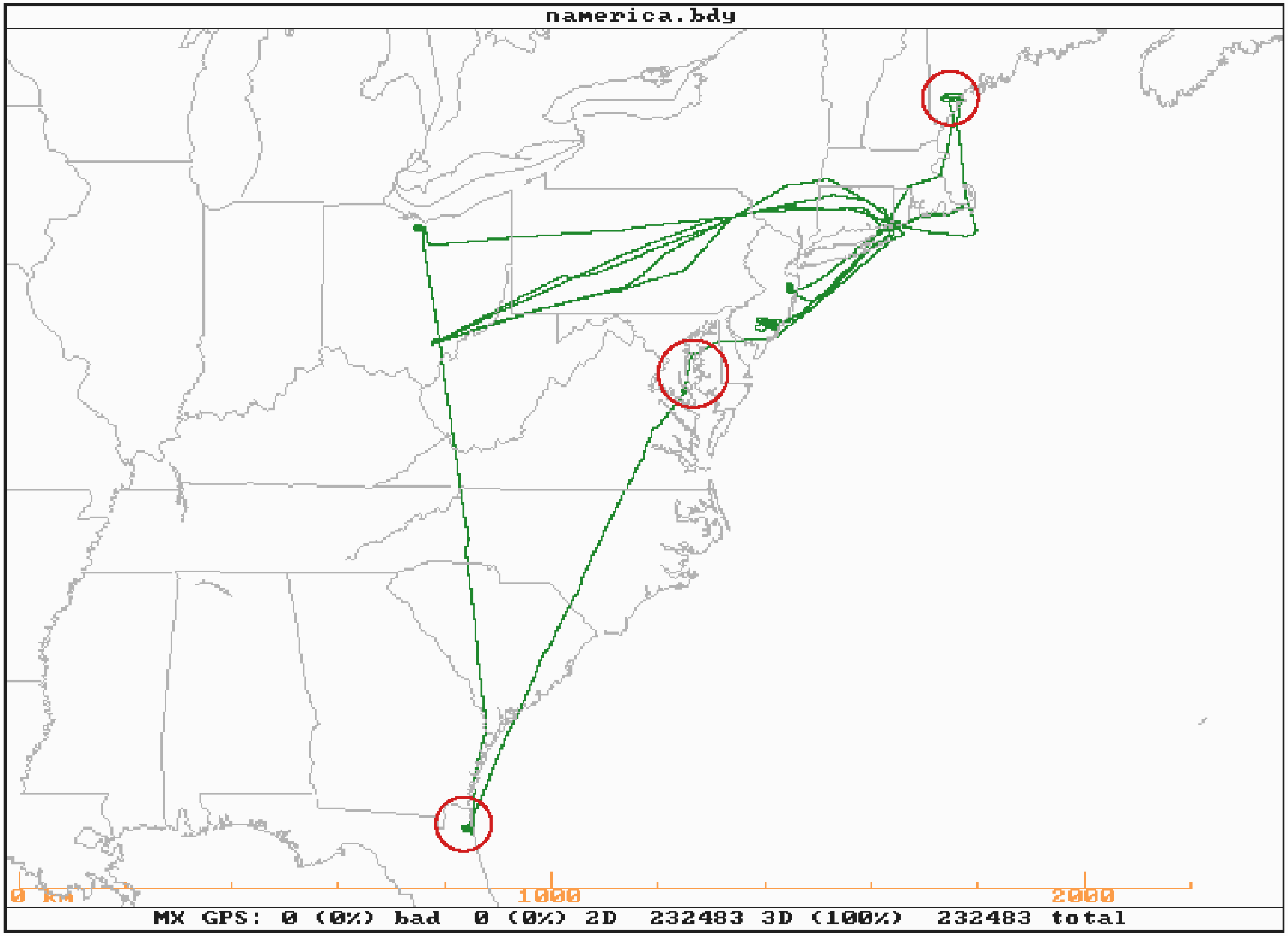
Monterey, California



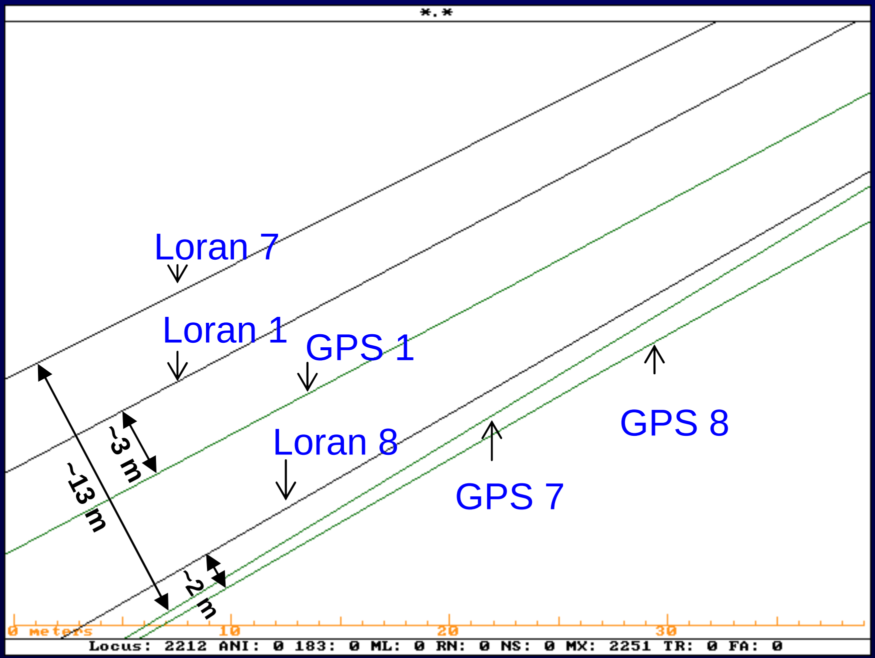
Pensacola/Destin, Florida

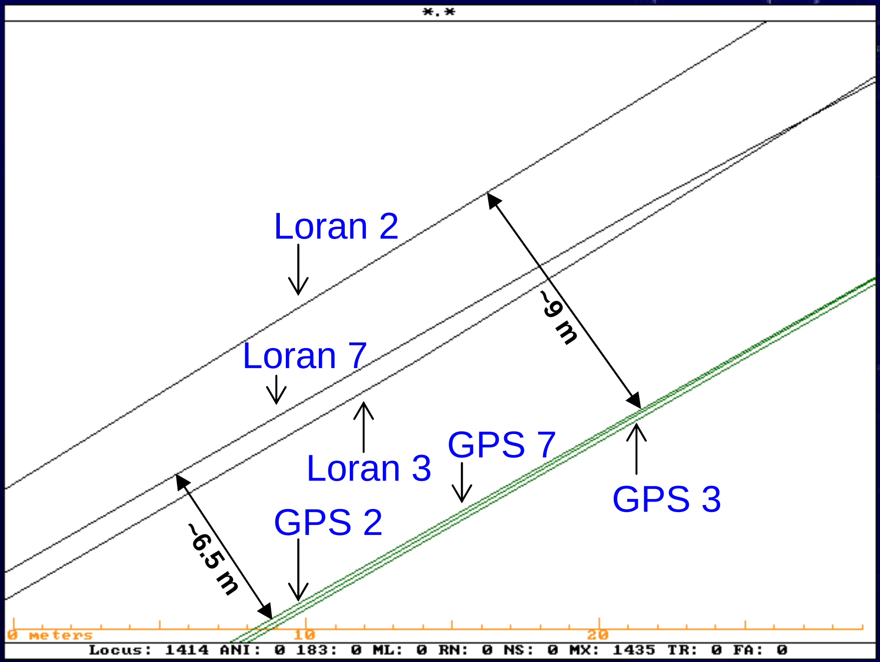
ASF Characterization Flights

August 2002 and March 2003



Exceptional Accuracy Results

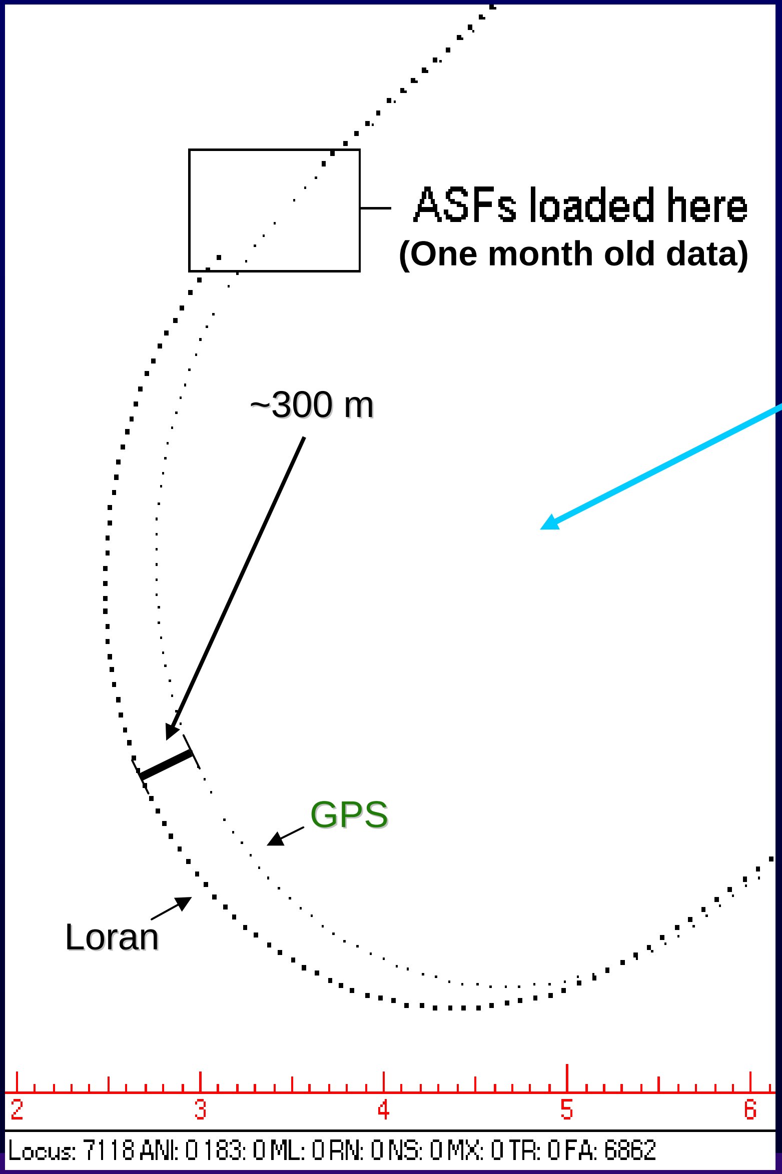


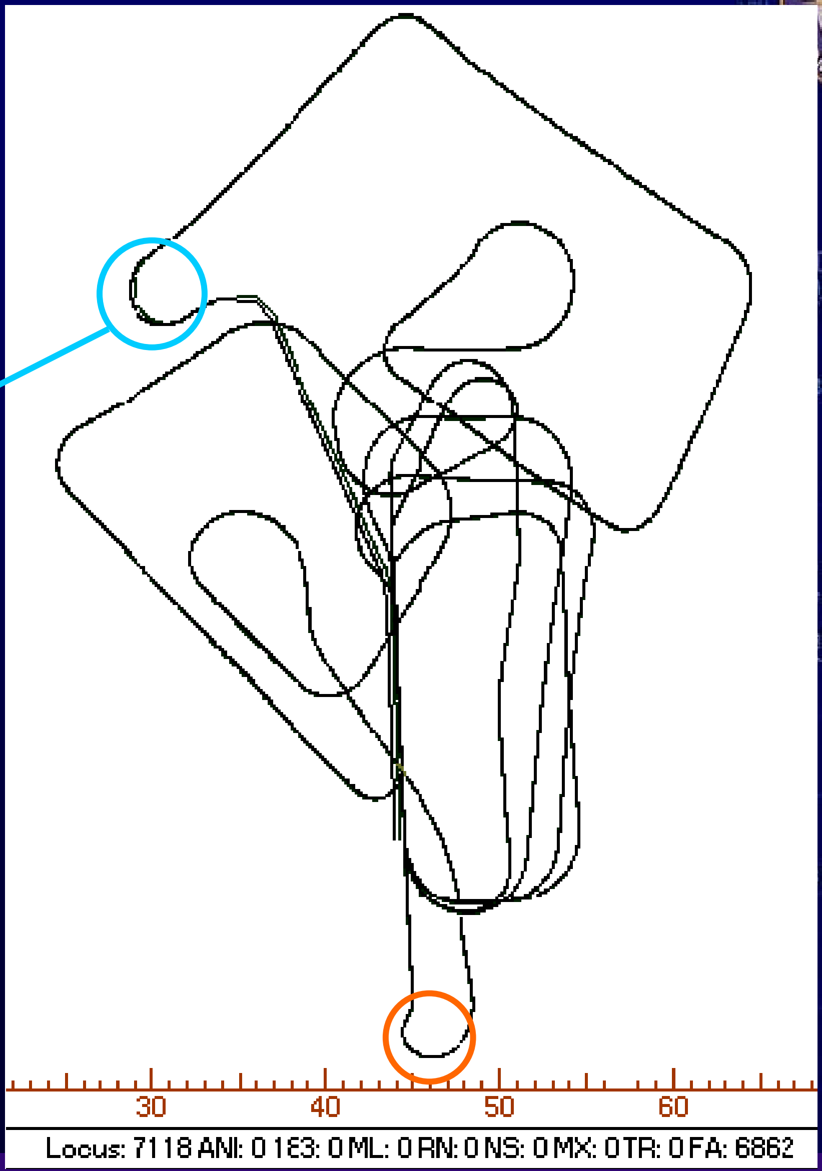


NPA Requirement: 307 m

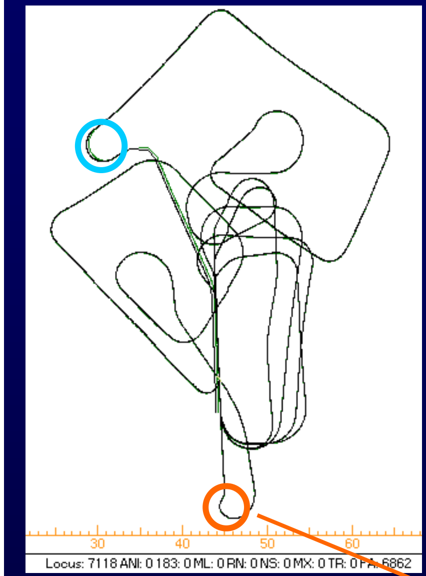
HEA Requirement: 8-20 m

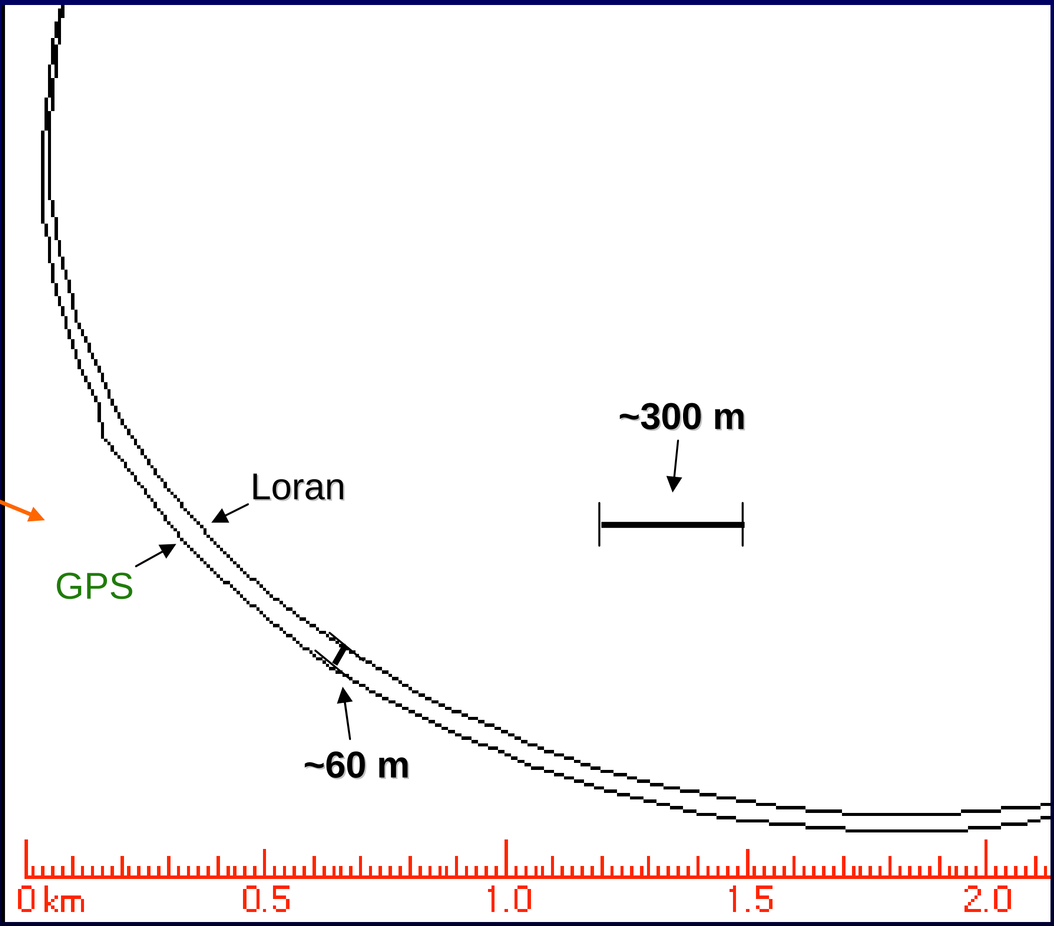
Waco, Texas – December 2003



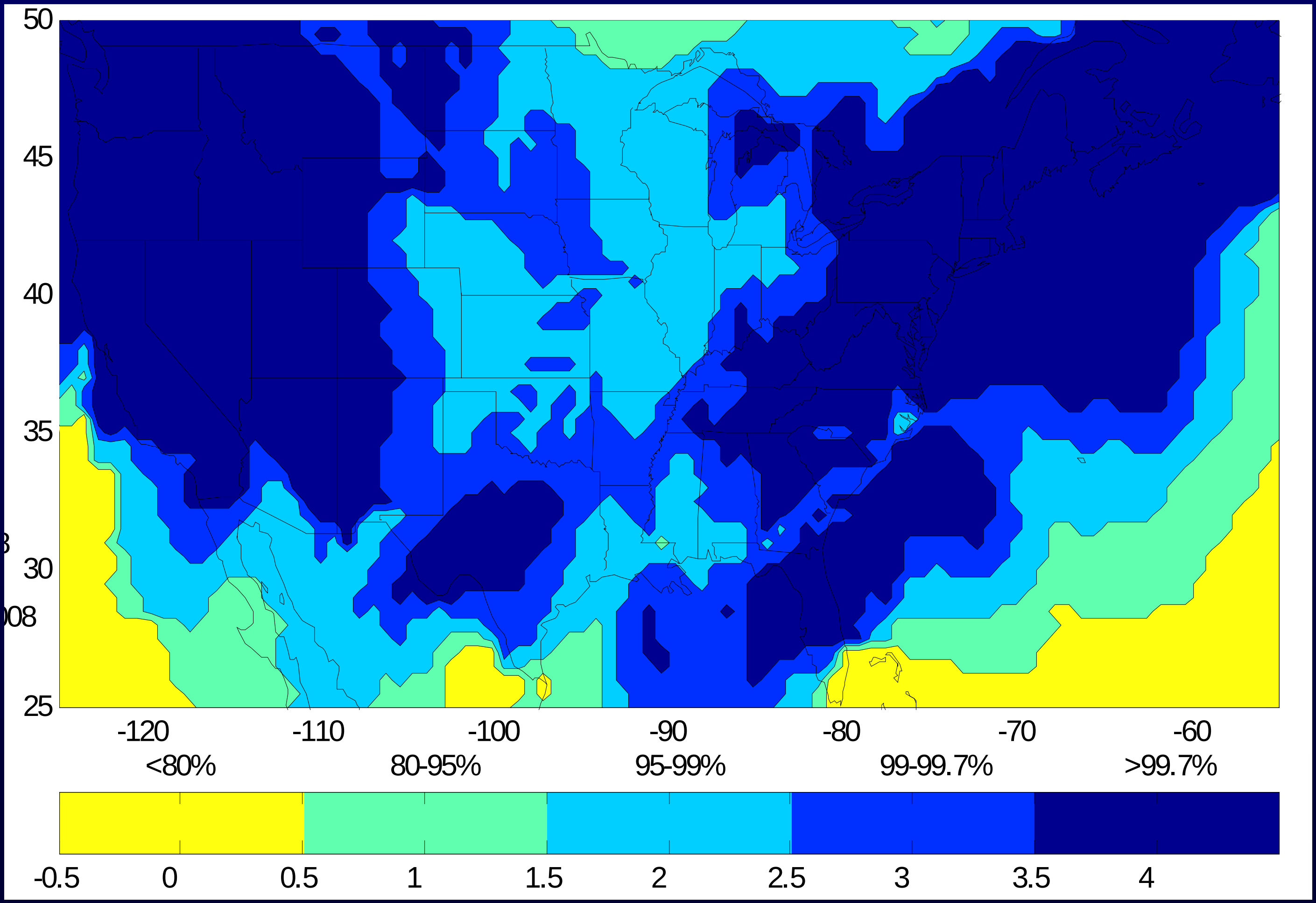


Waco, Texas – December 2003





Availability (All Year)



Continuity (All Year)