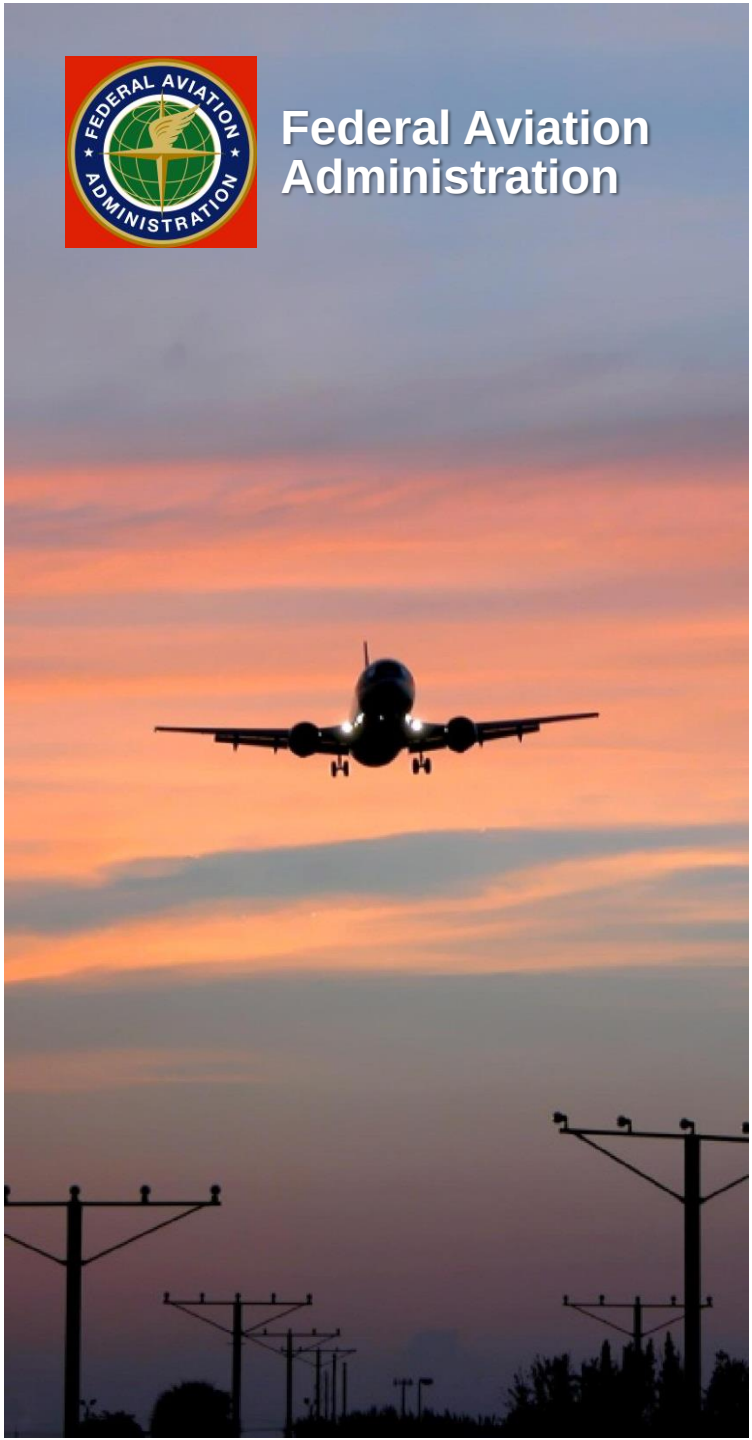
The Global Loran / eLoran Infrastructure Evolution

A Robust and Resilient PNT Backup for GNSS

Mitch Narins
Chief Systems Engineer – Navigation

Space-Based PNT Advisory Board
3 June 2014



Background

Loran-C Basics

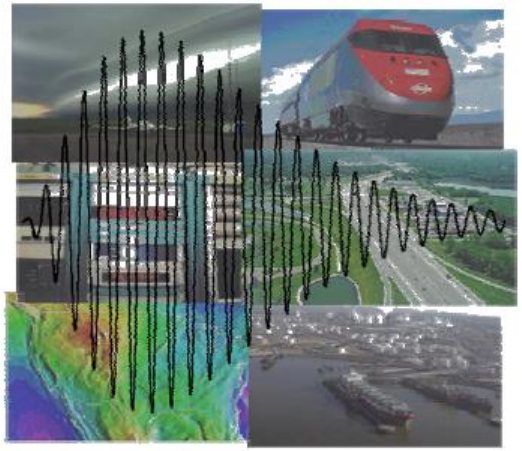
- **A hyperbolic radionavigation system…**
  - …operating between 90 kHz and 110 kHz…
  - …that uses a very tall antenna…
  - …that broadcasts primarily a groundwave
  - …at high power…
  - …that provides both lateral position…
  - …and a robust time and frequency standard
- **Previously in the US:**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

US Loran Policy (2000 FRP)

"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."

The Report:

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

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The Loran Evaluation Specifics

- **Determined whether an enhanced Loran (*eLoran*) system 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 *eLoran* would be cost-beneficial**

The *eLoran* Technical Challenge

Current Capabilities vs. Future Requirements*

	Accuracy	Availability	Integrity	Continuity
Loran-C 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

Report Executive Summary

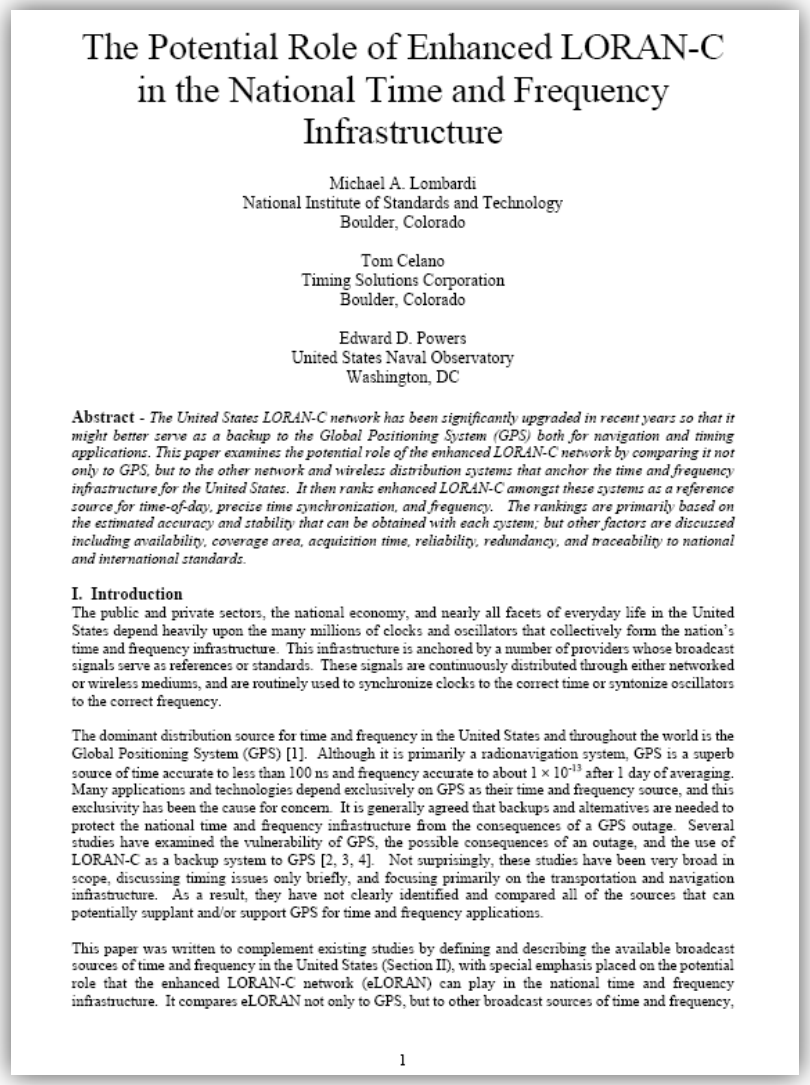
- The report documented the FAA-led Team's Loran evaluation program results as requested by the DOT Undersecretary for Policy in his role as the Chair of the DOT Positioning and Navigation Committee.
- The government agency, industry, and academic evaluation team focused on determining whether Loran could meet aviation and maritime radionavigation, and time/frequency application requirements, thus providing a viable, cost-effective alternative to the GPS in the event of a GPS outage.
- Applications evaluated included aviation navigation through non-precision approach (NPA) operations, maritime navigation through harbor entrance and approach (HEA) operations, and time and frequency distribution through the Stratum 1 level.

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."

eLoran as a Backup to GPS Time and Frequency



The Potential Role of Enhanced LORAN-C in the National Time and Frequency Infrastructure

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Timing Solutions Corporation
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United States Naval Observatory
Washington, DC

Abstract - *The United States LORAN-C network has been significantly upgraded in recent years so that it might better serve as a backup to the Global Positioning System (GPS) both for navigation and timing applications. This paper examines the potential role of the enhanced LORAN-C network by comparing it not only to GPS, but to the other network and wireless distribution systems that anchor the time and frequency infrastructure for the United States. It then ranks enhanced LORAN-C amongst these systems as a reference source for time-of-day, precise time synchronization, and frequency. The rankings are primarily based on the estimated accuracy and stability that can be obtained with each system; but other factors are discussed including availability, coverage area, acquisition time, reliability, redundancy, and traceability to national and international standards.*

I. Introduction

The public and private sectors, the national economy, and nearly all facets of everyday life in the United States depend heavily upon the many millions of clocks and oscillators that collectively form the nation's time and frequency infrastructure. This infrastructure is anchored by a number of providers whose broadcast signals serve as references or standards. These signals are continuously distributed through either networked or wireless mediums, and are routinely used to synchronize clocks to the correct time or syntonize oscillators to the correct frequency.

The dominant distribution source for time and frequency in the United States and throughout the world is the Global Positioning System (GPS) [1]. Although it is primarily a radionavigation system, GPS is a superb source of time accurate to less than 100 ns and frequency accurate to about 1×10^{-13} after 1 day of averaging. Many applications and technologies depend exclusively on GPS as their time and frequency source, and this exclusivity has been the cause for concern. It is generally agreed that backups and alternatives are needed to protect the national time and frequency infrastructure from the consequences of a GPS outage. Several studies have examined the vulnerability of GPS, the possible consequences of an outage, and the use of LORAN-C as a backup system to GPS [2, 3, 4]. Not surprisingly, these studies have been very broad in scope, discussing timing issues only briefly, and focusing primarily on the transportation and navigation infrastructure. As a result, they have not clearly identified and compared all of the sources that can potentially supplant and/or support GPS for time and frequency applications.

This paper was written to complement existing studies by defining and describing the available broadcast sources of time and frequency in the United States (Section II), with special emphasis placed on the potential role that the enhanced LORAN-C network (eLORAN) can play in the national time and frequency infrastructure. It compares eLORAN not only to GPS, but to other broadcast sources of time and frequency,

1

Conclusions

1. "***eLoran*** is the best available backup provider to GPS as a reference source for precise time synchronization and frequency control."
2. "With its large coverage area, its high level of redundancy due to multiple transmitters, and its ability to be received indoors ***eLoran*** also has the potential to become a leading provider of time-of-day information in the United States, a role that legacy Loran could not fulfill."

2006 - 2008 Independent Assessment Team (IAT)

- **Assembled by the Institute for Defense Analysis (IDA) at the request of the DOT Under Secretary for Policy to:**
  - *review and assess continuing need for the current US Loran infrastructure*
  - *report findings & recommendations directly to Under Secretary of Transportation for Policy*
- **IAT Membership:**
  - **Dr. Bradford Parkinson** – Stanford University – Chair
  - **James Doherty** – IDA, former USCG NAVCEN – Exec Director
  - **John Darrah** – IDA, former Chief Scientist USAF Space Command
  - **Arnold Donahue** – NAPA, former OMB
  - **Dr. Leon Hirsch** – IDA Research Staff Member
  - **Donald Jewell** – IDA, former AF Space Command
  - **Dr. William Klepczynski** – IDA, former US Naval Observatory
  - **Dr. Judah Levine** – NIST Time Services
  - **L. Kirk Lewis** – IDA, Executive Director GPS IRT
  - **Dr. Edwin Stear** – IDA, former VP Boeing & USAF Chief Scientist
  - **Philip Ward** – IDA, former Texas Instruments (GPS receivers)
  - **Pamela Rambow** – IDA Research Assistant

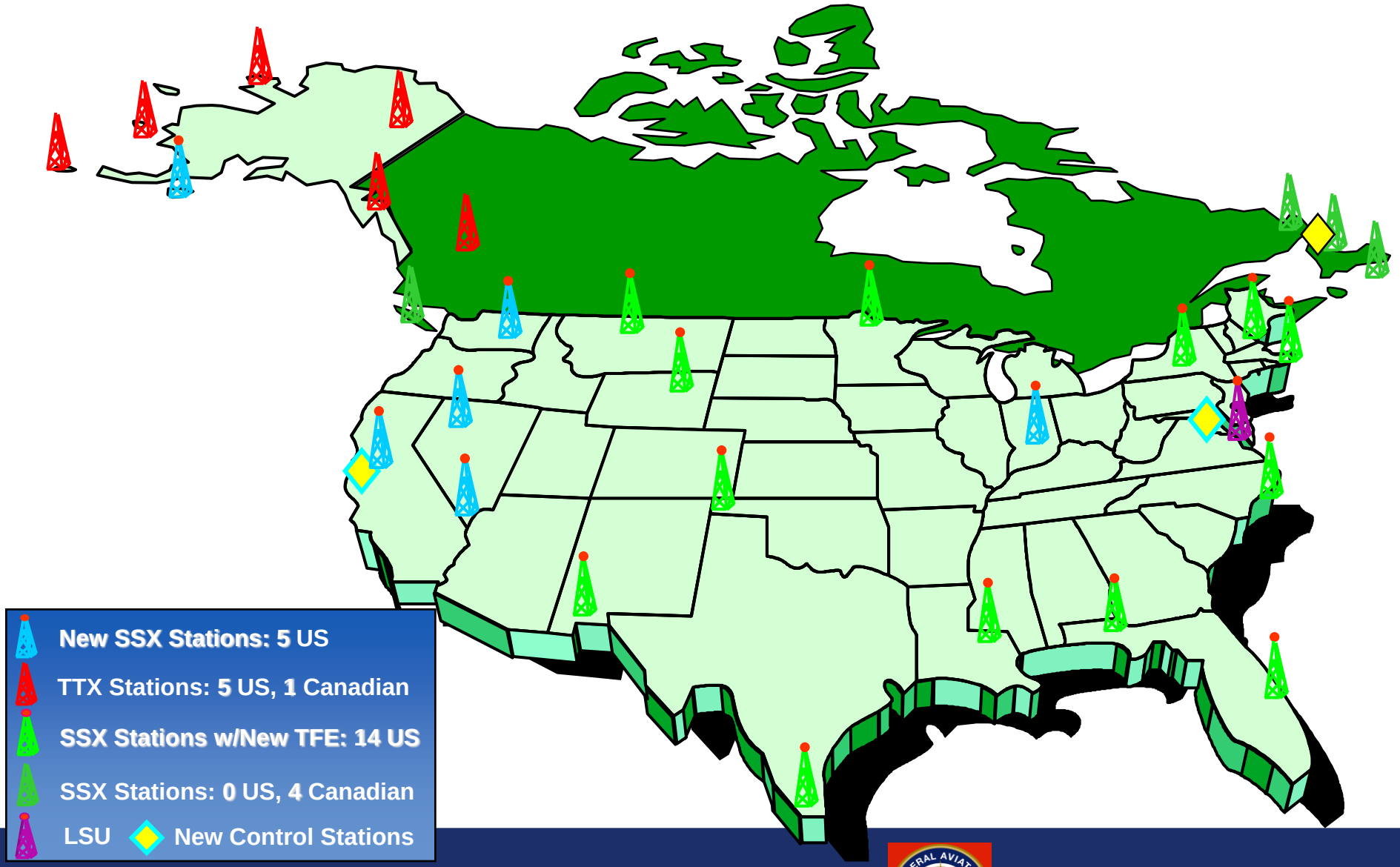
IAT : Why eLoran?

- **eLoran meets needs of identified critical applications – and others**
  - *10-20 meter accuracy for harbor entrance*
  - *0.3 nautical mile required navigation performance (RNP 0.3)*
  - *Stratum 1 for time & frequency users – 50 ns time accuracy*
- **eLoran is NOT 1958 Loran-C**
  - *New infrastructure – solid state transmitters, state-of-the-art time & frequency equipment, uninterruptible power supplies*
  - *New operating concepts – time of transmission, all-in-view signals, message channel with differential corrections, integrity, etc.*
  - *New user equipment - digital, processes eLoran & GPS signals interchangeably, compact H-field antennas to eliminate "p-static"*
- **eLoran upgrade & 20 year ops affordability**
  - *$159M invested to date – nonrecurring $17-25M/yr*
    - Additional $143M will complete eLoran – 5-8 years at current funding level
  - *Ops & maintenance currently $37M/yr – recurring*
    - Reduce routine O&M costs with eLoran efficiencies – apply savings to identified major maintenance backlog ($289M
  - *Avoid $146M costs of decommissioning existing Loran-C infrastructure*

IAT Conclusions and Recommendations

- **Reasonable assurance of national PNT availability is prudent & responsible policy**
  - *For critical safety of life & economic security applications*
  - *And for all other "quality of life" applications*
- ***eLoran* is a cost effective backup – *to protect & extend GPS* – for identified critical *(& other GPS-based)* applications**
  - *Interoperable & independent*
  - *Different physical limitations & failure modes*
  - *Seamless operations & GPS threat deterrent*
- **Given US Government support, anticipate users will equip with *eLoran* as the backup of choice**
  - *International community looking for US leadership*
- ***Recommend* complete *eLoran* upgrade & commit to operate for 20 years**
  - *Affordable within recent funding history*

North American Loran System – 2006-2008



DHS Letter to US Senate Authorization Committee 20 Sep 2007

The Spaced-Based Positioning, Navigation and Timing (PNT) Executive Committee, co-chaired by the Deputy Secretaries of the Department of Defense (DOD) and the Department of Transportation (DOT), concurred with a joint Department of Homeland Security (DHS)-DOT policy recommendation to pursue "enhanced" LORAN (eLoran) as a national PNT backup to the Global Positioning System (GPS) for the U.S. homeland. *As a result, DOT and DHS are jointly preparing proposed transition plans to move operations, maintenance, construction, and funding for the Loran system from DHS/Coast Guard to another government agency so that eLoran may be implemented, upon which the Secretary of Homeland Security and the Secretary of Transportation can base a final decision on the future of the current Loran system, DHS and DOT are in the process of completing these actions and are scheduled to make a joint announcement of a decision on Loran by the end of this year.*

Press Office
U.S. Department of Homeland Security

Homeland Security

February 7, 2008
Contact: (202) 282-8010

STATEMENT FROM DHS PRESS SECRETARY LAURA KEEHHNER ON THE ADOPTION OF NATIONAL BACKUP SYSTEM TO GPS

Today the U.S. Department of Homeland Security will begin implementing an independent national positioning, navigation and timing system that complements the Global Positioning System (GPS) in the event of an outage or disruption in service.

The enhanced Loran, or eLoran, system will be a land-based, independent system and will mitigate any safety, security, or economic effects of a GPS outage or disruption. GPS is a satellite-based system widely used for positioning, navigation, and timing. The eLoran system will be an enhanced and modernized version of Loran-C, long used by mariners and aviators and originally developed for civil marine use in coastal areas.

In addition to providing backup coverage, the signal strength and penetration capability of eLoran will provide support to first responders and other operators in environments that GPS cannot support, such as under heavy foliage, in some underground areas, and in dense high-rise structures. The system will use modernized transmitting stations and an upgraded network.

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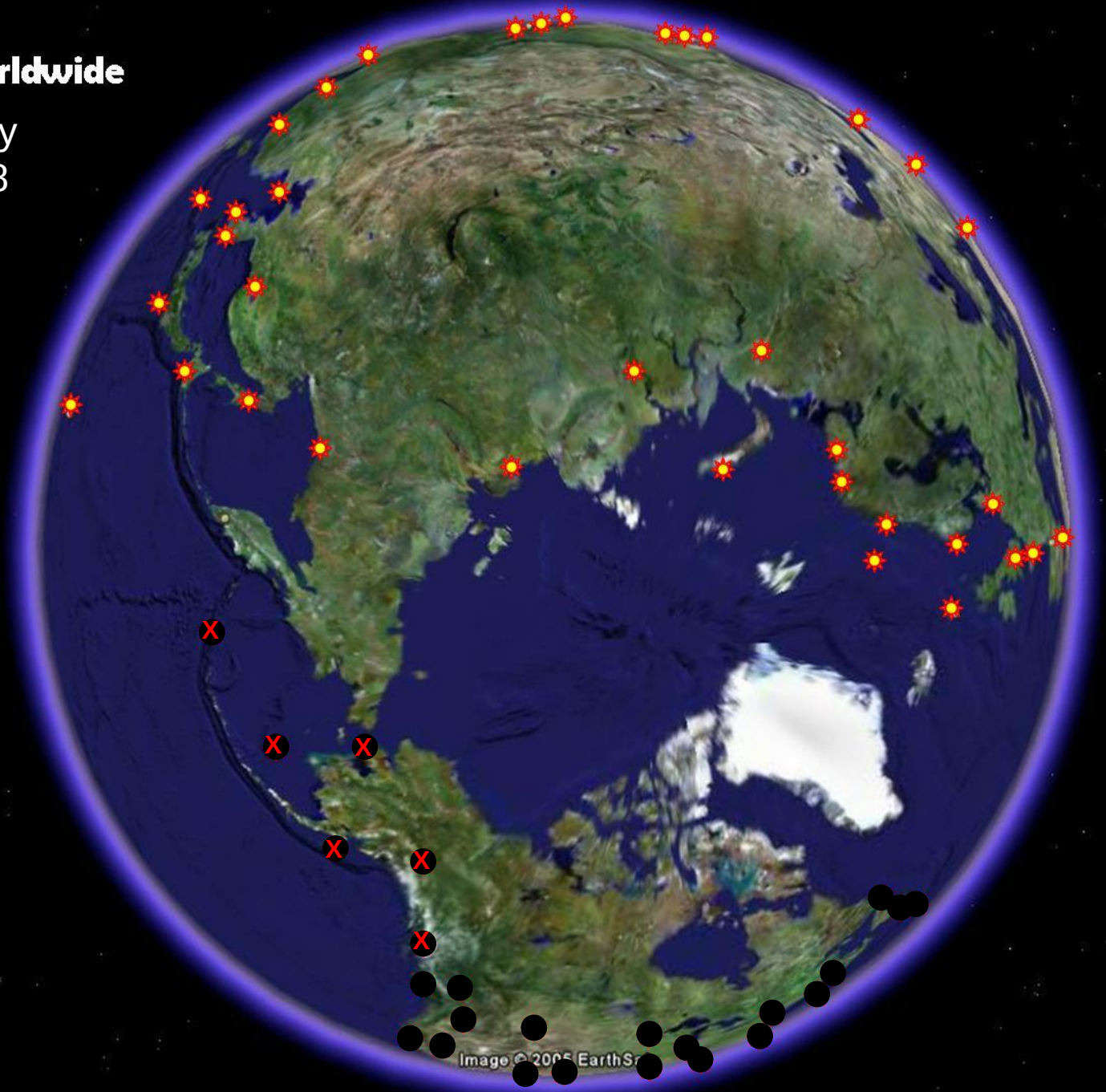
Loran Worldwide

Today
2008



Loran-C / eLoran Status Worldwide

Loran Stations in Northern Europe (9)

All Stations Used in a Prototype *eLoran* Mode

- **United Kingdom**
  - Anthorn
- **France**
  - Lessay
  - Soustons
  - Brest (Control Centre)
- **Germany**
  - Sylt
- **Denmark**
  - Ejde
- **Norway**
  - Berlevag
  - Bo
  - Jan-Mayen
  - Vaerlandet

Northern European Loran Station Status

- **United Kingdom**
  - Anthorn Station built at low cost/operated at low cost commercially through contract with General Lighthouse Authorities of the UK and Ireland
    - Costs spread across multiple UK Gov't Agencies
    - Coordinated by Centre for the Protection of National Infrastructure (Cabinet-level organization)
  - Used nationally for precise timing and by a Gov't agency for secure data
  - Finances continued operation of Sylt station (Germany)
  - Fully supportive of *eLoran* as a PNT alternative to GNSS
- **France**
  - Lessay and Soustons Stations and Brest Control Centre operated by French DCNS
  - Current economic situation/politics is putting continuation of current stations in jeopardy
    - No decision had been made
    - Gov't under positive pressure from commercial interests, including telecom sector
    - Significant interest in commercial operation of the system

Northern European Loran Station Status

- **Germany**
  - Continues to operate Sylt station financed in part by UK
- **Denmark**
  - Continues to operate Ejde Station financed by France
- **Norway**
  - Has announced that the Gov't intends to discontinue its Loran-C operations in 2016
    - Support of Loran has changed a number of times over the years depending on the Government
- **The Netherlands**
  - Has no stations, but testing highest accuracy enhanced differential Loran (*eDLoran*) to ensure efficiency and capacity in the Port of Rotterdam
  - Extreme support for the need for *eLoran* to ensure continuation of operations in the event of a GNSS service disruption

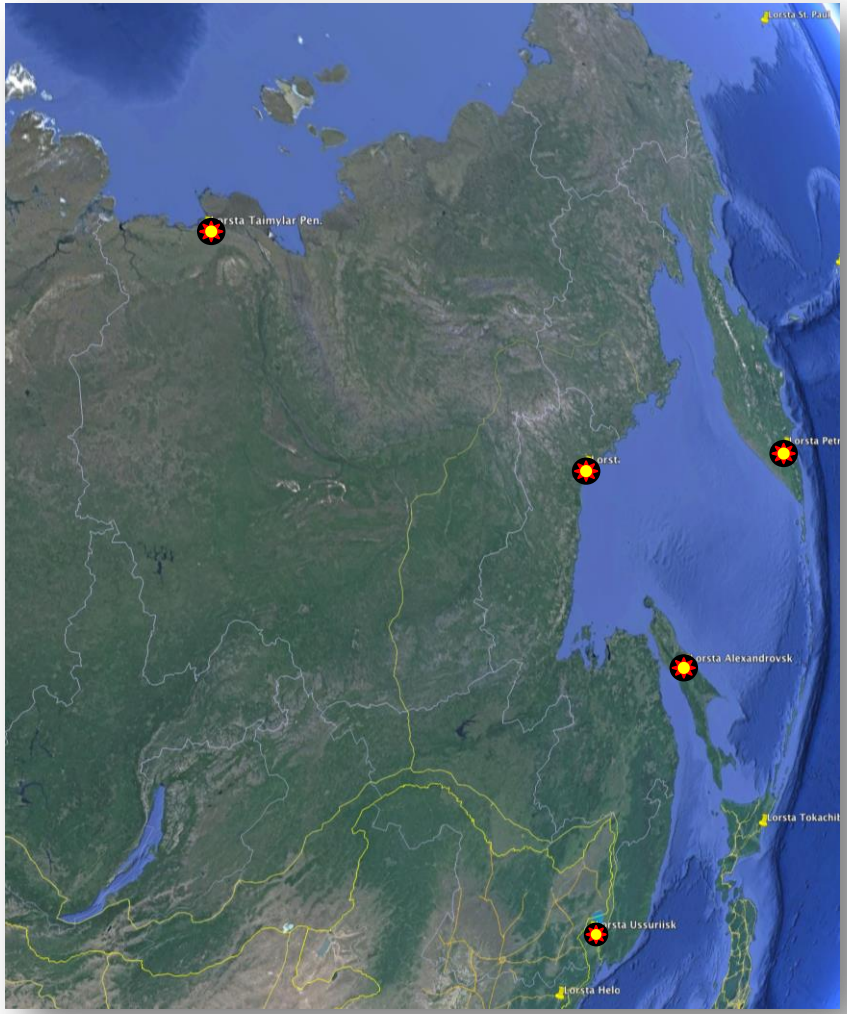
eLoran configuration at Rotterdam harbor

eDLoran Measurements at Hoek van Holland

Chayka Stations in Western Russia (9)

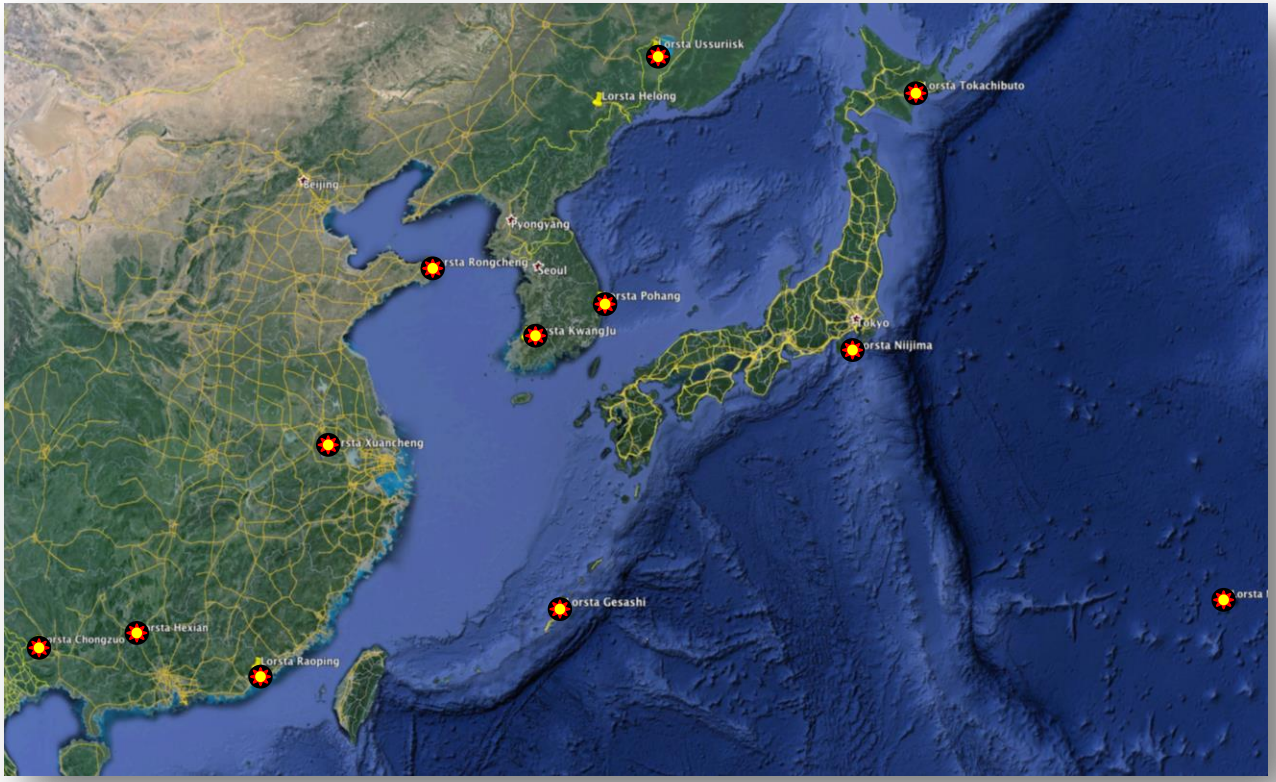
- **Chayka stations compatible with Loran-C**
- **Currently in discussions with UK as means to develop *eChayka* compatible with eLoran**
- **Russia currently investigating upgrade of Eastern Stations:**
- **Big driver is coverage of high north shipping**
  - Bryansk -- Simferopol
  - Inta -- Slonim
  - Norilsk -- Syzarin
  - Pankratyev -- Petrozavodsk
  - Tumanny

… and Five More in Eastern Russia



- Tamylar
- Okhotsk
- Alexandrovsk
- Petropavlovsk
- Ussuriisk

Loran Stations in China (6) , Korea (2), and Japan (4)



- **China**
  - Chongzuo
  - Hexian
  - Raoping
  - Xuancheng
  - Rongcheng
  - Helong
- **Korea**
  - Pohang
  - Kwangju
- **Japan**
  - Gesashi
  - Niijima
  - Tokachibuto
  - Minnamitorishima

Loran Stations in China (6) and Japan (4)

- **China**
  - Possibly in process of upgrading all stations to an *eLoran* solution
- **Japan**
  - Announced that they intend to shut down stations in near future
  - Situation remains fluid

Loran Stations in Korea (2)

- **Korea**
  - Recognizes that "Global Navigation Satellite Systems (GNSS) have vulnerabilities to intentional and unintentional interference and that a complementary system is needed for resiliency"*
  - Recognizes that "*eLoran* is the only proven electronic system that can provide such resiliency"*
  - Upgrading and expanding eLoran coverage
    - Phased approach
      - First upgrade current two stations and add one additional station
    - Up to total of five stations
  - Driven by land-mobile requirements

* Jiwon Seo and Je-Bong Oh, "Update on the Korean eLoran Program," 2014 ENC

Korean Intentional High Power Jamming Incidents

[Source: The Central Radio Management Office, South Korea]

Dates	August 23-26, 2010 (4 Days)	March 4-14, 2011 (11 Days)	April 28 – May 13, 2012 (16 Days)
Jammer Locations	Kaesong	Kaesong, Mount Kumgang	Kaesong
Affected Areas	Gimpo, Paju, etc.	Gimpo, Paju, Gangwon	Gimpo, Paju
GPS Disruptions	181 cell towers 15 airplanes 1 battleship	145 cell towers 106 airplanes 10 ships	1,016 airplanes 254 ships

Korean *eLoran* Program – Initial Plan

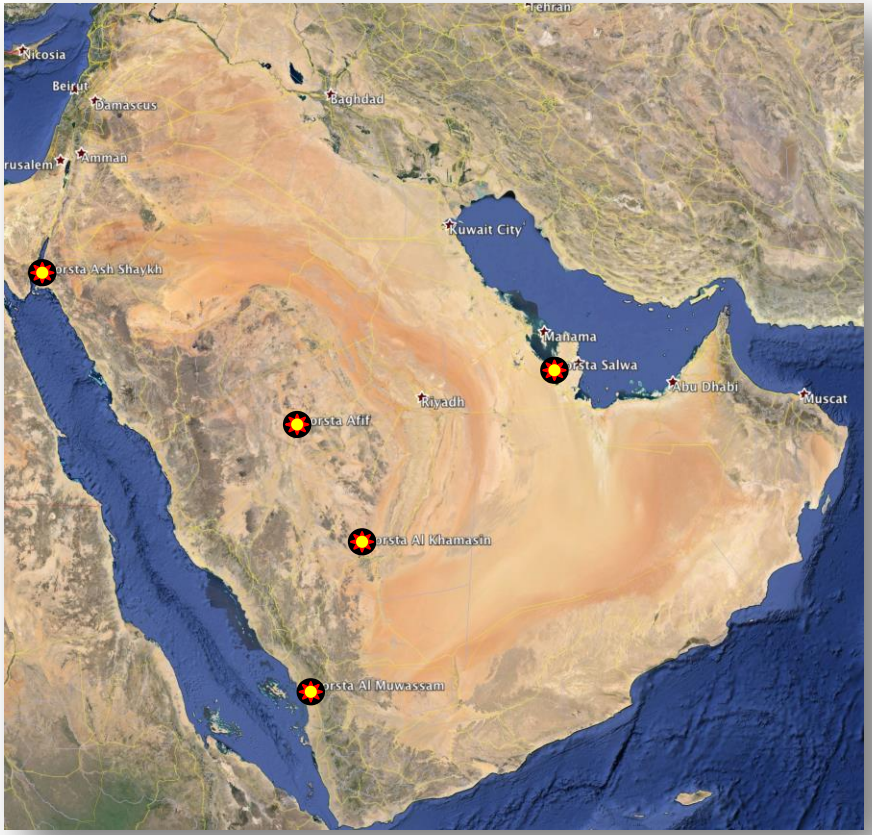
- **Convert existing stations to *eLoran* operation**
- **Build three new *eLoran* stations**

- **43 differential *eLoran* stations**
  - Intended to cover entire country with 20 m accuray

Revised Korean *eLoran* Program

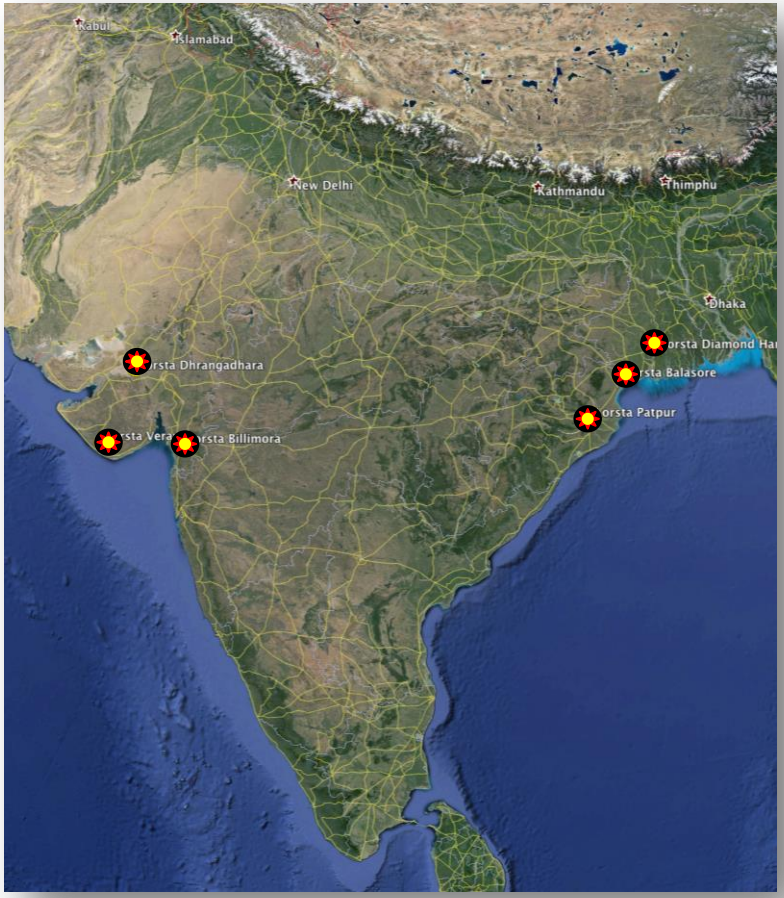
- Two phase approach
  - Implement maritime *eLoran* for the West Sea of Korea with 3 transmitters and 2 differential stations by the end of 2015
  - If demonstrated performance is satisfactory, deploy more transmitters and differential stations to cover other areas
- Phase 1
  - Upgrade existing two Loran-C transmitters to *eLoran* operation
    - Pohang (150 kW)
    - Kwangju (50 kW)
  - Deploy a 250 kW *eLoran* transmitter at Ganghwa
  - Deploy two differential *eLoran* stations at locations proposed by contractor
  - Provide 20 m maritime accuracy within 30 km of differential stations

eLoran Stations in Saudi Arabia (5)



- **Saudi Stations all upgraded to *eLoran* capable (Eurofix) standard**
- **Working on tender for *eLoran* receivers**
  - Government has considered making *eLoran* required equipage for Red Sea transits
- **Very interested in land-mobile/time applications**
  - Afif
  - Al Khamasin
  - Al Muwassam
  - Ash Shaykh
  - Salwa

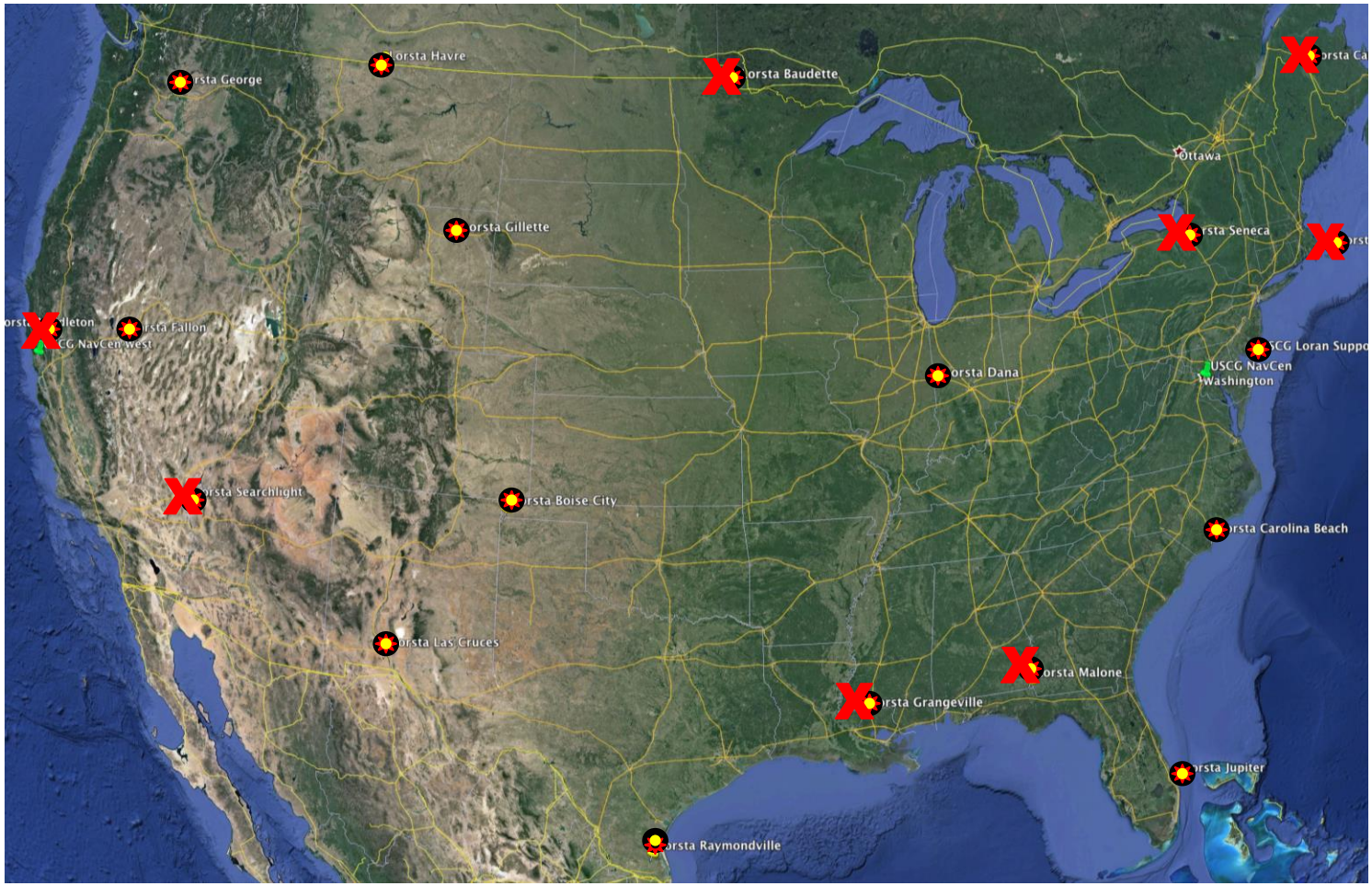
Loran Stations in India (6)



- **Two "mini-chains" providing coverage to ports on east and west coasts**
  - Veraval
  - Billimora
  - Dhrangadhara
  - Diamond Harbor
  - Balasore
  - Patpur
- **Government considering phased expansion of *eLoran* coverage**
  - Perhaps an additional 11 stations
- **Upgrade of existing stations**

… and finally

Loran Stations in CONUS



X -Tower Removed

eLoran in the United States

- **US Coast Guard – UrsaNav Cooperative R&D Agreement (CRDA)**
  - Using remaining USG assets and newly developed equipment/techniques to demonstrate *eLoran* precise time and frequency capability
- **USCG and Maritime Subcommittee Hearing and subsequent 2014 USCG and Maritime Transportation Act Language:**
  - *(a) In General.--The Secretary of the department in which the Coast Guard is operating may not carry out activities related to the dismantling or disposal of infrastructure that supported the former LORAN system until the later of-- (1) the date that is 1 year after the date of enactment of this Act; or (2) the date on which the Secretary provides to the Committee on Transportation and Infrastructure of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate notice of a determination by the Secretary that such infrastructure is not required to provide a positioning, navigation, and timing system to provide redundant capability in the event GPS signals are disrupted. (b) Exception.--Subsection (a) does not apply to activities necessary for the safety of human life. (c) Agreements.--The Secretary may enter into cooperative agreements, contracts, and other agreements with Federal entities and other public or private entities, including academic entities, to develop a positioning, timing, and navigation system, including an enhanced LORAN system, to provide redundant capability in the event GPS signals are disrupted.*

Summary

- **The US provided the *eLoran* vision, but then dropped out; others have carried on**
  - It has become a working system for maritime and land navigation, precise time frequency, and secure data
  - It works better than we envisioned it would when we wrote the 2004 report
- **Next Steps (IMHO) :**
  - Take advantage of what has come before, both here and abroad
  - Figure out how to redeploy a robust and resilient PNT capability in the US
  - Just do it / Make it so!

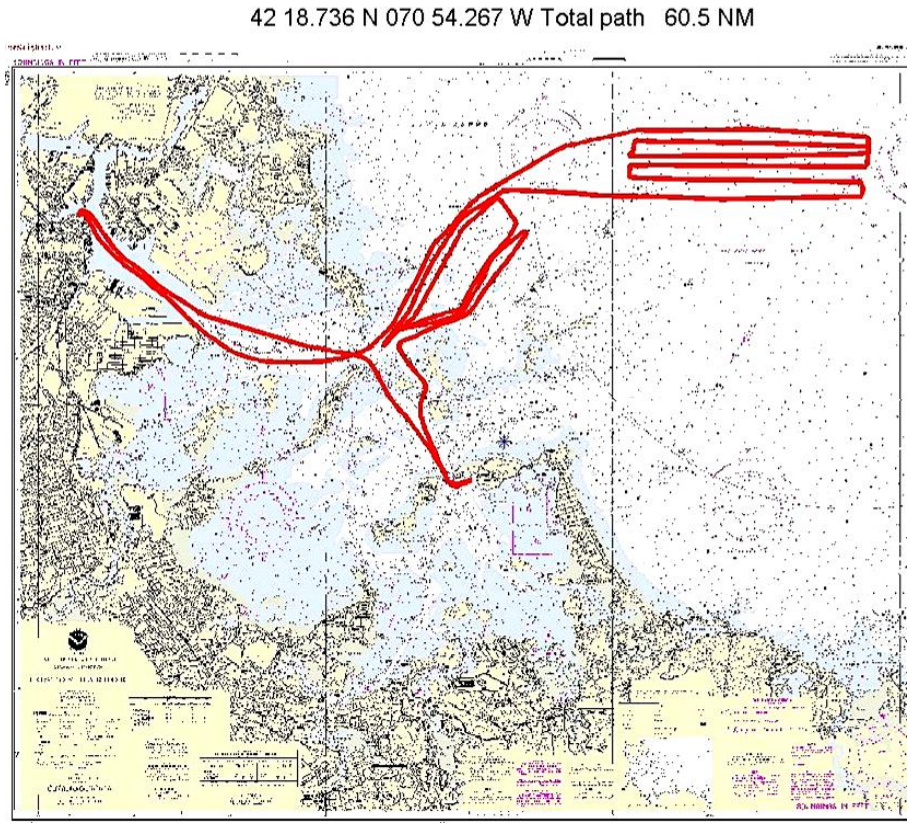
Questions

Backup

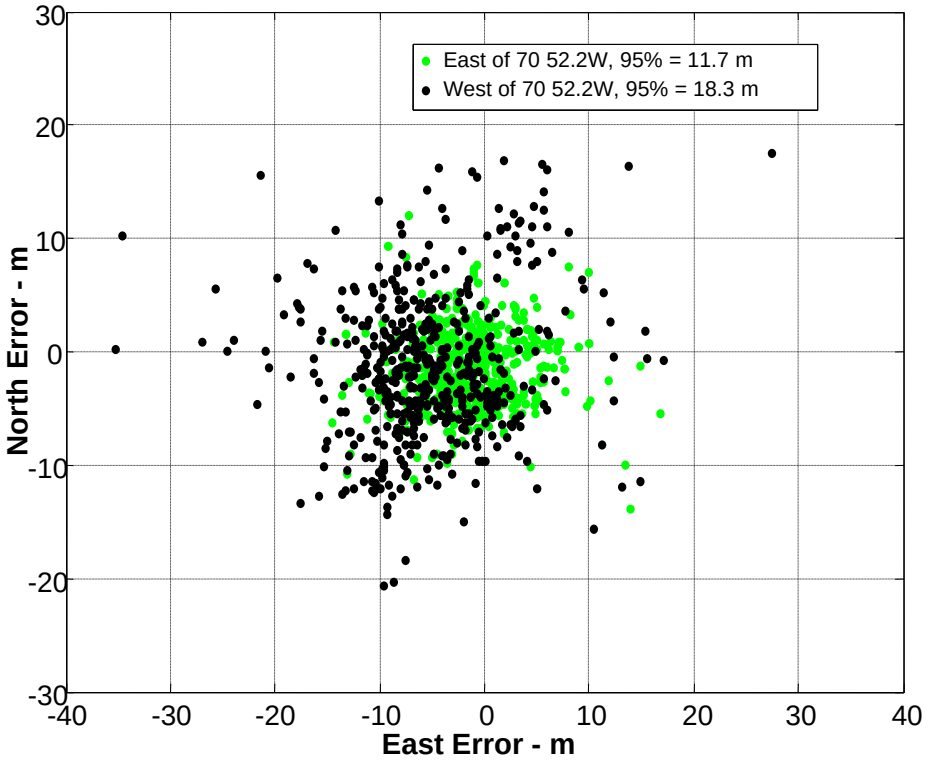
Loran-C Performance

- A predicted 2d rms 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

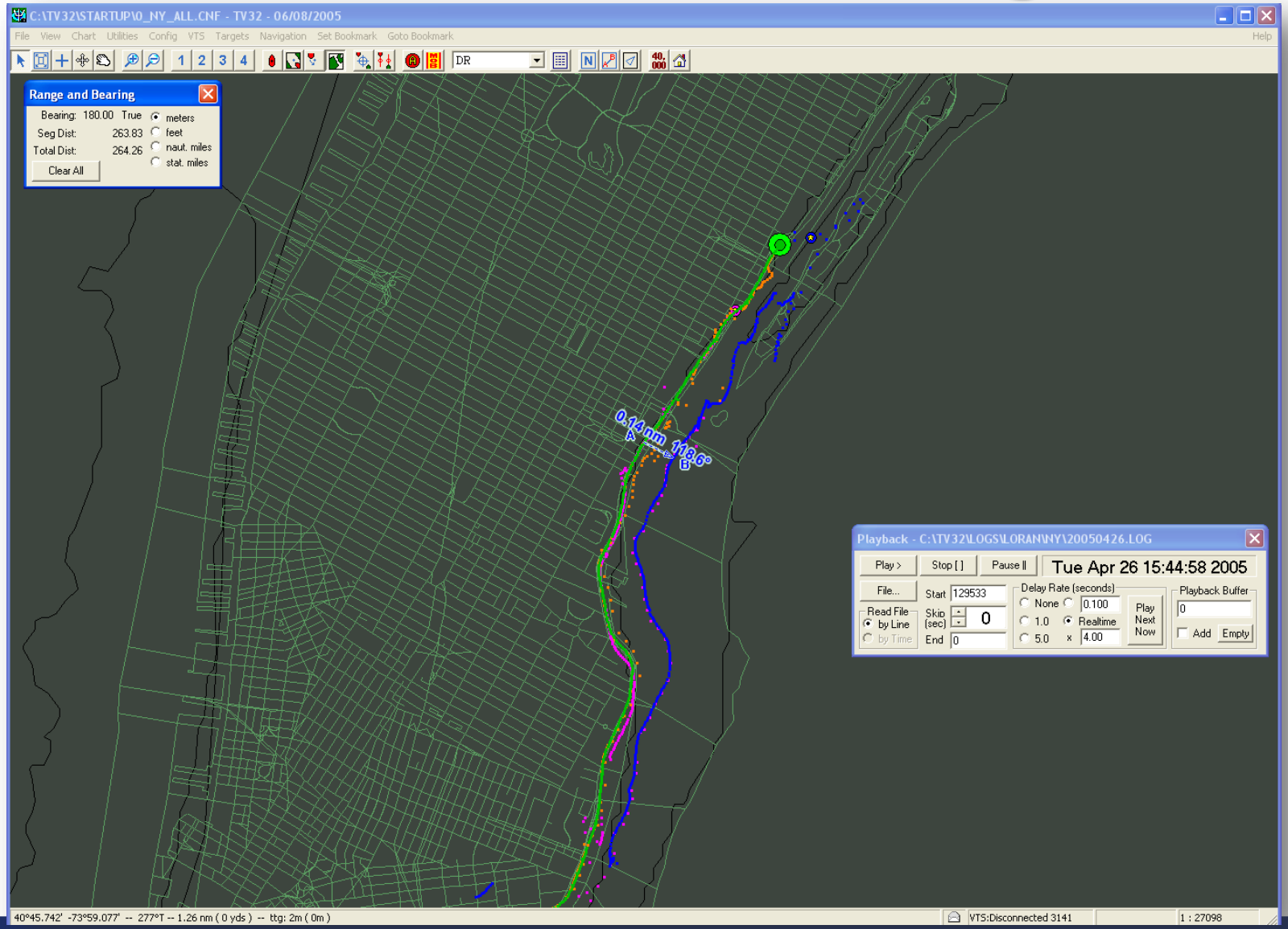
Example: Harbor Testing 2005: Boston



Overall 95% accuracy 16.4 m



Urban Environment Testing



Airship Testing to Determine ASF Variation as a Function of Altitude

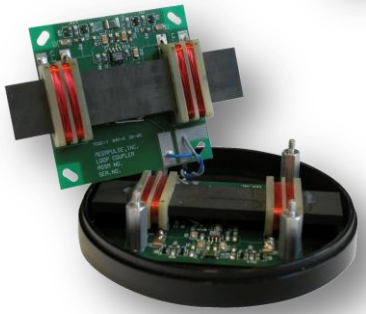
Prototype Loran Card in Rockwell Collins Multi-Mode Receiver

- Rockwell Collins has continued the work *on their own* to incorporate low cost gyros into the integrated receiver solution
- Integrated GPS/Loran receiver for general aviation is also being developed by FreeFlight Systems and Locus under FAA contract

FreeFlight/Locus
GA Multi-Mode Receiver

- **Phase I Prototype (Two-box initial solution) similar to GPS/WAAS/Loran Rockwell Collins MMR/Locus development**
- **Phase I Prototype testing of Integrated GPS/WAAS/Loran receiver testing progressing at this time**
- **Phase II Prototype will be available for testing Spring 2005**

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



Loran Evaluation Program Funding