SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

GNSS Surveying Technologies for the Future

Texas Society of Professional Surveyors

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National Coordination Office

For Space Based PNT

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Seminar Outline

Module 1

- NCO Overview
- GPS Modernization and Augmentations

Module 2

- GPS Accuracy in an Urban & Suburban Environment (Census Data)

Modules 3A & 3B

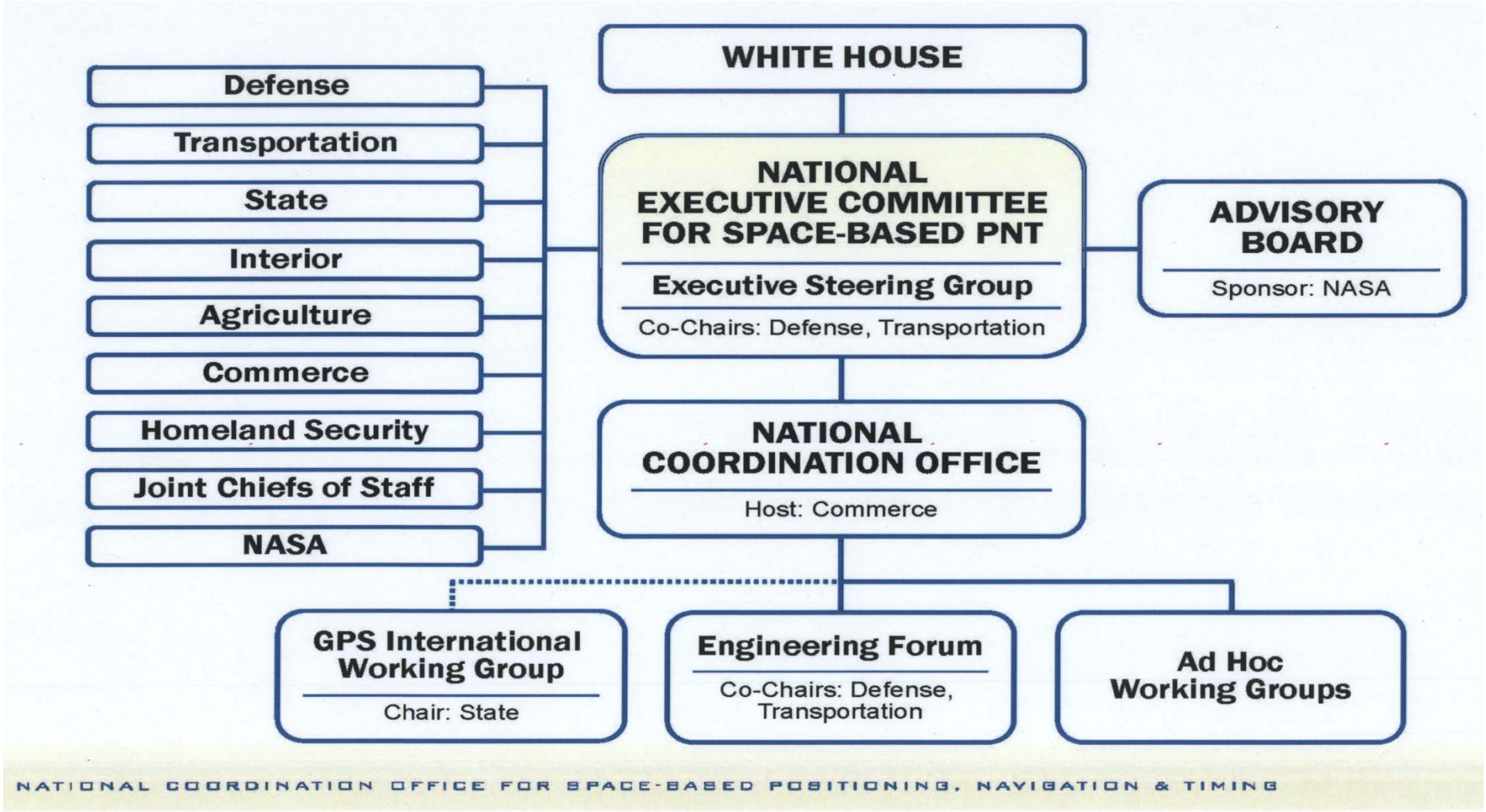
- Technologies of Interest to Surveyors in 2025

U.S. Policy Promotes Global Use of GPS Technology

- No direct user fees for civil GPS services
  - Provided on a continuous, worldwide basis
- Open, free access to information necessary to use civil GPS and augmentations
  - Anyone can develop applications, user equipment, and value-added services
  - Encourages market-driven competition
- Global compatibility and interoperability with GPS
- Service improvements for civil, commercial, and scientific users worldwide
- Protection of radionavigation spectrum from disruption and interference

U.S. policy on civil GPS access has been stable and consistent for 25+ years

US Space-Based PNT Organization Structure



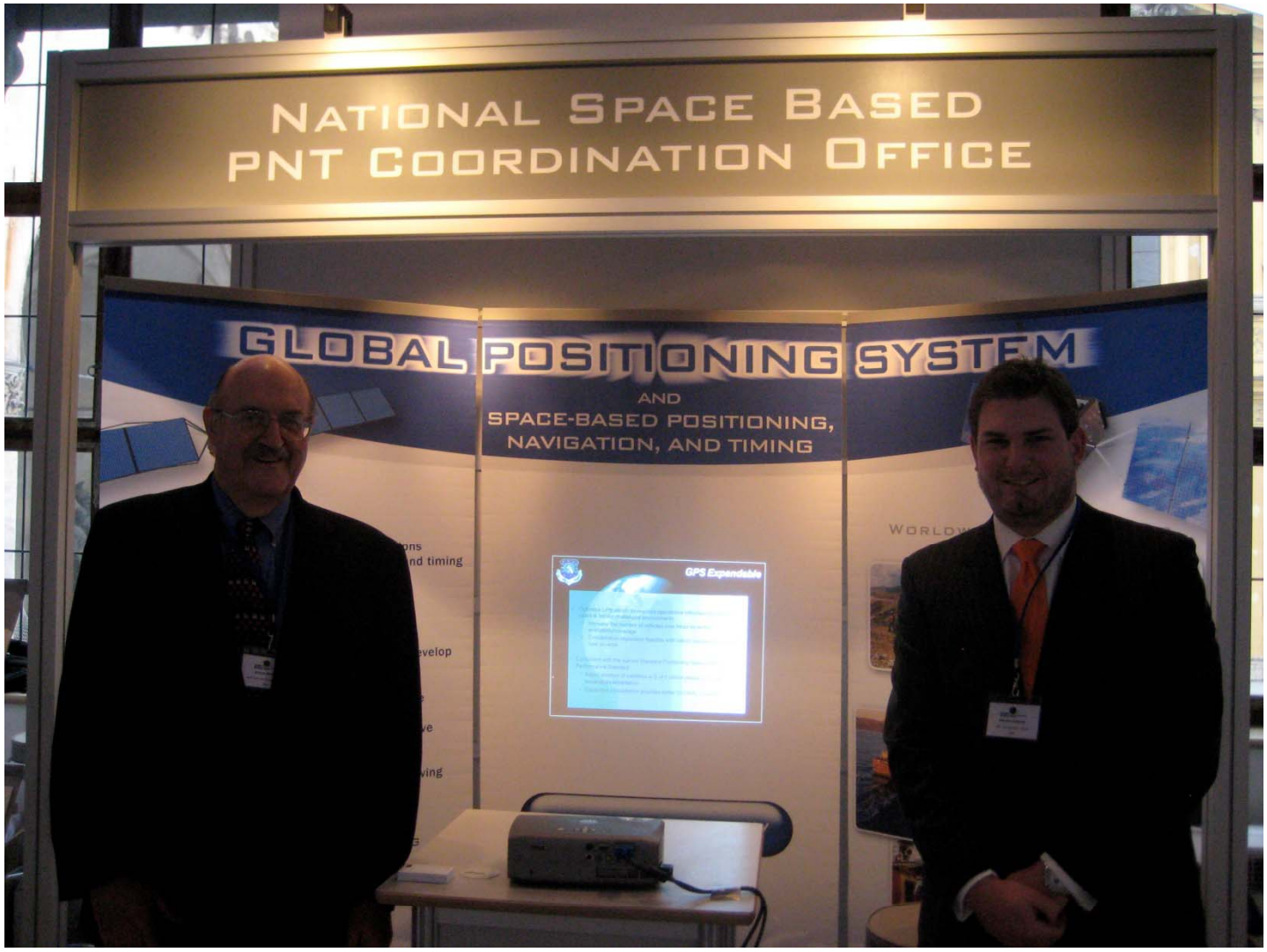
NCO Staffing in 2010

• Director	SES	Department of Transportation
• DOT	1 PTE	Department of Transportation
• DoD	2 FTE's	Department of Defense
• State	1 FTE	Department of State
• DOC	2 PTE's	Department of Commerce
• DHS	1 FTE	Department of Homeland Security
• DOI	1 PTE	Department of Interior
• USDA	1 PTE	Department of Agriculture
• NASA	1 PTE	National Aeronautics and Space Administration
• Contr.	2 FTE'S	Overlook & SAIC

NCO Activities

- Track presidential GPS budgets and liaison with congressional staff on legislative issues
- Review policy and provide recommendations
- Coordinate international outreach
- Review government presentations for national and international conferences and meetings
- Provide staffing support for Executive Steering Group (ESG) and EXCOM meetings
- Prepare yearly reports and update Five Year Plan
- Take NCO booth to national and international conferences

Munich Satellite Navigation Summit 2010



Executive Committee Activities

- Program Coordination
  - Five-Year National Plan
  - National PNT Architecture
  - GPS modernization
  - Civil GPS funding
  - Semi-codeless GPS transition
  - Nationwide Differential GPS
  - Enhanced Loran
  - Distress Alerting Satellite System
- International Cooperation
  - Bilateral
  - Multilateral
- Spectrum Management
  - Interference Detection and Mitigation Plan
  - Spectrum protection plan
- Outreach
  - Publications, websites
  - Educational exhibits
  - Conferences, workshops, other venues
  - Coordination of U.S. message

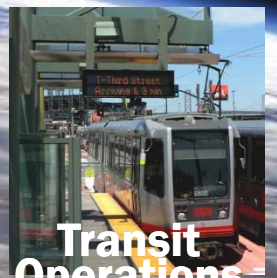
GPS stimulates productivity and increases efficiency in our economy

Satellite Operation

Surveying & Mapping

Power Grids

Precision Agriculture



Transit Operations

NextGen

Disease Control

IntelliDrive

TeleComm

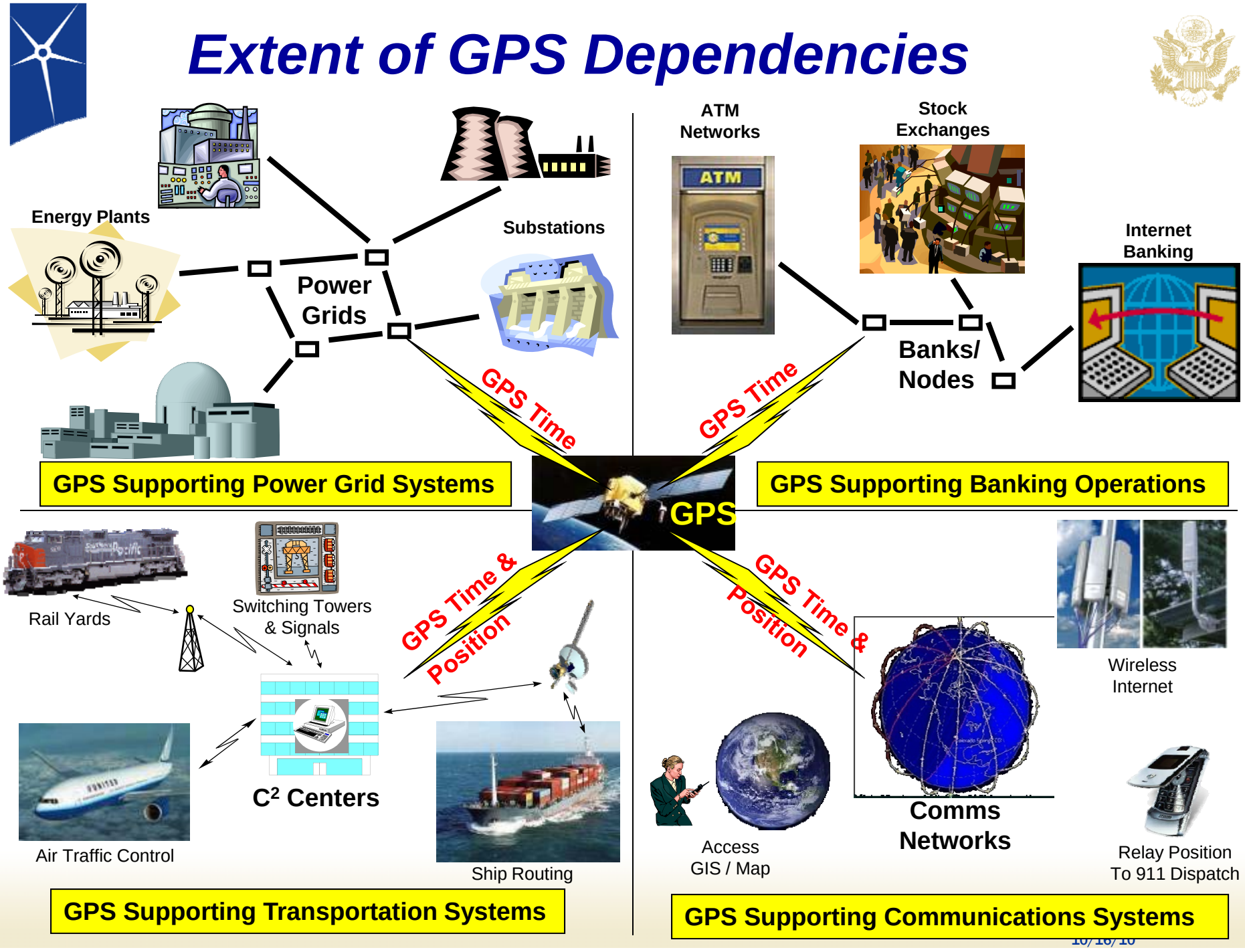
Trucking & Shipping

Personal Navigation

Oil Exploration

Fishing & Boating

Extent of GPS Dependencies

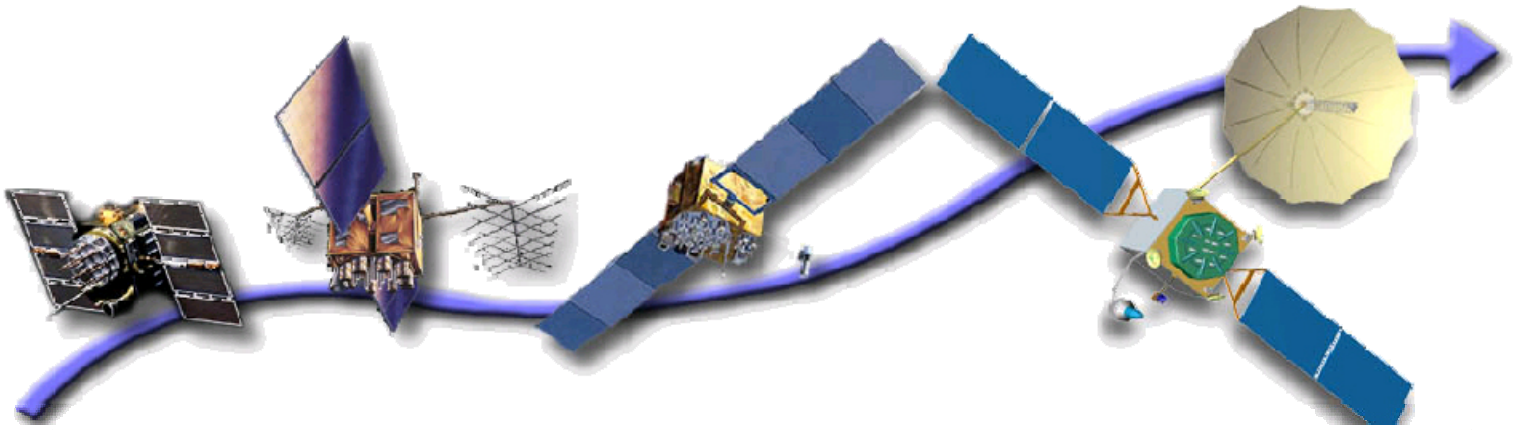


GPS Constellation Status

30 Operational Satellites (Baseline Constellation: 24)

- 11 Block IIA
- 12 Block IIR
- 7 Block IIR-M
  - Transmitting new second civil signal
  - 1 GPS IIR-M in on-orbit testing
- 3 additional satellites in residual status
- IIF-1 launched May 27th, 2010
  - First of 12 Boeing satellites
- Global GPS civil service performance commitment met continuously since December 1993

GPS Modernization Program



Increasing System Capabilities ◆ Increasing Defense / Civil Benefit

Block IIA/IIR

Basic GPS

- Standard Service
  - – Single frequency (L1)
  - – Coarse acquisition (C/A) code navigation
- Precise Service
  - – Y-Code (L1Y & L2Y)
  - – Y-Code navigation

Block IIR-M, IIF

IIR-M: IIA/IIR capabilities plus

- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

IIF: IIR-M capability plus

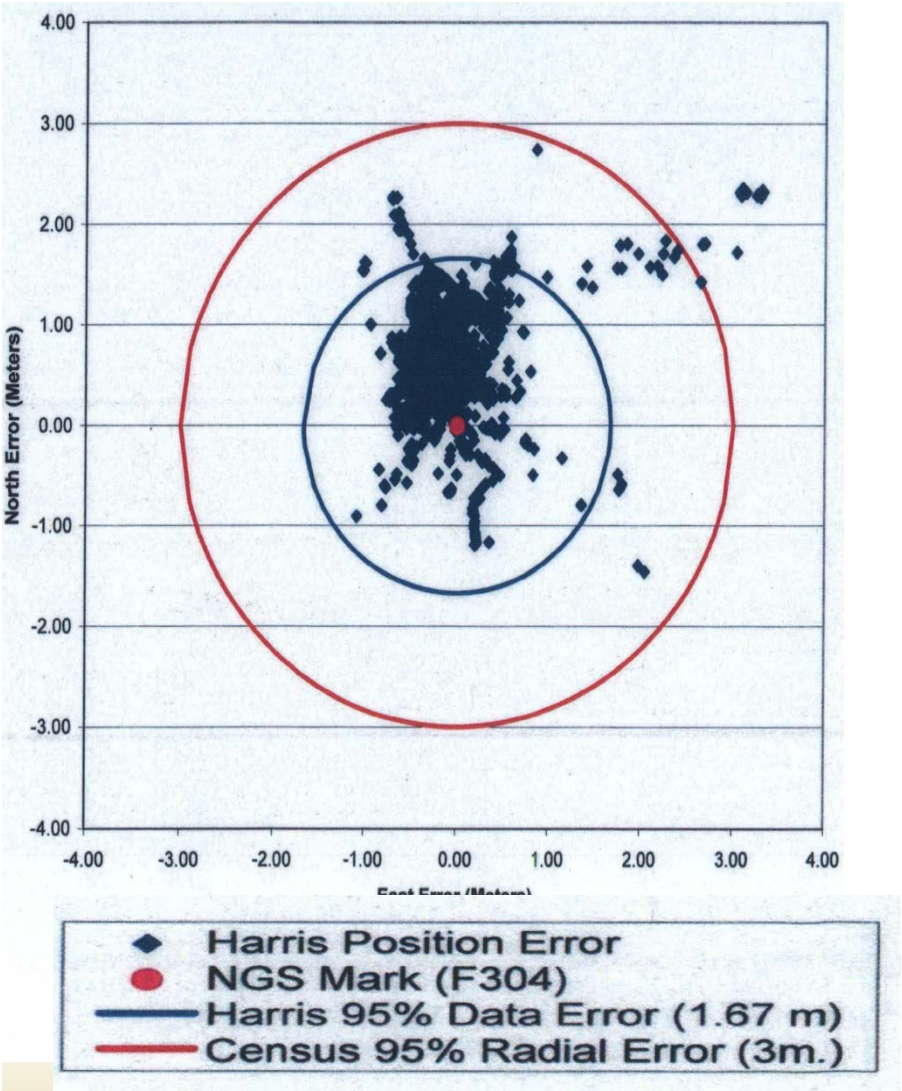
- 3rd civil signal (L5)
- Anti-jam flex power

Block III

- Backward compatibility
- 4th civil signal (L1C)
- Increased accuracy
- Increased anti-jam power
- Assured availability
- Navigation surety
- Controlled integrity
- Increased security
- System survivability

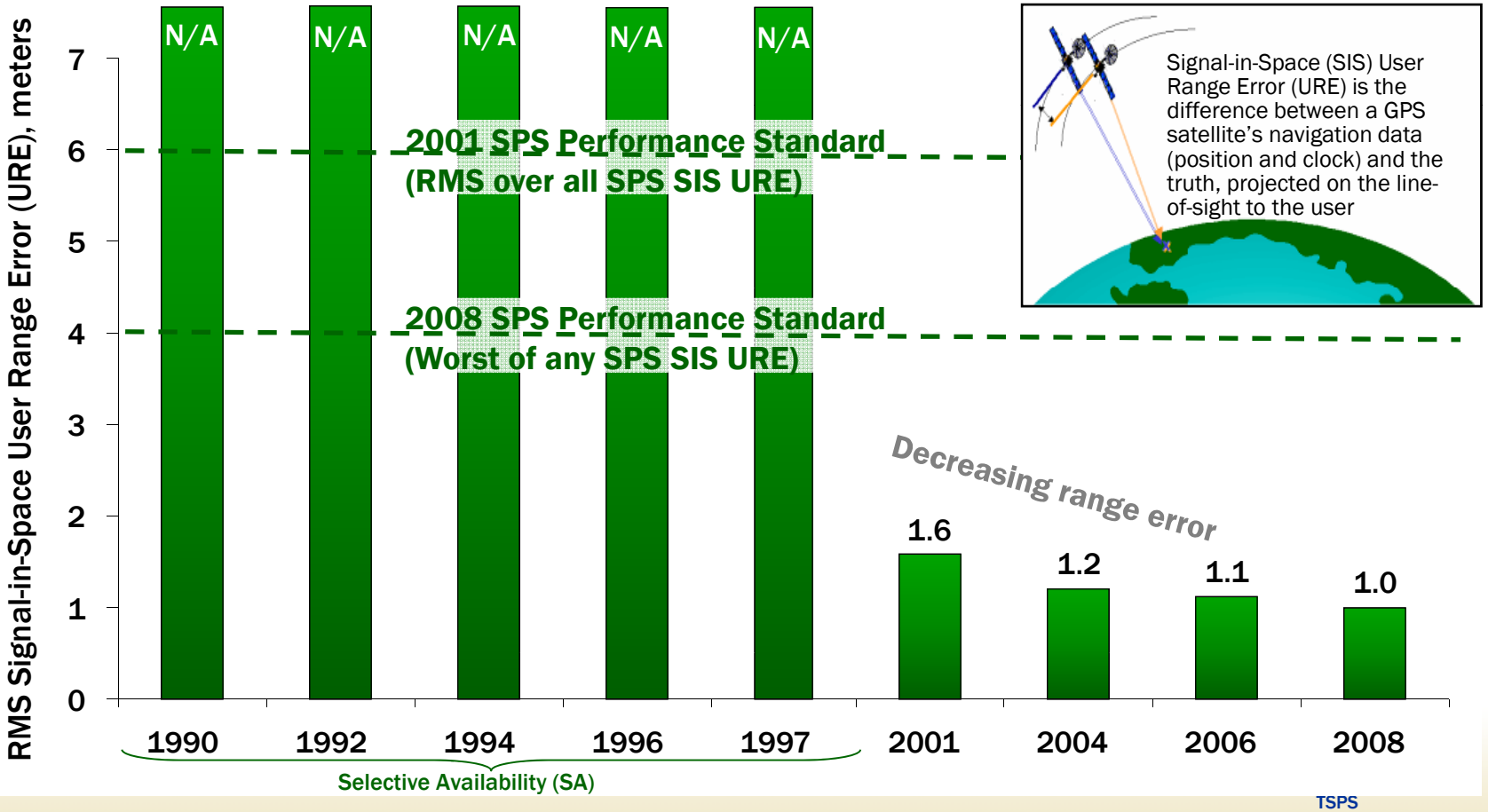
A Review of Accuracy

Hand held GPS Post Processed Position Errors – Ref. Station @ 50 Km.

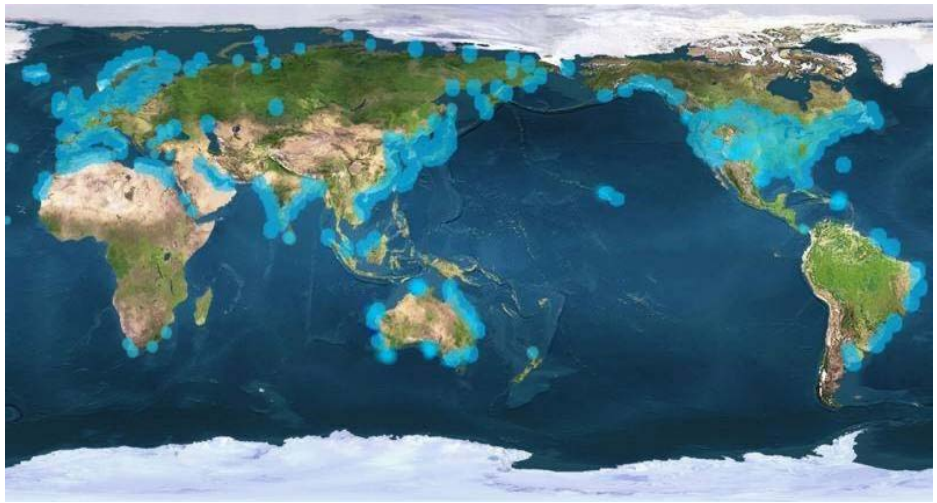


Current GPS Accuracy

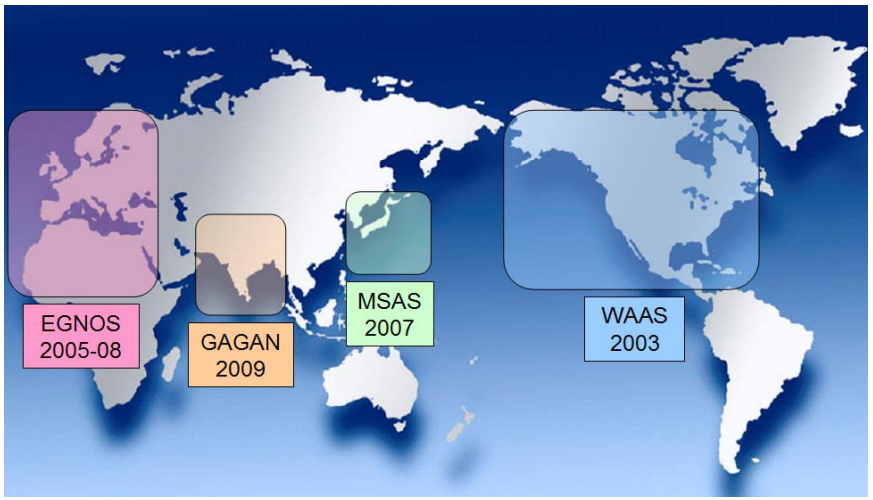
- SPS Signal-in-Space (SIS) User Range error (URE)
  - One-year RMS through September 2009: .90 meters
- SPS Zero Age-of-Data (AOD) URE
  - One-year RMS through September 2009: 0.50 meters



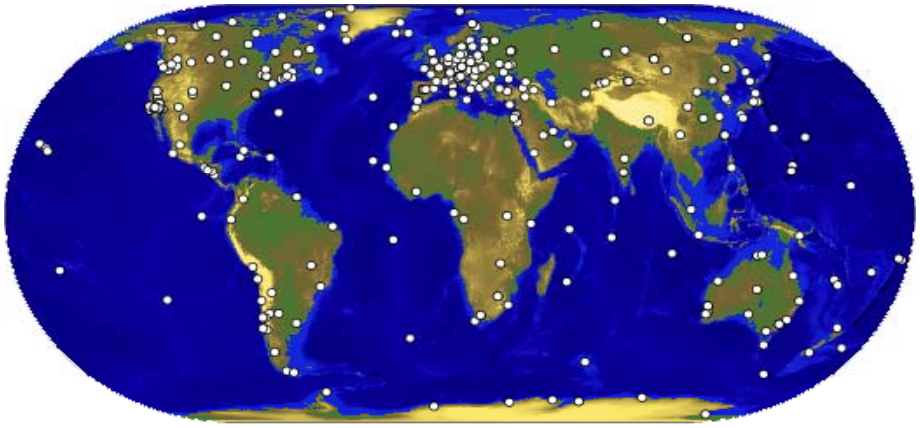
International Augmentations



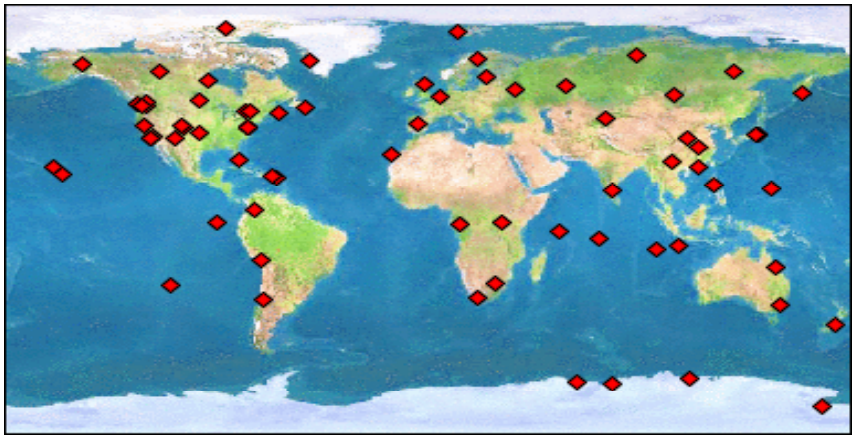
Differential GPS Networks



Satellite-Based Augmentation Systems



International GNSS Service



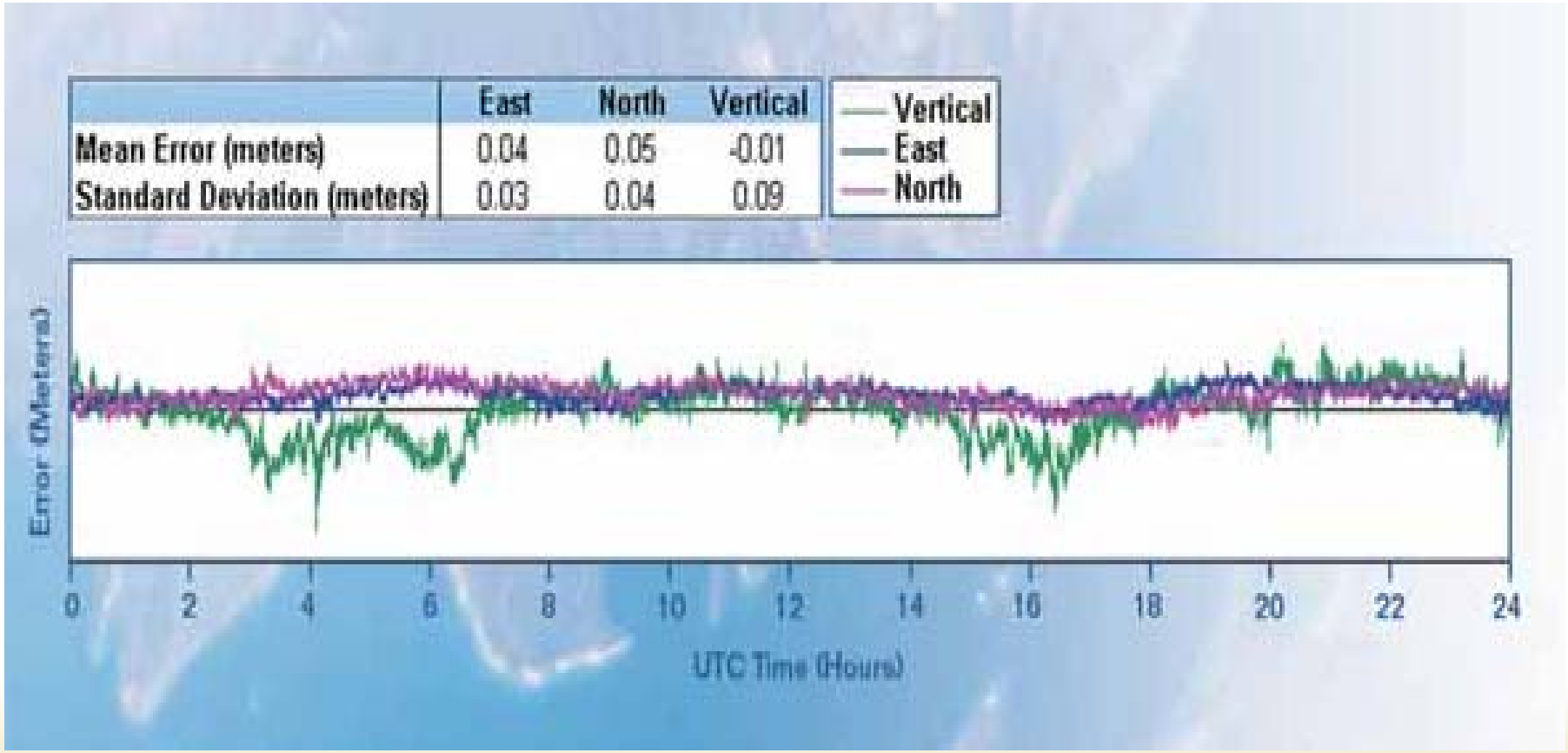
Global Differential GPS System

Global Satellite Based Augmentation System (GSBAS)

- GPS satellite orbit and clock corrections are calculated from a global tracking network of dual frequency receivers.
- The GSBAS algorithms developed by NavCom are based on technology licensed from NASA's Jet Propulsion Laboratory.
- Orbit and clock corrections from both processing centers are distributed via dedicated circuits with multiple communication backups to three Inmarsat satellite uplink stations.
- StarFire accuracy is independent of the distance to the nearest reference station.

Accuracy

- NavCom / Starfire - 20 cm horizontal and 30 cm vertical accuracy (2 sigma – 95%).



Canada-wide DGPS Service

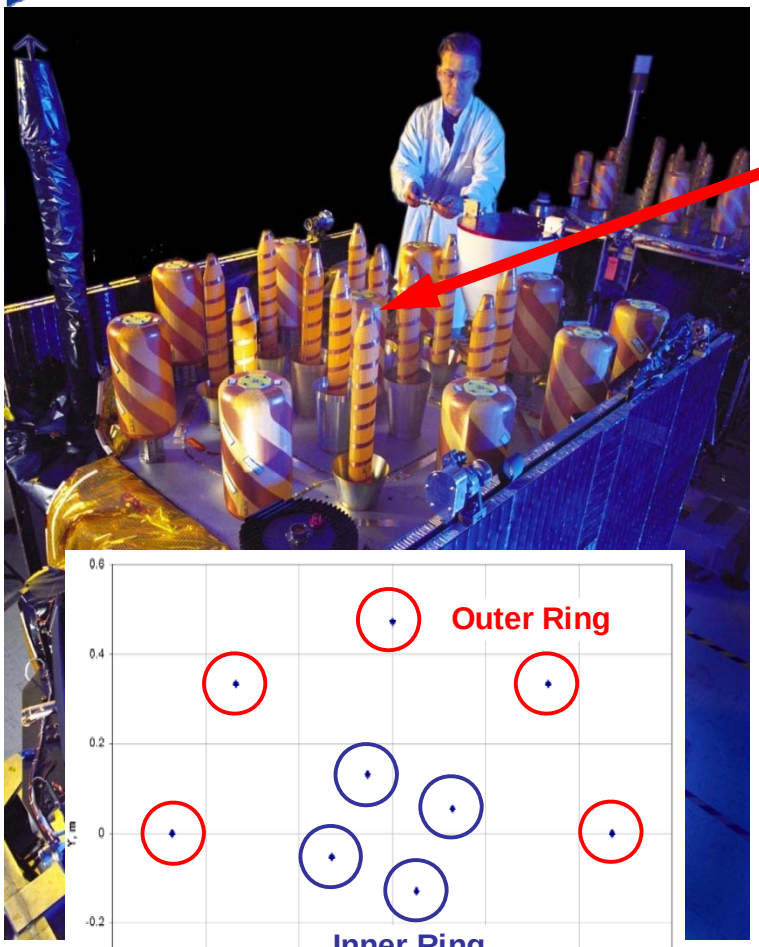
- GNSS augmentation initiated as a free public service since October 2003 (CDGPS)
- North American footprint extends from Mexico to 15 degrees north of the Arctic Circle
- The satellite provider broadcasting the CDGPS L-band signal will upgrade to next-generation satellites this year.
- This upgrade would require a significant infrastructure investment to migrate to the new communications satellite
- As similar commercial services are available, Canada has decided to decommission CDGPS by 03/31/2011.

SVN-49 Issues

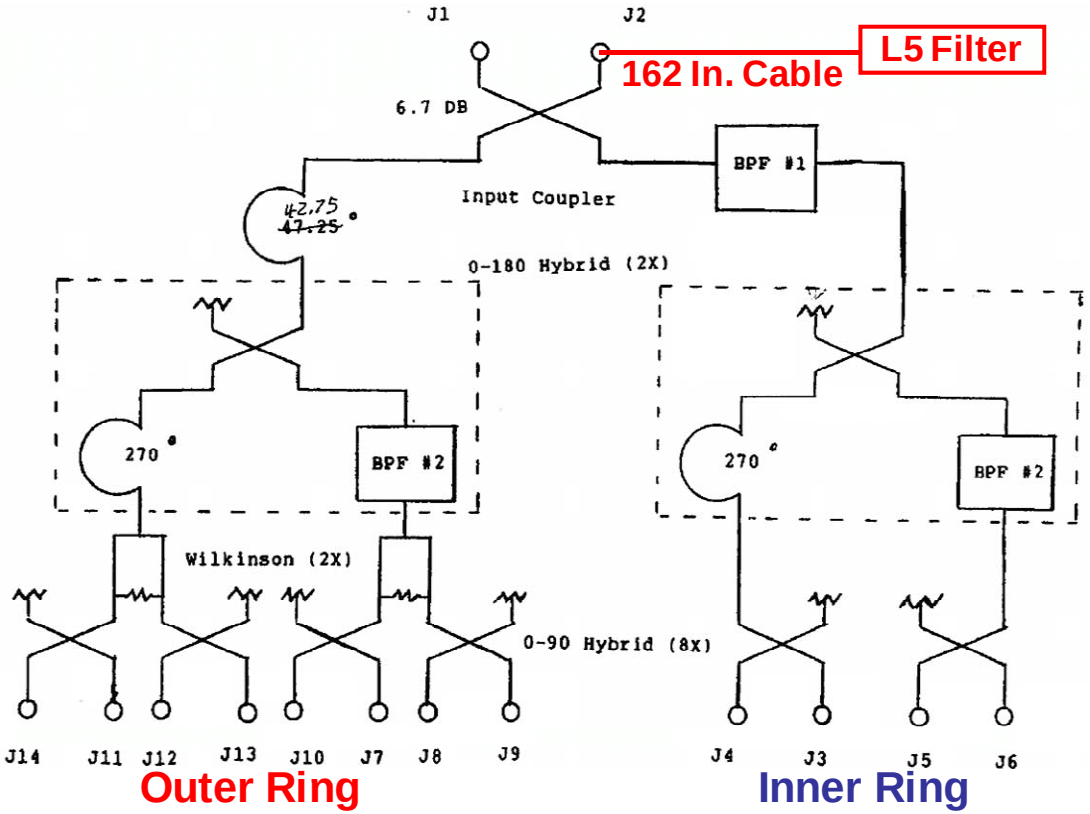
SVN-49 unlike other GPS IIR Satellites had L5 R&D Demonstration Payload Demo payload made use of Auxiliary Payload port

- No impact on L1 and L2 signals was intended or expected
- "Out of family" elevation angle dependent Pseudo Range Residuals (PRR) seen at monitor stations and by other GPS users world-wide
  - Root cause studied and established Signals reflecting off L5 filter and transmitted through satellite antenna
  - Installation method is unique to this satellite –other GPS satellites will not be affected
  - SVN-49 signal is not compliant with IS-GPS-200 for the spurious transmission specification, but does meet all other specifications and requirements

GPS IIR L-Band Antenna with L5 Demo Filter

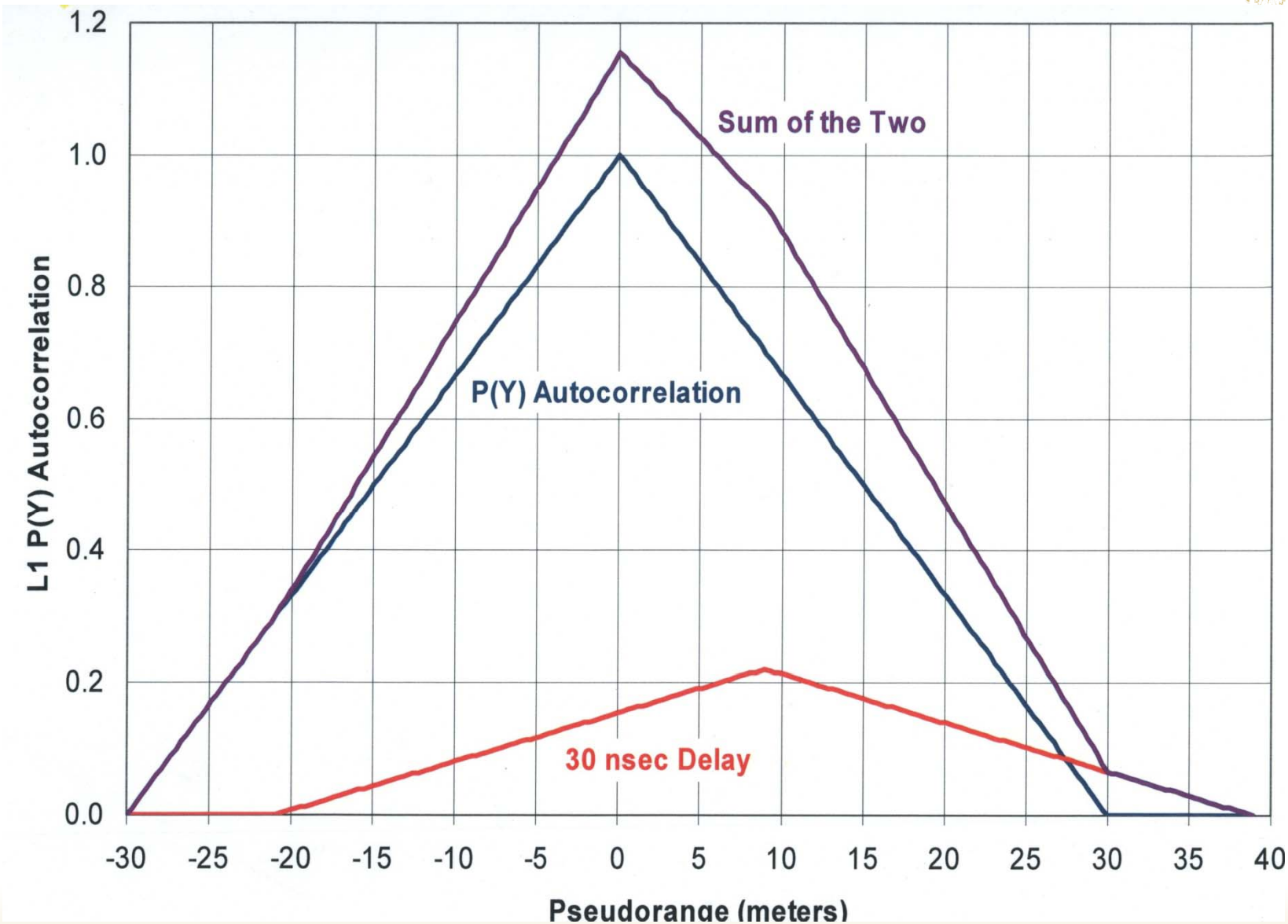


L-Band antenna array with
12 helical elements



Source: USAF, ION-GNSS-2009.

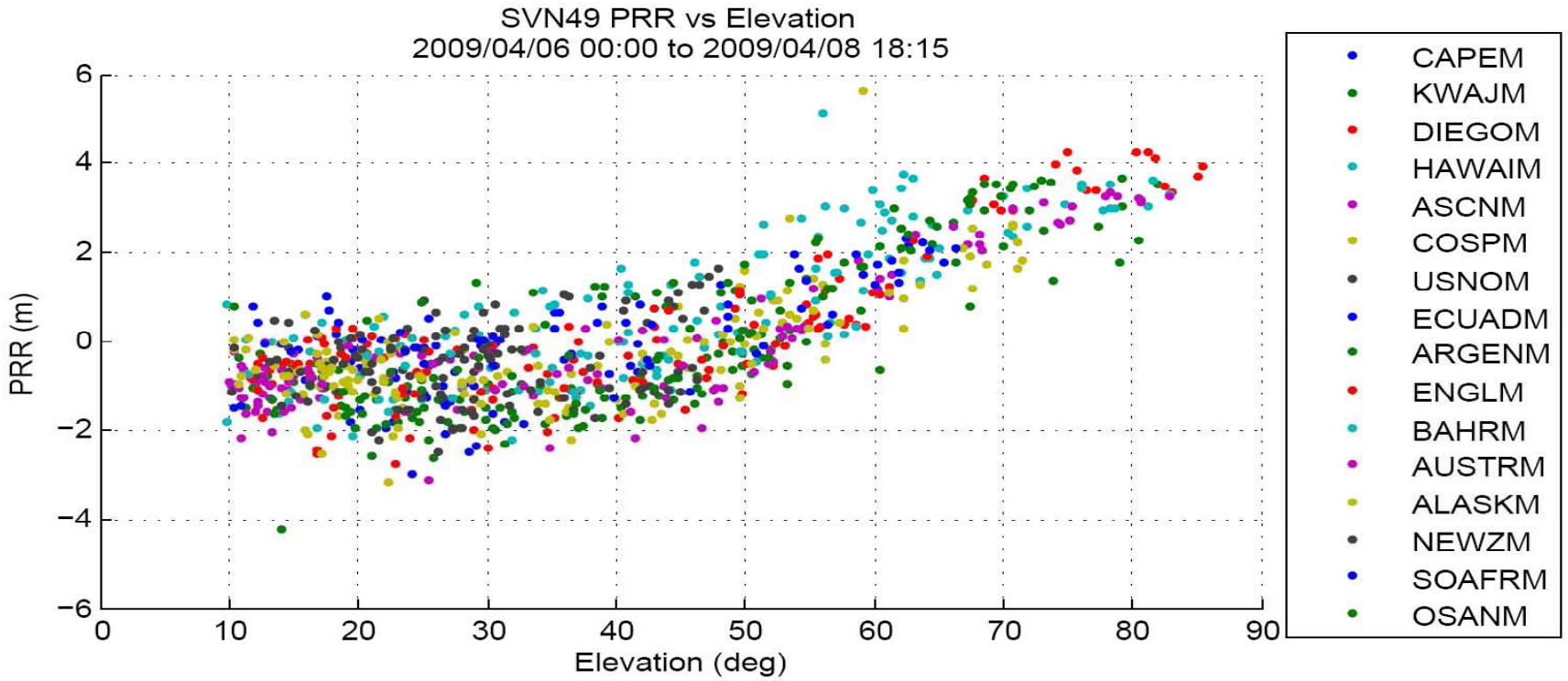
Max Impact on L1 P(Y) Autocorrelation



SVN-49 Issues (Continued)

- Result is permanent, static multipath signal within satellite
  - Signal distortion is user elevation angle dependent
  - Little or no distortion at low elevation angle
- Signal distortion impacts receivers differently depending on unique designs
- Non IS-GPS-200 compliant receivers greatly complicate the issue
- Varying impacts prevent a single solution for all forms of user equipment

SVN-49 Pseudorange Residuals (Monitor Station PR –Predicted PR)

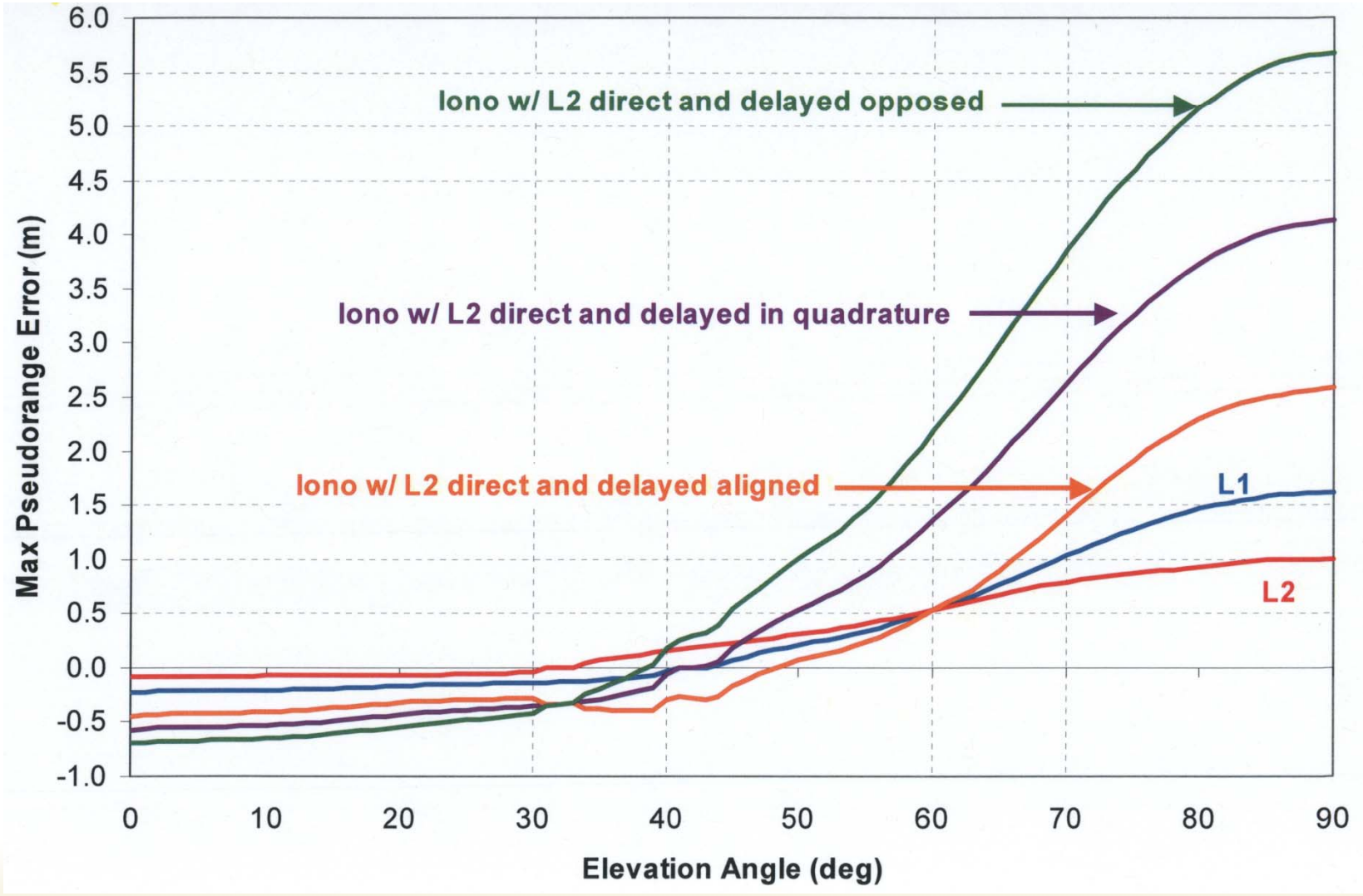


- **Dual frequency ionosphere refraction corrected pseudoranges**
- **Relative to "best fit" orbit during initial test period (6 April 2009)**
- **Roughly 4+ meter spread from 10 to 80 degrees**

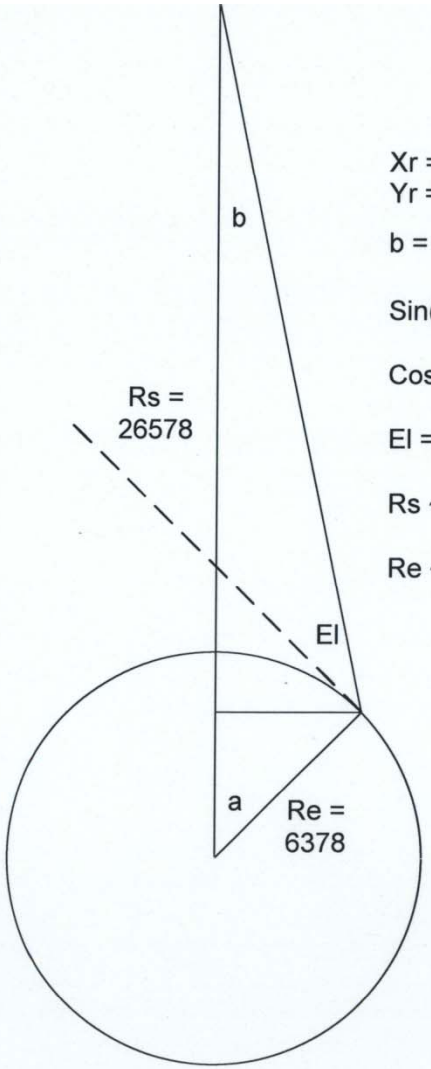
Refraction Corrected Error Possibilities

- Assume the direct and reflected L1 signals are in phase so at zenith the L1 pseudorange is 1.62 m too long
- If the direct and reflected L2 signals are in quadrature, the L2 pseudorange error is negligible
- Therefore, the refraction corrected pseudorange error is (2.55 x 1.62 – 1.55 x 0) = 4.14 m
- If the direct and reflected L2 signals are in the same phase, the L2 pseudorange error is ~0.95 m
- Therefore, the refraction corrected pseudorange error is (2.55 x 1.62 – 1.55 x 0.95) = 2.66 m
- If the direct and reflected L2 signals are in opposite phase, the L2 pseudorange error is ~ -1.1 m
- Therefore, the refraction corrected pseudorange error is (2.55 x 1.62 – 1.55 x –1.1) = 5.84 m

SVN-49 Pseudorange Error Model



Raise the Orbit, Offset the Clock



Xr = Re Sin(a)
Yr = Re cos(a)

b = atan(Xr/(Rs - Yr))

Sin(90+El)/Rs = Sin(b)/Re

Cos(El)/Rs = Sin(b)/Re

El = acos(Rs Sin(b)/Re)

Rs ~ 26,560,601 meters

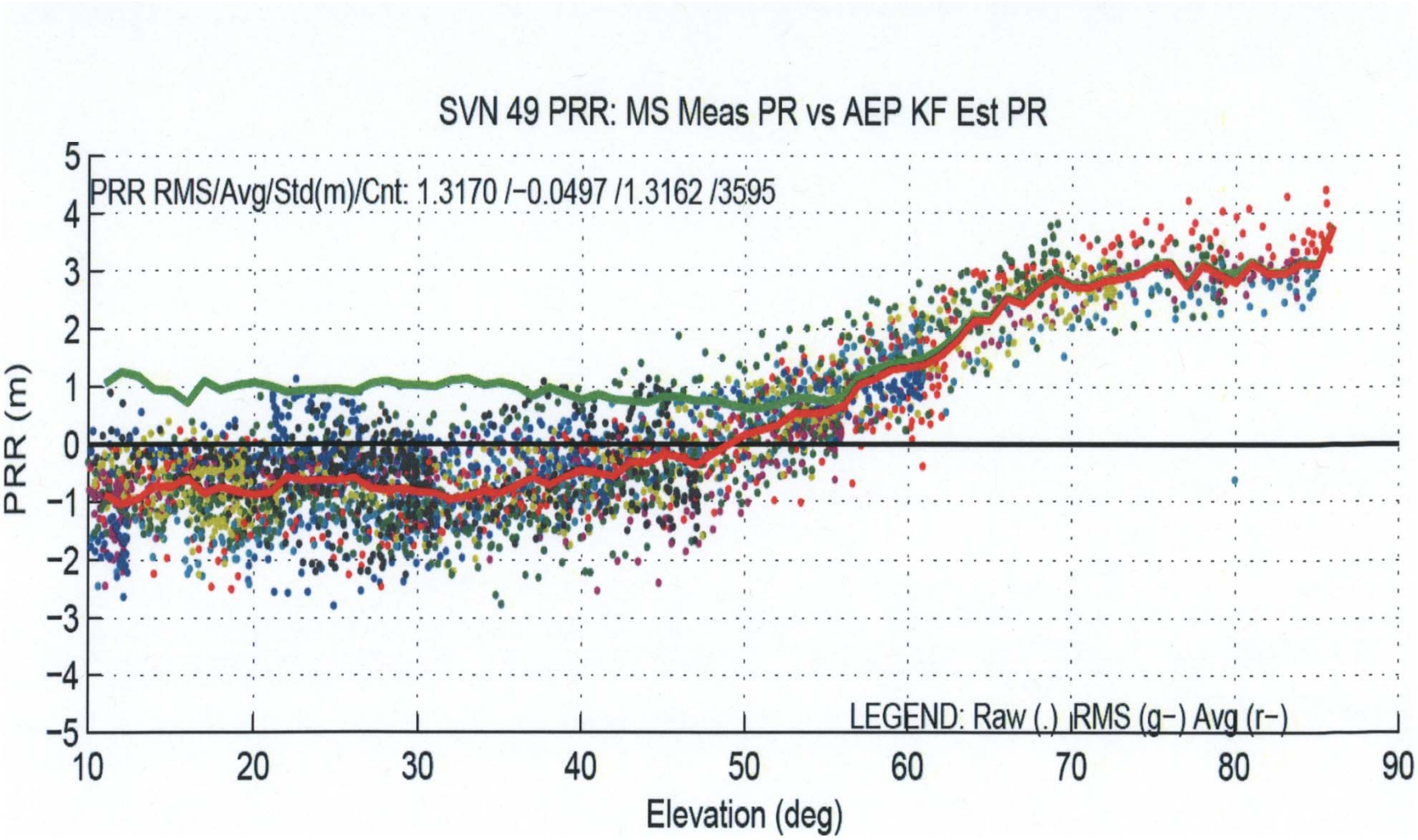
Re ~ 6,378,137 meters at equator

- **If Rs effective = Rs + δ**
- **The impact on pseudorange is δ cos(b)**
- **The following plot shows the effect of δ = 152.586 m with a clock offset of 496.2 nsec (148.754 m)**

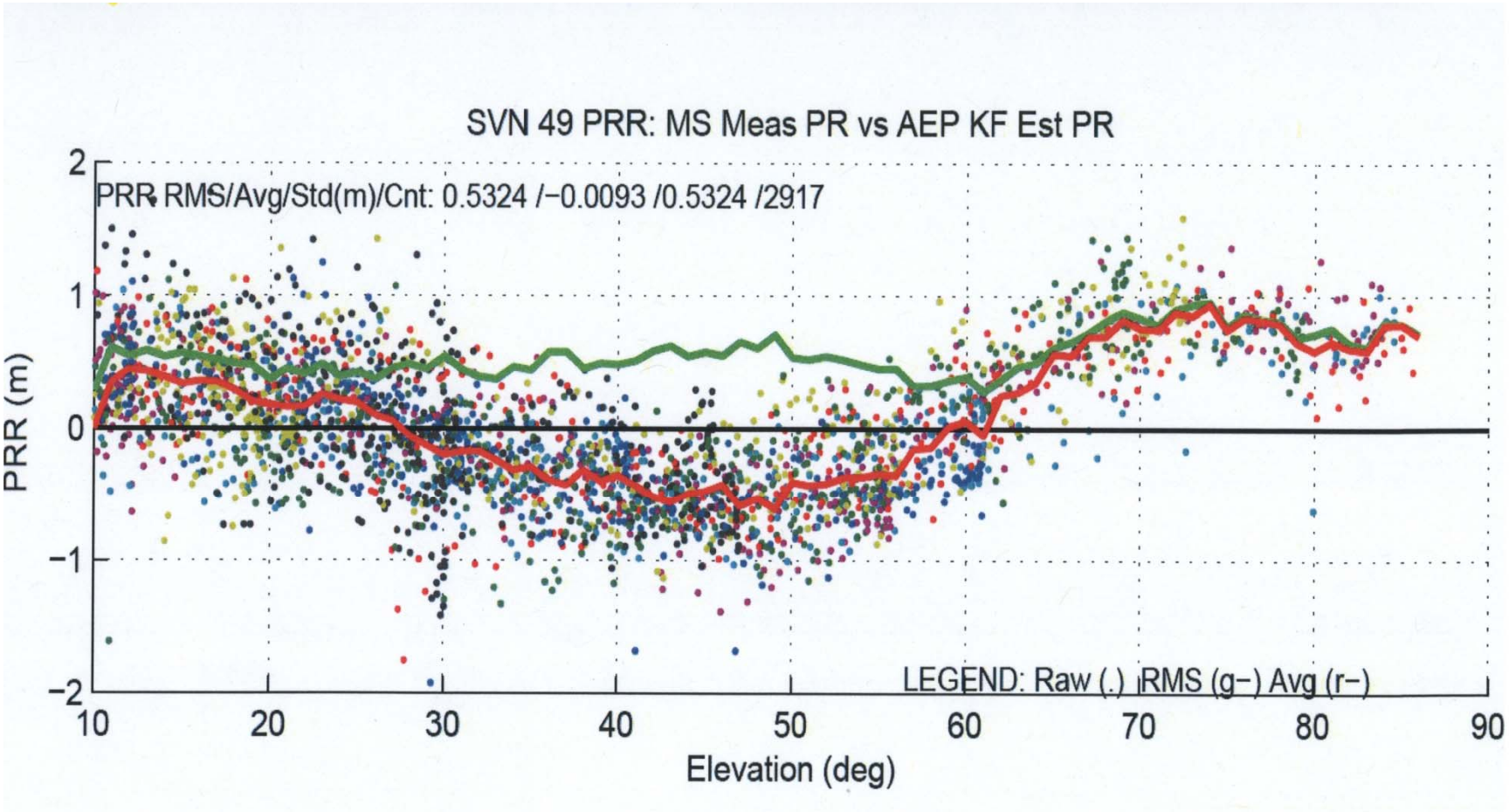
A Partial Fix

- **In order to reduce the elevation-dependent tracking residuals, 2SOPS has experimented with placing the antenna phase center about 152 meters above the satellite rather than slightly below as normal**
  - (How can you fix a 4-5 meter problem with a 152 meter solution?)
- **The Kalman filter then provides orbit and clock parameters which best fit the tracking data**
  - The key parameter is clock offset

Uncompensated Residuals



Compensated Residuals



SVN-49 Optional Mitigations

- Set healthy with current 152m Antenna Phase Center (APC) and associated clock offsets
- Set healthy with factory Antenna Phase Center (APC) offset
- ❖ Users switch to multipath-resistant receivers
- ❖ Modify receiver software to use look-up table corrections
- Increase URA index to a minimum value of '3'
- Remove data modulation from L2 P(Y)-code
- Change L2C PRN code to a "unique sequence"
- Change SVN-49 from PRN-01 to PRN-32
- Use spare health code so future users could use SVN 49 despite unhealthy setting

GPS SVN 49 Mitigation / JAVAD GNSS Receiver Using Triumph Technology