GPS Modernization and Program Update

Briefing to the Stanford Center for PNT Symposium
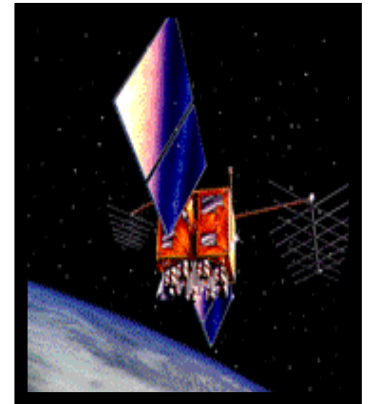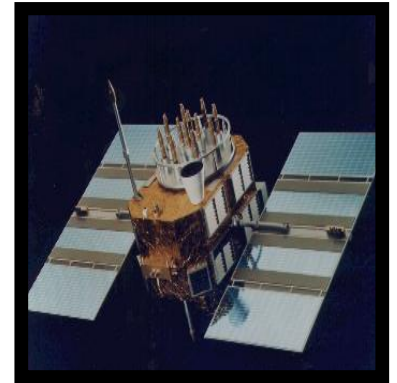
9 Nov 10

Col Bernard Gruber
Commander
GPS Wing

Contents

- **Current Constellation**

- **Modernization**

- **Other Improvements**
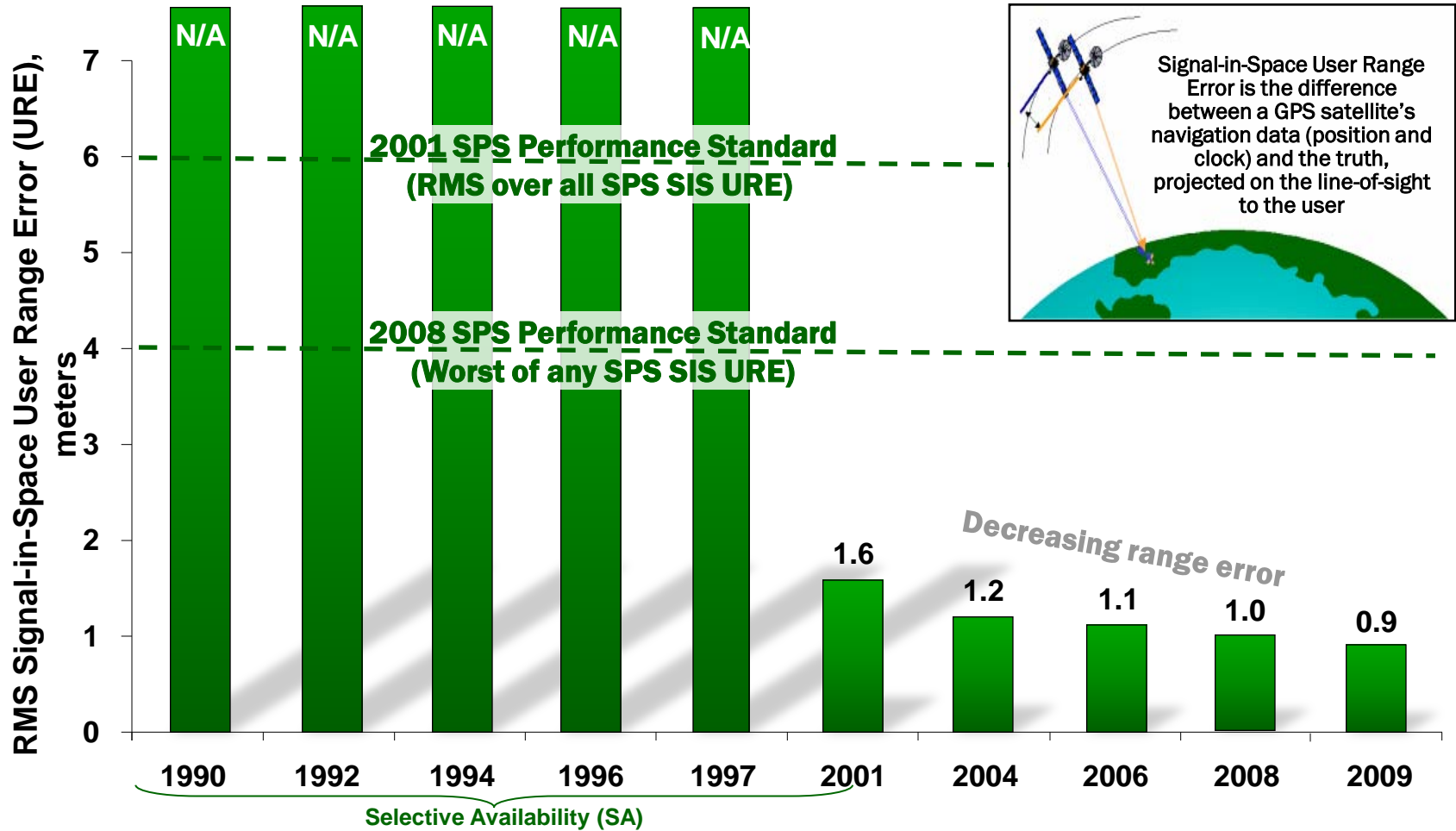
- **Very robust constellation**

  - 31 space vehicles currently in operation

    - 11 GPS IIA

    - 12 GPS IIR

    - 7 GPS IIR-M

    - 1 GPS IIF

  - 3 additional satellites in residual status

  - 1 satellite in "test" mode – SVN 49

- **Global GPS civil service performance commitment met continuously since Dec 1993**
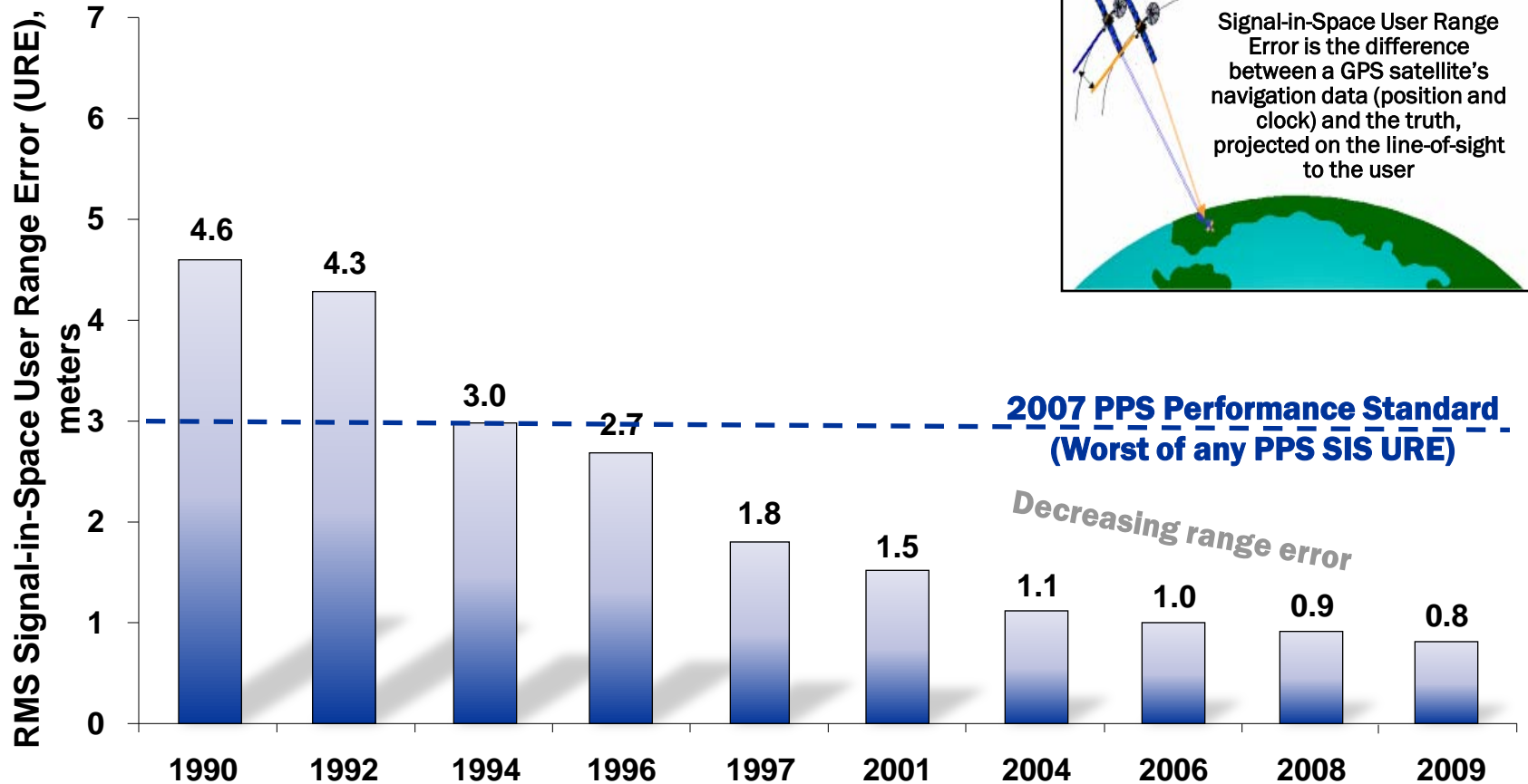
SPS Signal in Space Performance

Signal-in-Space User Range Error is the difference between a GPS satellite's navigation data (position and clock) and the truth, projected on the line-of-sight to the user

RMS Signal-in-Space User Range Error (URE), meters

2001 SPS Performance Standard
(RMS over all SPS SIS URE)

2008 SPS Performance Standard
(Worst of any SPS SIS URE)

Decreasing range error

Year	Value
1990	N/A
1992	N/A
1994	N/A
1996	N/A
1997	N/A
2001	1.6
2004	1.2
2006	1.1
2008	1.0
2009	0.9

Selective Availability (SA)

System accuracy exceeds published standard

PPS Signal in Space Performance

Signal-in-Space User Range Error is the difference between a GPS satellite's navigation data (position and clock) and the truth, projected on the line-of-sight to the user

2007 PPS Performance Standard (Worst of any PPS SIS URE)

Decreasing range error

RMS Signal-in-Space User Range Error (URE), meters

| Year	1990	1992	1994	1996	1997	2001	2004	2006	2008	2009
Value	4.6	4.3	3.0	2.7	1.8	1.5	1.1	1.0	0.9	0.8

System accuracy exceeds published standard

Expanded 24 SV Constellation

- **Current 24 SV 95% procurement implies many more SVs on-orbit**
  - 24 primary slots and other auxiliary slots
- **Move 3 auxiliary slots to expanded primary slots = Expanded 24**
- **Improves performance in robustness to failures, integrity & accuracy**
- **Can fall back to 24 SVs if SV/booster shortage**
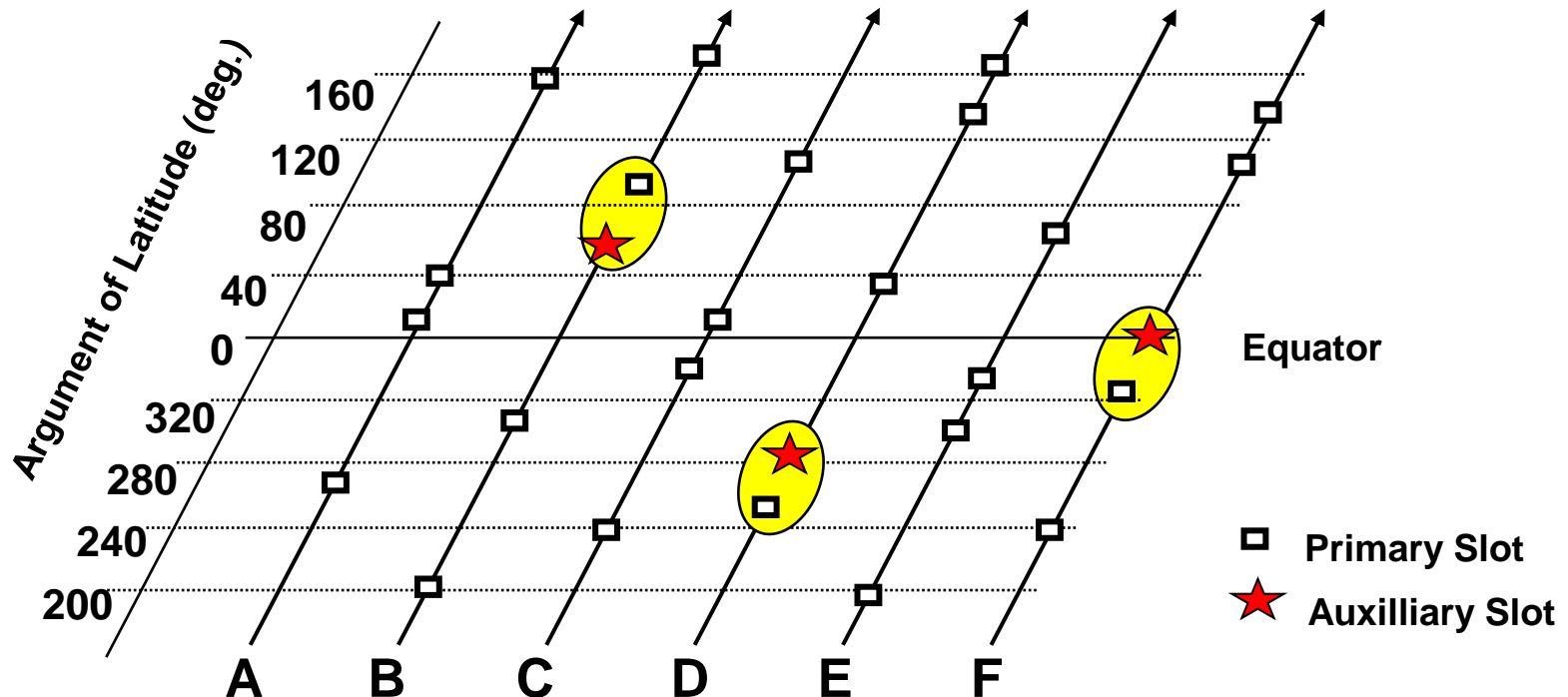
Coming Up: SPS PS Update

- **Planning a draft update of the SPS PS by 1QFY11**
  - Name change to "Open Service Performance Standard" (OS PS)
  - Addition of L2C signal to current L1 C/A signal
  - Same performance values
  - Draft update will be circulated for review & comment within U.S. Government
  - SPS PS update approval before Initial Operational Capability (IOC) declaration for L2C

- **Planning subsequent draft updates for L5 signal & for L1C signal**
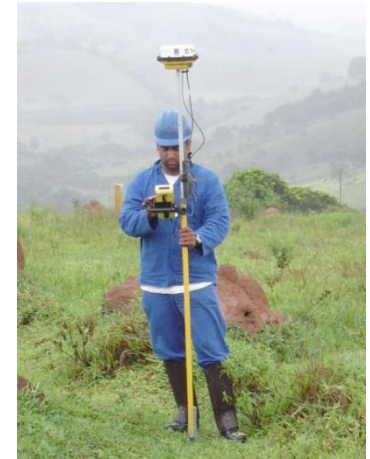 - Prior to each subsequent IOC declaration

SPS PS

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GPS Modernization – New Civil Signals

- **Second civil signal "L2C"**
  - Designed to meet commercial needs
  - Available since 2005 without data message
  - Phased roll-out of CNAV message
  - Full capability: 24 satellites and full CNAV ~2016 *

- **Third civil signal "L5"**
  - Designed to meet transportation safety-of-life requirements
  - Uses Aeronautical Radio Navigation Service band
  - Available since 2010; 24 satellites and full CNAV ~2020*

- **Fourth civil signal "L1C"**
  - Designed for GNSS interoperability
  - Specification developed in cooperation with industry
  - Launches with GPS III in 2014
 - Available on 24 SVs by ~ 2026*

Urban Canyons

Improved performance in challenged environments

* FOC dates are based on our best guess for launch schedule

IIR/IIR-M Satellites

- **All GPS IIR and IIR-M satellites have now been launched**

  - Current backbone of the GPS constellation

- **Excellent on-orbit performance**

  - SIS URE of .50 meters - 1 Year Performance Jul 2010

- **Excellent life expectancy**

  - Solar array capacity far exceeds specified Mean Mission Duration

  - No clock failures to date

- **Completed deployment of IIR-M**

  - L2C CNAV message type 0 capability deployed this year on IIR-M to support testing of civil UE

  - Full CNAV message with OCX
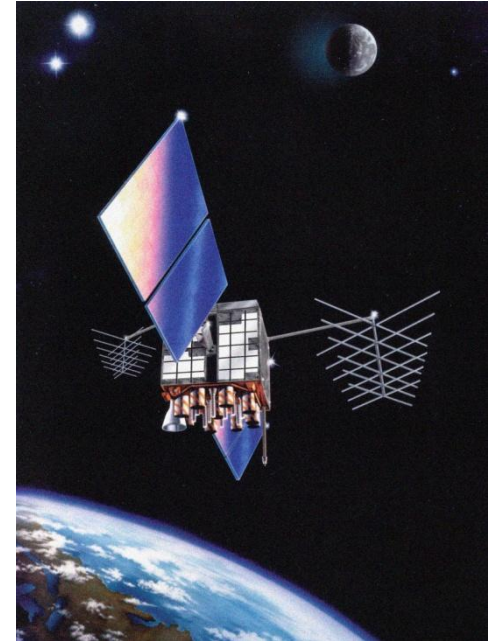
- **Launched GPS IIF SV-1 in May 2010**
  - SVN62, PRN 25
  - Was set healthy 26 Aug 10
  - First operational L5
  - Excellent clock performance

- **11 more IIFs in the pipeline**
  - SVs 2-5 are in production

- **IIF SV-2 launch by Jun 2011**

- **Newest block of GPS satellites**

  - First satellite to broadcast common L1C signal

  - Multiple civil and military signals; L1 C/A, L1 P(Y), L1M, L1C, L2C, L2 P(Y), L2M, L5

  - +10 dB earth coverage power increase on M-Code

  - Three Rubidium clocks

- **Completed Critical Design Review for Block IIIA**

  - Two months in advance

- **Completed Delta System Requirements Review for Block IIIB**

- **Conducting Analysis of Alternatives for Blocks IIIB and IIIC**

  - Revalidate requirements and associated cost/benefits

Ground Segment

Monitor Station

Master Control Stations at Schriever AFB, Colorado
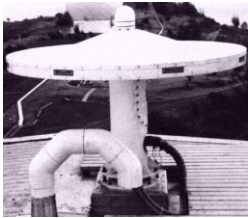
Ground Antenna

- **Deployed several AEP upgrades including SAASM upgrade**

- **Conducted flex power demo with live IIR-M SVs**

- **Awarded OCX Phase B to Raytheon Feb 2010**
  - Completed Technical Baseline Review Mar 2010
  - Completed Independent Baseline Review Aug 2010
  - Completed Software Specification Review Sep 2010
  - Preliminary Design Review planned for Apr 2011
  - OCX Block I deployment planned for 2015

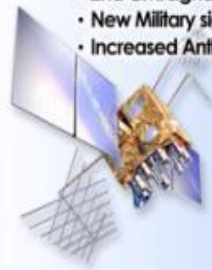**Modernization is on track across the enterprise**

Space Segment (Satellites)

Legacy (Block IIA/IIR)
- Basic GPS
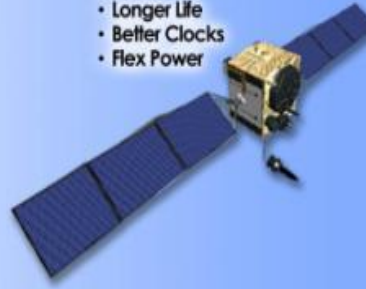- NUDET (Nuclear Detonation) Detection System (NDS)

GPS IIR-M
- 2nd Civil signal (Better Acuracy)
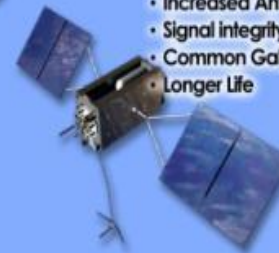- New Military signal
- Increased Anti-Jam power

GPS IIF
- Longer Life
- Better Clocks
- Flex Power

GPS III
- Increased Accuracy
- Increased Anti-Jam power
- Signal integrity
- Common Galileo signal
- Longer Life

Control Segment

Legacy
- Mainframe System
- Command & Control
- Signal monitoring

AEP
- Distributed Architecture
- Increased Signal Monitoring Coverage
- Security
- Accuracy
- Launch And Disposal Operations

OCX Block I/2
- Control of Block III Satellites
- Net Centric Operations
- Upgraded Information Assurance

OCX Block 3/4
- Improved Integrity
- Improved Security
- Improved Performance

User Segment (Receivers)

Legacy
- First Generation System

User Equipment
- Improved Anti-Jam & Systems
- Reduced Size, Weight & Power

Upgraded Antennae
- Improved Anti-Jam Antennaes

Modernized
- M-Code Receivers
- Common GPS Module

- **Space Segment starting with IIRM (L2C), IIF (L5) and III (L1C)**
- **Ground Segment in OCX blocks 2 and 3/4**
- **User Segment in MGUE**

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- **Modernized GPS SVs have Flex Power capabilities**

  - Can shift power between M-Code, P(Y) code and C/A code

- **Previous on-orbit testing conducted in 2005 and 2007**

- **Conducted extensive on-orbit Flex Power test Sep 7-11, 2010**

  - Turned on Flex Power for 8 IIR-M satellites

- **Identified two issues**

  - Canadian Differential GPS Service - planned for decommissioning NLT Mar 2011

  - FAA integrity monitors gave false positives – mitigations being developed

- **Developing Flex Power Concept of Operations (CONOPS)**

Capability Deployment

- **GPS receiver anomalies were reported several times this year coinciding with testing activities**

  - Almanac problem in Nov 2009, SAASM problem in Jan 2010, etc.

- **Problems were traced to non-compliant UE**

  - Unauthorized use of reserved bits, incorrect assumption on almanac time, incorrect implementation/interpretation of a security function

- **Problems mitigated by working extensively with UE vendors to fix non-compliance issues**

- **Undertaking improvements in deployment method and certification paradigm**

Smooth Deployment of New Capabilities Key to Modernization

New Transition and Certification Paradigms

- **Instituting methodical capability transition process**

    - Carefully planned transition event testing

    - Extensive participation by representative users and applications

    - Identification of potential issues prior to capability deployment

- **Improvements in compliance verification are being put in place**

    - Exploring Underwriters Laboratories construct for independent certification of ICD compliance and associated testing

- **Seeking feedback from user community on transition approaches and compliance verification**

ICD Compliance is Critical for GNSS Success

PRN Expansion

- **Control segment is currently limited to 32 PRNs, limitation removed with OCX**

- **Legacy UE are limited to 32 satellites**

- **Current constellation has 31 operational satellites and 3 residual non-operational satellites**

- **63 sets of L1 C/A, L2C, L5, and L1C codes have been defined**

- **Developing CONOPS and ICD changes to exploit additional PRN capability while remaining backward compatible with legacy UE**

  - Proposing to assign higher PRNs to the worse performing satellites

 - Soliciting feedback from user community

- **Developing an updated set of performance metrics**

    - Include different user applications and terrain environments

- **Need to shift away from just counting satellites in the sky**

    - 95% probability of 24 satellites anywhere in the constellation

- **Goal is to identify a short list of most meaningful metrics and report on them regularly**

    - Cover the big five, i.e. Availability, Accuracy, Bounded inaccuracy, Integrity, Interference (inadvertent or malicious)

    - Cover key user applications

- **Challenge is representing the metrics in terms of effect on users/application**

Summary

- **Modernization of all GPS Segments is on track**
- **GPS has continuously met its commitments to all users since FOC**
- **Striving to continually improve navigation and timing services while maintaining backward compatibility with legacy equipment**

Space Segment

Control Segment

User Segment
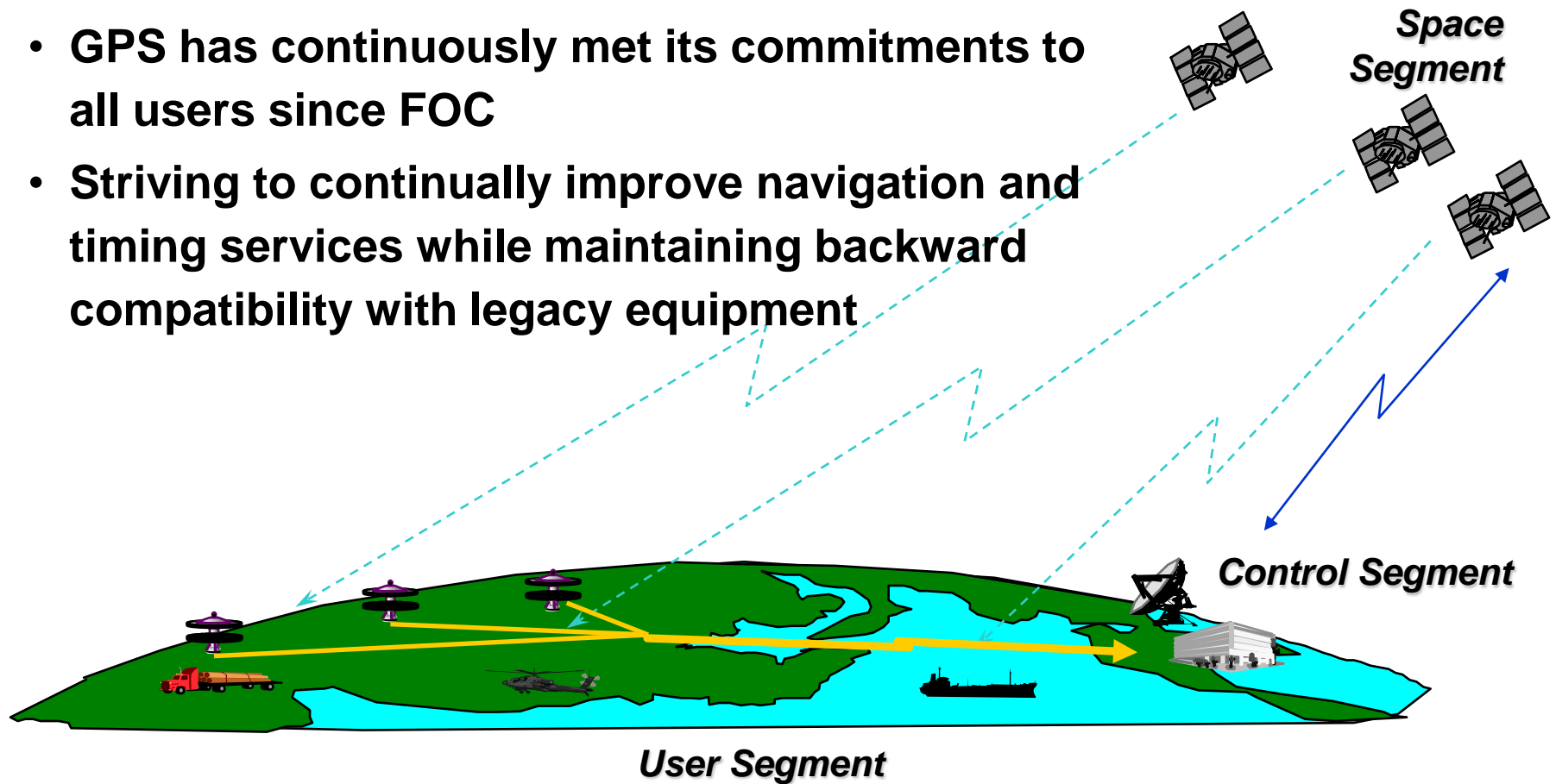
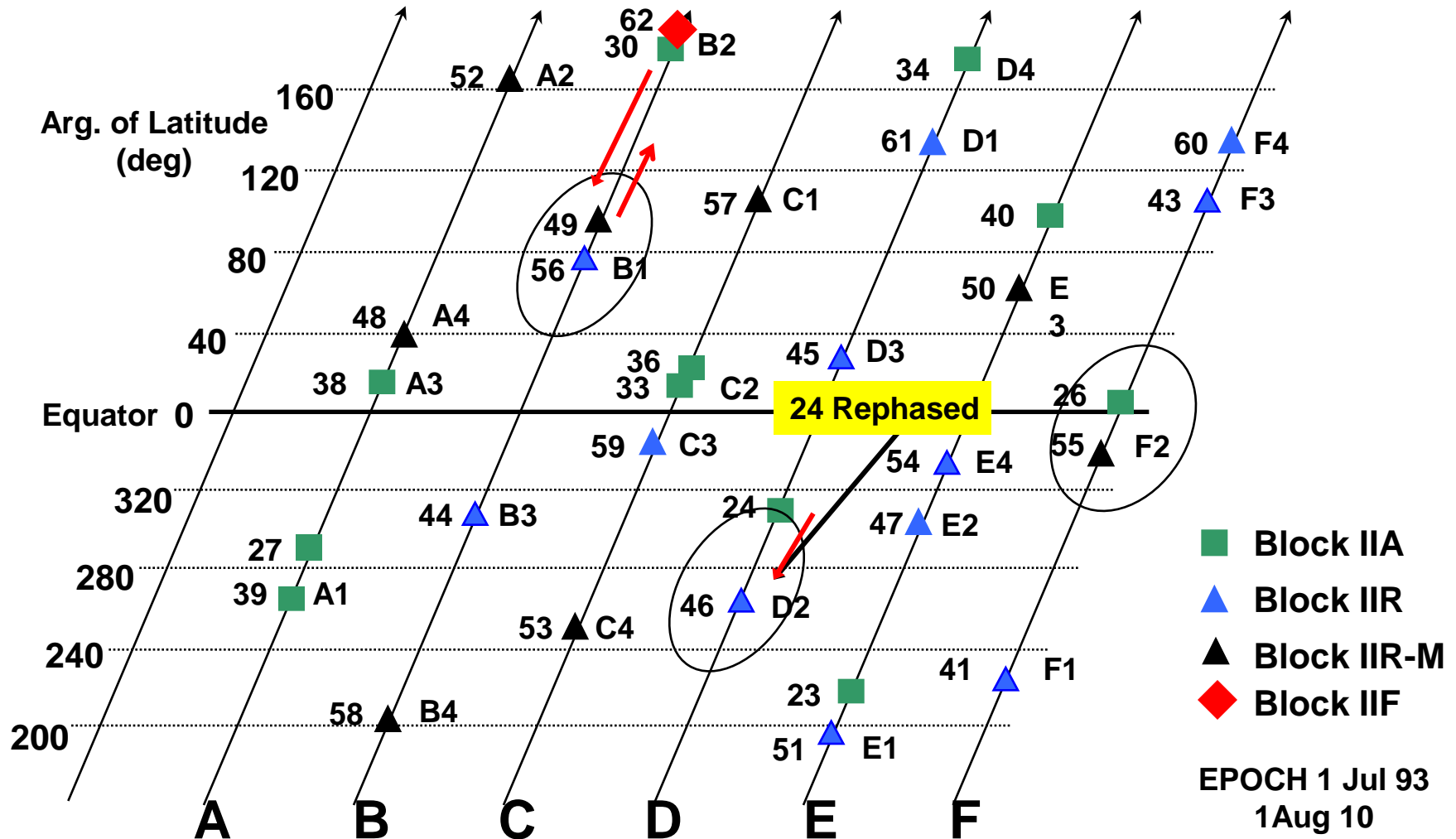*Maintaining And Improving GPS Services For All Users Is Job #1*

Back-Ups

Current Satellite Positions

Expanded Constellation will be fully achieved by Jun 2011

- **SVN 49 was the 7th IIR-M, launched with demo L5 payload**

- **Exhibited signal distortion due to internal multipath between L5 filter and L1/L2 signals**

- **Removed from almanac while mitigations are developed and implemented**

- **Hoping to make SVN-49 usable in the next 2 to 3 years**

SVN49 PRR vs Elevation
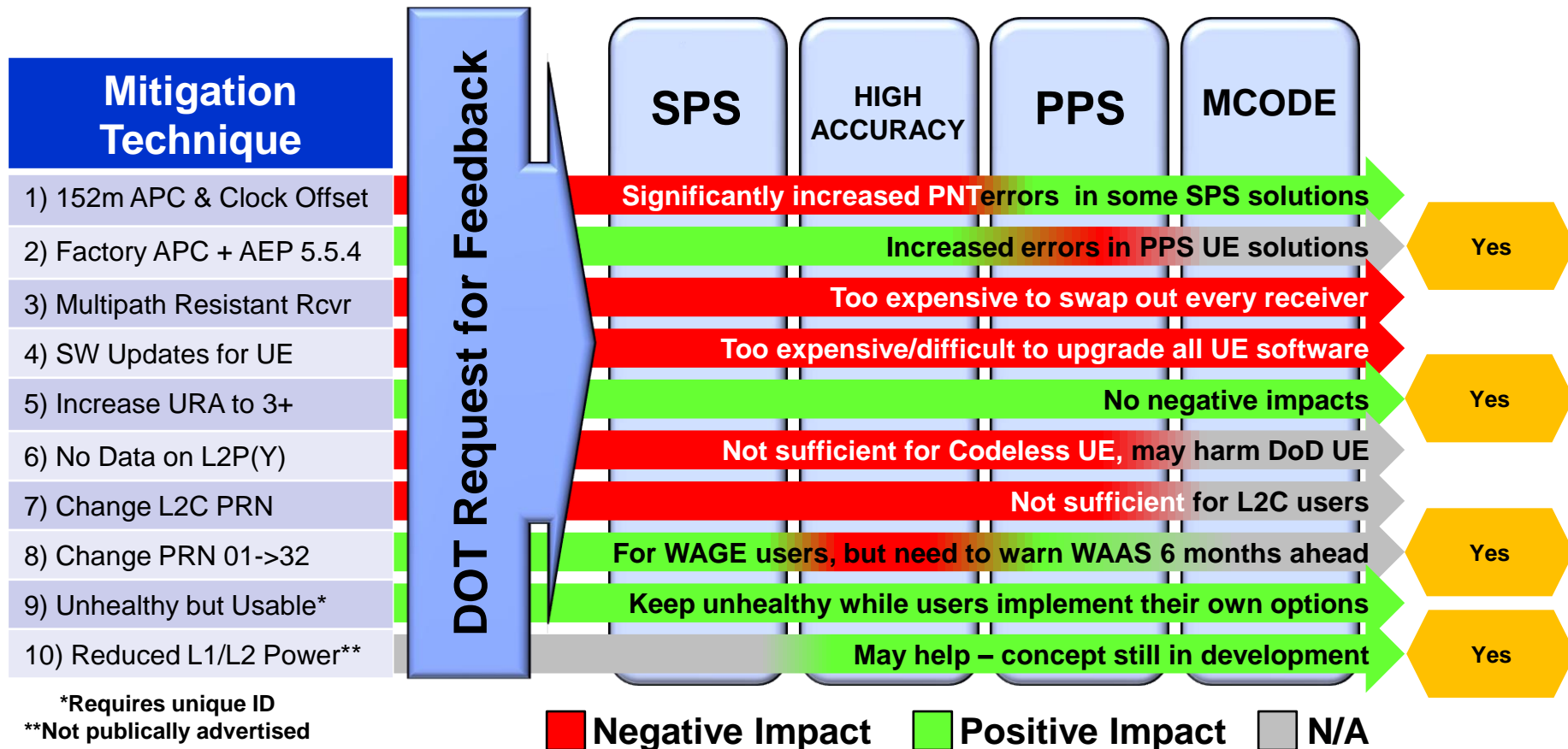2009/04/06 00:00 to 2009/04/08 18:15
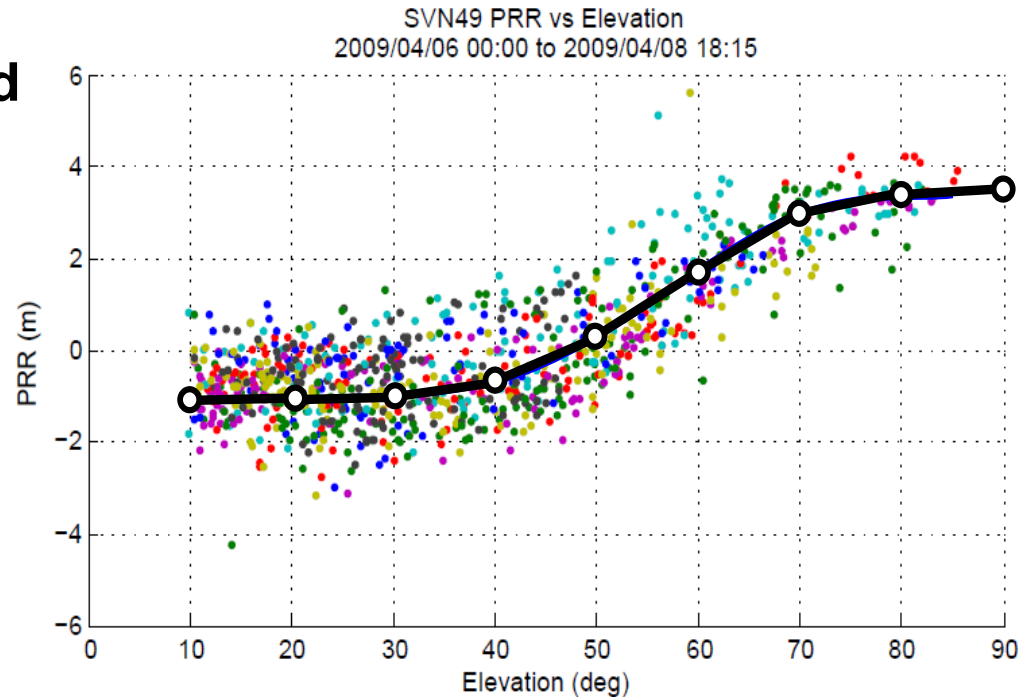
SVN 49 Status

- **9 initial mitigations to reduce adverse impact to users considered**

- **Completed International Review of first 9 mitigation techniques**
  - Conducted telecons with vendors, users, experts and media
  - No single solution identified which solves all issues for all users

- **New mitigation technique (#10) under investigation**
  - Will require testing with SVN 49 to observe & directly measure improvement
  - May reduce error to all or some users
  - Test plan under development, possible test late 2010 or early 2011
  - SVN 49 will remain unhealthy during this test

- **Simulation scenario of SVN 49 distorted signal validated**
  - Working now with simulator vendor to make scenario available to the public
  - Team writing a paper for dissemination at next ION

Striving to Maximize Usefulness of SVN 49

Response of stakeholders

Mitigation Technique	DOT Request for Feedback	SPS	HIGH ACCURACY	PPS	MCODE	
1) 152m APC & Clock Offset		Significantly increased PNT errors in some SPS solutions				
2) Factory APC + AEP 5.5.4		Increased errors in PPS UE solutions				Yes
3) Multipath Resistant Rcvr		Too expensive to swap out every receiver				
4) SW Updates for UE		Too expensive/difficult to upgrade all UE software				
5) Increase URA to 3+		No negative impacts				Yes
6) No Data on L2P(Y)		Not sufficient for Codeless UE, may harm DoD UE				
7) Change L2C PRN		Not sufficient for L2C users				
8) Change PRN 01->32		For WAGE users, but need to warn WAAS 6 months ahead				Yes
9) Unhealthy but Usable*		Keep unhealthy while users implement their own options				
10) Reduced L1/L2 Power**		May help – concept still in development				Yes

*Requires unique ID
**Not publically advertised

Negative Impact ■   **Positive Impact** ■   **N/A** ■

GPSW is pursuing mitigations 2, 5, 8, and 10
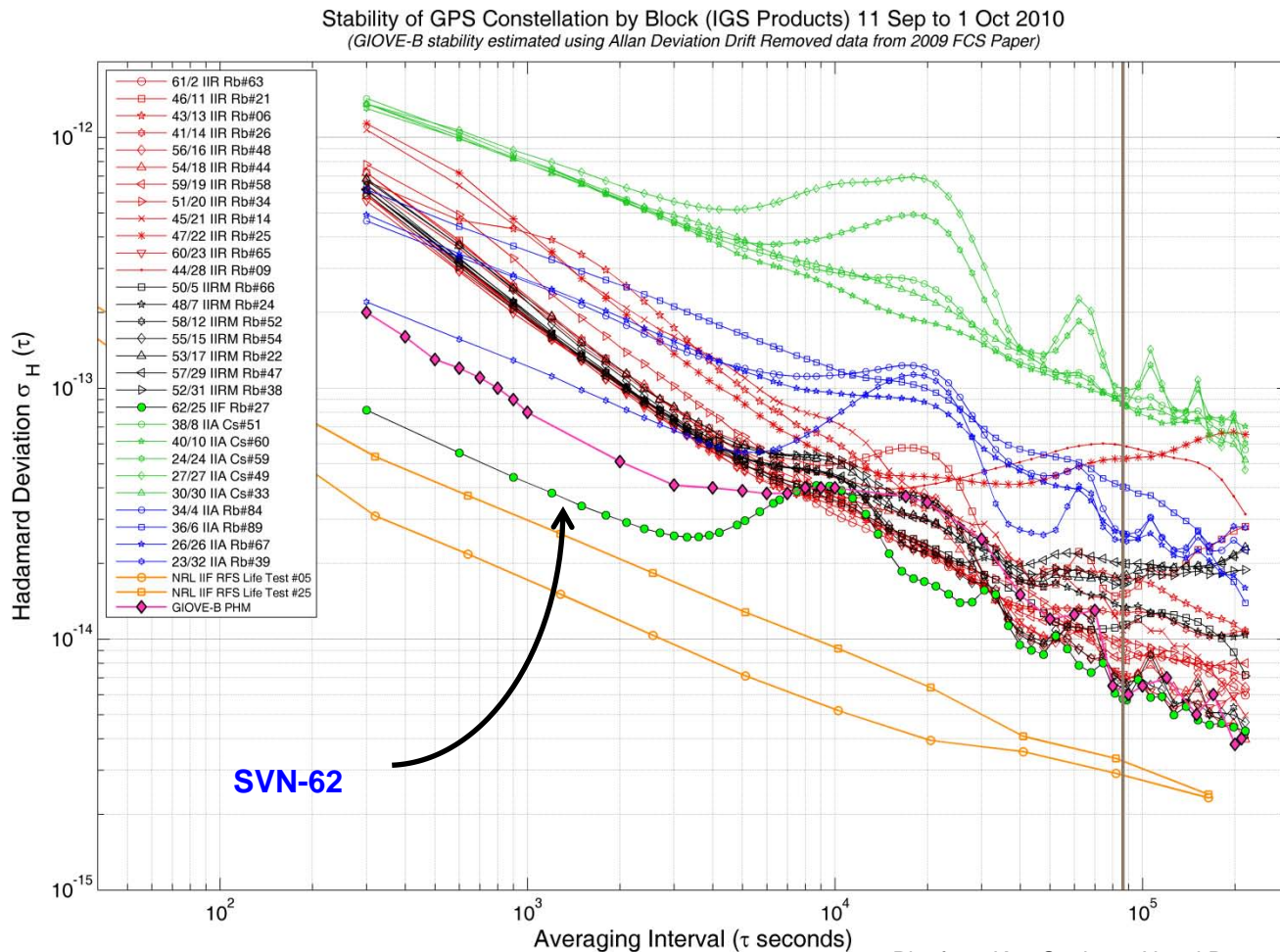*Receiver vendors are encouraged to pursue 3 and 4*

- **IIF-1 is SVN 62 and PRN-25**
  - Launched May 2010, set healthy Aug 2010

- **Three SVN-62 signals characteristics have generated interest recently**
  - Clock performance
  - L5 phase variation
  - L5 digital distortion

- **L1 C/A, L1 P(Y), L2 P(Y) signals meet specs**
  - Comply with the ISs/ICDs and the Performance Standards (PSs)

- **L2C, L5, M-Code will meet specs with OCX**
  - OCX required for CNAV or MNAV data messages
  - Modernized signal PSs will be published as signal IOCs approach
 - No SVN-62/PRN-25 technical problems to prevent meeting specs

- **Rubidium clock is among best ever seen**
  - Stability of "apparent clock" affected by orbit-period harmonic errors
    - Similar effect seen with other high-stability satellite clocks

Stability of GPS Constellation by Block (IGS Products) 11 Sep to 1 Oct 2010
(GIOVE-B stability estimated using Allan Deviation Drift Removed data from 2009 FCS Paper)

Plot from Ken Senior at Naval Research Laboratory

- **L5 carrier not as coherent as L1 and L2**
  - L1/L2 carriers & all PRN codes are coherent with each other
  - L5 carrier is coherent with other signals within ±0.06 m worst case
- **Well within related GPS III specification value of ±6.1 m worst case (FAA)**
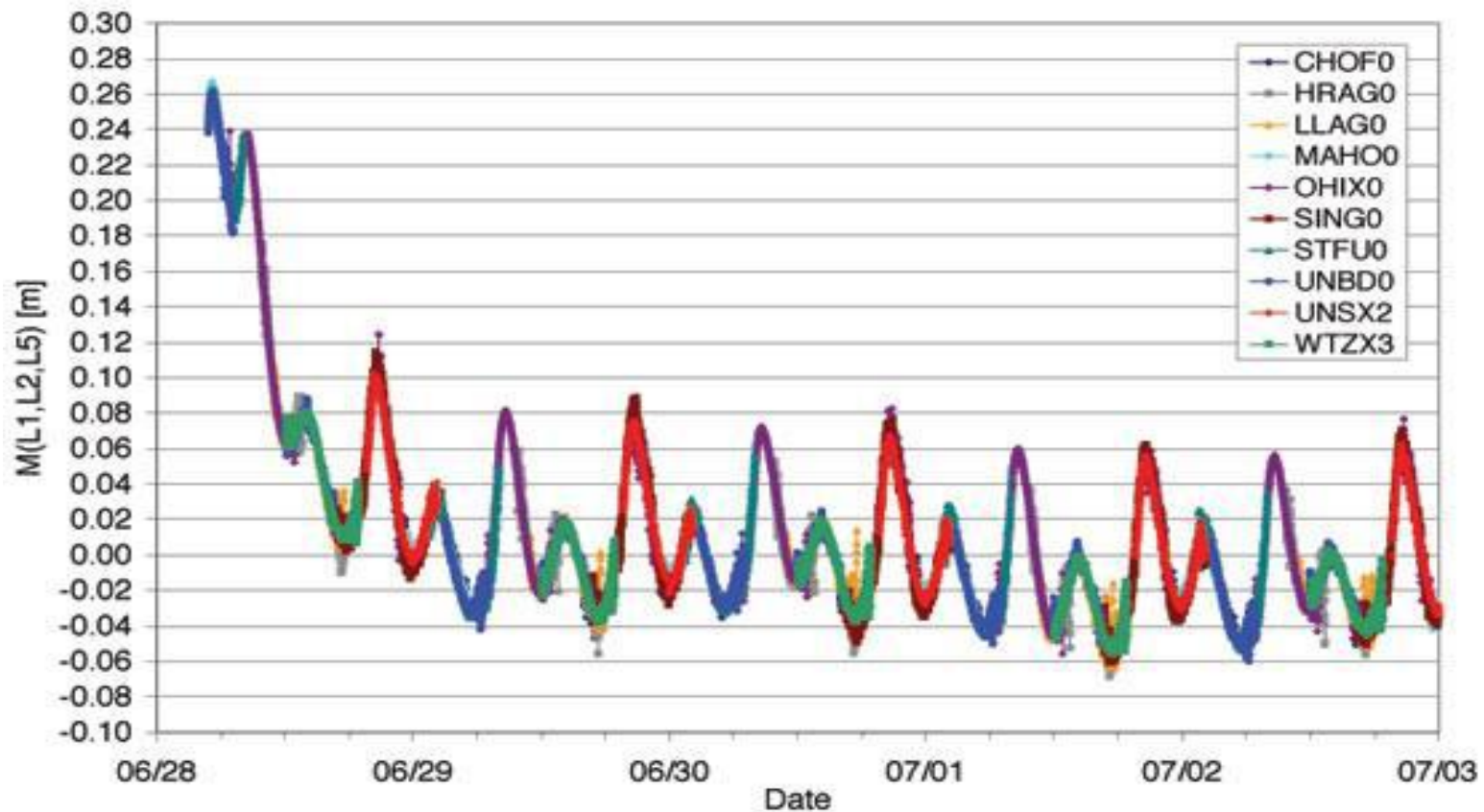
Plot from Montenbruck, Hauschild, Steigenberger, and Langley; "Three's the Challenge"; published by *GPS World*, 20 July 2010

- **L5 codes are slightly more distorted than usual**
  - The benchmark for "usual" is L1 C/A-code
  - L5 codes have a slight Δ values (+1 vs -1 chip duration mismatch)
- **Well within related GPS III specification value of 10 nsec worst case (FAA)**
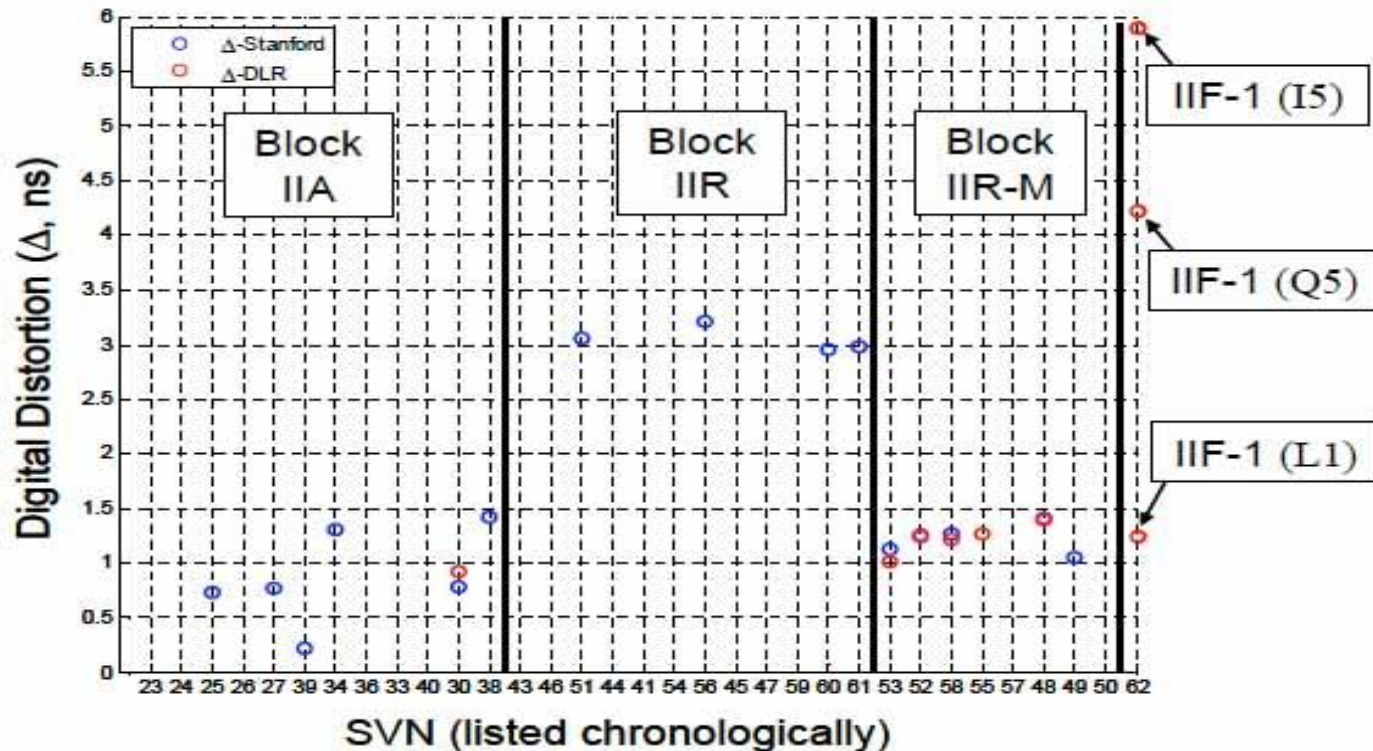
Plot from Phelts, Gao, Wong, Heng, Walter, Enge, Erker, Thoelert, and Meurer; "Aviation Grade"; published by *Inside GNSS*, July/August 2010