International Committee on Global Navigation Satellite Systems

GPS/GNSS

What is it?

How Does it Work?

What are its Applications?

Historic Navigation

- Reference points in the sky used for navigation
  - The Sun
  - The Pole Star / North Star
  - Southern Cross

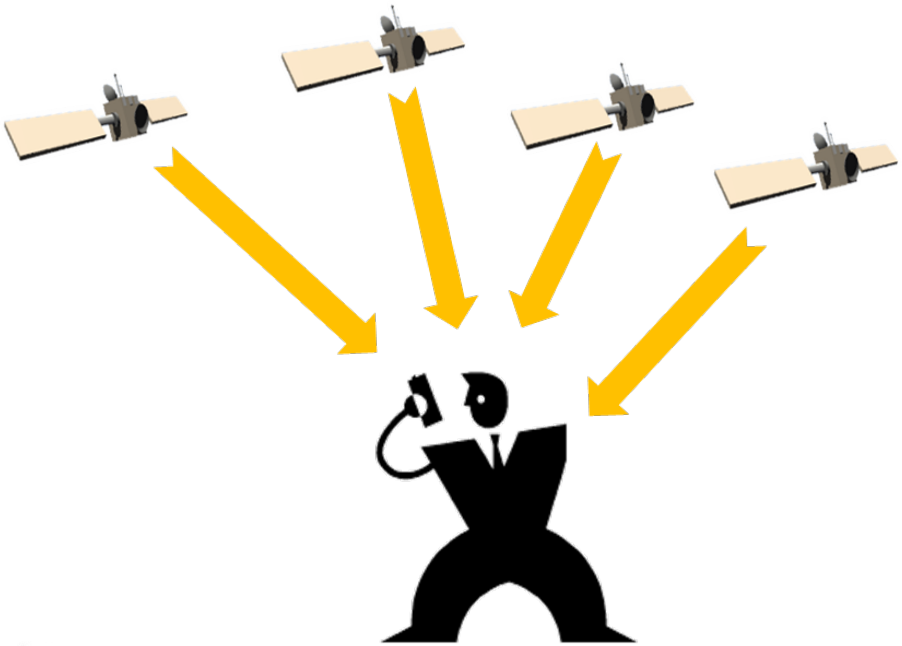
- Gives Direction, but not position

- Add a sextant to give latitude

- And a clock to give longitude

GNSS Principles

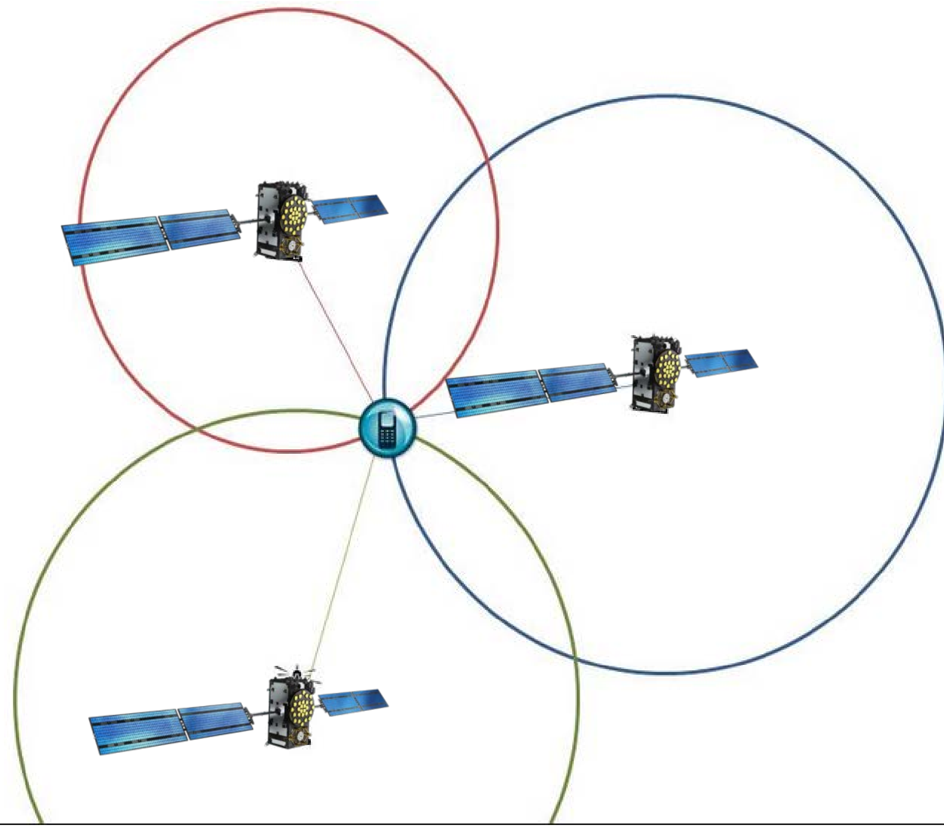
- GNSS satellites in the sky are the new reference points
- If my GNSS receiver "sees" 4 or more satellites, it can compute my position
  – "see" means track and process navigation signals



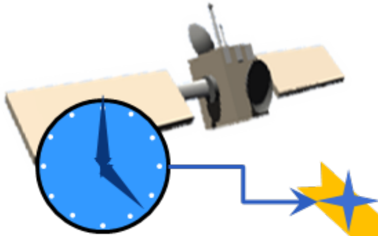
ICG International Committee on Global Navigation Satellite Systems

Satellites as Accurate Reference Points

- GNSS signals contain information about the satellites' positions
  - very accurate reference points
- Measure the distance from the satellites to the receiver
- Knowing at least three distances from three reference points gives position



How do you measure distance?



speed = distance / time

⇨ **distance = speed x time**

satellite signals contain 'time stamps'

time = $t_{sent} - t_{received}$

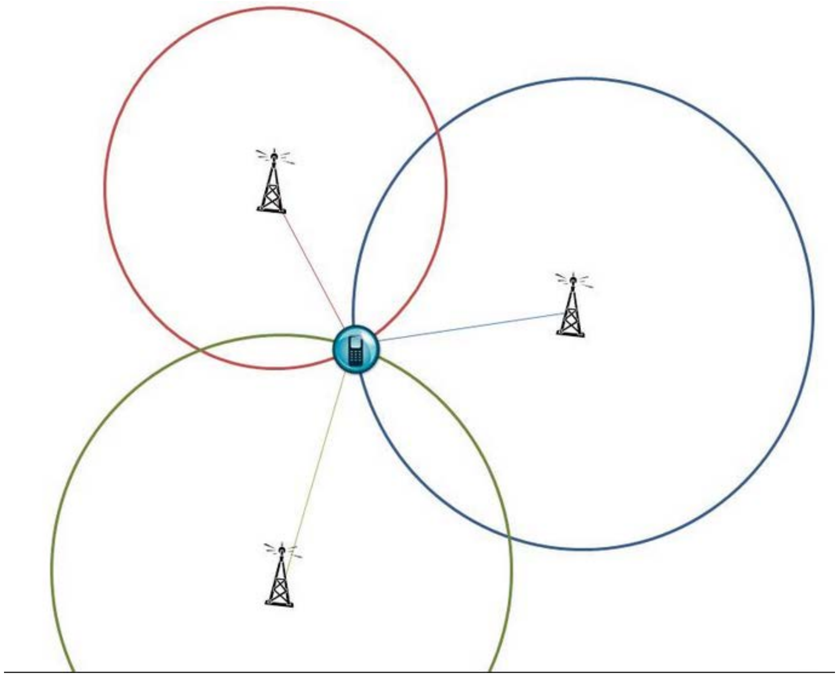
radio waves travel

at light speed **"c"**

- 300,000km in 1 second
- 300km in 1ms (1/1000th)
- 300m in 1μs (1/millionth)
- 300mm in 1ns

Compute position

distance = speed x time



- **speed** = 3×10^8 m/s
- **time** = $t_{sent} - t_{received}$

- but, receiver time not accurately known
- so the time stamp from a fourth satellite is measured
- compensates for the missing receiver time

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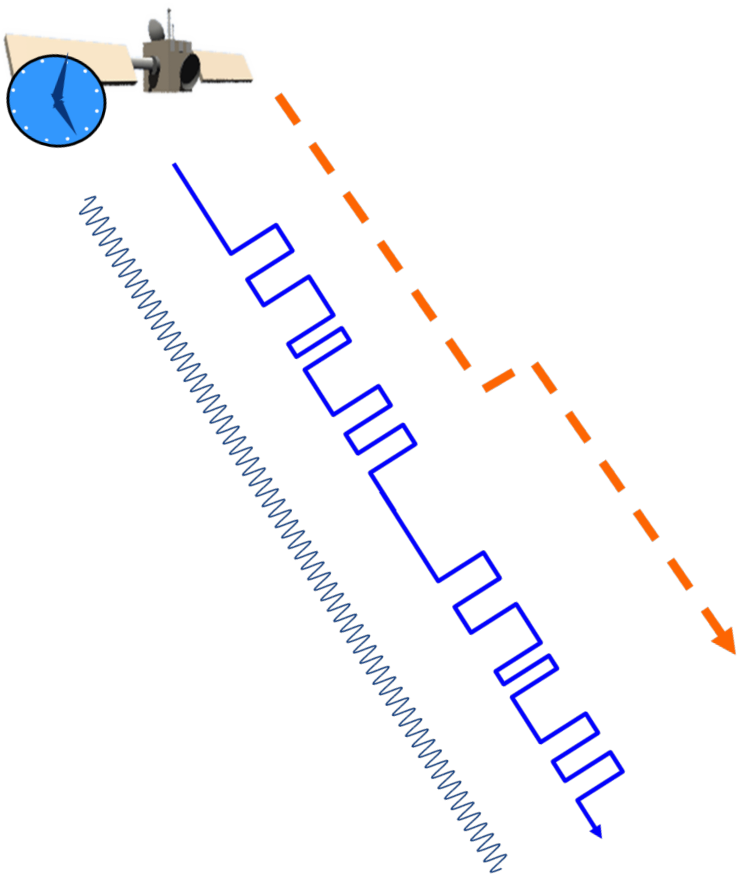
Example GNSS Signal



- radio frequency at "L-band"
  - typically 1575MHz
- at satellite: signal energy spread by a code
- at receiver: spread signal energy is unlocked and refocused
  - "code gain"
- allows simple antennas to receive low power signals

- and to share the frequency with other satellites/systems

Position relative to?

- A position is pointless without having a ground reference
- A world reference is used, eg WGS84
  - World Geodetic System 1984
- Allows position fix to be placed on a World grid
- Maps can be referenced to the same grid
- you can determine where you are on a map

What is GNSS used for?

PNT

- Positioning… surveying and mapping
  - location based services
  - air traffic management
  - search and rescue
- Navigation… a given. cars, ships, cranes
  - remember GNSS gives position, you still need reliable/up-to-date maps and routing software
- Timing?... most large networks synchronised
  - telecoms
  - electricity distribution
  - banking… microseconds matter for transactions!

What about?

- Monitoring sea/lake/snow levels
  - uses GNSS reflections seen into a fixed receiver
- Atmospheric measurements
  - GNSS signals change as they pass through atmosphere: air quality, gaseous content, etc
- Space weather monitoring
  - measuring changes in the ionosphere
- Soil and vegetation moisture measurements
- Volcanic plume density measurements
  - atmospheric ash uncertainty after eruptions
- Sea surface roughness, wind direction and more
- Earthquake/tsunami monitoring….

etc, etc……

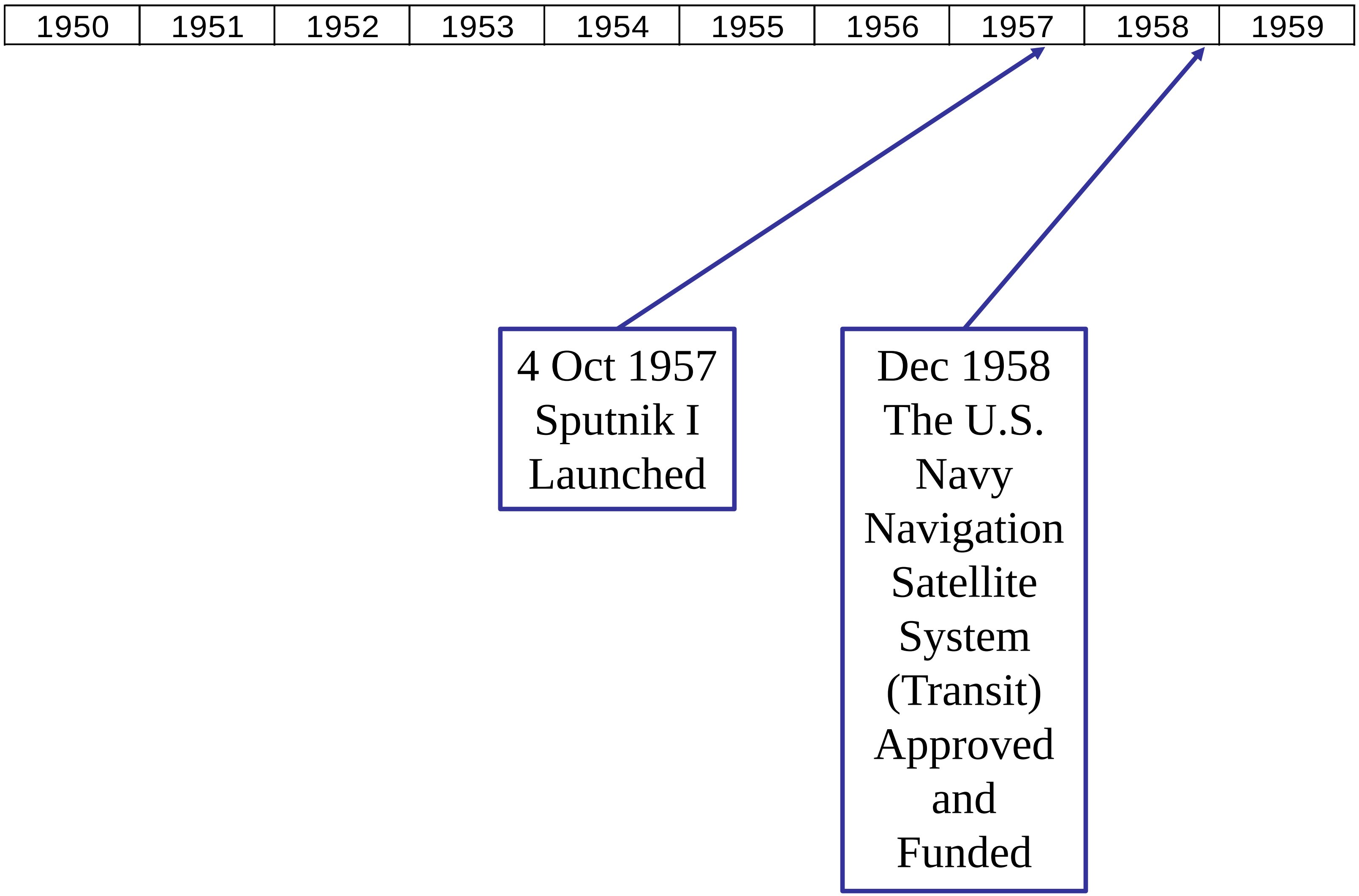
Thank You

Questions?

International Committee on
Global Navigation Satellite Systems

GNSS History

Satellite Navigation in the 1950s



Satellite Navigation in the 1960s (1 of 3)

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969

13 April 1960
First Successful Transit Experimental Satellite (1B)

5 Dec 1963
First Operational Satellite

Jan 1964
Transit Became Operational

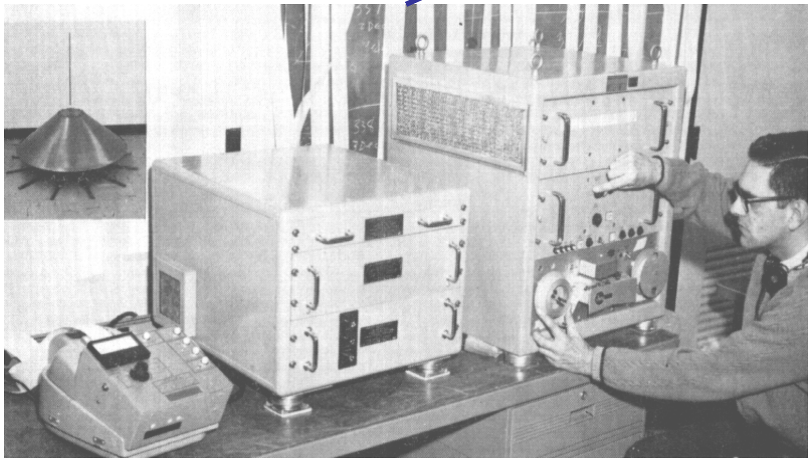
Other Successful Experimental Satellites:
2A, 22 Jun 1960
3B, 21 Feb 1961
4A, 29 Jun 1961
4B, 15 Nov 1961

July 1967
Transit Released for Commercial Use
- - - -
Establishing U.S. Dual Use SatNav Policy

Operational Transit Satellite

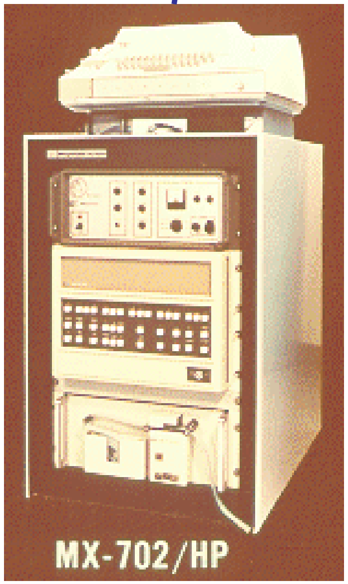
Satellite Navigation in the 1960s (2 of 3)

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969



1964
World's First Surface Ship
Satellite Navigator
AN/SRN-9 (XN-5)

1968
World's First
Portable Satellite
Doppler Geodetic
Surveyor
AN/PRR-14
Geoceiver

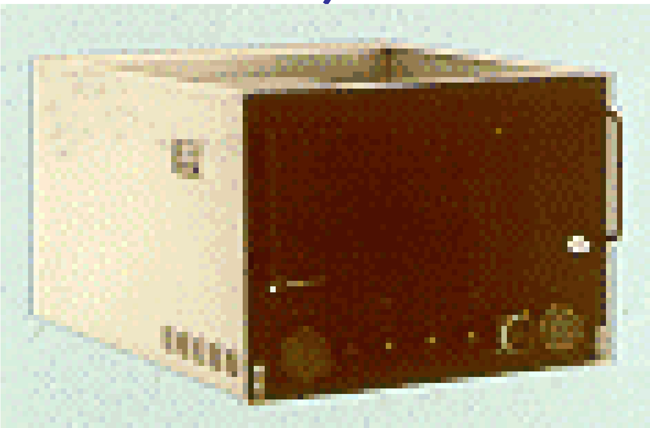


1969
World's First
Commercial
Oceanographic
Navigator

Satellite Navigation in the 1960s (3 of 3)

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969

1969
First Steps Toward GPS;
Air Force 621B Program;
World's First Spread Spectrum
Navigation Receiver, MX-450

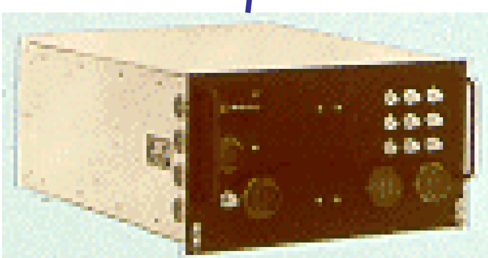


Satellite Navigation in the 1970s

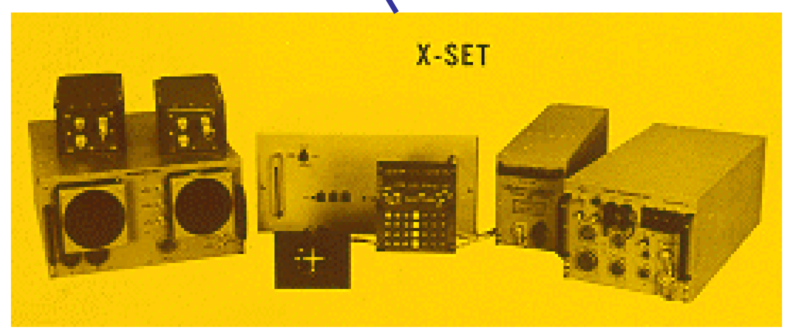
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979

April 1973
Formation of the GPS Joint Program Office (JPO)

1978 GPS Launches
22 Feb, 13 May,
7 Oct, 11 Dec

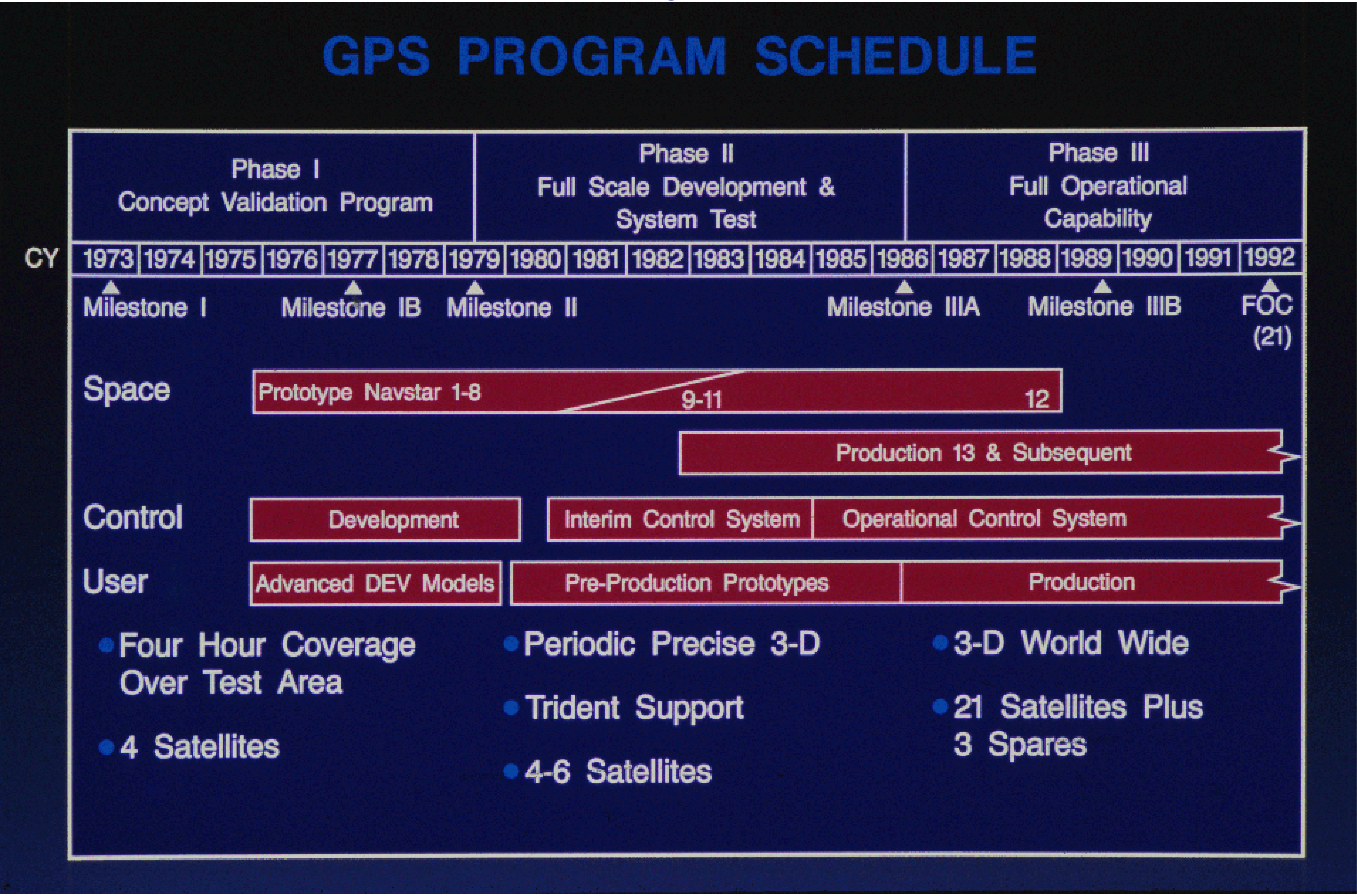


1971
First Timation Receiver for the Naval Research Lab (NRL)

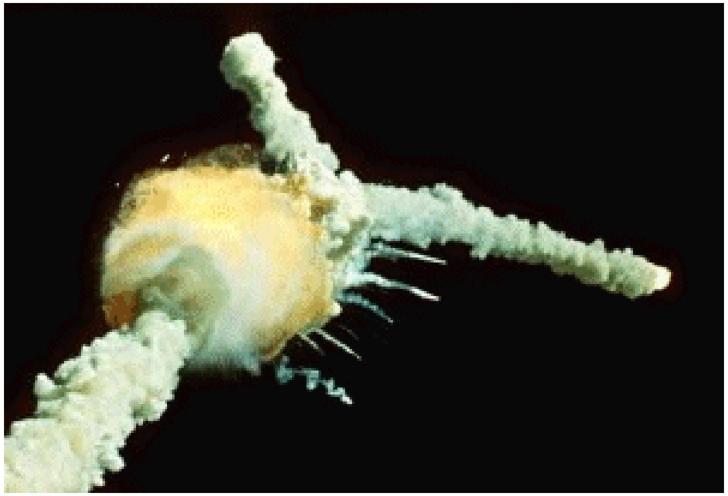


1975
First Concept Validation GPS Navigator, the GPS X-Set

Original


GPS PROGRAM SCHEDULE
Phase I
Concept Validation Program
Phase II
Full Scale Development &
System Test
Phase III
Full Operational
Capability
CY
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992
Milestone I
Milestone IB
Milestone II
Milestone IIIA
Milestone IIIB
FOC
(21)
Space
Prototype Navstar 1-8
9-11
12
Production 13 & Subsequent
Control
Development
Interim Control System
Operational Control System
User
Advanced DEV Models
Pre-Production Prototypes
Production
• Four Hour Coverage Over Test Area
• 4 Satellites
• Periodic Precise 3-D
• Trident Support
• 4-6 Satellites
• 3-D World Wide
• 21 Satellites Plus 3 Spares

GPS Launch Plans



National policy was to launch all operational GPS satellites with the space shuttle

The Atlas Booster launched all Block I GPS Satellites

The January 28, 1986 Challenger disaster forced a change

Satellite Navigation in the 1980s

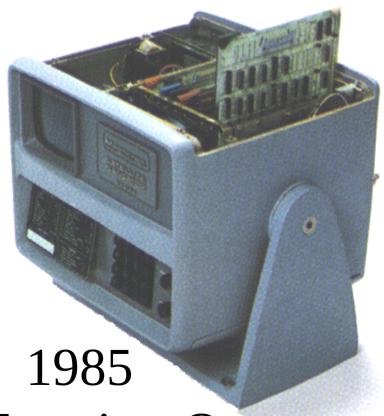
1980	1981	1982	1983	1984	1985	1986	1987	1988	1989

9 Oct ‘85
Last Block I
Launch

28 Jan ‘86
Challenger
Disaster

14 Feb ‘89
Launches
Resume

1984
Commercial 5
Channel GPS
Navigator

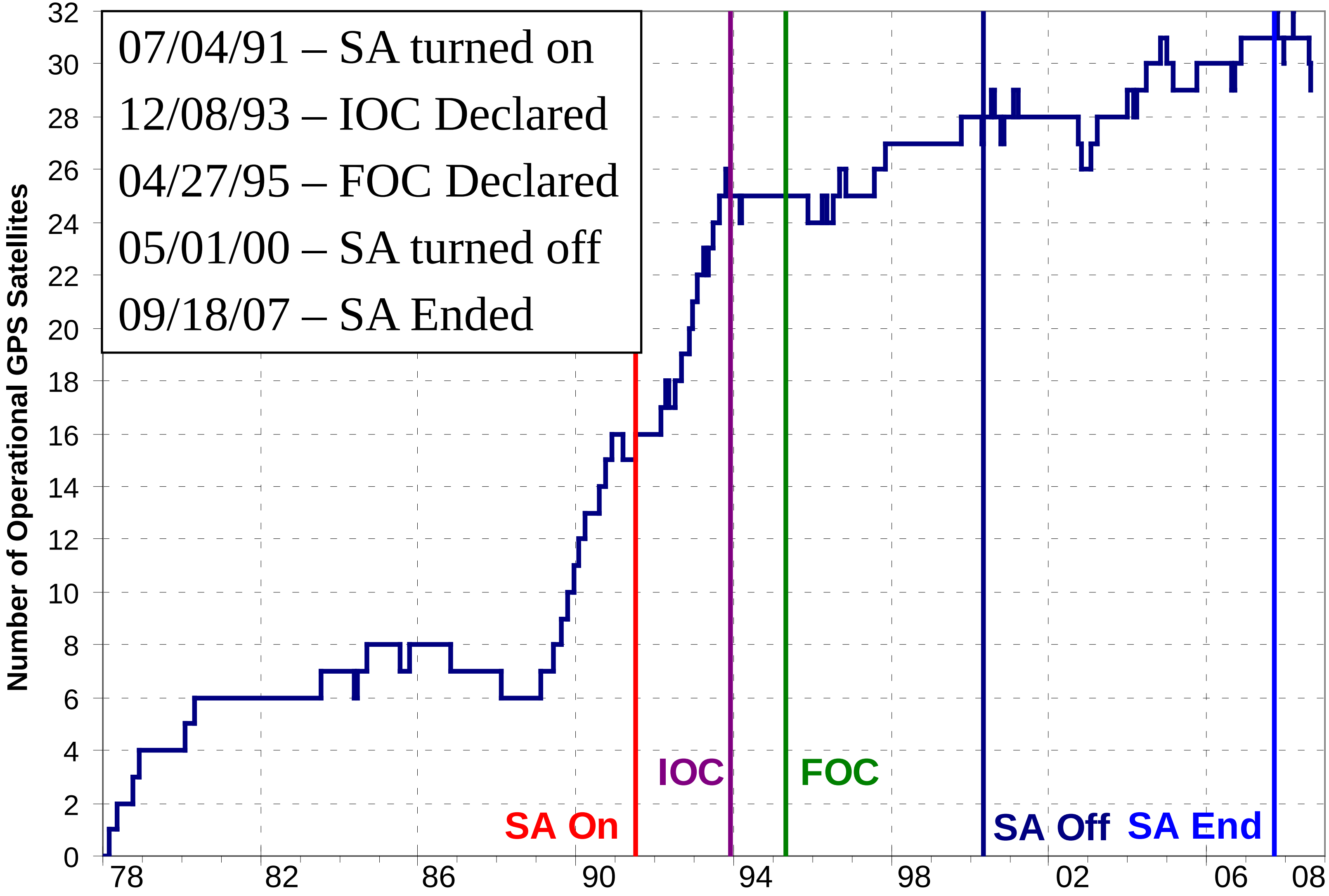


1985
GPS + Transit + Omega

1986
6 Channel GPS
Navigator

1986
WM101 GPS Satellite
Surveying Set

GPS Selective Availability, IOC, and FOC



Satellite Navigation in the 1990s

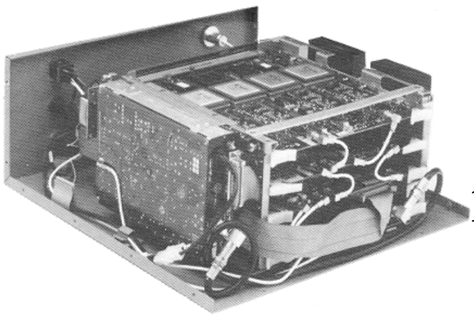
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999

4 Apr '91
SA Turned On

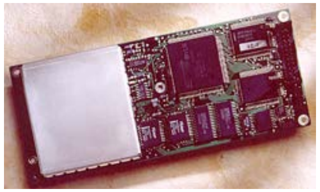
8 Dec '93
GPS IOC

27 Apr '95
GPS FOC

1996 Professional Marine DGPS Navigator



1990 GPS/GLONASS Navigator



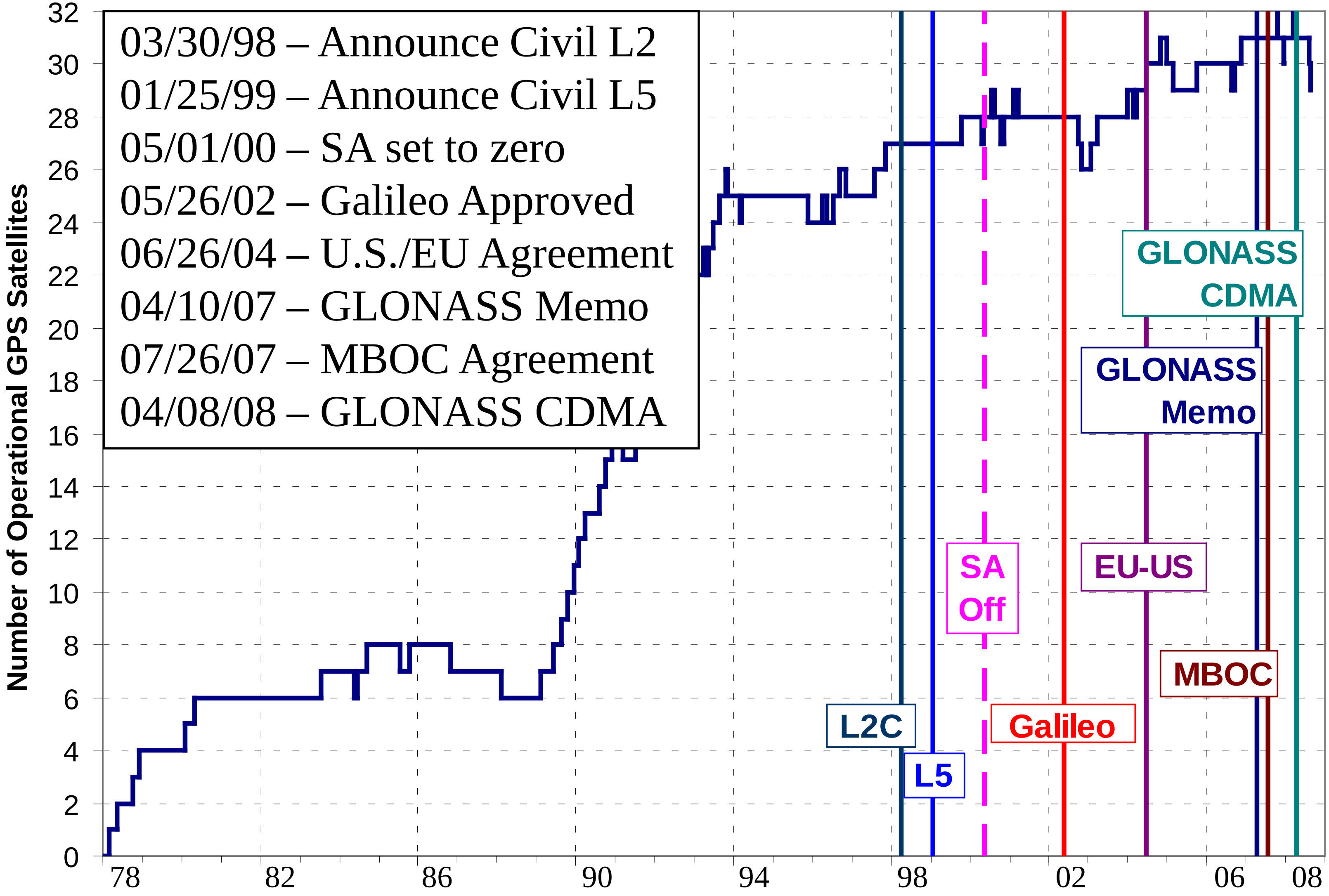
1991 6 Channel GPS Engine

26 Dec '91
Dissolution of the Soviet Union Enacted

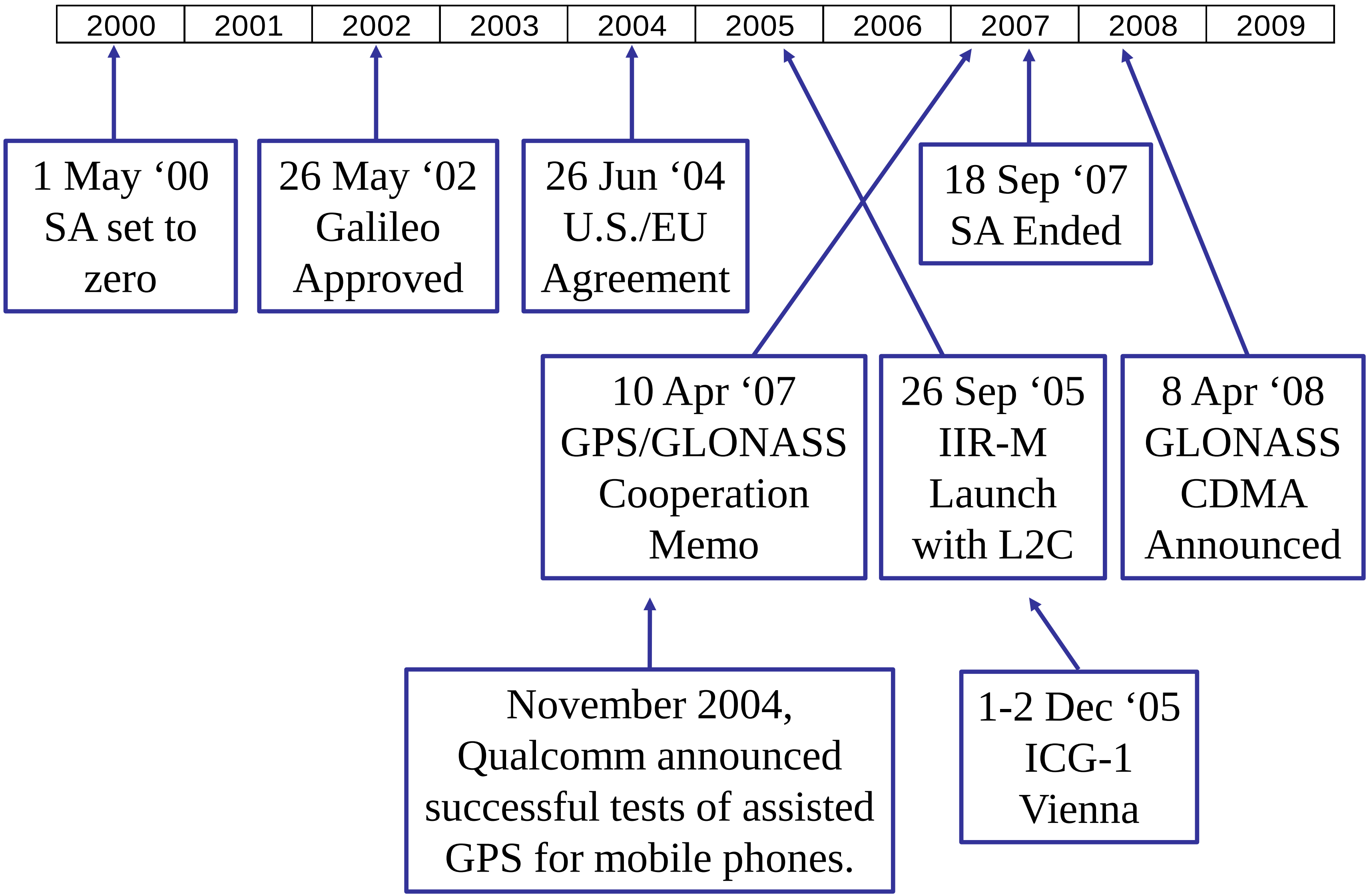
1991 Compact GPS Surveyor

1997 Machine Control, 10 Hz, 30 ms, 1 cm

Modernization and GNSS Initiatives



Satellite Navigation in the 2000s



Satellite Navigation in the 2010s

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019

28 May '10
IIF Launch
with L5

11 Sep '10
QZSS
Launch

21 Oct '11
Operational
Galileo
Launch

2-6 Oct '15
ICG-10
Boulder, CO

6-11 Nov '16
ICG-11
Sochi, Russia

2-7 Dec '17
ICG-12
Kyoto, Japan

- Approaching a new GNSS Golden Era
  - Many more satellites (GPS, Galileo, BeiDou, QZSS) with L1 and L5 interoperable signals
  - Much better availability, accuracy, integrity, e.g., enabling ARAIM
- Anticipating CDMA signals from GLONASS
- What does the future hold?

Who Anticipated GPS in Cell Phones?

More than a Billion Cell Phone GPS Users

- Sparked by the E911 requirement
- Use of Location Based Services (LBS) is exploding
- Improved by Assisted GPS (A-GPS)
  - Better accuracy
  - Location in seconds
  - Turn-by-turn navigation

Who Anticipated Precision Agriculture?

- One to 10 cm accuracy
- Far better productivity, efficiency, and protection of the environment
- Enabled, e.g., by MSS signals for the John Deere StarFire Service and several others

Automatic Steering

Automatic Spray Control

Thank You

Questions?

GPS Program

Status

Future Plans

Augmentations

Applications

GNSS: A Global Navigation Satellite System of Systems

- Global Constellations
  - **GPS (24+3)**
  - GLONASS (24+)
  - GALILEO (24+3)
  - BDS/BEIDOU (27+3 IGSO + 5 GEO)

- Regional Constellations
  - QZSS (4+3)
  - IRNSS/NAVIC (7)

- Satellite-Based Augmentations
  - **WAAS (3)**
  - MSAS (2)
  - EGNOS (3)
  - GAGAN (3)
  - SDCM (3)
  - BDSBAS (3)
  - KASS (2)

GPS Economic Benefits Assessment
(2013 -- U.S. Only)

Application	Range of Benefits ($B)	Mid-Range Benefits ($B)
Precision agriculture: grain	10.0–17.7	13.7
Construction: earthmoving w/ machine guidance	2.2–7.7	5.0
Surveying	9.8–13.4	11.6
Air transportation	0.119–0.168	0.144
Rail transportation: positive train control	0.010–0.100	0.055
Maritime transportation: private sector use of nautical charts and related information	0.106–0.263	0.185
Road: fleet vehicle connected telematics	7.6–16.3	11.9
Road: consumer and other non-fleet vehicles	7.3–18.9	13.1
Timing	0.025–0.063	0.044
TOTAL	37.1–74.5	55.7

U.S. National Space Policy

Space-Based PNT Guideline: Maintain leadership in the service, provision, and use of GNSS

- Provide civil GPS services, free of direct user charges
  - Available on a continuous, worldwide basis
  - Maintain constellation consistent with published performance standards and interface specifications
  - Foreign PNT services may be used to complement services from GPS
- Encourage global compatibility and interoperability with GPS
- Promote transparency in civil service provision
- Enable market access to industry
- Support international activities to detect and mitigate harmful interference

GPS Constellation Status

35 Total Satellites / 31 Operational (Set Healthy)
(Baseline Constellation: 24)

Four Generations of Operational Satellites

- Block IIA - 3 Residual
  - 7.5 year design life
  - Launched 1990 to 1997
- Block IIR - 12 Operational
  - 7.5 year design life (oldest operational satellite is 19 years old)
  - Launched 1997 to 2004
- Block IIR-M - 7 Operational, 1 Residual
  - 7.5 year design life
  - Launched 2005 to 2009
  - Added 2nd civil navigation signal (L2C)
- Block IIF - 12 Operational
  - 12 year design life
  - Launched 2010 to 2016
  - Added 3rd civil navigation signal (L5)


Block IIA Satellite – Designed & Built by Rockwell International


Block IIR/IIR-M Satellite – Designed & Built by Lockheed Martin


Block IIF Satellite – Designed & Built by Boeing

GPS III: Newest Block of GPS Satellites

- 4 civil signals: L1 C/A, L1C, L2C, L5
  - First satellites to broadcast common L1C signal
- 4 military signals: L1/L2 P(Y), L1/L2M
- 3 improved Rubidium atomic clocks
- Better User Range Error than IIF Satellites
- Increased availability
- Increased integrity
- 15 year design life

First GPS III Launch Expected Later in 2018

GPS Ground Segment

- Current Operational Control Segment (OCS)
  - Flying GPS constellation using Architecture Evolution Plan (AEP) and Launch and Early Orbit, Anomaly, and Disposal Operations (LADO) software capabilities
  - Increasing Cyber security enhancements

Monitor Station

- Next Generation Operational Control System (OCX)
  - Modernized command and control system - replaces legacy system and adds modern features
  - Modern civil signal monitoring and improved PNT performance
  - Robust cyber security infrastructure
  - New capabilities including civil signal performance monitoring capability

Ground Antenna

Modernized GPS Civil Signals

- Second civil signal "L2C"
  - Designed to meet commercial needs
  - Broadcast since 2005
  - Currently 19 satellites broadcasting L2C

- Third civil signal "L5"
  - Meets transportation safety of life requirements
  - Uses Aeronautical Radio Navigation Service band
  - Enables triple-frequency positioning techniques
  - Currently 12 satellites broadcasting L5

- Fourth civil signal "L1C"
  - Designed for GNSS interoperability
  - Specification developed in cooperation with industry
  - Improved performance in challenged environments
  - Launches with GPS III in 2018

Continuous Broadcast of the new civil navigation "CNAV" message on L2C and L5 began April 28, 2014

GPS SIS Performance Scoreboard

Wide Area Augmentation System (WAAS)

- Satellite Based Augmentation System (SBAS)
- Designed for aviation use, but available and used by many GPS users today
- Localizer Performance with Vertical Guidance (LPV)-200 approach is comparable to ILS Category I
- Provides the capability for increased availability and accuracy in position reporting, allowing more time for uniform and high quality air traffic management.
- Provides service for all classes of aircraft in all phases of flight

WAAS/SBAS Aviation Benefits

- Increased Runway Access
- More direct en route flight paths
- New precision approach services
- Reduced and simplified equipment on board aircraft
- Potential elimination of some ground-based navigation aids (NDB, VOR, ILS) can provide a cost saving to air navigation service provider

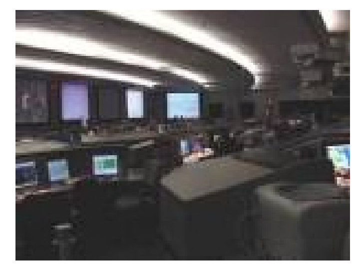
Wide Area Augmentation System (WAAS) Architecture

38 Reference Stations

3 Master Stations

6 Ground Earth Stations

3 Geostationary Satellite Links

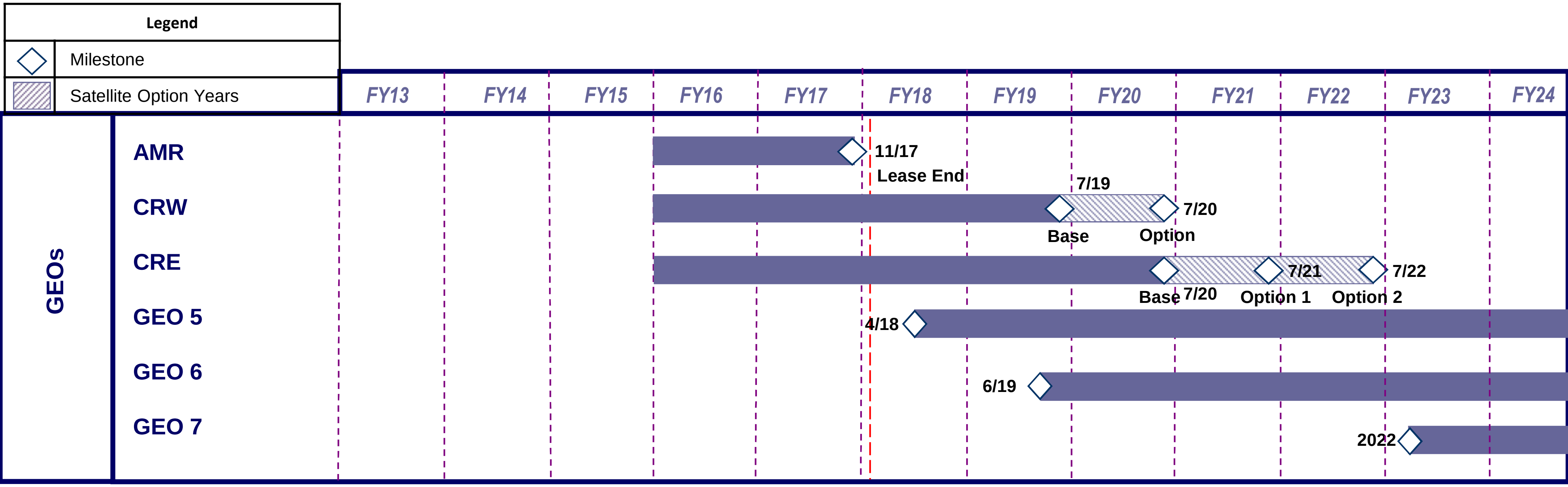


2 Operational Control Centers

GEO Constellation

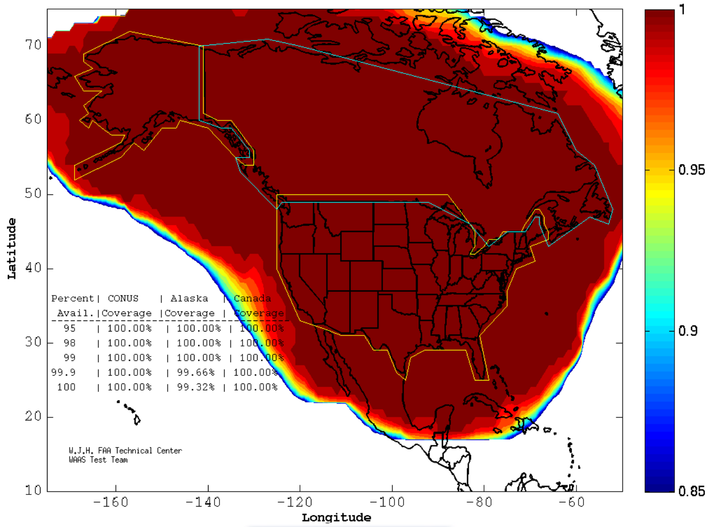
- **GEO 5/6 Satellite Acquisition**
  - GEO 5
    - EUTELSAT 117 West B (ex SatMex 9) satellite
      - Provides full coverage of CONUS and Alaska
    - Integration activities started, expected operational 2018
  - GEO 6
    - Host satellite is SES-15, planned for 129 West
    - In-Orbit Testing completed December 2017
    - Expected Operational in mid-2019

- **GEO 7 Satellite acquisition**
  - Multiple IDIQ contracts awarded September 2017
  - Targeting early 2018 to award task order for delivery of GEO 7 to one vendor

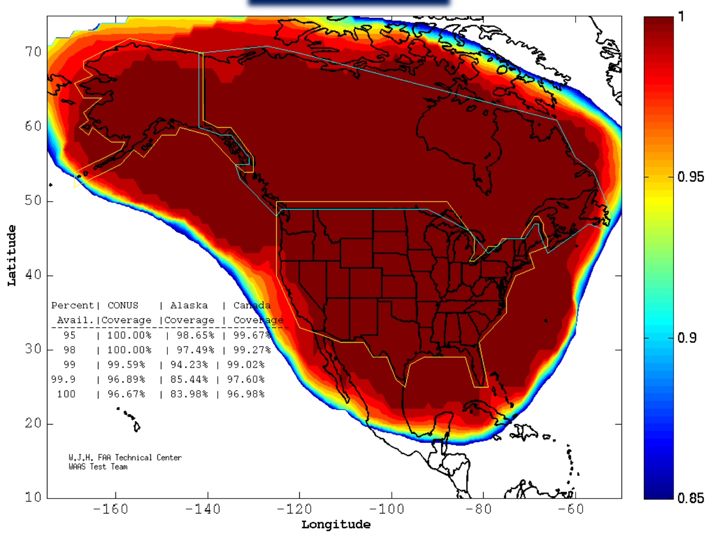


Current WAAS Performance

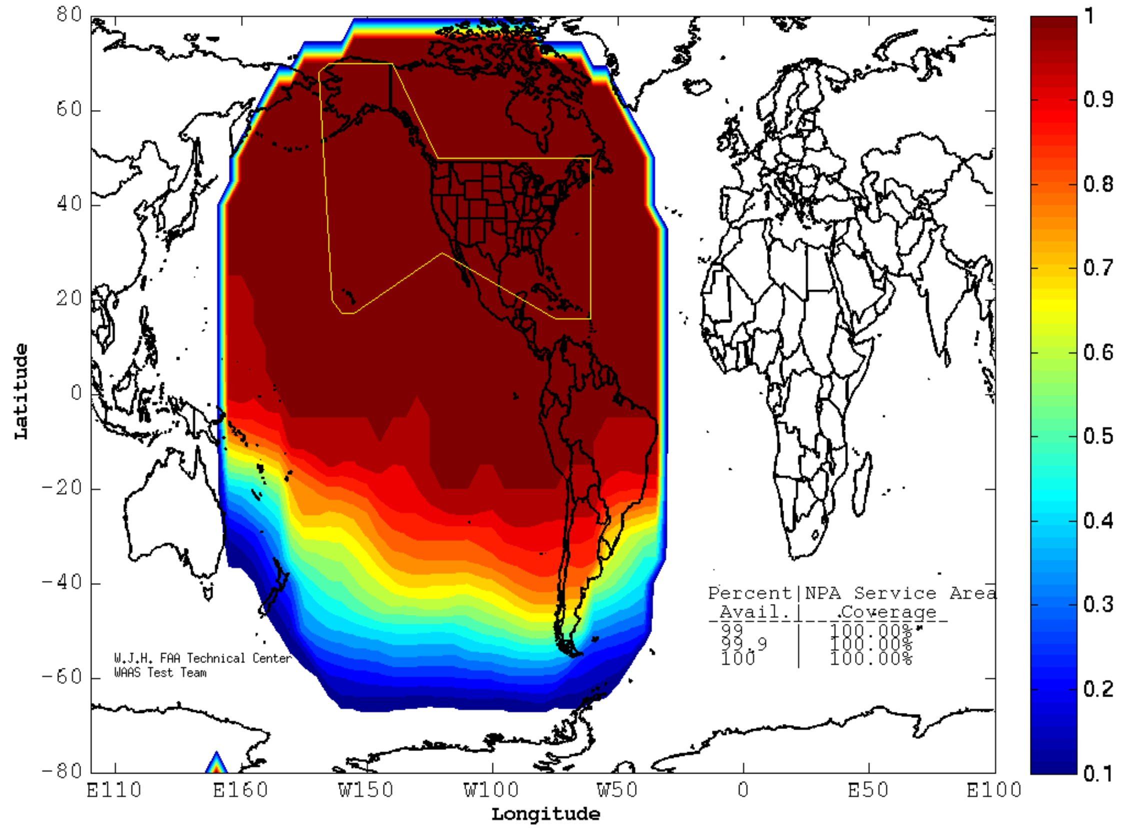
LPV



LPV - 200



RNP 0.3



WAAS Dual Frequency Service

- WAAS has implemented system changes to enable a L1/L5 user
  - Upgraded reference station receivers to receive L5
  - Upgraded communication network to handle additional data (Dec 2017)
  - New safety computer with improved processor performance (Sep 2019)

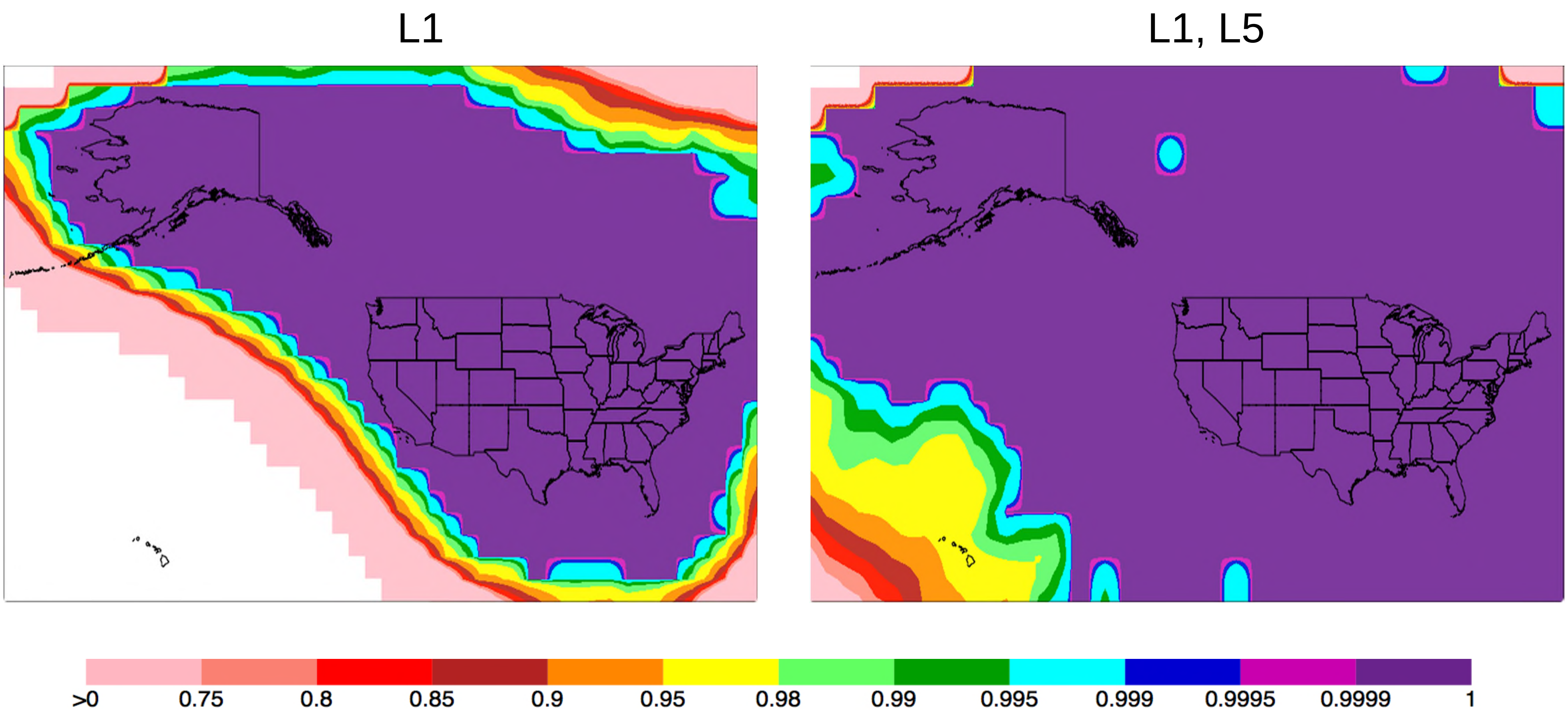
- Minimum Operational Performance Standards (MOPS) and Standards And Recommended Practices (SARPS) requirements development is underway

- Significant additional work needed to implement a dual frequency WAAS Service
  - Preparing for FAA investment decision in 2019

- Have also installed non-operational test receivers at 6 WAAS reference sites to record Galileo data
  - Currently being collected for research purposes only

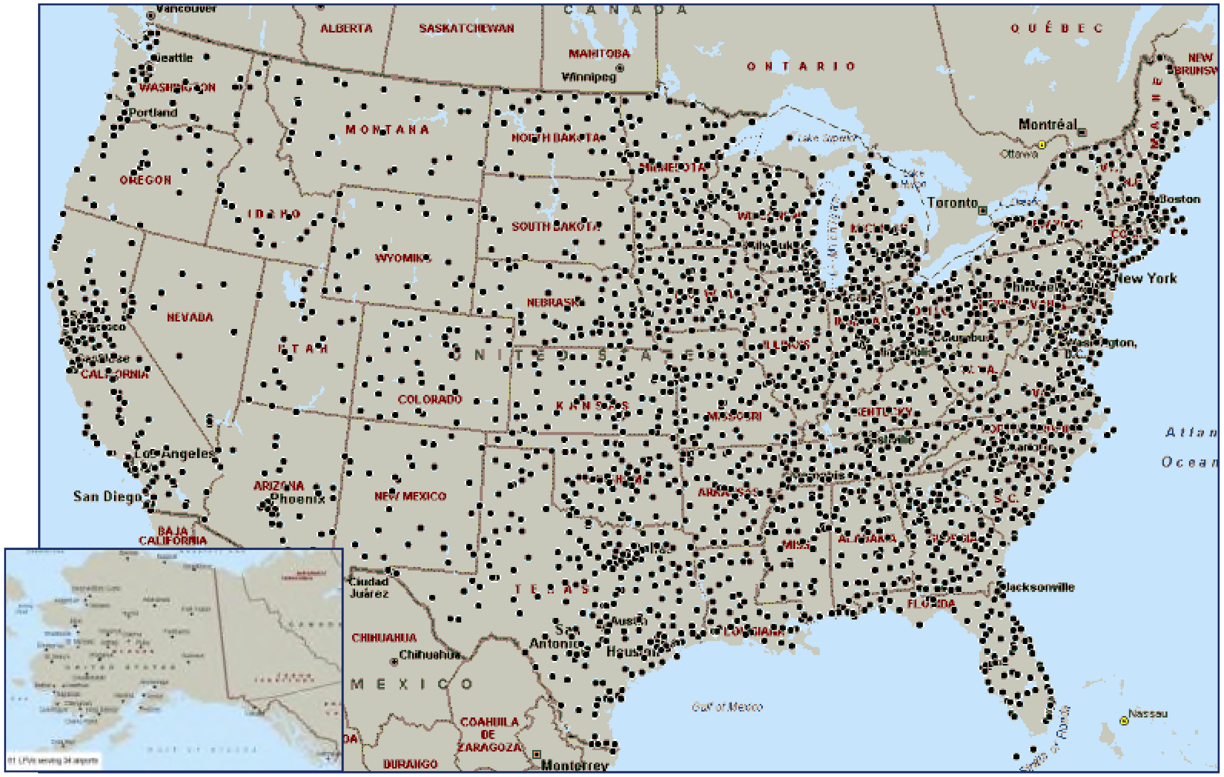
Benefits of Dual Frequency Operations

- Dual frequency L1/L5 service improves availability and continuity



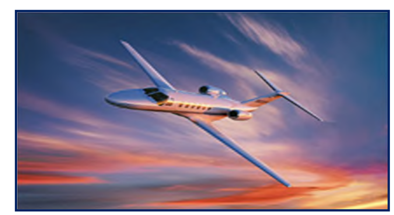
Simulation

Procedures and Users Depending on WAAS



Approach Procedures

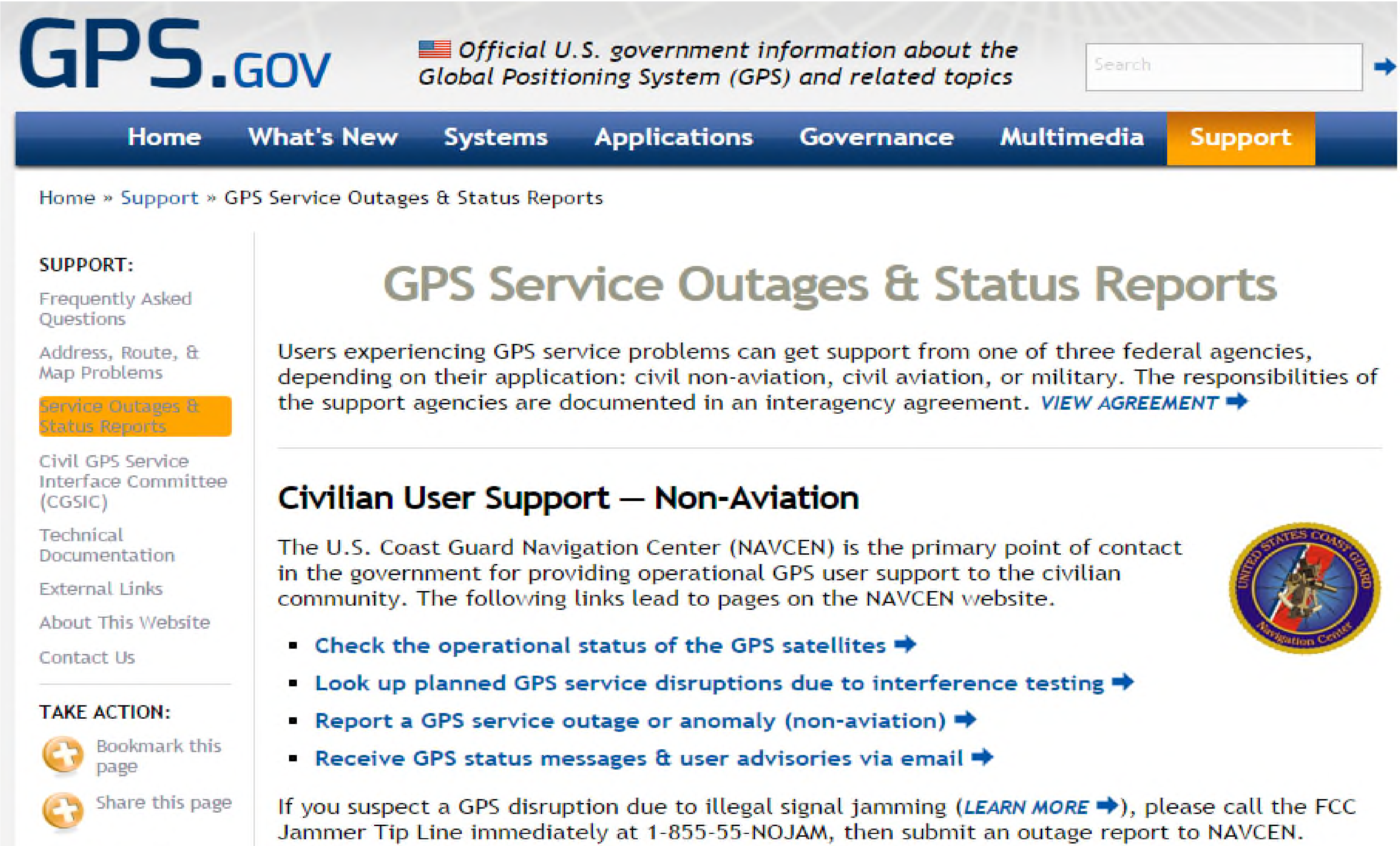
- 4527 WAAS Procedures published (as of Jan 2018)
  - 3872 Localizer Performance with Vertical guidance (LPV) procedures
  - 655 Localizer Performance (LP) procedures



Users

- Over 91,000 WAAS/SBAS equipped aircraft
- All aircraft classes served in all phases of flight
- WAAS/SBAS is enabling technology for FAA NextGen
  - Automatic Dependent Surveillance Broadcast (ADS-B)
  - Performance Based Navigation (PBN)

For Additional Information…


GPS.GOV

Official U.S. government information about the Global Positioning System (GPS) and related topics

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Home » Support » GPS Service Outages & Status Reports

SUPPORT:

- Frequently Asked Questions
- Address, Route, & Map Problems
- Service Outages & Status Reports
- Civil GPS Service Interface Committee (CGSIC)
- Technical Documentation
- External Links
- About This Website
- Contact Us

TAKE ACTION:

- Bookmark this page
- Share this page

GPS Service Outages & Status Reports

Users experiencing GPS service problems can get support from one of three federal agencies, depending on their application: civil non-aviation, civil aviation, or military. The responsibilities of the support agencies are documented in an interagency agreement. *VIEW AGREEMENT*

Civilian User Support — Non-Aviation

The U.S. Coast Guard Navigation Center (NAVCEN) is the primary point of contact in the government for providing operational GPS user support to the civilian community. The following links lead to pages on the NAVCEN website.

- Check the operational status of the GPS satellites
- Look up planned GPS service disruptions due to interference testing
- Report a GPS service outage or anomaly (non-aviation)
- Receive GPS status messages & user advisories via email

If you suspect a GPS disruption due to illegal signal jamming (*LEARN MORE*), please call the FCC Jammer Tip Line immediately at 1-855-55-NOJAM, then submit an outage report to NAVCEN.

www.gps.gov

Thank You

Questions?