GPS Modernization Update & NASA's GNSS Activities

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Overview

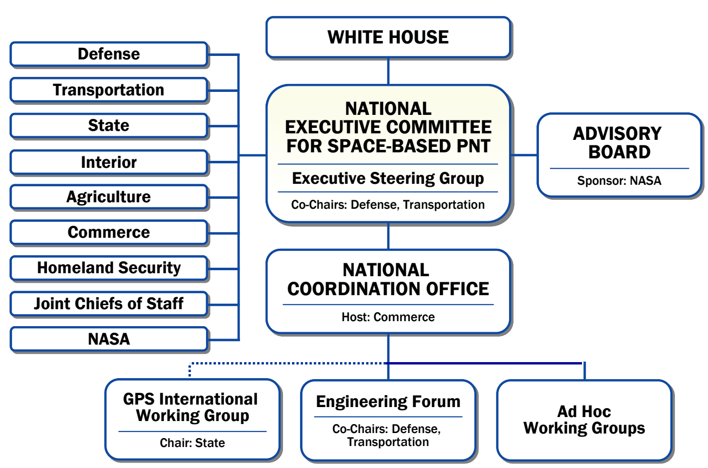
- U.S. Space-Based Positioning, Navigation and Timing (PNT) Policy Activities
- GPS Modernization Update
- Key NASA GPS/GNSS R&D Interests

U.S. Space-Based PNT Policy

GOAL: Ensure the U.S. maintains space-based PNT services, augmentation, back-up, and service denial capabilities that…

- Provide uninterrupted availability of PNT services
- Meet growing national, homeland, economic security, and civil requirements, and scientific and commercial demands
- Remain the pre-eminent military space-based PNT service
- Continue to provide civil services that exceed or are competitive with foreign civil space-based PNT services and augmentation systems
- Remain essential components of internationally accepted PNT services
- Promote U.S. technological leadership in applications involving space-based PNT services

U.S. Space-Based PNT Organization Structure



NASA's Role: The NASA Administrator is tasked, in cooperation with the Secretary of Commerce, to develop and provide to the Secretary of Transportation requirements for the use of GPS and its augmentations to support civil space systems.

U.S. Policy Promotes Worldwide Use of GPS/GNSS Technology

- No direct user fees for civil GPS services
  - Provided on a continuous, worldwide basis
- Open, public signal structures for all civil services
  - Promotes equal access for user equipment manufacturing, applications development, and value-added services
  - Encourages open, 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. Initiatives Towards Greater International GNSS Interoperability

Bilateral Meetings led by the U.S. Department of State

- **U.S.-Japan Joint Statement on GPS Cooperation in 1998**
  - Japan's Japan s Quasi Zenith Satellite System (QZSS) designed to be fully compatible and highly interoperable with GPS
  - Bilateral agreements to set up QZSS monitoring stations in Hawaii and Guam. Guam station completed!
- **U.S.-EU GPS-Galileo Agreement signed 2004**
  - Four working groups were set up under the agreement
  - Improved new civil signal (MBOC) adopted in July 2007
  - First Plenary Meeting successfully held in October 2008
  - Planning now for next Plenary meeting in 2010
- **U.S.-Russia Joint Statement issued in Dec 2004**
  - Negotiations for a U.S.-Russia Agreement on satellite navigation cooperation underway since late 2005
  - Working Groups on compatibility/interoperability, search and rescue
- **U.S.-India Joint Statement on GNSS Coop. in 2007**
- Technical Meetings focused on GPS-India Regional Navigation Satellite System (IRNSS) compatibility and interoperability held in 2008 and 2009
- **U.S.-China operator-to-operator coordination under ITU Auspices**
  - Bilateral Meetings at Geneva, June 2007; Xian, China, May 2008; Geneva, Oct 2009

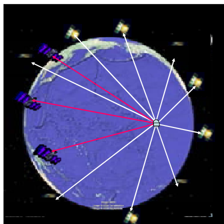
International Committee on GNSS / GNSS Providers Forum

- Following the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space **(UNISPACE III) in 1999**, in its resolution 54/68, the United Nations General Assembly endorsed the "Vienna Declaration: Space Millennium for Human Development."
- Dept of State-led US delegation to work in collaboration with other provider agencies to create the ICG and PF in order to engage GNSS provider agencies in multilateral discussions leading to **compatibility, interoperability and transparency of all systems**.
- **Members:** China, European Commission, India, Japan, Russian Federation, US
- **Associate Members (ICG only)**: EUPOS, EUREF, FIG, IAG, IGS, UNOOSA
- **Observers (ICG only):** BIPM, IAIN, ARCSSTE-E, CRASTLE-LF, CRECTEALC, ICAO, EUROCONTROL, SGAC
- **Secretariat**: UN Committee for the Peaceful Uses of Outer Space
- **Website:** http://www.oosa.unvienna.org/oosa/SAP/gnss/icg.html
- **Last meeting**: ICG-4 on 14-18 September, 2009 (St. Petersburg, Russia)
- **Next meeting**: ICG-5 in 18 – 22 October 2010 (Turin, Italy)

US-Japan GNSS Cooperation Areas

NASA-JAXA 2009 Agreement

- GPS / QZSS monitoring station at Kokee Park, Hawaii
- Overall goal to improve interoperability



Kokee Park Geophysical Observatory

Asia-Pacific Economic Cooperation (APEC) Japan 2010

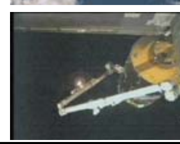
GIT/13 goals:

- Improved feedback to providers from non-government users of GNSS
- Improved infrastructure so as to develop better mapping capabilities in Asia and Latin America
- Improved collection of data to demonstrate the benefits of GNSS

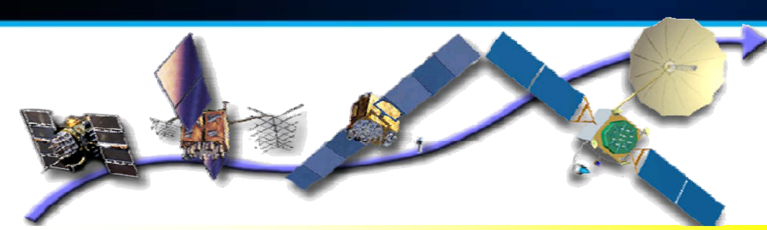
APEC JAPAN 2010

GPS for Rendezvous with the International Space Station

- H-II Transfer Vehicle (HTV) to determine its relative position and velocity to the ISS using Relative GPS while communicating interactively via the Proximity Communication System (PROX)
- Initial tests on HTV-1 Mission to ISS in 2009
- HTV-2 Mission in 2011



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

Modernized GPS

IIR-M: IIA/IIR capabilities plus

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

IIF: IIR-M capability plus

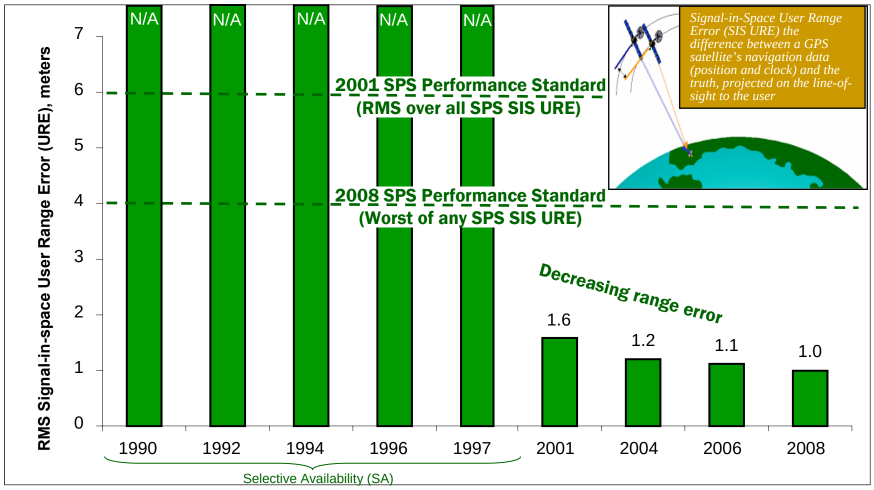
- 3rd civil signal (L5)
- Anti-jam flex power

Block III

Next Generation

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

SPS Signal in Space Performance



System accuracy exceeds published standard

GPS Constellation Status

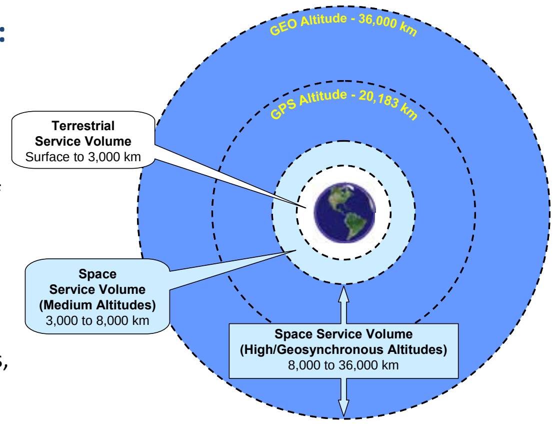
30 Operational Satellites
(Baseline Constellation: 24)

- 11 Block IIA
- 12 Block IIR
- 7 Block IIR-M
  - Transmitting new second civil signal
  - 1 additional GPS IIR-M in on-orbit testing
- 3 additional satellites in residual status
  - Next launch: First Block IIF - May 20, 2010
- Global GPS civil service performance commitment met continuously since December 1993

GPS Extends the Reach of NASA Networks for Space Ops and Science Missions

GPS services already enable:

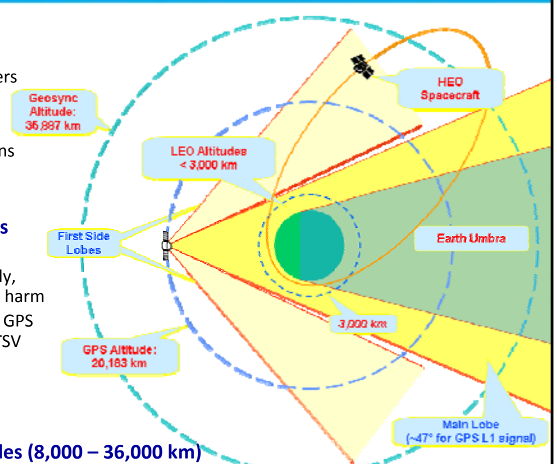
- ***Real-time On-Board Autonomous Navigation:*** Allows NASA to maximize the “autonomy” of spacecraft and reduces the burden and costs of network operations. It also enables new precise methods of spaceflight such as formation flying (ESA ATV, HTV, Dragon/Space-X, Orion, etc.).
- ***Attitude Determination:*** Use of GPS enables some missions to meet their attitude determination requirements, such as ISS.
- ***Earth Sciences:*** GPS used as a remote sensing tool supports atmospheric and ionospheric sciences, geodesy, and geodynamics -- from monitoring sea level heights and climate change to understanding the gravity field.



- ***Approximately 95%*** of projected worldwide space missions over the next 20 years will operate within the GPS service envelope
- ***NASA is investing over $130 million*** over the next 5 years in support of GPS R&D and implementation to support NASA operations and science missions

GPS Space Service Volume: LEO and Beyond

- **Terrestrial Service Volume (TSV) LEO (≤ 3,000 km) Characteristics**
  - PNT performance consistent with terrestrial users
  - Uniform received power levels
  - Fully overlapping coverage of GPS main beams
  - Instantaneous point position navigation solutions
  - 100% GPS coverage for < 1 meter URE
- **Space Service Volume (1): Medium Altitudes (3,000 – 8,000 km)**
  - Four GPS signals usually available simultaneously, however poor geometry & coverage gaps cause harm
  - 1 meter accuracies still feasible, however space GPS receivers have more difficulty processing than TSV
  - GPS performance degrades with altitude due to geometry and classic near/far problem



- **Space Service Volume (2): High/GSO Altitudes (8,000 – 36,000 km)**
  - Users will experience periods when no GPS satellites are available – Point Positioning no longer available
  - Nearly all GPS signals received over limb of the Earth – High variability in signal strength and beam paths
  - Received power levels are weaker than those in TSV or MEO SSV – Side Lobe processing needed
  - Specially designed receivers will be capable of maintaining accuracies ranging from 10-100 meters depending on receiver sensitivity and local oscillator stability

NASA GPS/GNSS Receiver Developments: Navigator & BlackJack "Family"

Goddard Space Flight Center

- Navigator GPS Receiver: GPS L1 C/A
  - Flew on Hubble Space Telescope SM4 (May 2009), planned for MMS, GOES, GPM, Orion (commercial version developed by Honeywell)
  - Onboard Kalman filter for orbit/trajectory estimation, fast acquisition, RAD hard, unaided acquisition at 25 dB-Hz
- Possible Future Capabilities
  - High-sensitivity Signal Acquisition and Tracking:
    - Acquisition thresholds down to 10-12 dB-Hz
    - Applicable to HEO, lunar, and cislunar orbits
  - Reception of New GPS Signals: L2C and L5
  - GPS-derived Ranging Crosslink Communications
    - Developed for MMS Interspacecraft Ranging and Alarm System (IRAS) to support formation flying
    - Features S-band communications link with code phase ranging, used in formation flying


Jet Propulsion Laboratory

- BlackJack Flight GPS Receiver: GPS L1 C/A, P(Y) and L2 P(Y)
  - Precise orbit determination (JASON, ICESat, SRTM missions)
  - Occultation science (CHAMP, SAC-C, FedSat, 2 GRACE , 6 COSMIC)
  - Gravity field (CHAMP, GRACE)
  - Surface reflections (SAC-C, CHAMP)
  - 18 BlackJack receivers launched to-date
- IGOR GPS receiver: Commercial version from Broad Reach Engineering
- CoNNeCT Software Defined Radio: GPS L1 C/A, L2C, L5
- Tri GNSS Receiver (TriG) is under development: GPS L1, L2(C), L5, Galileo E1, E5a, GLONASS (CDMA)
  - Features: open-loop tracking, beam-forming 2-8 antennas, 36 channels, RAD hard
  - Engineering models: 2011, production: 2013


GNSS Mission Areas: POD, Time, Relative Nav for Rendezvous, Docking, Formation Flight, Occultation, Oceanography

Mission	GNSS	Application	Orbit	Receiver	Signals	Launch
Glory	GPS	Orbit	LEO	BlackJack	L1	2010
LandSat	GPS	Orbit	LEO	GD Viceroy	L1	2012
COSMIC IIA	GPS, GLONASS, Galileo	Occultation	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2013
Jason III	GPS, GLONASS, Galileo	Oceanography	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2013
GPM	GPS	Orbit, time	GEO	Navigator	L1 C/A	2013
COSMIC IIB	GPS, GLONASS, Galileo	Occultation	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2014
Orion Crew Vehicle	GPS	Orbit, trajectory	LEO, MEO, GEO,trans-lunar	2 HI (Navigator)	L1 C/A	2014
MMS	GPS	Rel. range, orbit, time	up to 30 Re	Navigator	L1 C/A	2014
CLARREO	GPS, GLONASS, Galileo	Occultation	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2015
GOES-R	GPS	Orbit	GEO	Navigator	L1 C/A	2015
DESDynl	GPS	Precise orbit	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2016

Augmenting GPS in Space with TASS

- TDRSS Augmentation Service for Satellites (TASS)
- Supports <u>all</u> space users
  - Communication channel tracking / ground-in-the-loop users
  - GNSS-based on-board autonomous navigation

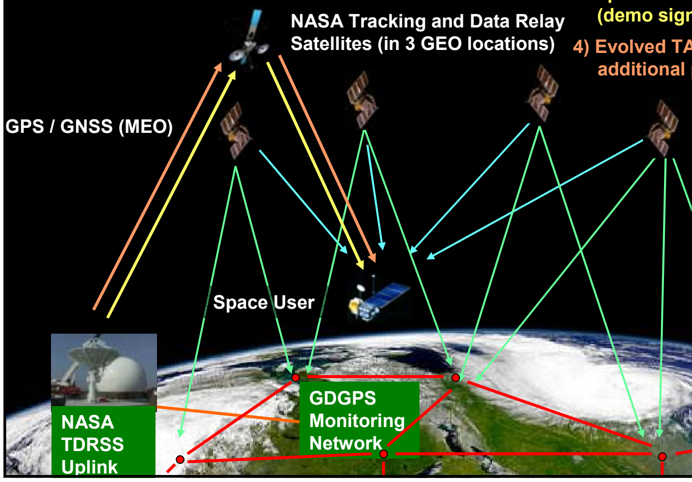
1) User spacecraft acquires GNSS signals

2) A ground network monitors GNSS satellites

3) GEO Space Network satellites relay GNSS differential corrections to space users on an S-band signal (demo signal since 2006)

4) Evolved TASS signal incorporates additional parameters

- GNSS integrity Information
- Tracking Satellite Information (health, ephemerides, maneuvers)
- Space Weather Data
- Solar Flux Data
- Earth Orientation Parameters
- User-specific Command Fields
- Pseudorandom Noise (PRN) ranging code



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