Use of GPS/GNSS for Future NASA Missions

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Space Communications & Navigation

Space Operations Mission Directorate

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Space Agency Forum

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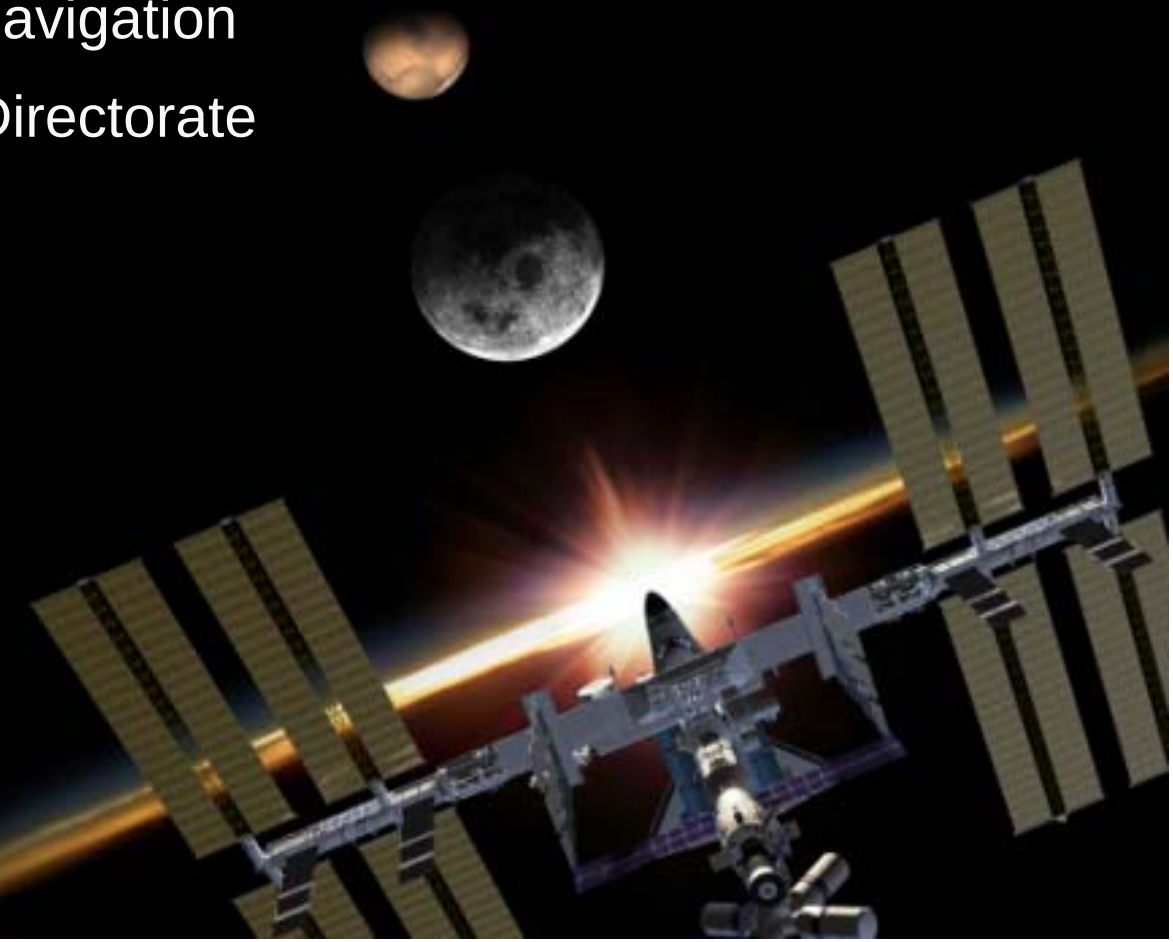
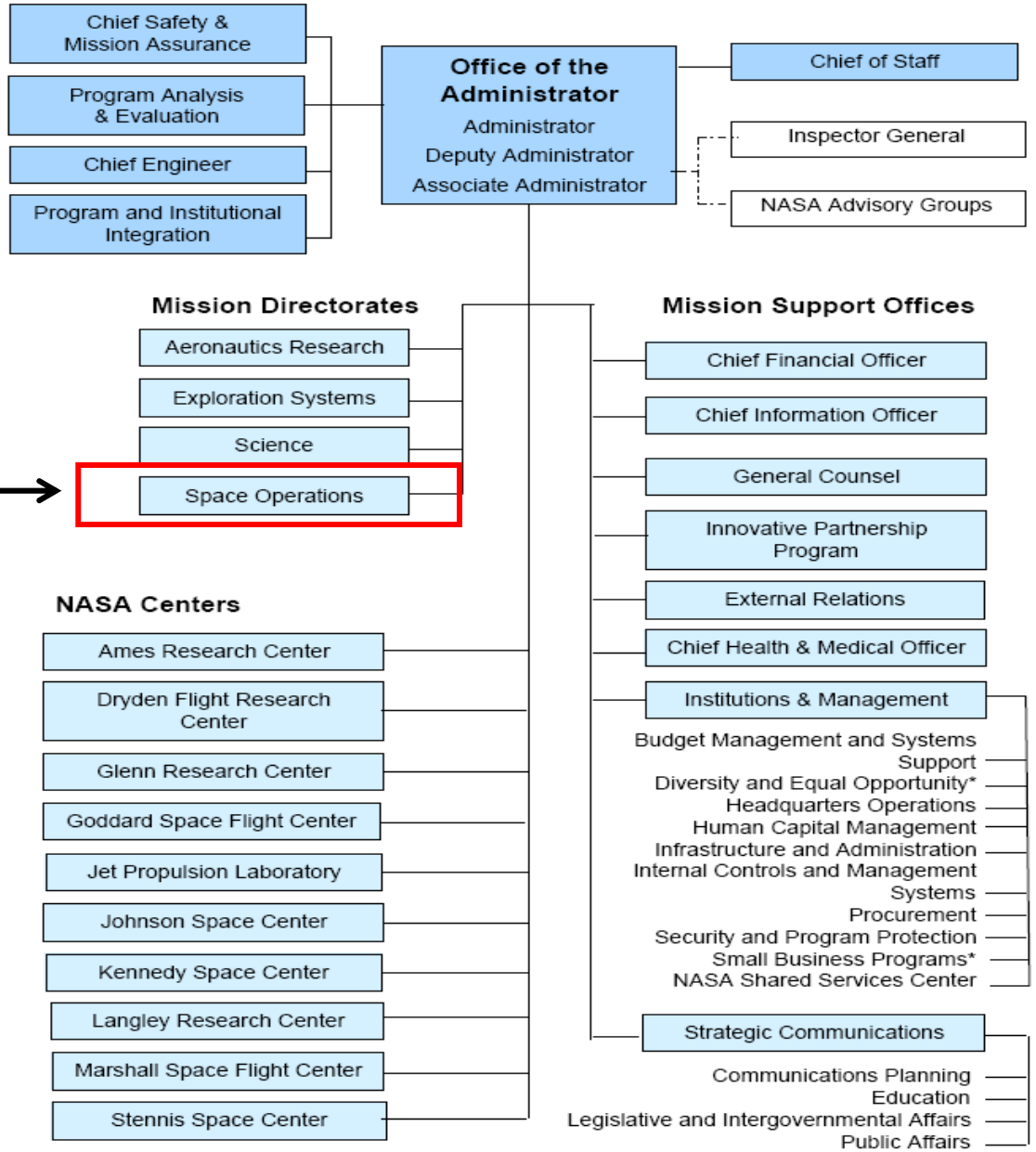


Presentation Overview

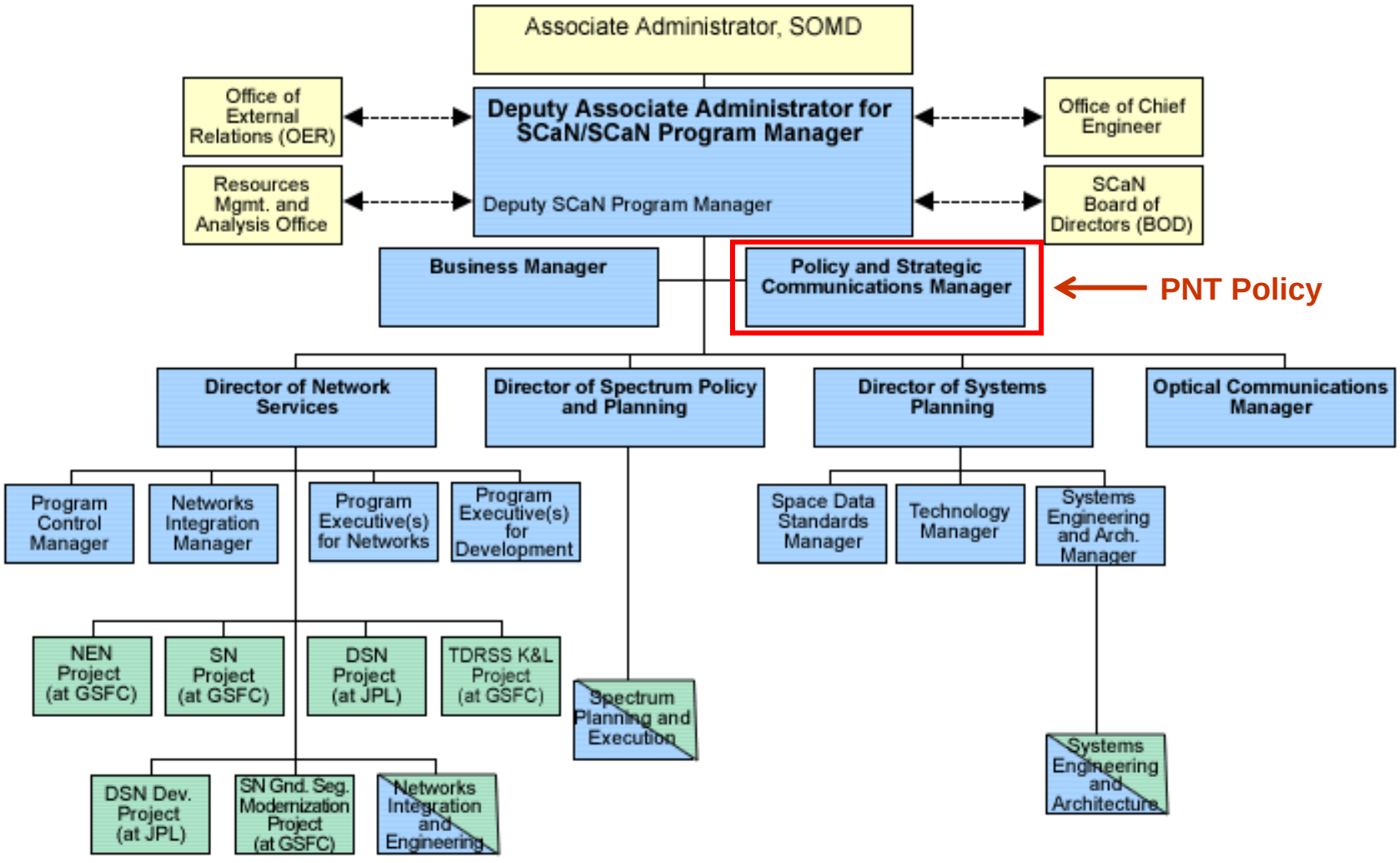
- SCaN Organization & Role at NASA
- GPS as a PNT Enabler for Space Ops & Science
- Current GPS Activities and Mission Areas
- Research and Future GNSS Mission Areas

NASA Organization Chart

Space Communication and Navigation (SCaN) Office



Space Communications & Navigation (SCaN) Organization



What does the Global Positioning System (GPS) do for NASA?

- **Positioning, Navigation, & Timing (PNT) are the GPS "*services*" that enable:**

1. **Real-time On-Board Autonomous Navigation:** Use of GPS as a source for position and time 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.

2. **Attitude Determination:** Use of GPS enables some missions to meet their attitude determination requirements, such as the International Space Station (ISS).

3. **Earth Science:** 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.

GPS as a PNT Enabler: Emerging Trends

- Trend analyses based on worldwide launch logs, launch manifests, and missions under R&D indicate that:
  - Approximately 60% of future worldwide space missions to operate in Low Earth Orbit (LEO), which is inside the GPS Terrestrial Service Volume
  - And additional 35% of missions to operate beyond LEO and up to Geosynchronous Orbit (GSO) altitude, which is inside the GPS Space Service Volume
- In summary, approximately 95% of projected worldwide space missions over the next 20 years will operate within the GPS service envelope
- GPS Application Areas in Space
  - Navigation, Attitude Determination, Science, etc.

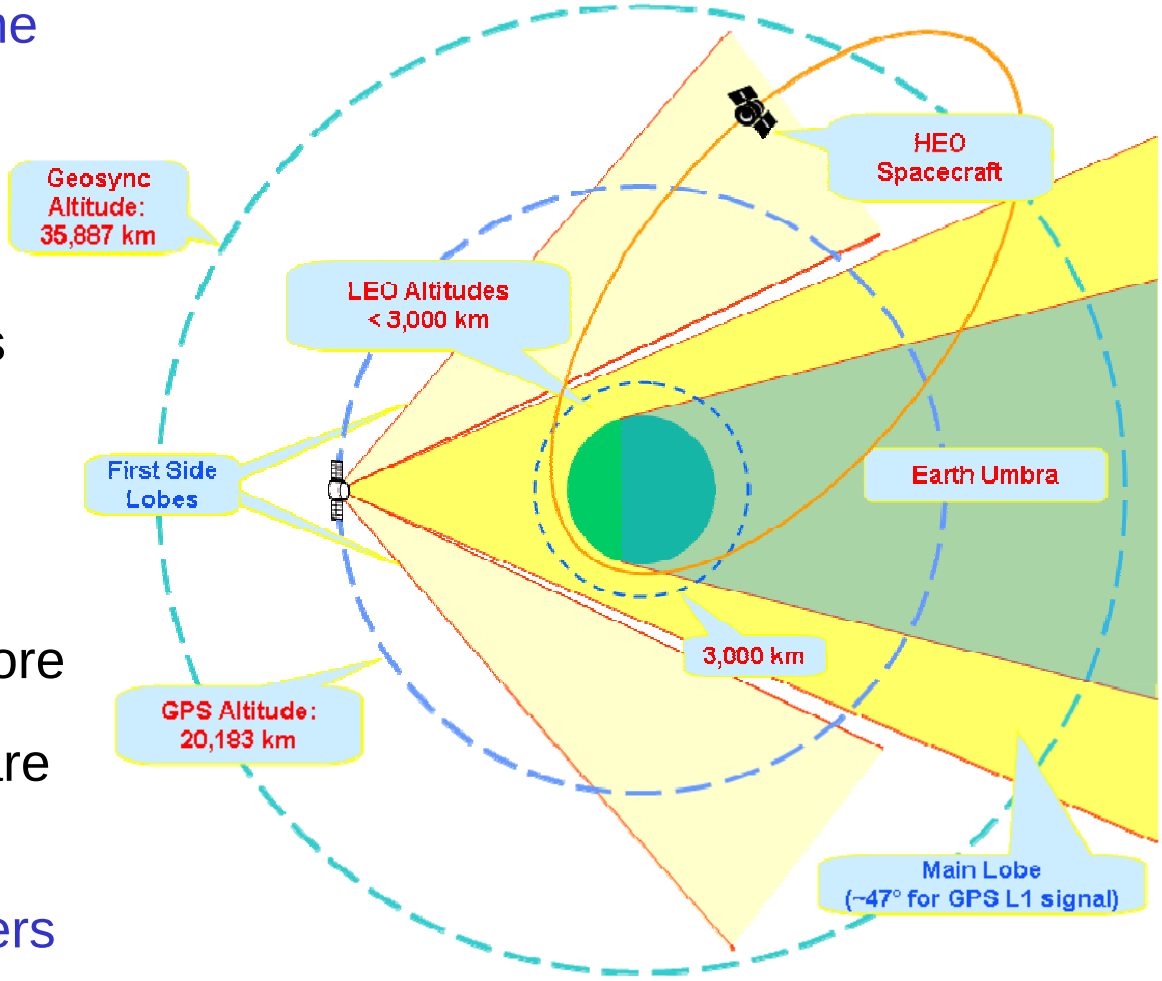
Space Shuttle
(Application: Navigation)

International Space Station
(Application: Attitude Determination)

Earth Observing System
(Application: Science)

Current GPS Activities and Mission Areas: Space Navigation with GPS

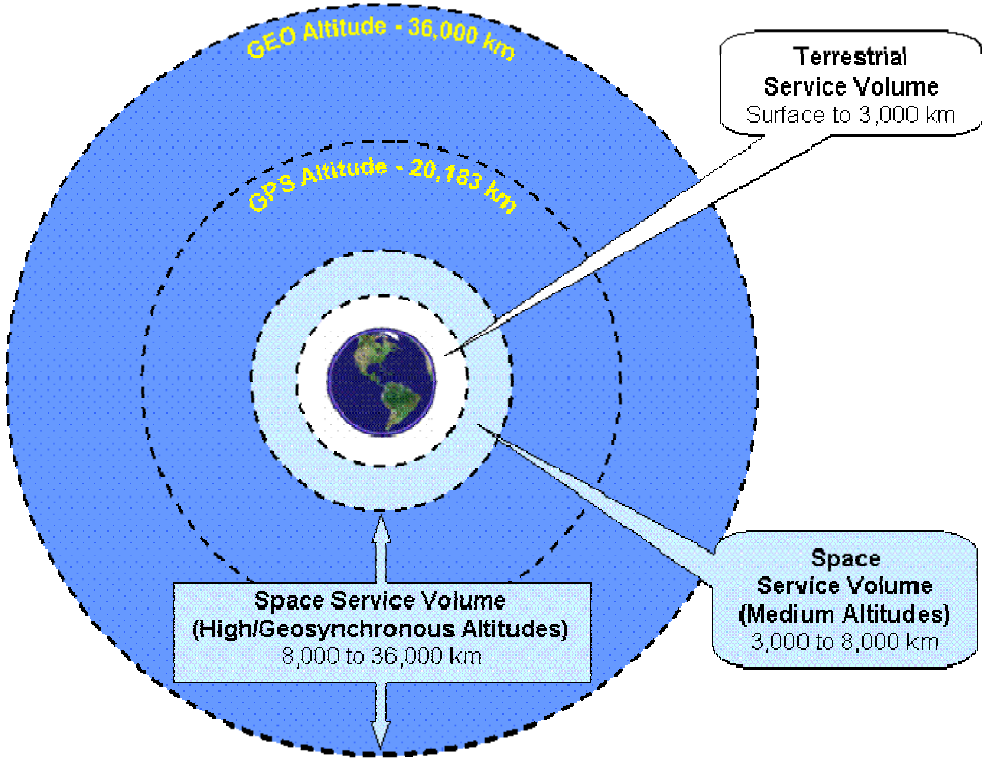
- GPS Terrestrial Service Volume
  - –Up to 3,000 km altitude
  - –Most current applications
- GPS Space Service Volume (SSV)
  - –3,000 km altitude to GEO
  - –Many emerging space users
  - –Geostationary Satellites
  - –High Earth Orbits (Apogee above GEO altitude)
- SSV users share unique GPS signal challenges
  - –Number of satellite views more limited
  - –GPS first side lobe signals are important
- Performance requirements established via three parameters
  - –Pseudorange accuracy
  - –Received power
  - –Signal availability



Current GPS Activities and Mission Areas: SSV Definitions

Space Service Volume (Medium Altitudes)

- Four GNSS signals available simultaneously a majority of the time
- GNSS signals over the limb of the earth become increasingly important with altitude
- One-meter orbit accuracies

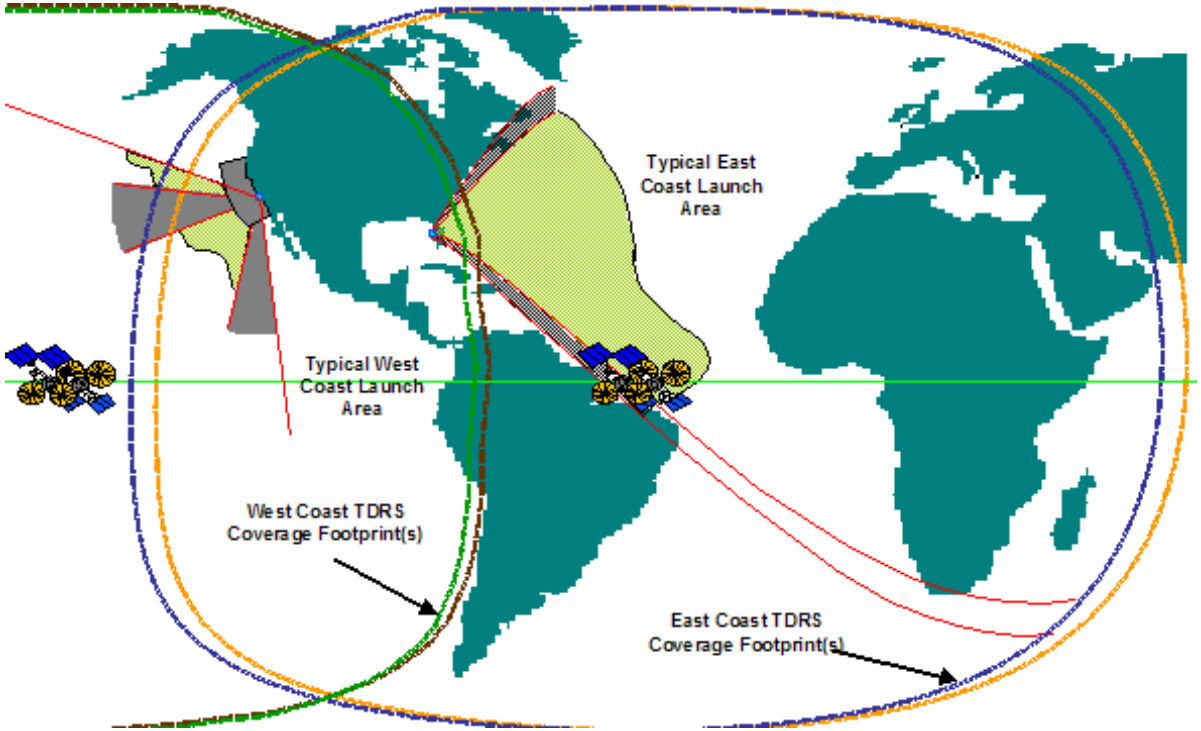


Space Service Volume (High Altitudes)

- Nearly all GNSS signals are received over the limb of the Earth
- Periods when no signals are available. Great benefit from additional GNSS satellites.
- Signal levels will be weaker than those in TSV or MEO SSV
- Positioning software uses orbital physics, and/or stable on-board oscillators, to achieve orbit accuracy of tens of meters

Current GPS Activities and Mission Areas: Tracking of Launch Vehicles

- Space-based navigation, GPS, and Space Based Range Safety technologies are key components of the **next generation launch and test range architecture**
- Provides a more cost-effective launch and range safety infrastructure while augmenting range flexibility, safety, and operability
- Memorandum signed in November 2006 for future **GPS Metric Tracking (GPS MT)** for all DoD, NASA, and U.S. commercial vehicles launched at the Eastern and Western ranges



Current GPS Activities and Mission Areas: Human Space Flight

Space Shuttle Program

- Specialized GPS receivers designed to accept Inertial Navigation System (INS) aiding
- One GPS receiver (retaining TACAN[1] as backup) installed on Discovery and Atlantis
- Three GPS receivers on Endeavour (TACAN removed)
- GPS taken to navigation for the first time on STS-115 / Atlantis during re-entry and landing
- GPS/INS – only navigation used on STS-118 / Endeavour for re-entry and landing

[1]Tactical Air Navigation System

STS-115:
9-21 Sept. 2006

STS-118:
8-21 Aug. 2007

ISS as viewed from STS-118

International Space Station (ISS)

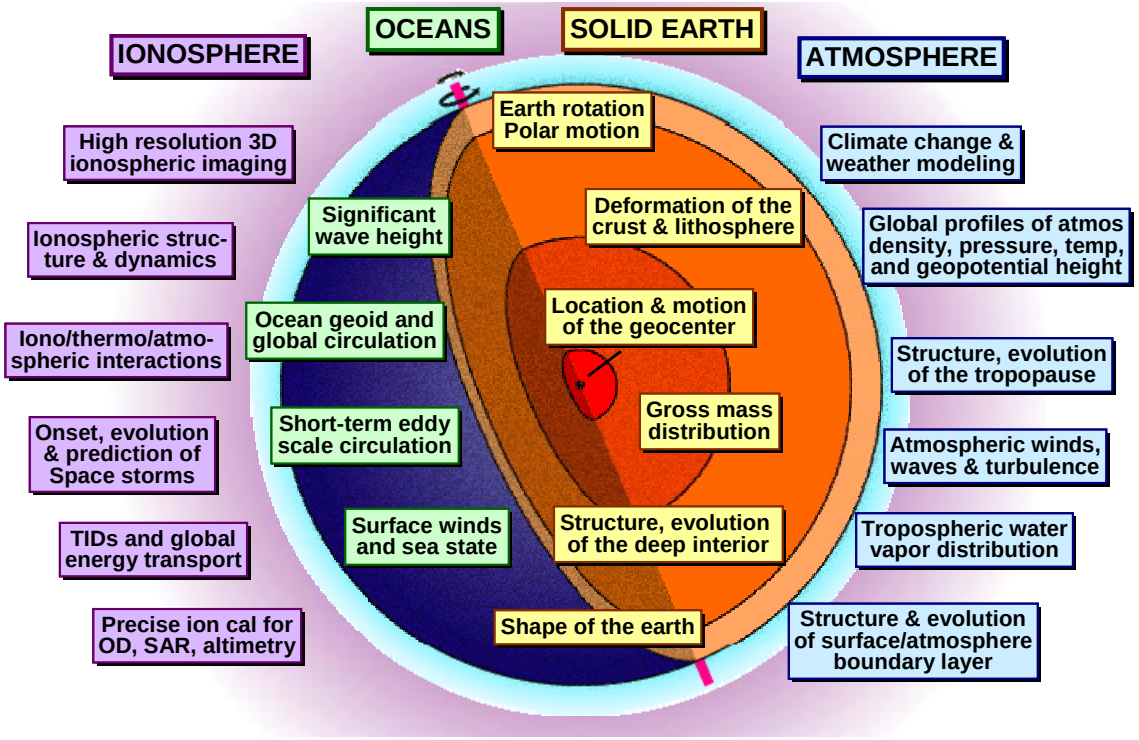
- Combined GPS + INS receiver tested on shuttle flights April 2002 (STS-110 / Atlantis)
- Four GPS antennas on the ISS truss assembly
- Used for attitude determination

Artist concepts of Orion approaching the ISS and Orion landing

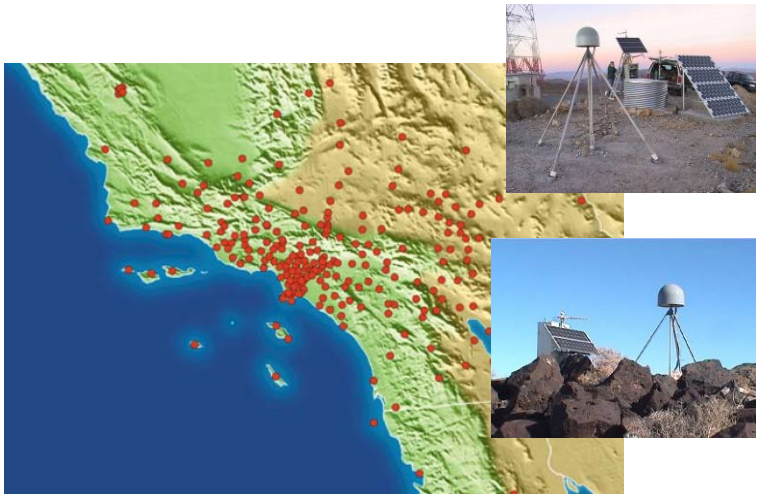
Project Constellation

- A combination of GPS receivers and INS will be used on Orion, which is scheduled to replace the Space Shuttle

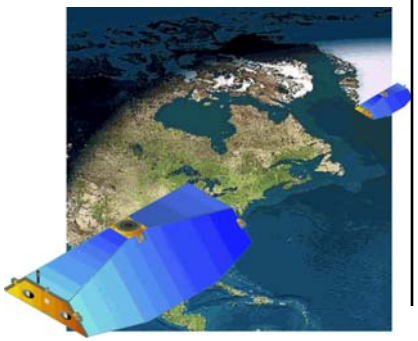
Current GPS Activities and Mission Areas: Earth Science Applications



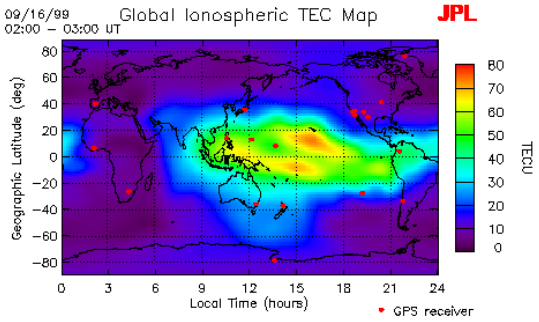
Southern California Integrated GPS Network



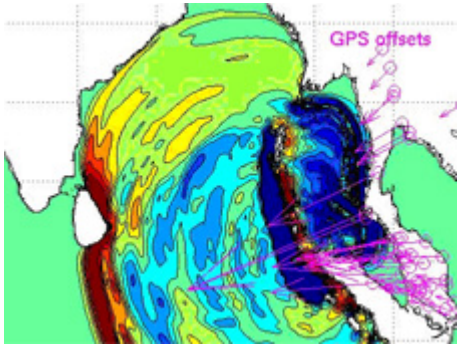
Gravity Field Measurements (GRACE Mission)



Ionospheric Remote Sensing using GPS Occultation



Ocean Topography



(2004 Tsunami with GPS offsets)

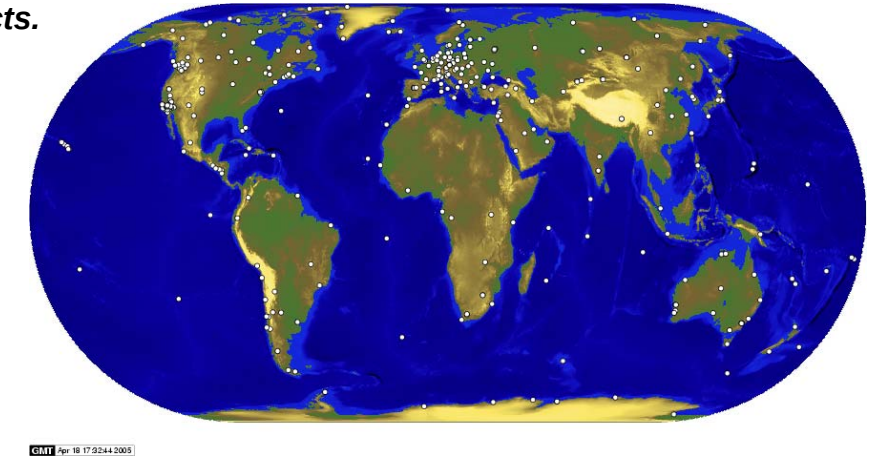
Current GPS Activities and Mission Areas: International GNSS Service (IGS)

The IGS is a voluntary federation of more than 200 worldwide agencies in more than 90 countries that pool resources and permanent GPS station data to generate precise GPS products.

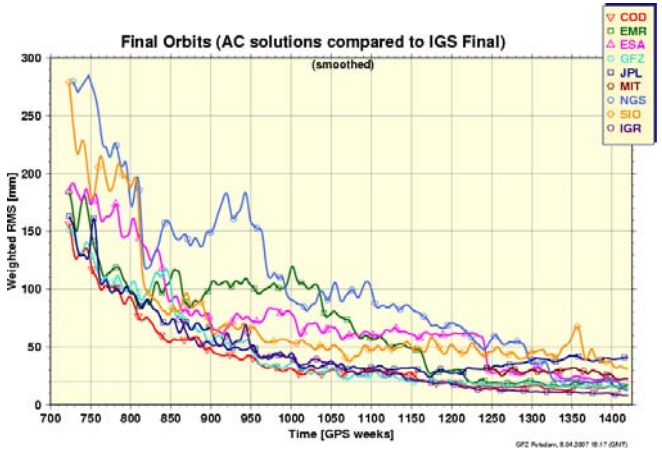
US agencies that contribute to the IGS include:

- ***National Aeronautics and Space Administration (NASA),***
- ***National Geospatial-Intelligence Agency (NGA),***
- ***National Oceanic and Atmospheric Administration (NOAA)***
- ***National Geodetic Survey (NGS),***
- ***Naval Research Laboratory (NRL),***
- ***National Science Foundation (NSF),***
- ***US Naval Observatory (USNO), and***
- ***US Geological Survey(USGS),***

… and numerous universities & research organizations.



Over 350 permanent tracking stations operated by more than 100 worldwide agencies comprise the IGS network. Currently the IGS supports two GNSS: GPS and the Russian GLONASS.



IGS products are formed by combining independent results from each of several Analysis Centers. Improvements in signals and computations have brought the centers' consistency in the Final GPS satellite orbit calculation to ~ 2cm

•Graph courtesy Analysis Coordinator

•G. Gendt, GFZ Potsdam

GPS Applications in IGS Projects & Working Groups

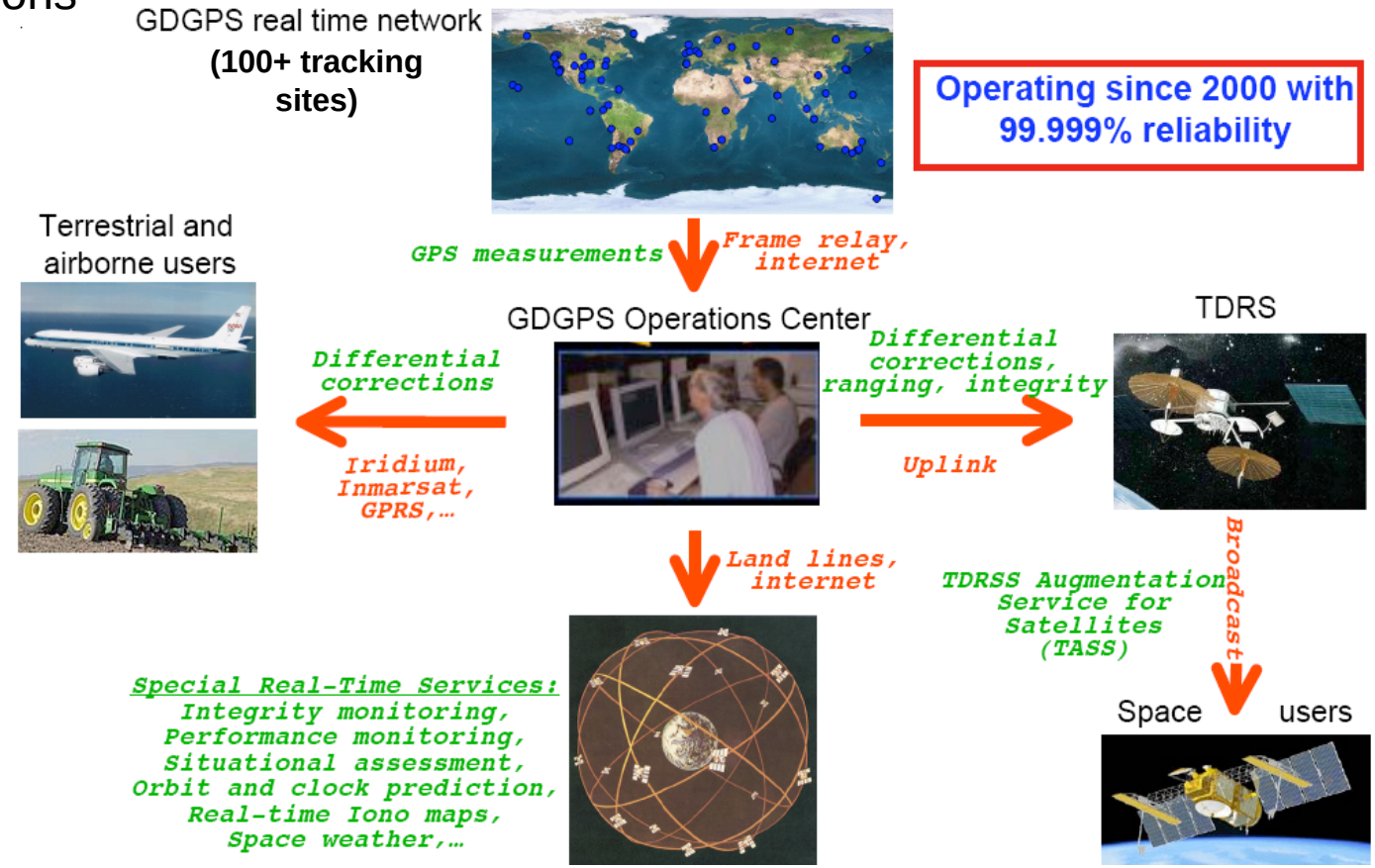
IGS Reference Frame
Supporting AREF - African Reference Frames
Precise Time & Frequency Transfer
GLONASS Pilot Service Project, now routine within IGS processes
Low Earth Orbiters Project
Ionosphere WG
Atmosphere WG
Sea Level - TIGA Project
Real-Time Project
Data Center WG
GNSS WG

http://igscb.jpl.nasa.gov

NASA funds the coordinating center the IGS Central Bureau

Current GPS Activities and Mission Areas: Global Differential GPS System (GDGPS)

- Global, seamless, GPS augmentation system developed and operated by NASA's Jet Propulsion Laboratory
  - Supports real-time positioning, timing, and environmental monitoring for agency science missions. Provides advanced real-time performance monitoring
  - Provides timely products for GPS situational assessment, natural hazard monitoring, emergency geolocation, and other applications.
  - Operational since 2000, has more than 100 dual-frequency GPS reference stations



Current GPS Activities and Mission Areas
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

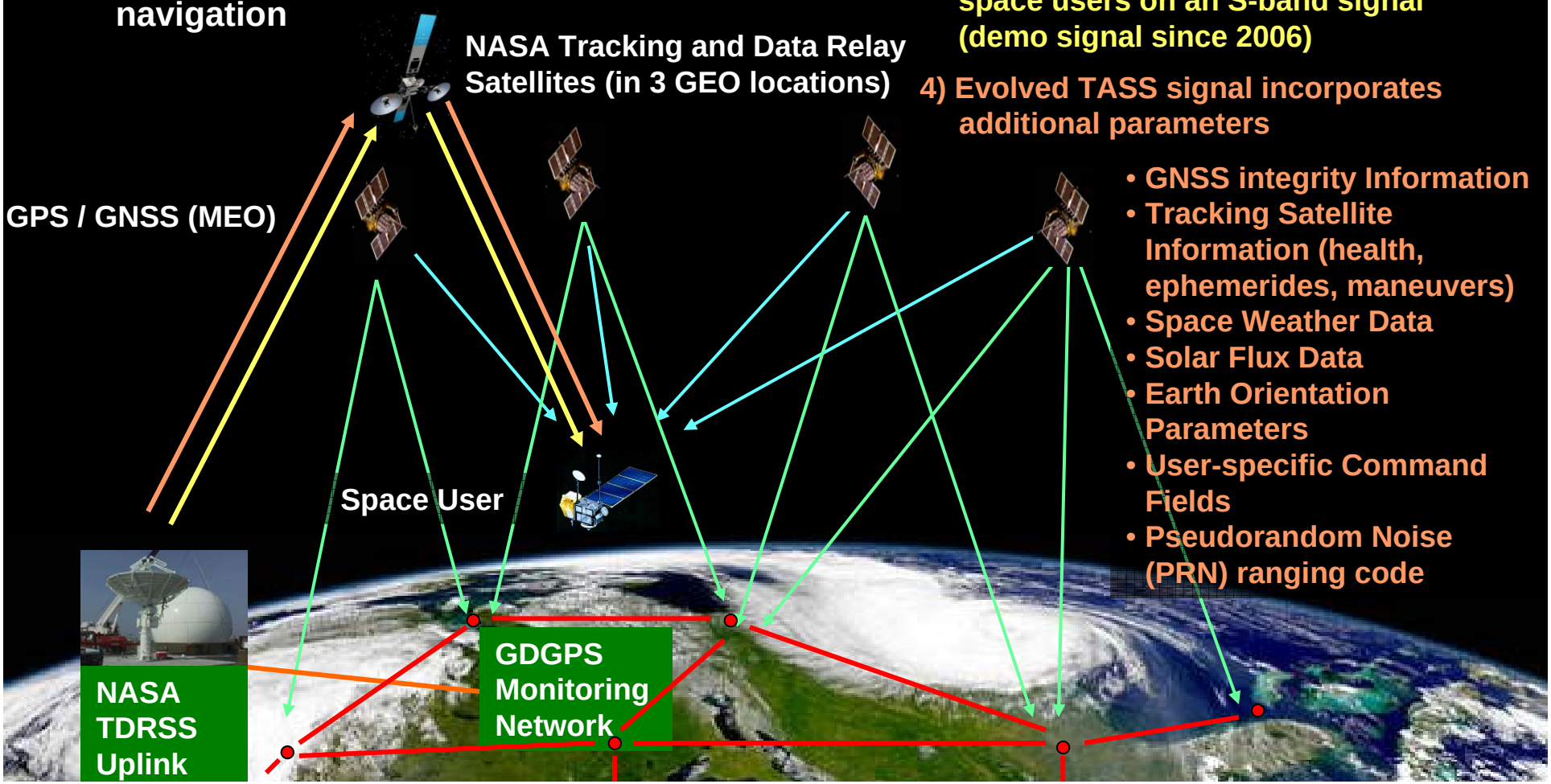
1) User spacecraft acquires GNSS signals

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

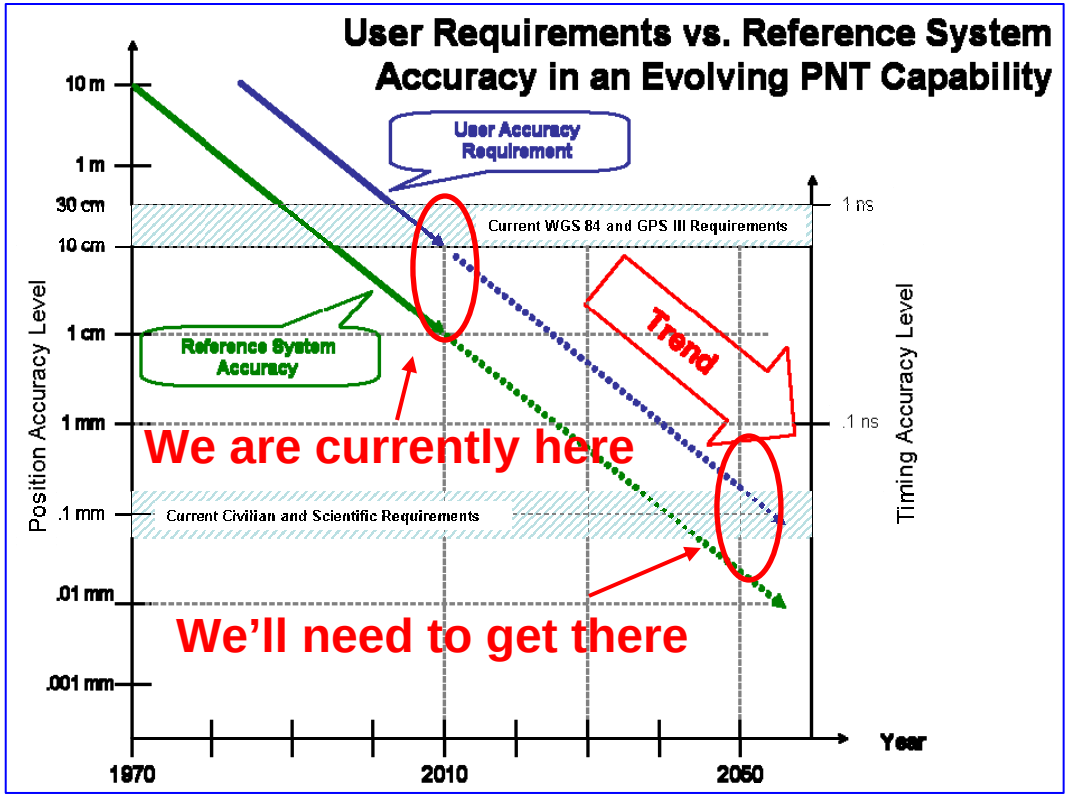
- GNSS integrity Information
- Tracking Satellite Information (health, ephemerides, maneuvers)
- Space Weather Data
- Solar Flux Data
- Earth Orientation Parameters
- User-specific Command Fields
- Pseudorandom Noise (PRN) ranging code

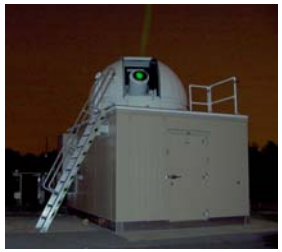


Current GPS Activities and Mission Areas: Reference Frame Evolution

Laser Retroreflectors on GNSS

- Enables the comparison of collocated radiometric and optical measurements used for model improvements
- Enables isolation of systematic errors in GNSS constellations and improves the reference frame accuracy
  - Variation of range and phase centers important for space users because they sample the signals far off the transmit boresight
- Improved models and reference frames necessary to support civilian and scientific requirements for higher PNT accuracy
  - Global sea height change measurement from space requires 1 mm/year precision, so reference frame needs to be constant to 0.1 mm/yr



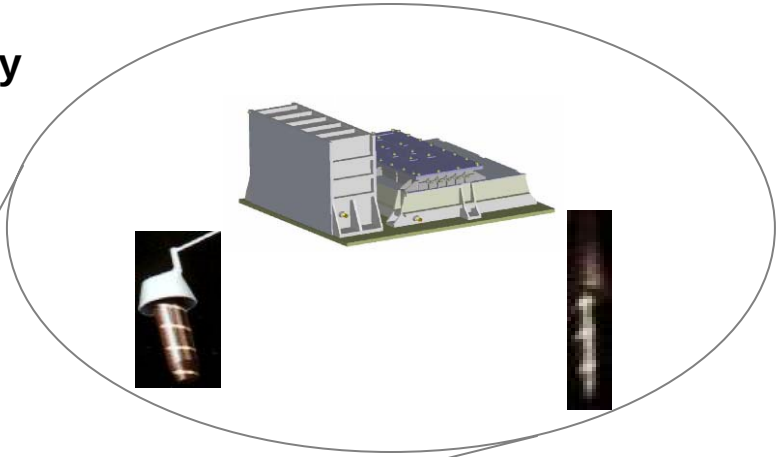


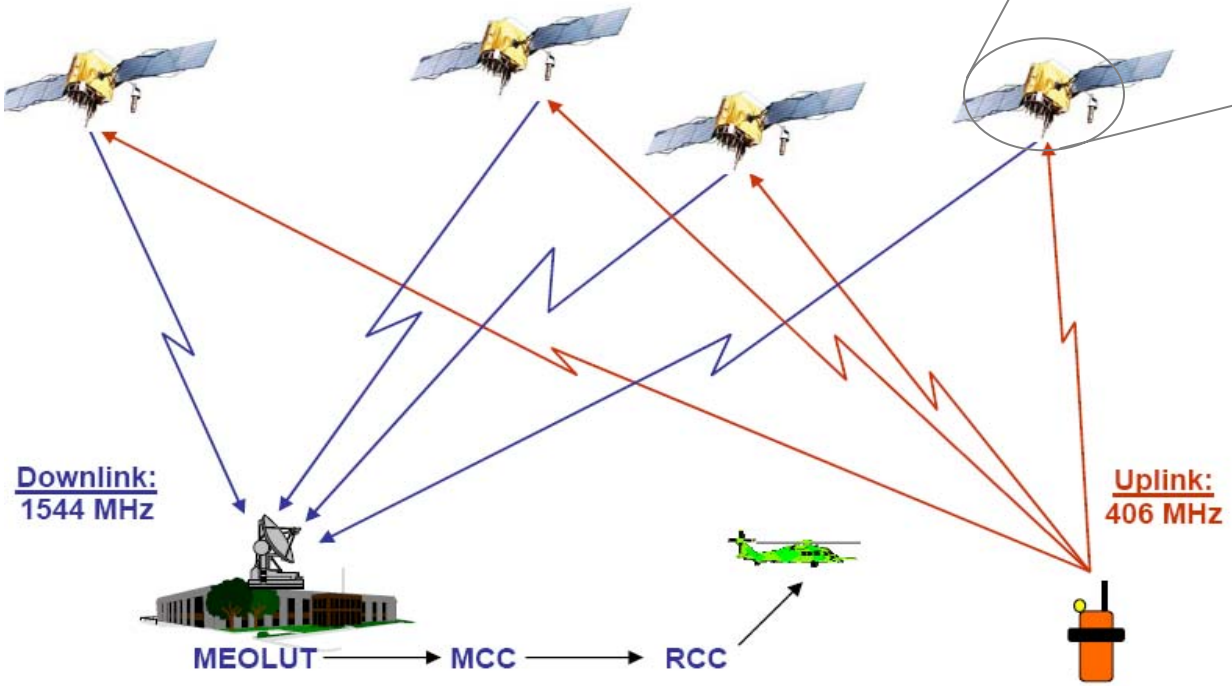
NASA SLR 2000 laser transmitter

ILRS Network

Current GPS Activities and Mission Areas
Distress Alerting Satellite System (DASS)

- **SARSAT Mission Need:**
- **More than 800,000 emergency beacons in use worldwide by the civil community – most mandated by regulatory bodies**
- **Expect to have more than 100,000 emergency beacons in use by U.S. military services**
- **Since the first launch in 1982, current system has contributed to saving over *20,000* lives worldwide**





- **Status:**
- **SARSAT system to be discontinued as SAR payload implemented on Galileo**
- **NASA and Air Force developed options for U.S. SAR system**
- **Successful NASA Proof-of-Concept DASS on GPS IIR(M) and IIF satellites**

GPS III transition underway

Research and Future GNSS Mission Areas: Upcoming Missions

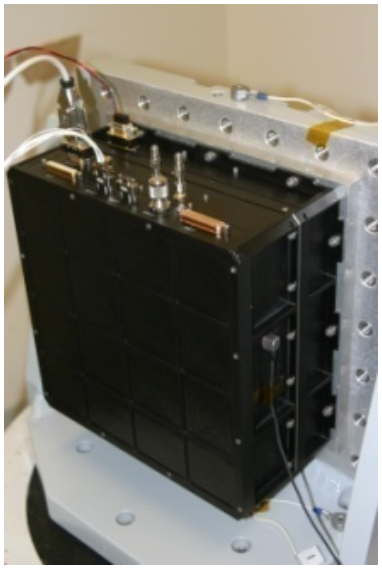
Mission	GNSS	Application	Orbit	Receiver	Signals	Launch
Glory	GPS	Orbit	LEO	BlackJack	L1	2010
LandSat	GPS	Orbit	LEO	GD Viceroy	L1	2012
COSMIC IIA	GPS, GLONASS, Galileo	Occultation	LEO	TriG (potential)	L1, L2, L5, Galileo, GLONASS	2013
Jason III	GPS, GLONASS, Galileo	Oceanography	LEO	TriG (potential)	L1, 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

Research and Future GNSS Mission Areas: GPS/GNSS Receiver Development (1)

- 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

- IGOR: Commercial version from Broad Reach Engineering
- CoNNeCT SDR: GPS L1, L2, L5
- 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 schedule: 2013

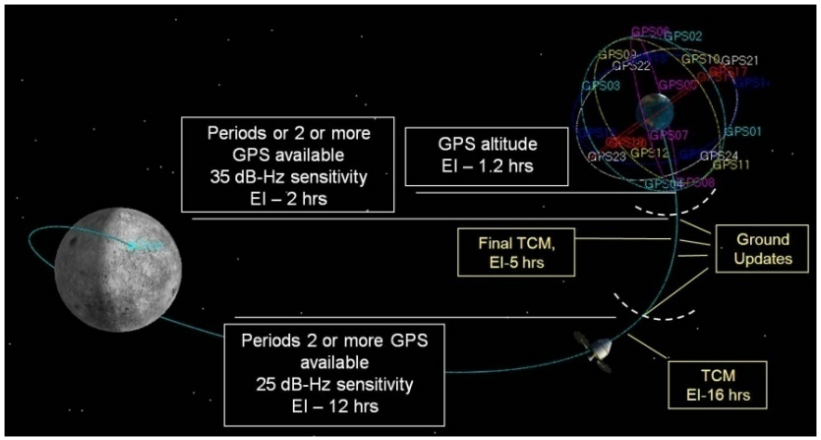
Research and Future GNSS Mission Areas: GPS/GNSS Receiver Development (2)

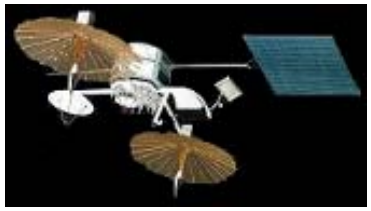


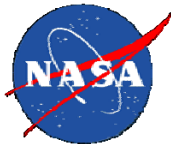
- Navigator GPS Receiver: GPS L1 C/A
  - Flew on Hubble Space Telescope SM4 (May 2009), planned for MMS, GOES, GPM, Orion/CEV
  - Onboard Kalman filter for orbit/trajectory estimation, fast acquisition, RAD hard, unaided acquisition at 25 dB-Hz
  - Honeywell is developing commercial version for Orion
- Possible Future Capabilities
  - High-sensitivity Signal Acquisition and Tracking
    - Acquisition thresholds down to 10-12 dB-Hz
    - Applicable to HEO, lunar, and cislunar orbits for CxP
    - GPS is a near term, complementary navigation solution for CxP
  - Reception of New GPS Signals: L2C and L5
  - GPS-derived Ranging Crosslink Communications (TRL 6)
    - Developed for MMS Interspacecraft Ranging and Alarm System (IRAS)
    - S-band communications link with code phase ranging
    - Signal processing and RF down conversion integrated into present Navigator receiver design
    - Applicable to future spacecraft formation flying missions and CxP automated rendezvous and docking sensing needs.

Research and Future GNSS Mission Areas: GPS concepts beyond the SSV

- Use of GPS satellites
  - Trans-lunar navigation (Orion)
    - Trans-lunar injection and cruise
    - Out to Earth-Moon L1 libration point
- Use of GPS signal structure
  - TDRS broadcast of GPS signal structure
  - Moon/Mars Relay Satellites with a GPS signal structure
  - Moon/Mars beacons with a GPS signal structure
  - GRAIL lunar gravity mission will use the GPS signal structure to transfer time between the pair of spacecraft
- Clock distribution
  - Time dissemination system with characteristics suitable for solar-system-wide operations
    - One-way navigation, VLBI, sensor webs, enhance radio-science







Questions?

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