Meeting Space User Requirements through Evolving PNT Services

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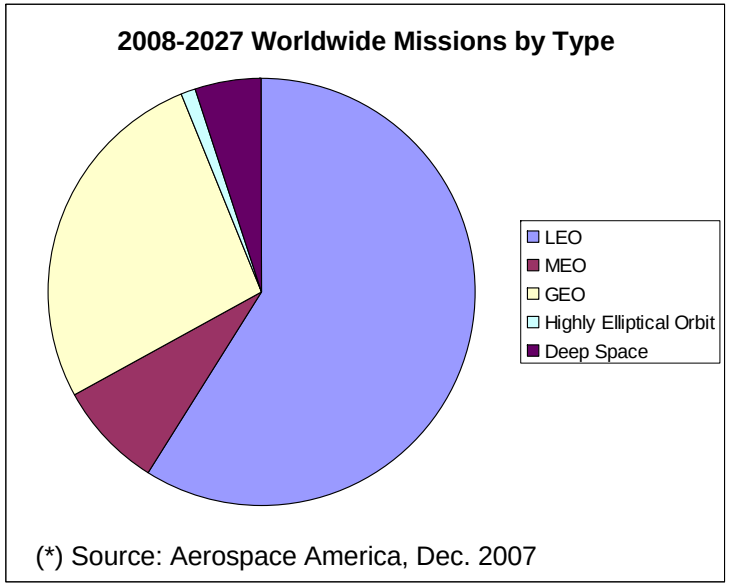
We Should Plan for GNSS Service to Space Users

- GNSS is valuable to space users
  - Autonomy saves money
  - PNT accuracy unavailable elsewhere
  - Enables new science measurements
- Without formal definition of space service
  - Power supplied past edges of earth could vary to unusable levels
  - Number of satellite signals may be inadequate
  - Quality of range and phase observations may be inadequate
- Recommend GNSS providers consider provision of PNT service to the space service volumes defined in this talk

GNSS Critical to Space Navigation & Science

- **Nearly 60%** of projected worldwide space missions 2008-2027* will operate in **LEO**
  - That is, inside the Terrestrial Service Volume
- **An additional 35%** of these space missions that will operate at higher altitudes will remain at or below **GEO**
  - That is, inside the Space Service Volume
- In summary, approximately **95%** of projected worldwide space missions over the next 20 years will operate within the GNSS service envelope
- GNSS **Application Areas** in Space
  - Navigation, Attitude Determination, Science, etc.



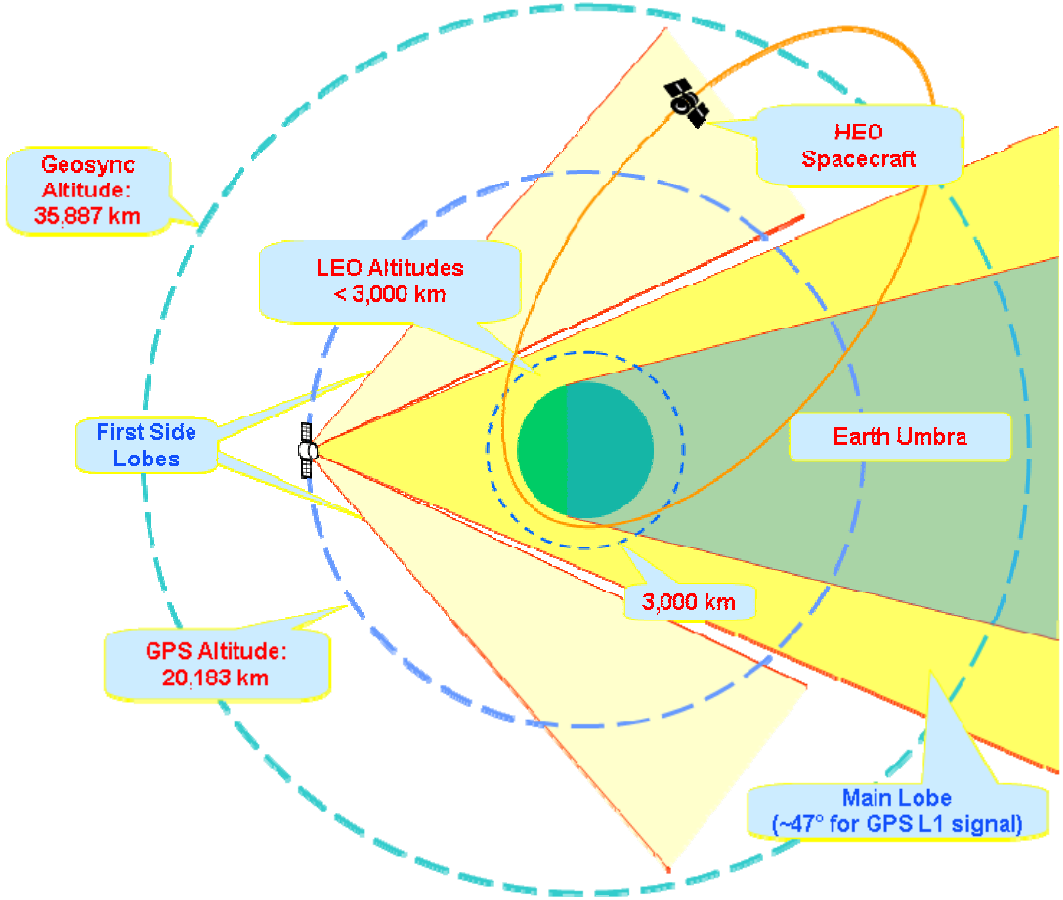
(*) Source: Aerospace America, Dec. 2007

Space Shuttle
(Application: Navigation)

Earth Observing System
(Application: Science)

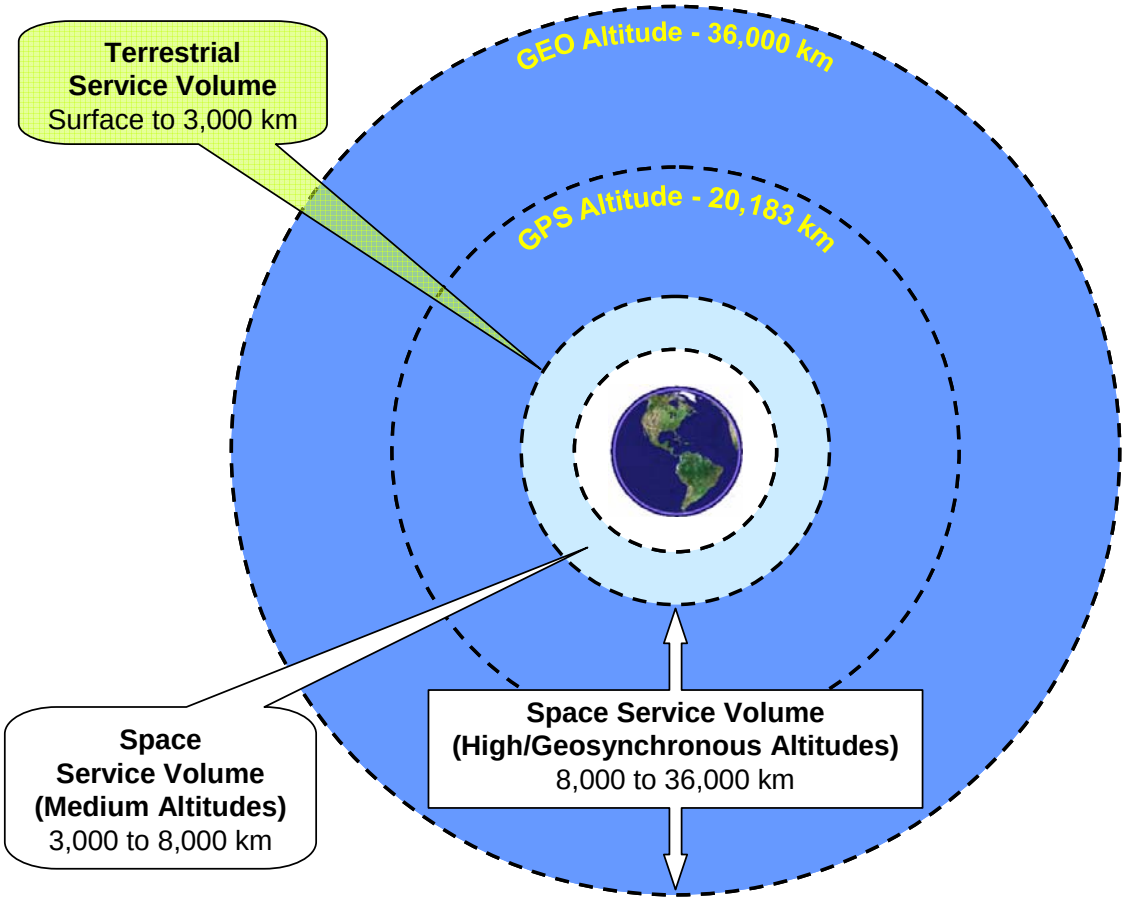
International Space Station
(Application: Attitude Determination)

The Big Picture



At high altitudes the only signals available are from GNSS satellites on the far side of the earth

Terrestrial and Space Service Volumes: Definition and Characteristics



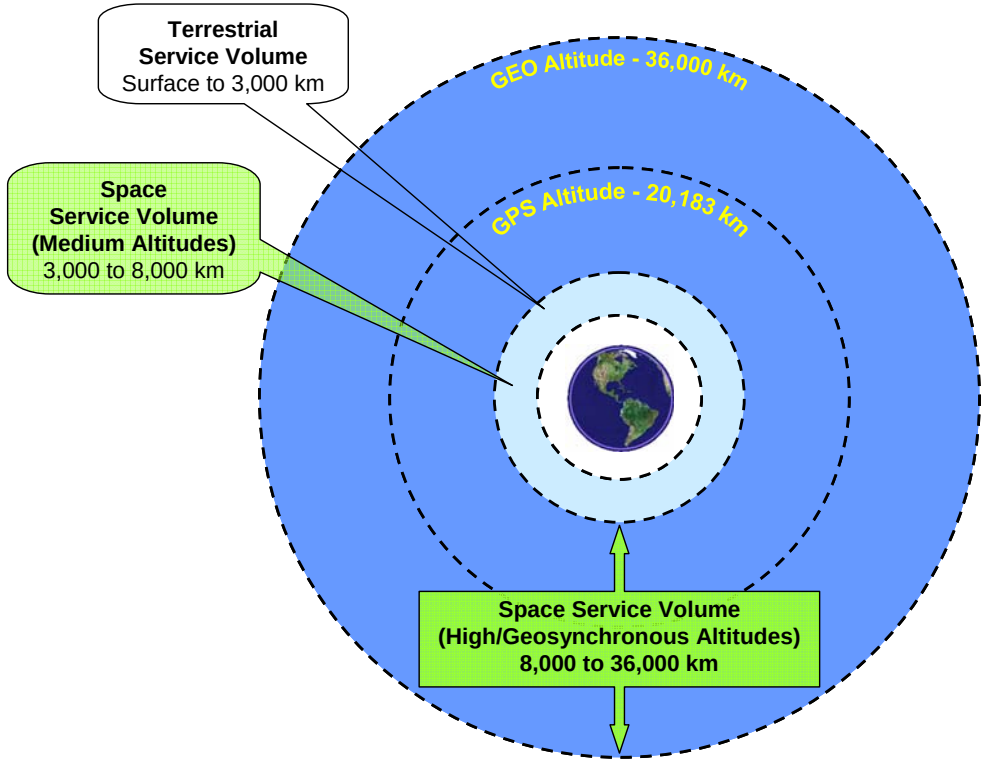
Terrestrial Service Volume

- PVT performance consistent with that enjoyed by terrestrial users
- 100% GNSS coverage
- Single-epoch navigation solutions

Terrestrial and Space Service Volumes: Definition and Characteristics

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

Space Service Volume: Defining GNSS User Requirements

- Performance requirements established via three system parameters
  - Signal availability from adequate number of satellites
  - Received power
  - Quality of range and phase signals (includes phase and group delay variations at edges of antenna pattern)

Space Service Volume: Missions Using GNSS

- Autonomous realtime navigation
  - Many satellites in LEO, MEO, HEO
  - Some phases of lunar missions
- Dozens of international science missions measuring
  - Spatial and temporal variations of gravity field
  - Remote sensing of ionosphere and neutral atmosphere
  - POD to support altimeter measurements of sea, ice, and land
- Proposed future missions
  - surface reflections for altimetry and roughness measurement, and tsunami detection.
  - Highly Elliptical Orbit satellite for orbiting VLBI (VSOP-2)

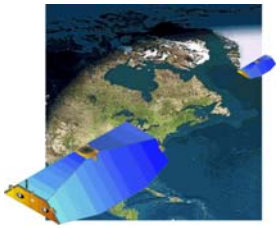
Activity Area: Space-Qualified GPS Receivers
(Supporting Evolving Space User Needs)

GPS Blackjack Science Receivers (JPL)

- Highest accuracy and flexibility for NASA science missions
- Dual/triple frequency, C/A and L2C code plus semi-codeless P(Y)1 and P(Y)2, L5 available
- Meter-level accuracy demonstrated with Real-Time GIPSY (RTG) software (SAC-C)
- Option to receive GNSS differential corrections from NASA's Global Differential GPS System (GDGPS) broadcast via TASS
- Millimeter-level post-processed baseline accuracy demonstrated for LEO satellite formations (GRACE)
- Future capability to include GPS + other GNSS systems (TriG receiver)
- 17 of 27 TurboRogue/BlackJack applications are on non-USA satellites

SAC-C

GRACE

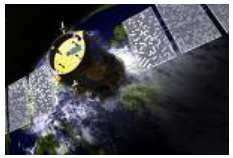


Navigator Flight Receivers (GSFC)

- High Earth Orbit (HEO) qualified GPS receiver
  - –Stringent radiation requirements (> 100 kRad)
  - –HEO applications include apogees up to 25 Earth Radii by 2014
- Supports Human Spaceflight
- Implements algorithms for trajectory determination
  - –Goddard Enhanced Onboard Navigation System (GEONS) used for on-board processing of data from various sources (GPS, TDRSS, Deep Space Network and Ground Networks, crosslinks to other satellites, celestial objects, accelerometer data)
- Acquires and track signals down to SNR 25 dB-Hz
- Longer term goal; acquire and track down to SNR 15 dB-Hz (60 Earth radii range – vicinity of the Moon)

Orion / ISS

TERRA (EOS AM-1)



CALYPSO

Activity Area:
Supporting GNSS Navigation with the Ground and Space Networks

- **For example, the prototype TDRSS Augmentation Service for Satellites (TASS),**
  - **Communication channel tracking / ground-in-the-loop users**
  - **GNSS-based on-board autonomous navigation**

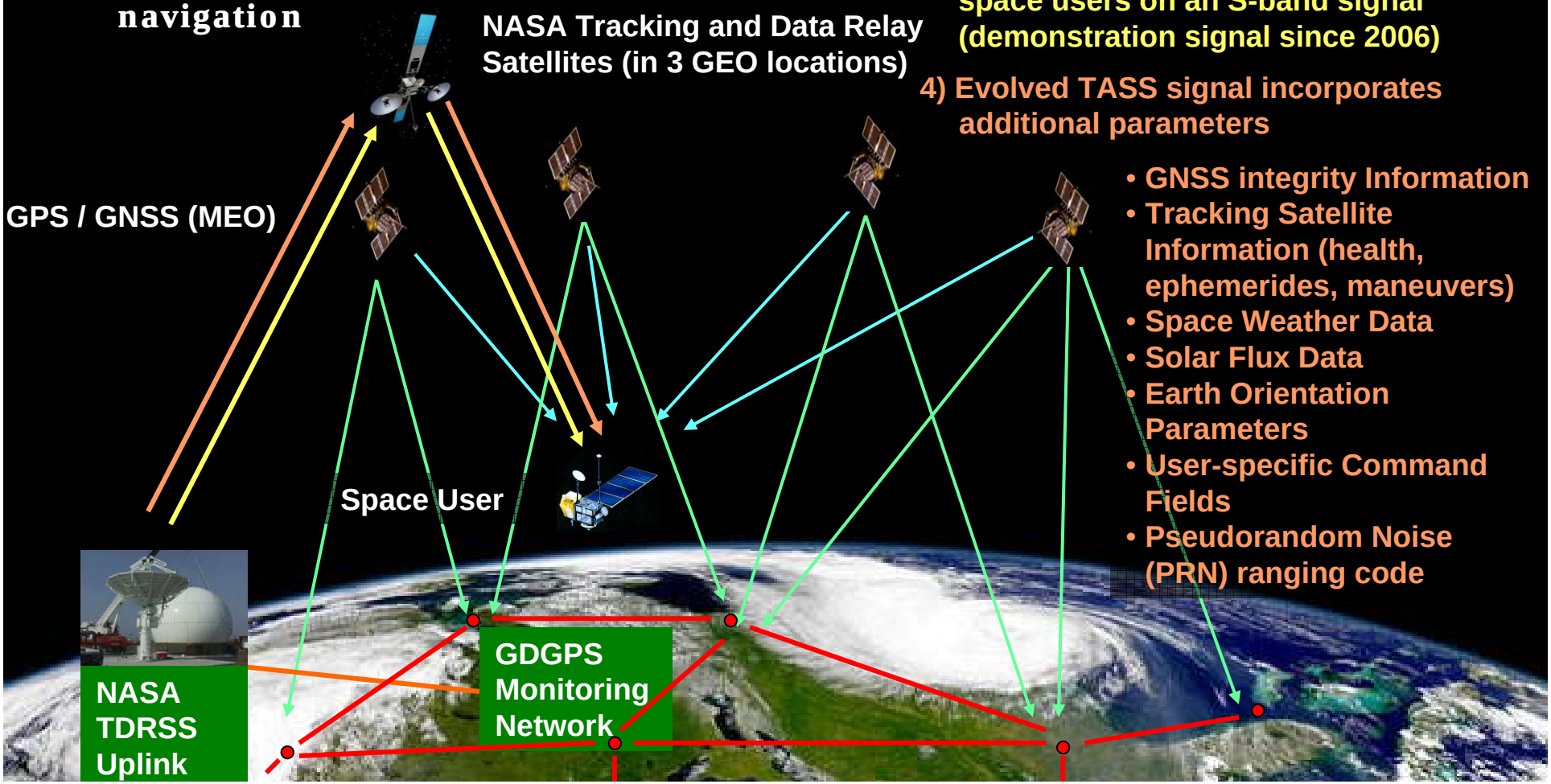
1) User spacecraft acquires GNSS signals

2) A ground network monitors GNSS satellites

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

4) Evolved TASS signal incorporates additional parameters

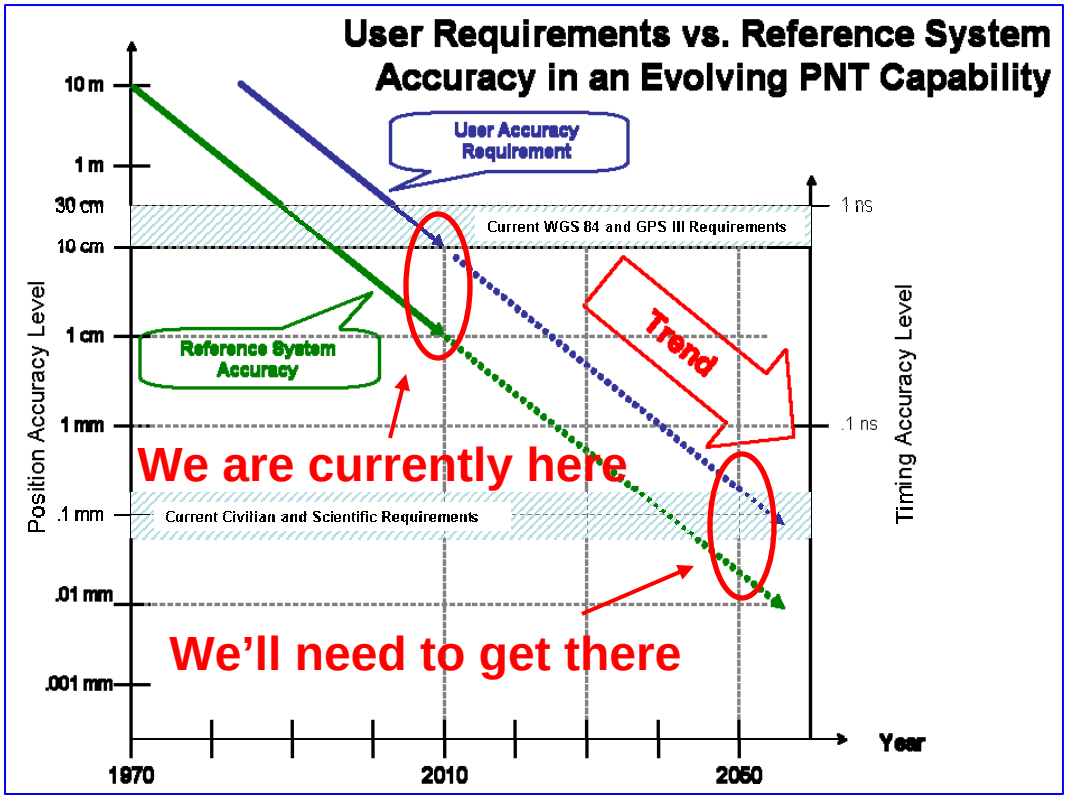
- **GNSS integrity Information**
- **Tracking Satellite Information (health, ephemerides, maneuvers)**
- **Space Weather Data**
- **Solar Flux Data**
- **Earth Orientation Parameters**
- **User-specific Command Fields**
- **Pseudorandom Noise (PRN) ranging code**

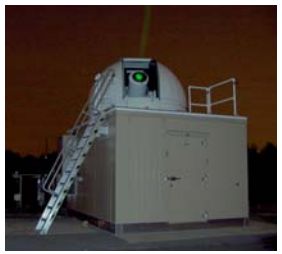


Activity Area: GNSS Reference Frame Evolution (Supporting Evolving Space User Needs)

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

Closing Remarks

- NASA and other space users rely on GNSS as a critical component of space navigation infrastructure over expanding range of orbital applications
- The space user community remains vulnerable unless the space user requirements are explicitly stated for GNSS systems
- GPS Space Service Volume example;
  - Space user requirements are already identified by provision of service in defined volumes based on altitude
    - Terrestrial Service Volume (TSV): surface to 3,000 km
    - Space Service Volume (SSV)
      - Medium Earth Orbit (MEO): 3,000 to 8,000 km
      - High Earth Orbit / Geostationary Earth Orbit (HEO/GEO): 8,000 to 36,000 km
  - NASA and the Air Force are collaborating to define the parameters that best define GPS services within the SSV
- Interoperability for all space users will be enhanced if all GNSS PNT service providers implement Space Service Volume requirements and operational capabilities similar to those of GPS