Impact of SLR tracking on GPS

Position Paper presented at the
ILRS Workshop on SLR tracking of
GNSS constellations

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Overview

- Current status
  - Satellite constellation
  - Retro-reflector, CoM offset
  - SLR network

- SLR data reduction
  - Bias corrections

- Analysis to date
  - Orbit validation results
  - SLR range residuals

- Summary of current status
- Potential benefits
- Future prospects
- Recommendations
Current status

• Retro-reflector arrays installed on two GPS satellites
  – GPS SVN 35 (PRN 05), Block IIA
    • launched August 1993
    • deactivated April 2009
  – GPS SVN 36 (PRN 06), Block IIA
    • launched March 1994
    • still in service

Satellite constellation

Current SLR installation on GPS II constellation
GPS retro-reflectors

- Purpose: Test of POD
- Dimensions: 239 mm × 194 mm × 37 mm, mass 1.27 kg
- 32 fused-quartz corner cubes in alternating rows of four and five
- Built by the Russian Institute for Space Device Engineering
- Design similar to GLONASS satellites retro-reflectors, but total reflecting area smaller

See Degnan, J.J. and E.C. Pavlis [1994]
CoM moves as fuel is expended

CoM expected to move by -4.6 mm in Z direction over life of satellite

Z difference of 2 mm reflects sat.-specific CoM of the SV (due to fuel)

CoM accuracy is about 3 mm

Offsets last updated in 2006 (add’l adapter plate now accounted for)
Current status  SLR network for GPS tracking

- Only limited set of SLR stations (~20/56) capable of tracking high GPS satellites
- ILRS Tracking Schedule (Night tracking only)
SLR data reduction  ■■■  Bias corrections (1/2)

- SLR observation bias corrections generally not applied by GPS analysts using SLR for validation or combination
- For “non-ILRS” analysts it is difficult to find out which biases should be applied in SLR data analysis
SLR data reduction  ■■■  Bias corrections (2/2)

Information provided on the ILRS web page

- **Data correction Sinex file**, in principle very nice solution, easy to apply, **BUT**
  - last update 2003!
  - should include **Range**, **Time**, **Pressure**, and **Stanford counter biases**, but does not include **S**
  - in many cases for the biases **only the validity periods** are given, but no actual values

- **Stanford counter corrections** (separate table)
- **Range corrections for Herstmonceux** (separate table)
- Independent validation of GPS orbits providing important information about
  - radial orbit accuracy
  - inter-system biases
  - orbit modeling problems
- Combination studies: GPS orbit estimation based on GPS and SLR observations (Zhu et al. [2007], Urschl et al. [2007])
  - until now no orbit improvement, due to limited amount and poor distribution of SLR data (temporal and geographical)
  - potential exists for GPS orbit improvement
Typical SLR range residuals for IGS final orbits

- 1-2 cm RMS
  - compares with ~1 cm RMS for SLR long-arc tracking of Lageos
  - residuals have improved due to orbit improvement
- 1.5-2.5 cm range bias reflecting
  - AC orbital scale analysis difference (range of +/-1.3 cm)
  - possible albedo mismodeling
  - possible CoM offset mismodeling

based on data of 2007, Springer [2007]
Analysis to date  GPS orbit validation (2/3)
for AC final GPS orbits
Deficiencies in a priori solar radiation pressure model found by Urschl et al. [2007]

- ROCK model [Fliegel et al., 1992] causes large residuals close to eclipse seasons
- CODE model [Springer et al., 1999] reduces systematic behavior
Analysis to date  SLR range residuals (1/3)
as function of satellites’ position wrt Sun

ROCK a priori SRP model
Analysis to date

SLR range residuals (2/3)
as function of satellites’ position wrt Sun

CODE a priori SRP model

Elevation of sun above orbital plane

\[ \beta (\text{deg}) \]

\[ u (\text{deg}) \]

Argument of latitude wrt sun

(cm)

-10 0 10

-90 60 30 0 -30 -60 -90 0 60 120 180 240 300 360
- SLR and GPS agree very well!
- Only a small bias (~1.8 cm) and eclipse season (attitude) effects remain.
Summary of current status

- SLR has been demonstrated to be viable, valuable and unique technique for independent analysis of GPS orbits through
  - evaluation of GPS error budget
    - provides radial orbit accuracy
    - detection of systematic errors (inter-system biases)
  - verification of orbit models (e.g. solar radiation pressure, albedo, attitude, ...)
- SLR has had very limited impact on GPS orbit improvement in combined data analyses due to sparseness of data
  - only 1-2 satellites with retro-reflectors, insufficient SLR stations, fragmentary data
- Unresolved data processing issues regarding bias corrections
- Included in routine ILRS SLR satellite tracking schedule
Potential benefits

Combination of GPS + SLR for GPS orbit determination

- Potential for GPS orbit improvement, but
  - inter-system biases have to be understood and modeled
  - orbit model deficiencies have to be resolved
  - SLR tracking data has to cover most of the orbital arc
    (today there are considerably more SLR sites on the northern hemisphere)

- SLR tracking data for GPS satellites are not used in routine GPS processing by IGS Analysis Centers
  - subject to change?
Potential benefits

Because laser retro-reflectors can be put on nearly any satellite, they provide basis for common observing systems of nearly all satellites

- **Common reference frame** (large amount of “space ties” would enable connections between the reference frames of the different techniques (IDS, IGS, ILRS))
  - tie GPS to ITRF
  - tie GPS to other GNSS
- **Interchangeability and consistency of results**
- **Quality assurance**
- **Improved long-term stability** of GPS data products
Goals for GPS III set by the multi-agency (U.S.) working group in 2007

- Achieve stable geodetic reference frame with accuracy >10 times better than user requirements for positioning, navigation, and timing
- Maintain a close alignment of the WGS 84 and ITRF
- Provide quality assessment capability independent of current “microwave” orbits and clocks
- Ensure interoperability of GPS with other GNSS constellations through a common, independent measurement technique

Reference: GPS III Geodetic Requirements, submitted to IFOR, 13 April 2007 (for Official Use only)
Future prospects

Conclusion of the WG

- SLR most practical, cost-beneficial and effective means of meeting these requirements

Proposal of the WG (in consultation with the ILRS)

- Concept of operations for the ILRS to control and schedule laser ranging to GPS
- Protocol would essentially apply to all GNSS
To take advantage of the potential benefits of SLR there is a need for

- Studies to demonstrate and quantify the potential benefits
- Studies to develop optimal observing strategy
- Improved ILRS tracking network
  - more sites with better geometry
  - better tracking and enhanced data acquisition
- Maintenance of accurate CoM offsets for GPS s/c
- GPS-SLR ties
  - Combining SLR/GPS normal equations may enable accurate space ties.
  - Are ground ties then needed?
To take advantage of the potential benefits of SLR there is a need for

- Greater number of GPS s/c with retro-reflectors
  - For science application: number not yet determined
  - Consensus of U.S. inter-agency working group: every GPS III s/c to carry a retro-reflector
Position Paper on Impact of SLR Tracking on GPS

- Yoaz Bar-Sever, JPL
- Rolf Dach, AIUB
- Jim Davis, CfA
- Claudia Flohrer, ESA
- Tom Herring, MIT
- Jim Ray, NOAA
- Jim Slater, NGA
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