Impact of SLR tracking on GPS

Position Paper presented at the

ILRS Workshop on SLR tracking of GNSS constellations

September 14-19, 2009

Metsovo, Greece

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

Current SLR installation on GPS II constellation

- 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

Current status

GPS retro-reflector planar array

- 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

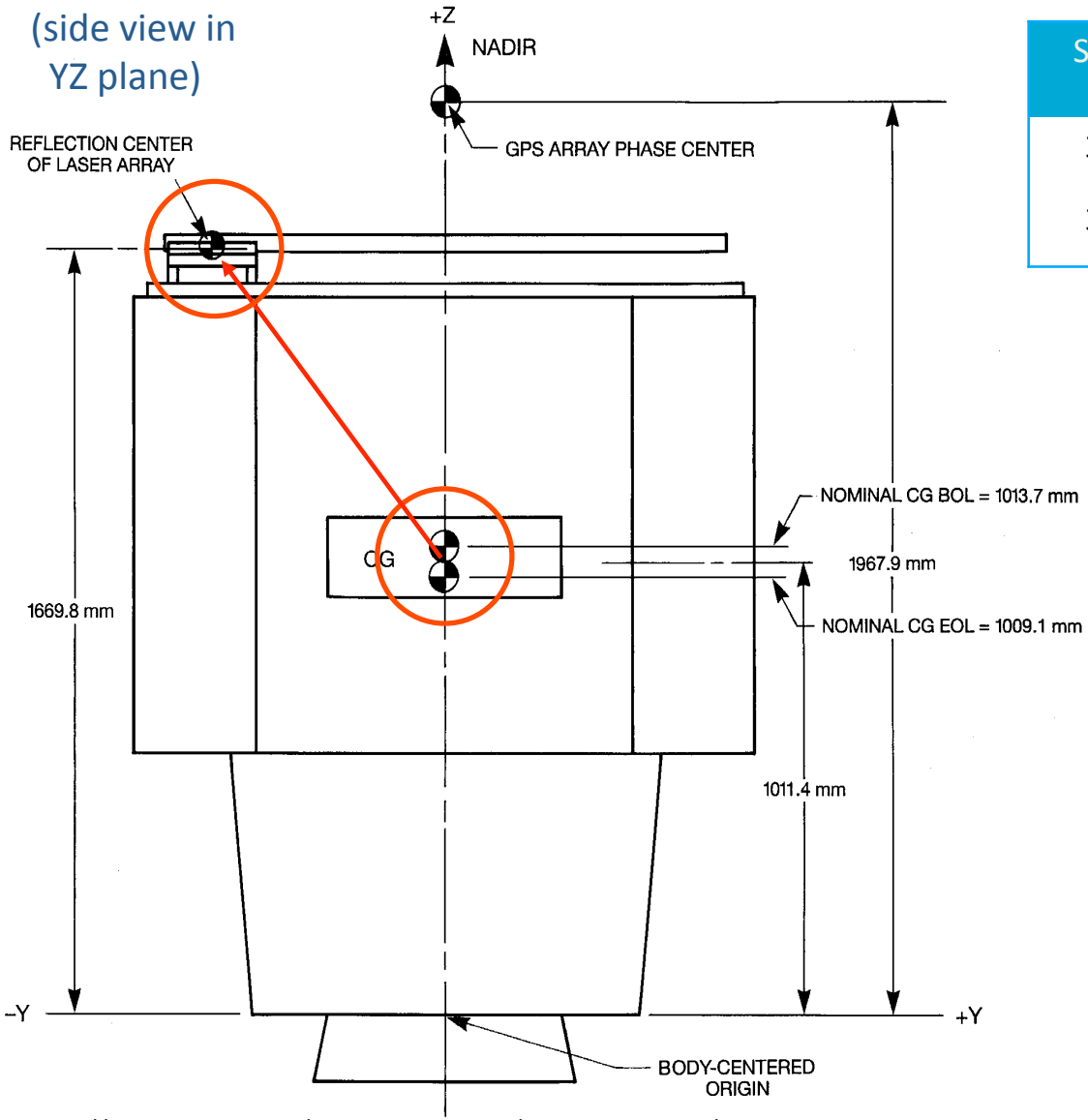
http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/gp35_reflector.html

- See *Degnan, J.J. and E.C. Pavlis* [1994]

Current status

GPS array CoM offsets

(side view in YZ plane)



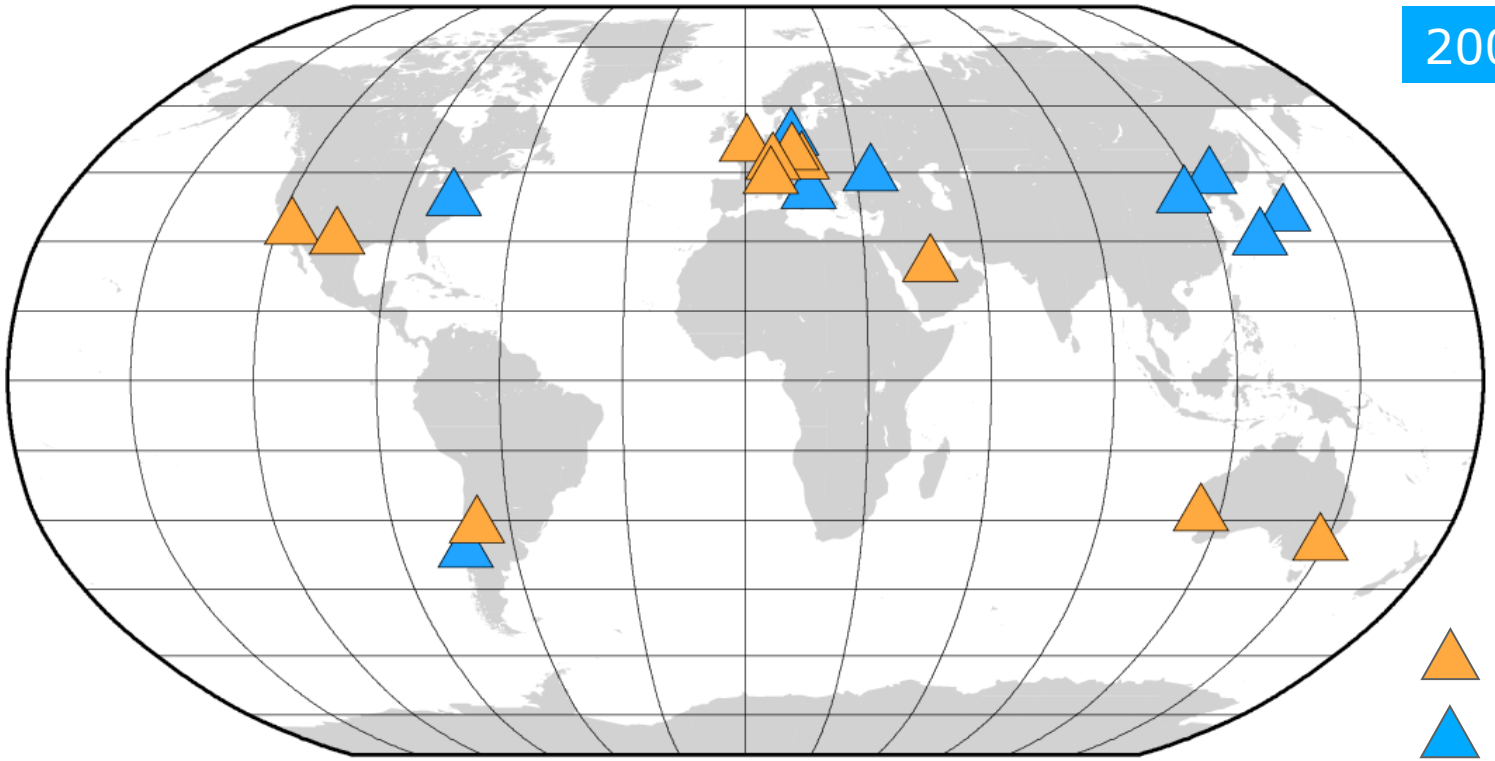
SVN	X offset (mm)	Y offset (mm)	Z offset (mm)
35	862.58	-524.51	669.5
36	862.58	-524.51	671.7

Davis and Trask [2007]

- 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)

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/gp35_com.html

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)

Analysis to date

SLR observations were used so far for

- 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

Analysis to date ■■■ GPS orbit validation (1/3)

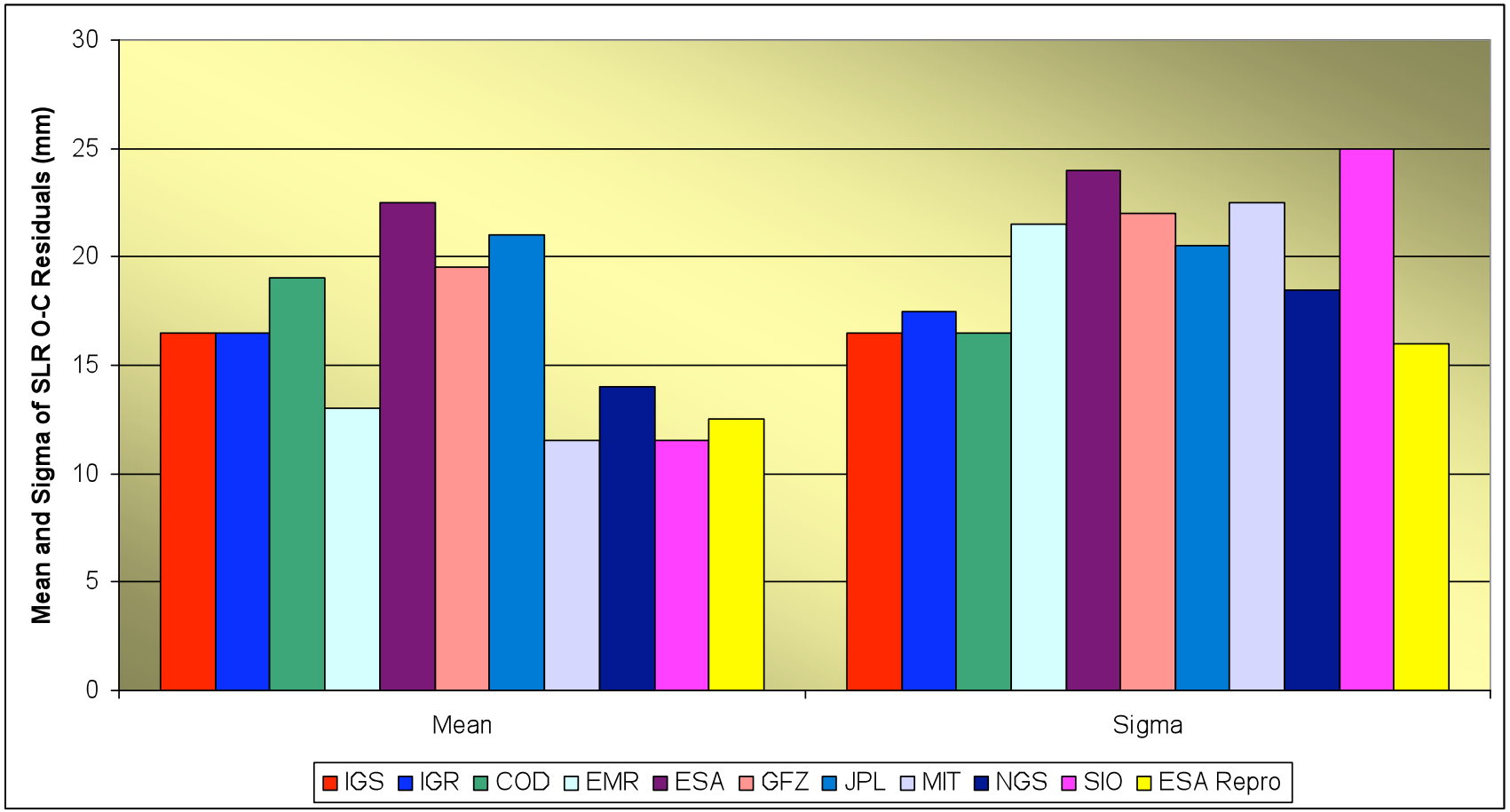
Typical SLR range residuals for IGS final orbits

based on data of 2007, *Springer* [2007]

- 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

Analysis to date ■■■ GPS orbit validation (2/3)

for AC final GPS orbits



Analysis to date ■■■ GPS orbit validation (3/3)

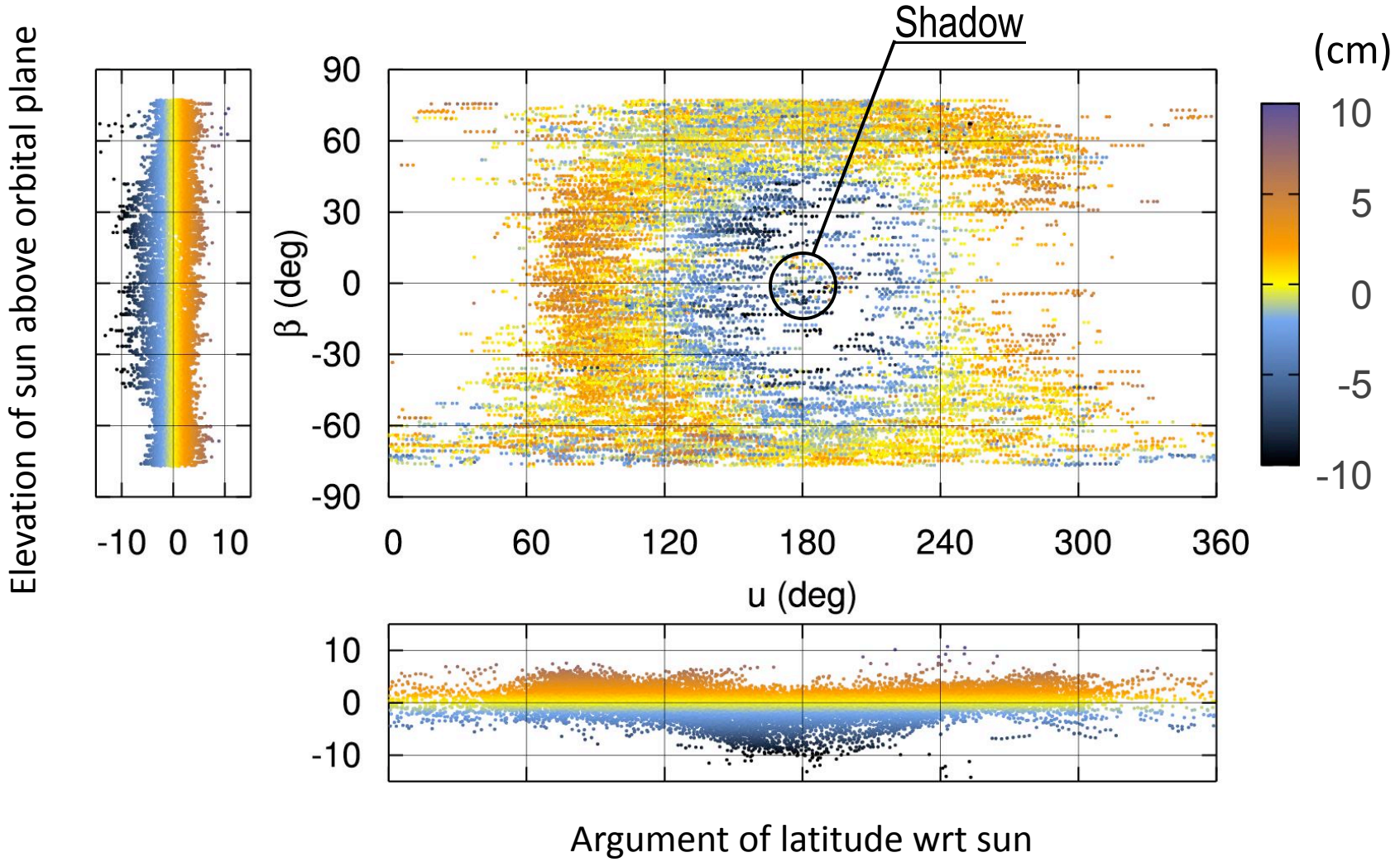
Detection of GPS orbit modeling problems

- 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)

ROCK a priori SRP model

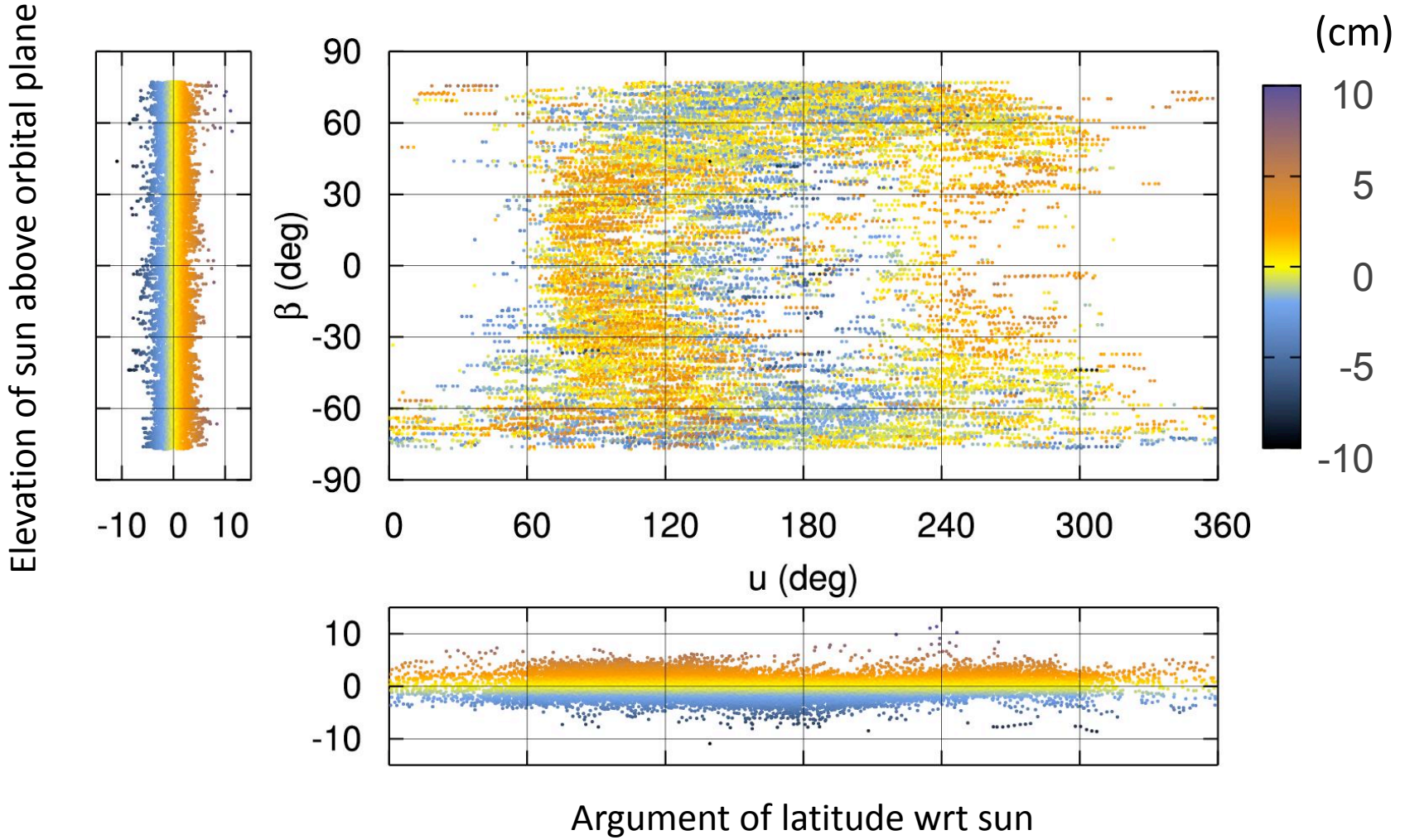
as function of satellites' position wrt Sun



Analysis to date ■■■ SLR range residuals (2/3)

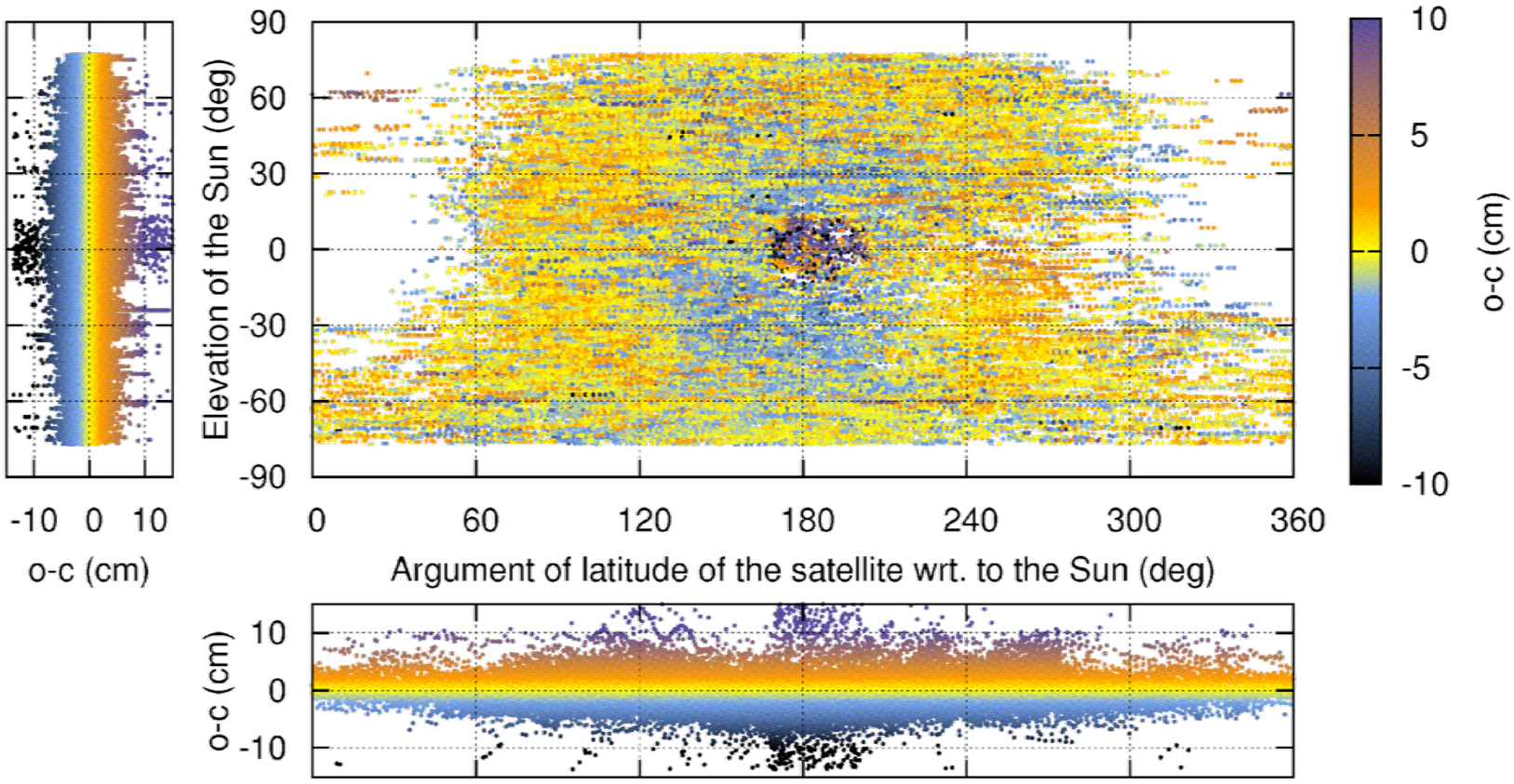
CODE a priori SRP model

as function of satellites' position wrt Sun



Analysis to date ■■■ SLR range residuals (3/3)

based on reprocessed ESOC orbit series 1995.0 – 2009.0



- 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 (1/2)

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 (2/2)

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

Future prospects (1/2)

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 (2/2)

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

Recommendations (1/2)

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?

Recommendations (2/2)

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

Contributors

Position Paper on Impact of SLR Tracking on GPS

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