GNSS satellite attitude characteristics during eclipse season

F. Dilssner[1], T. Springer[1], J. Weiss[2], G. Gienger[1], W. Enderle[1]
[1]ESA/ESOC, Darmstadt, Germany
[2]JPL, Pasadena, USA

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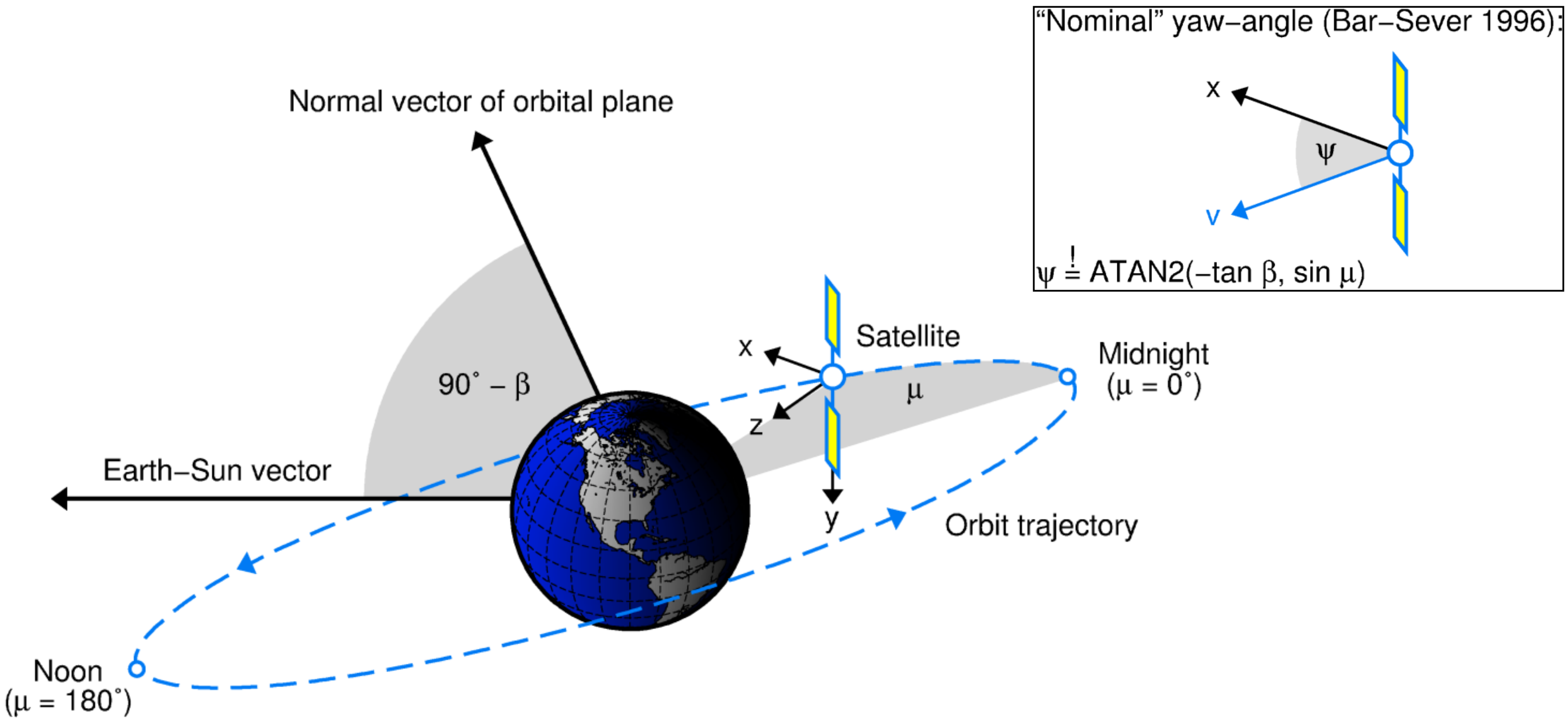
Outline

- Introduction
- Reverse kinematic PPP technique
  - Processing scheme
  - Accuracy assessment
- Satellite yaw attitude characteristics
  - Noon-/midnight-turn maneuvers
  - GPS IIA post-shadow maneuver modeling issues
- Conclusions

Attitude constraint: Sun-Earth-pointing

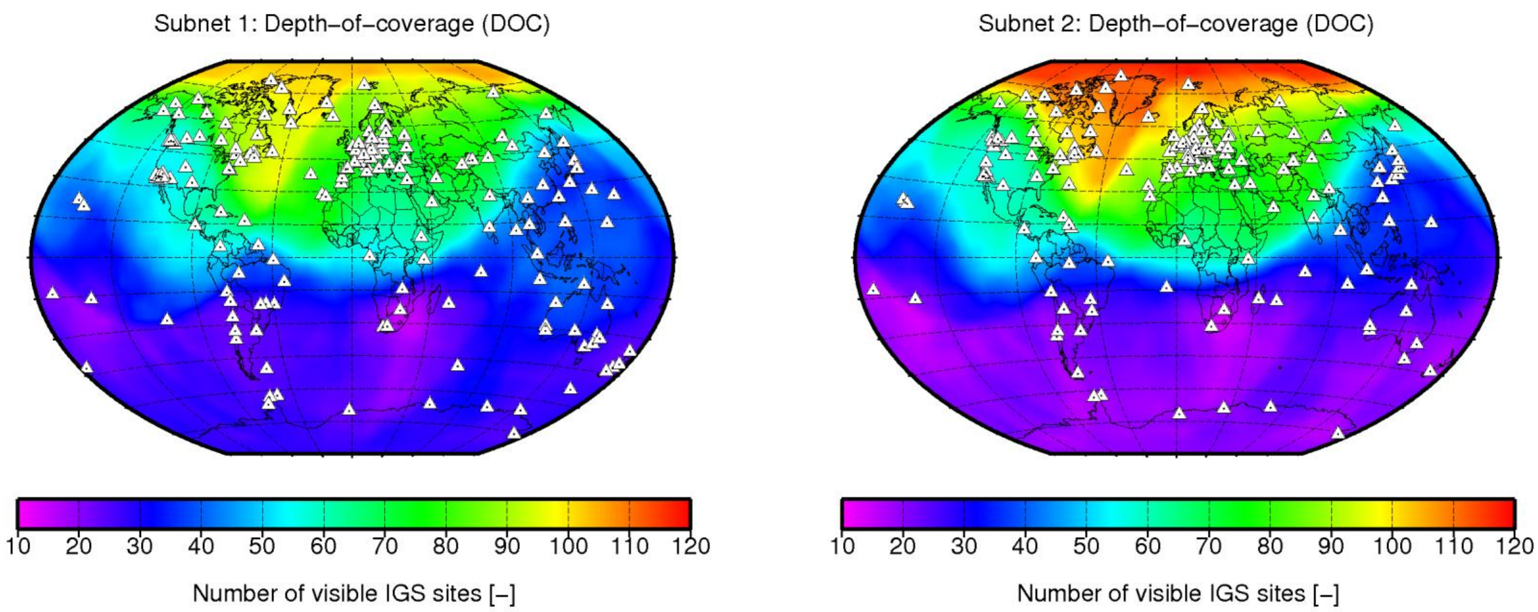


β = elevation of the Sun with respect to orbital plane; μ = geocentric orbital angle between satellite and midnight

Reverse Precise Point Positioning (PPP)

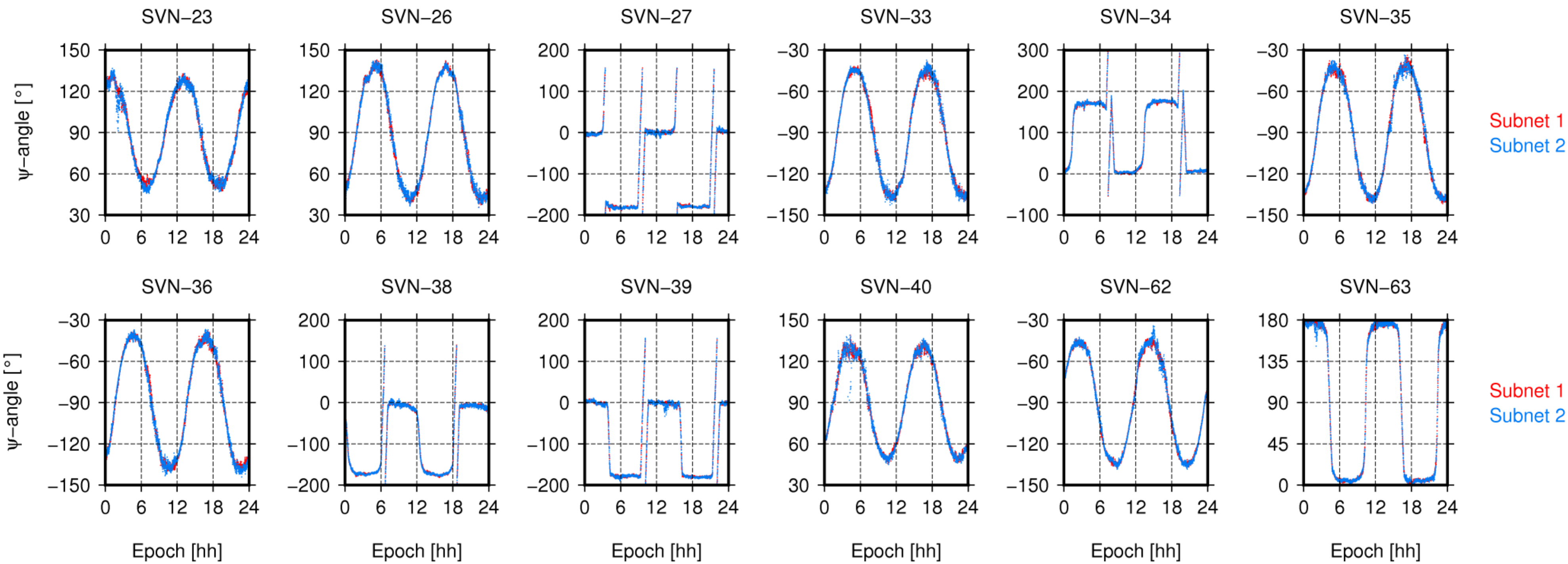
Parameter	Step 1: POD solution	Step 2: Reverse PPP
Data	undifferenced GPS/GLONASS phase and code observations	
Stations / Satellites	175 / 55	175 / 1
Sampling rate	5 min orbit, 30 sec clock	30 sec
Cut-off angle	10 deg	10 deg
Orbit	Initial positions and velocities; 3 constant plus 2 periodic RPRs; 3 along-track CPRs	From POD solution
Earth rotation	Daily pole coordinates and drifts, UT1 and LOD are estimated	From POD solution
Coordinates	Estimated per day	From POD solution
Troposphere	1-hourly ZPDs / daily gradients estimated	From POD solution
Ambiguities	Resolved (GPS-only)	From POD solution
Station clocks	Estimated per epoch	From POD solution
Satellite clocks	Estimated per epoch	Estimated per epoch
Satellite PCOs	Fixed to igs08.atx	Estimated per epoch
Antenna PCVs	Fixed to igs08.atx	Fixed to igs08.atx

Internal accuracy assessment (1/2)



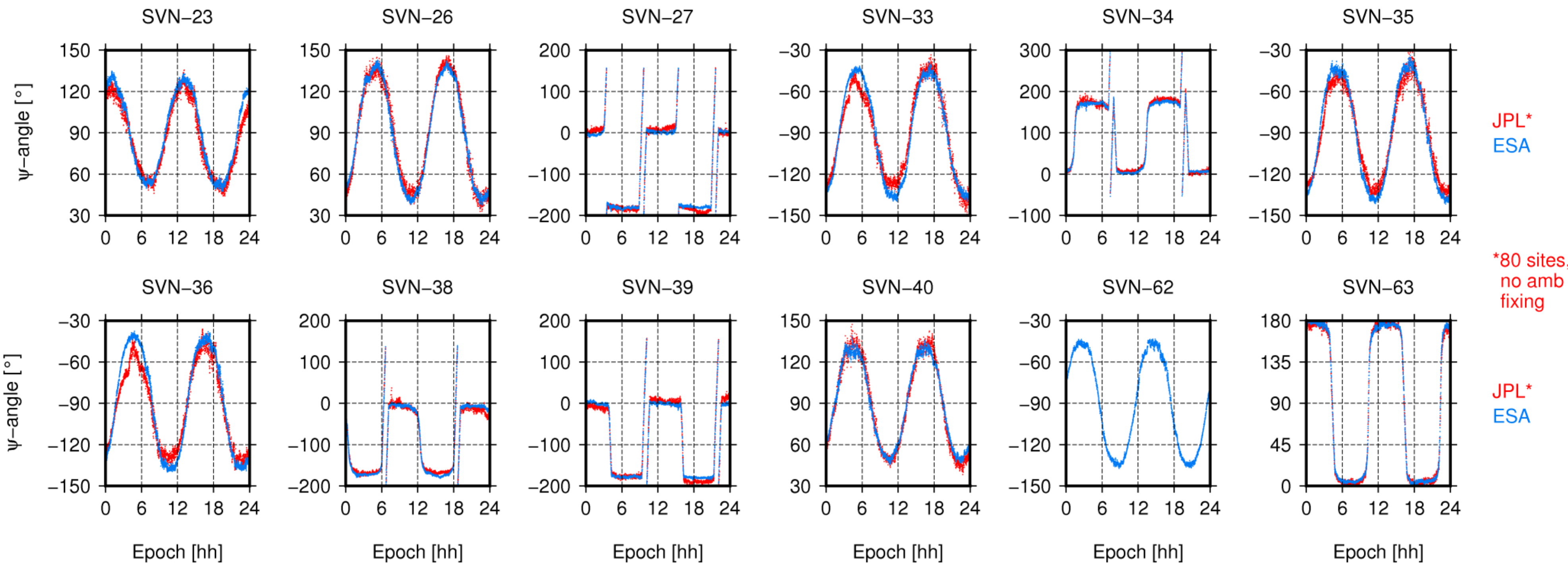
- IGS tracking data from 2012-03-13 for 12 GPS satellites
- Processed in two independent sub-networks consisting of 175 stations each
- Favorable geometry; permanent visibility to any GPS S/C from at least 13 sites
- Comparison of yaw-angle profiles from subnet 1 against subnet 2

Internal accuracy assessment (2/2)



SVN	23	26	27	33	34	35	36	38	39	40	62	63	∅
Beta [°]	-51.7	-42.6	-0.3	43.8	-4.5	41.8	41.8	6.2	1.0	-49.5	45.0	-4.3	-
$RMS_{\Delta\Psi}$ [°]	3.7	2.8	3.2	3.0	3.0	3.1	3.2	3.0	4.0	3.5	2.5	2.8	3.2

External accuracy assessment: ESA vs. JPL



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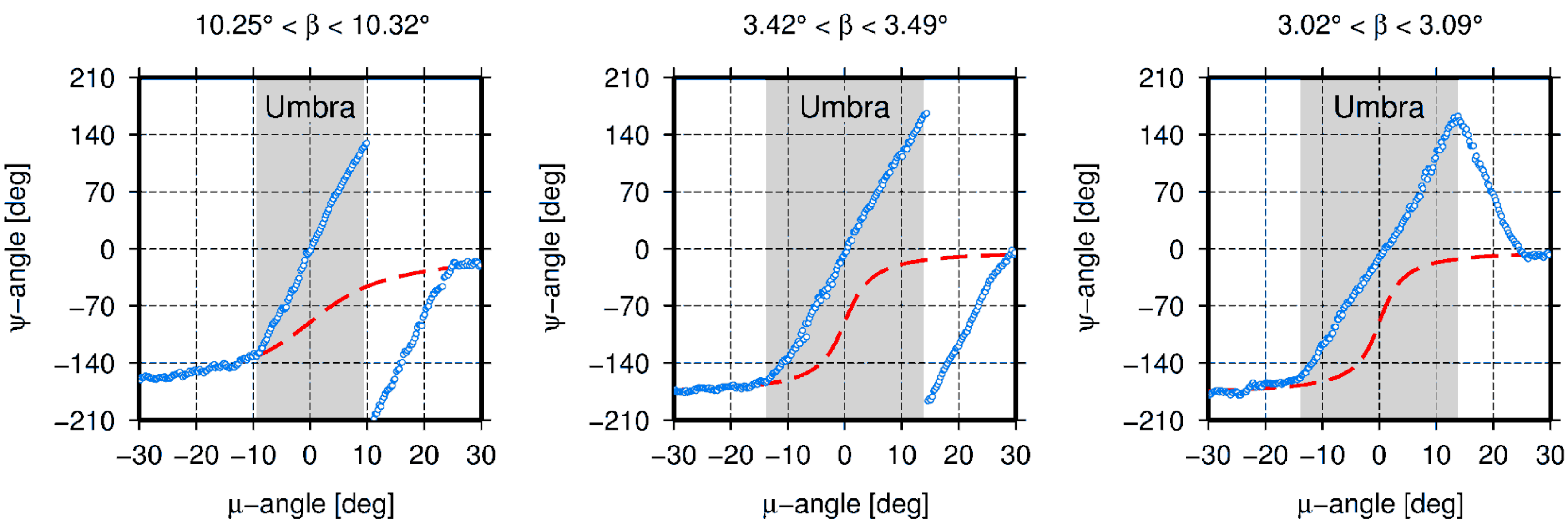
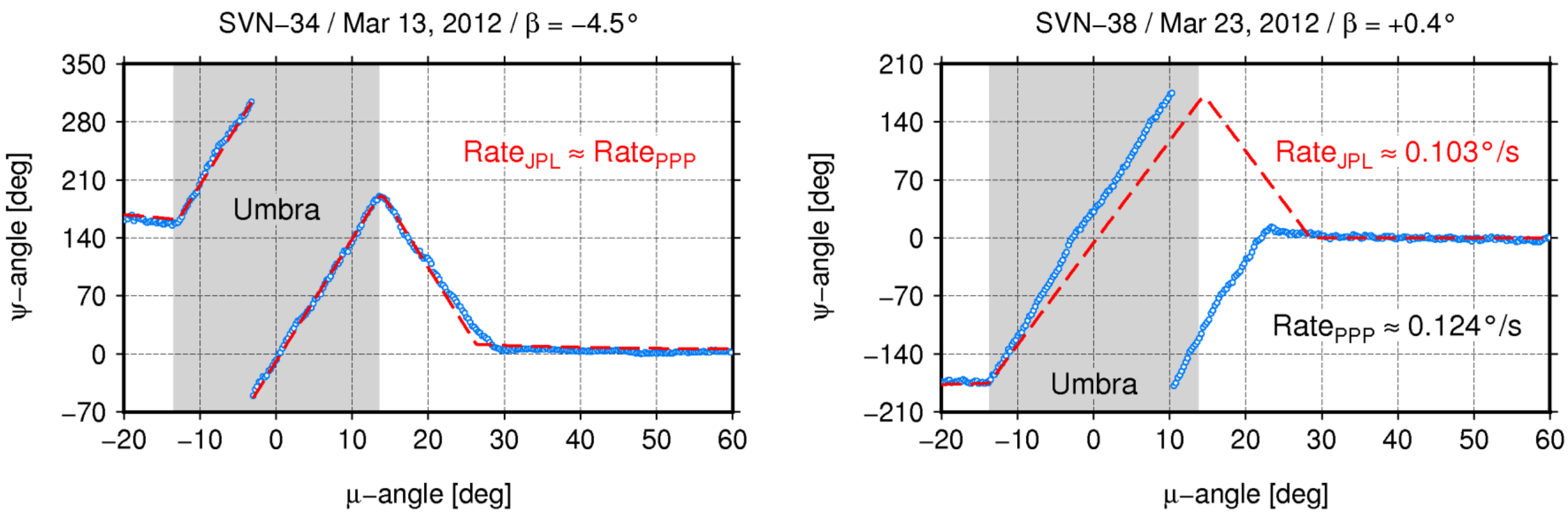
$RMS_{\Delta\Psi}$ [°]	6.7	4.6	7.7	7.4	5.6	6.9	9.0	6.8	8.8	4.5	-	3.0	<u>6.7</u>

GPS IIA midnight-turn maneuver



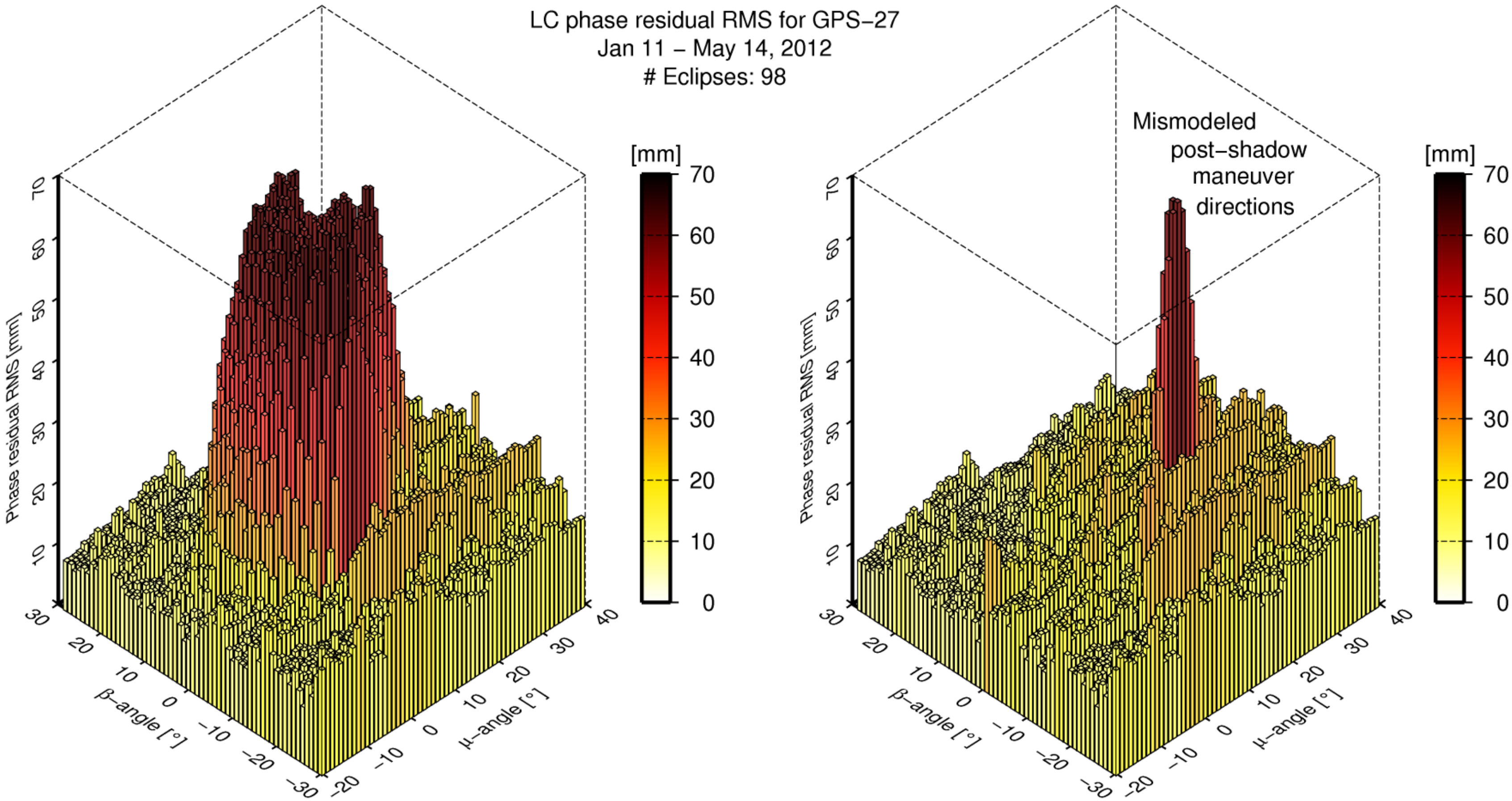
- S/C is rotating around its z-axis with 0.10…0.13°/s for up to 90 min
- Turn direction determined by sign of yaw bias; always positive (+0.5°)
- Yaw rate reversal may occur, depending upon yaw angle at shadow exit
- Determination of post-shadow maneuver particular challenging

Evaluation of JPL's GPS IIA midnight-turn model (1/4)



- Comparison between reverse PPP estimates and JPL attitude model using JPL yaw rate solutions (Bar-Sever, JoG 1996)
- Initial results indicate good agreement (left-hand figure)
- Incorrectly modeled post-shadow maneuver directions in consequence of an underestimated yaw rate parameter found (right)

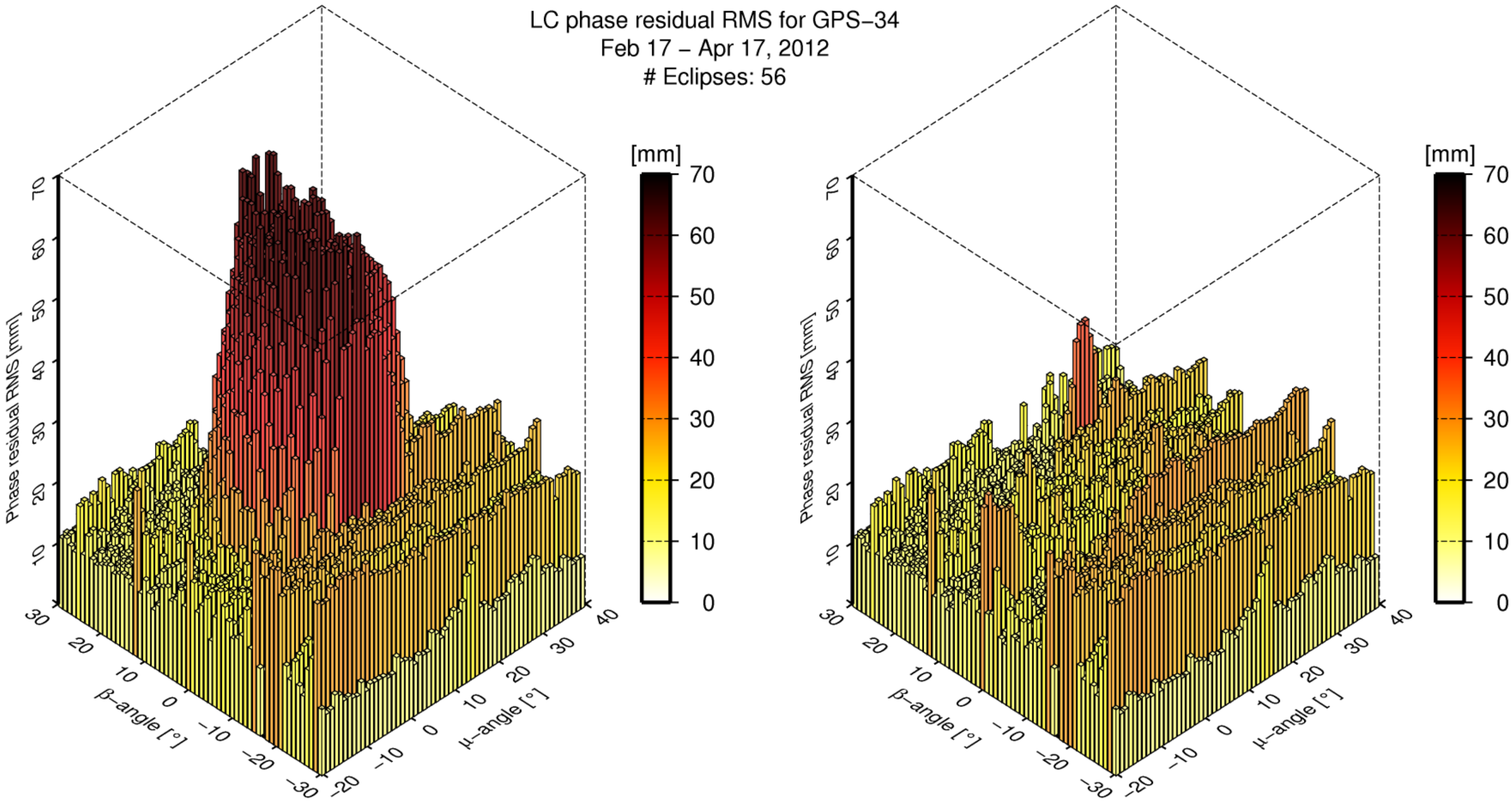
Evaluation of JPL’s GPS IIA midnight-turn model (2/4)



Nominal model applied

JPL model + JPL yaw rates applied

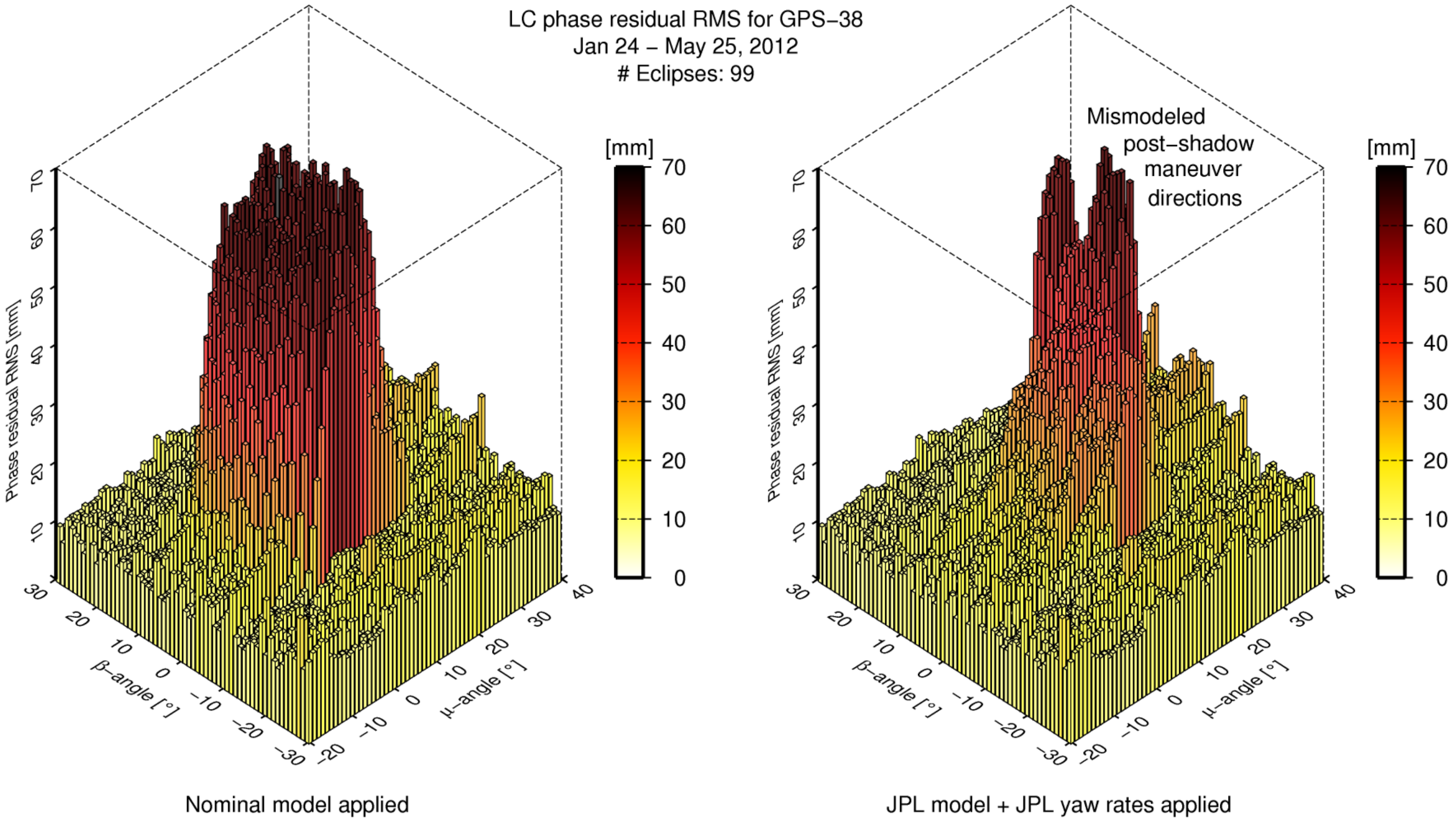
Evaluation of JPL's GPS IIA midnight-turn model (3/4)



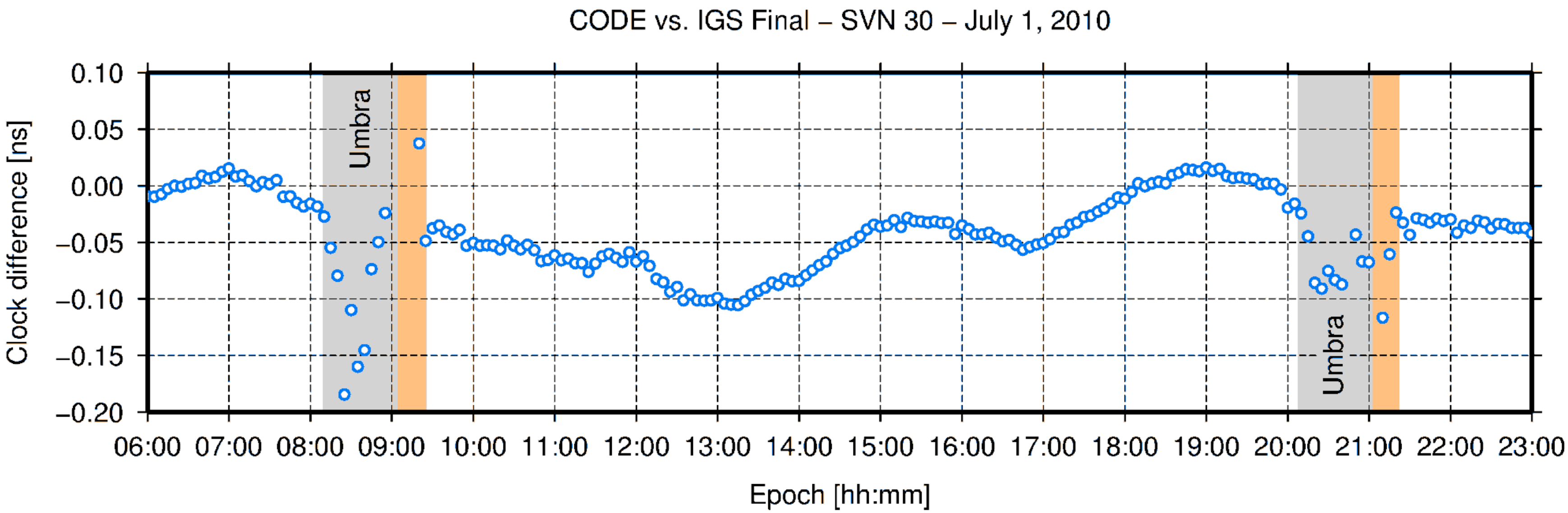
Nominal model applied

JPL model + JPL yaw rates applied

Evaluation of JPL's GPS IIA midnight-turn model (4/4)

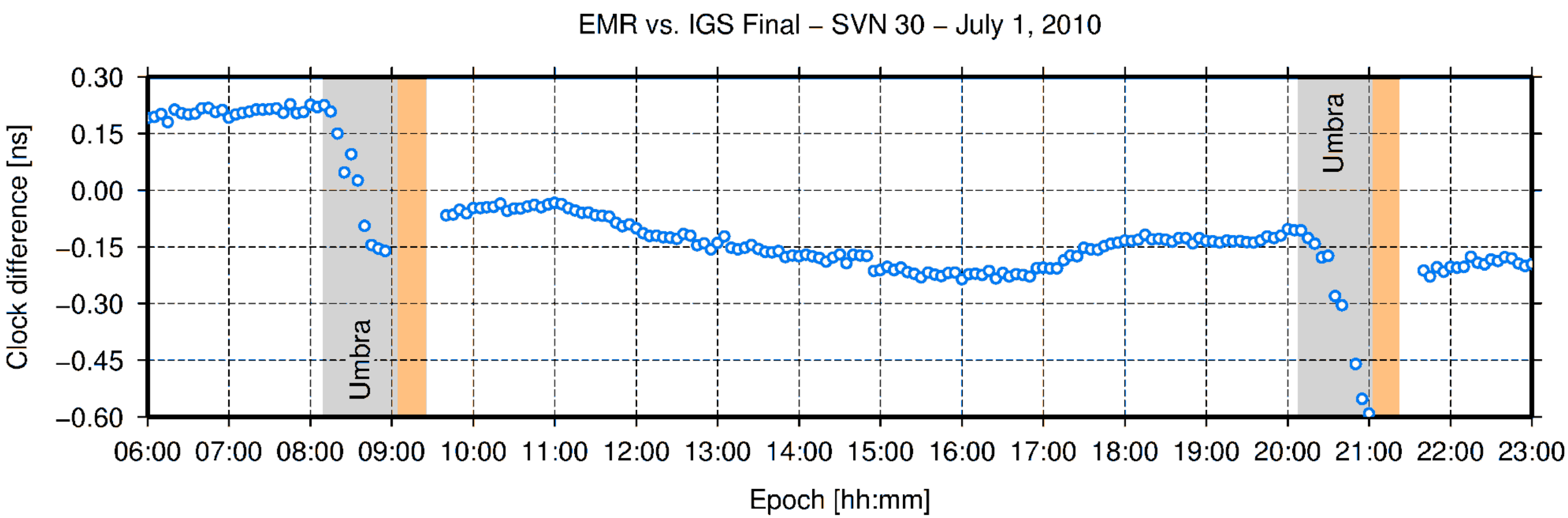


IGS clock solutions for GPS IIA (1/6)



- Inconsistencies among IGS ACs due to different yaw attitude handling
- Three ACs (EMR, GFZ, JPL) solve for yaw rates and use JPL model; the others stick to nominal attitude model
- EMR, GFZ and JPL reject data from shadow exit until 30 min thereafter

IGS clock solutions for GPS IIA (2/6)



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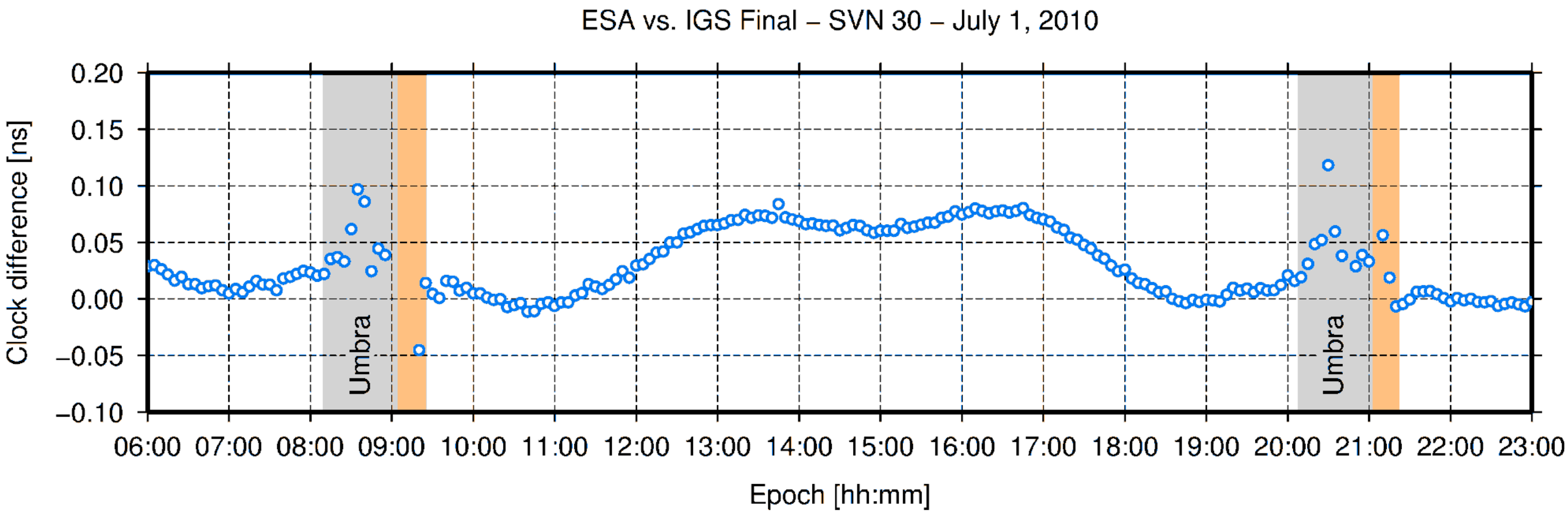

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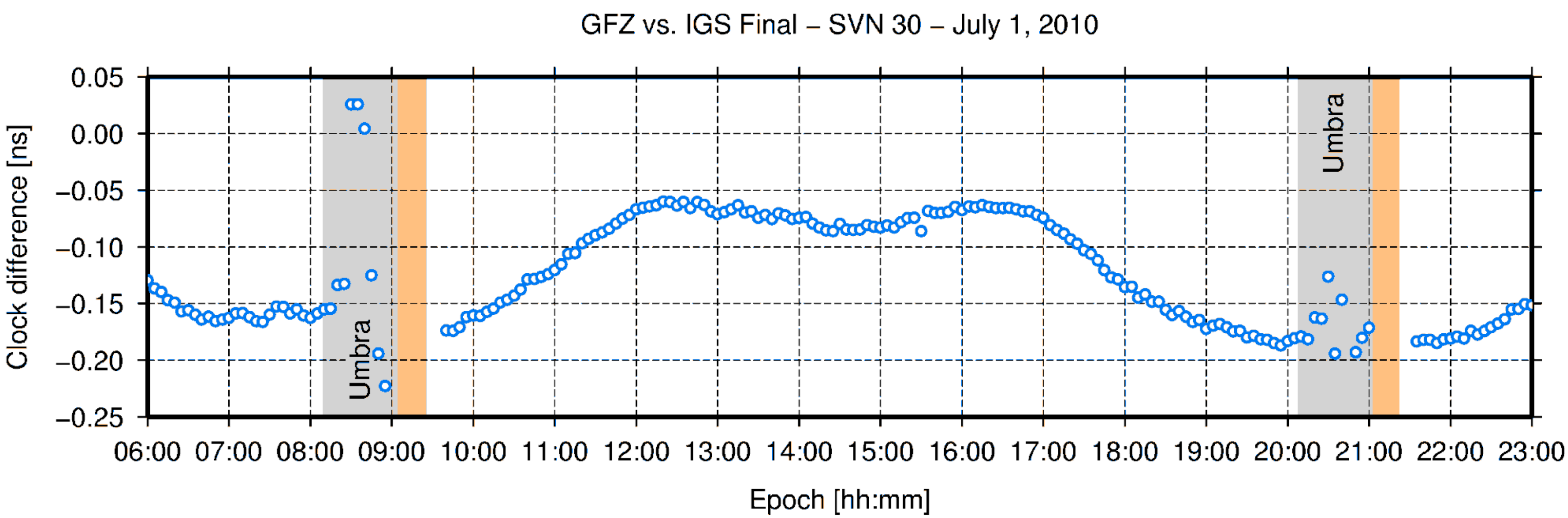

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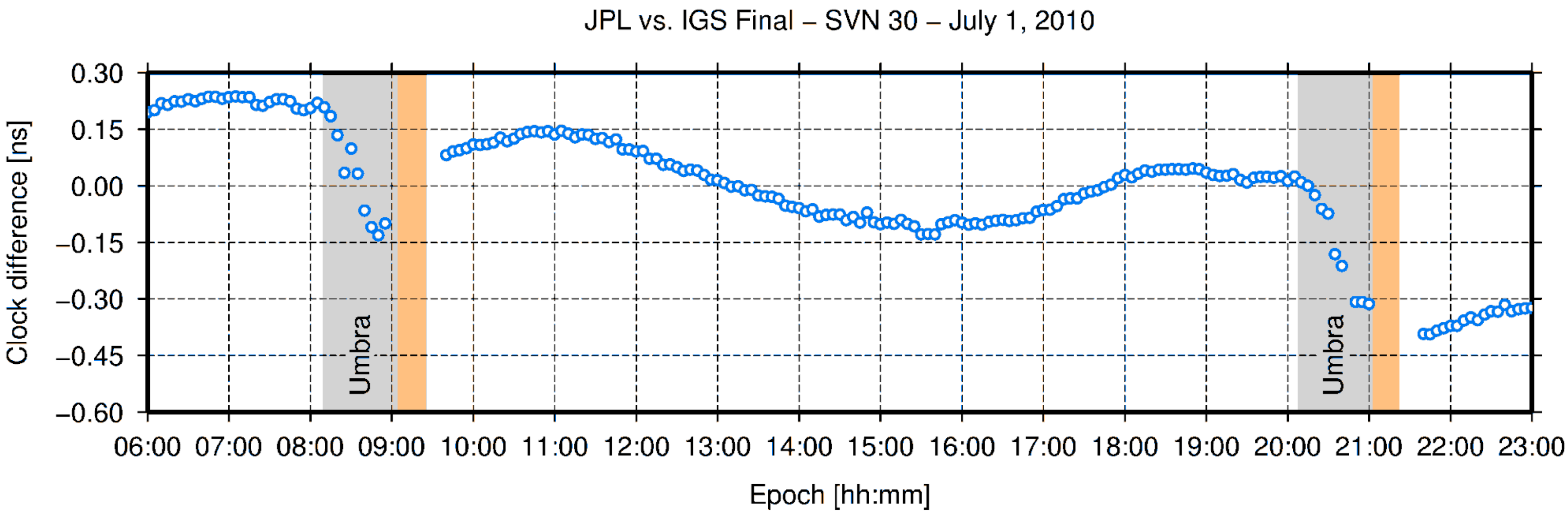
IGS clock solutions for GPS IIA (5/6)



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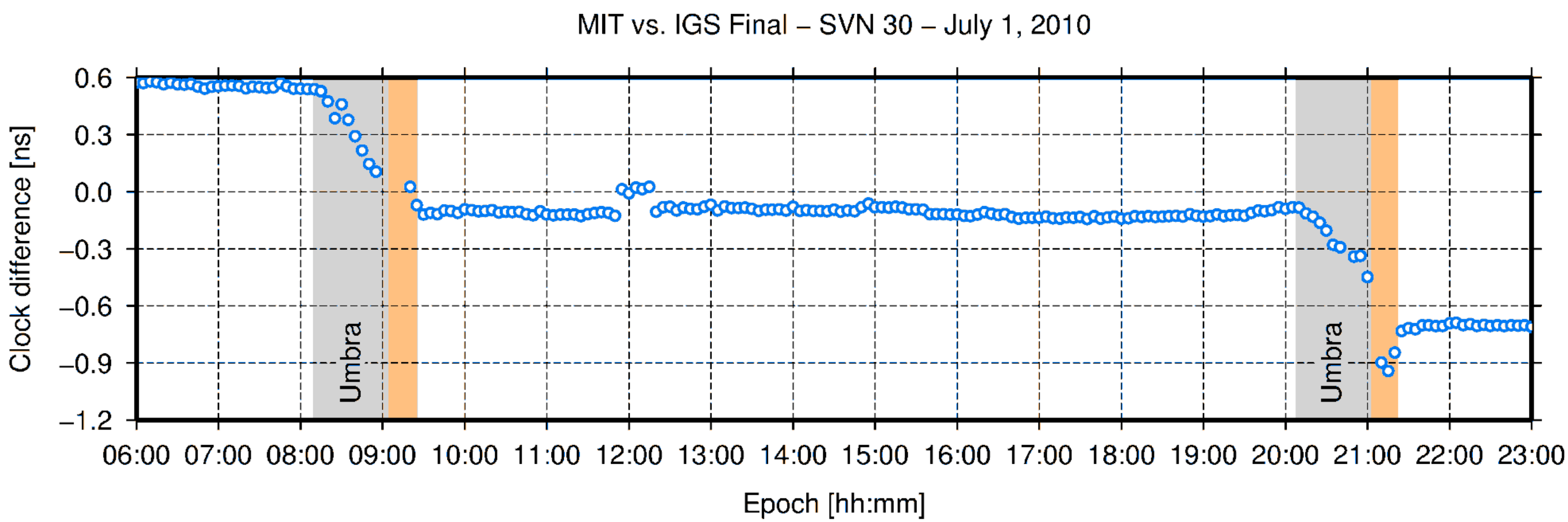
IGS clock solutions for GPS IIA (6/6)



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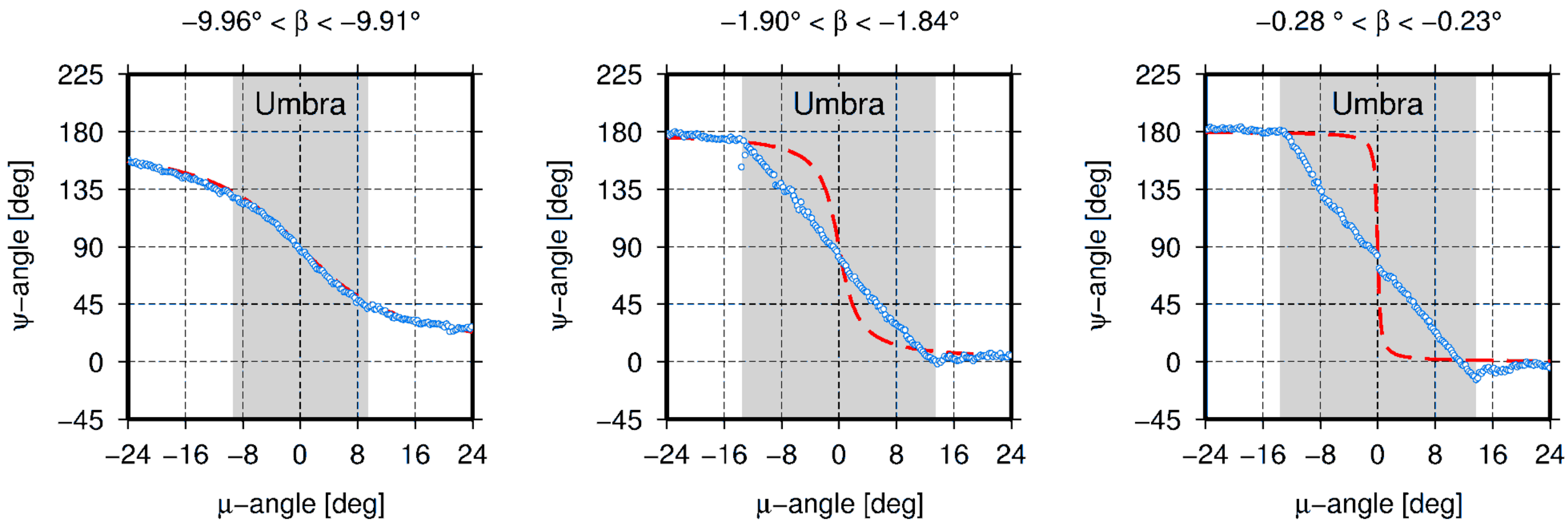
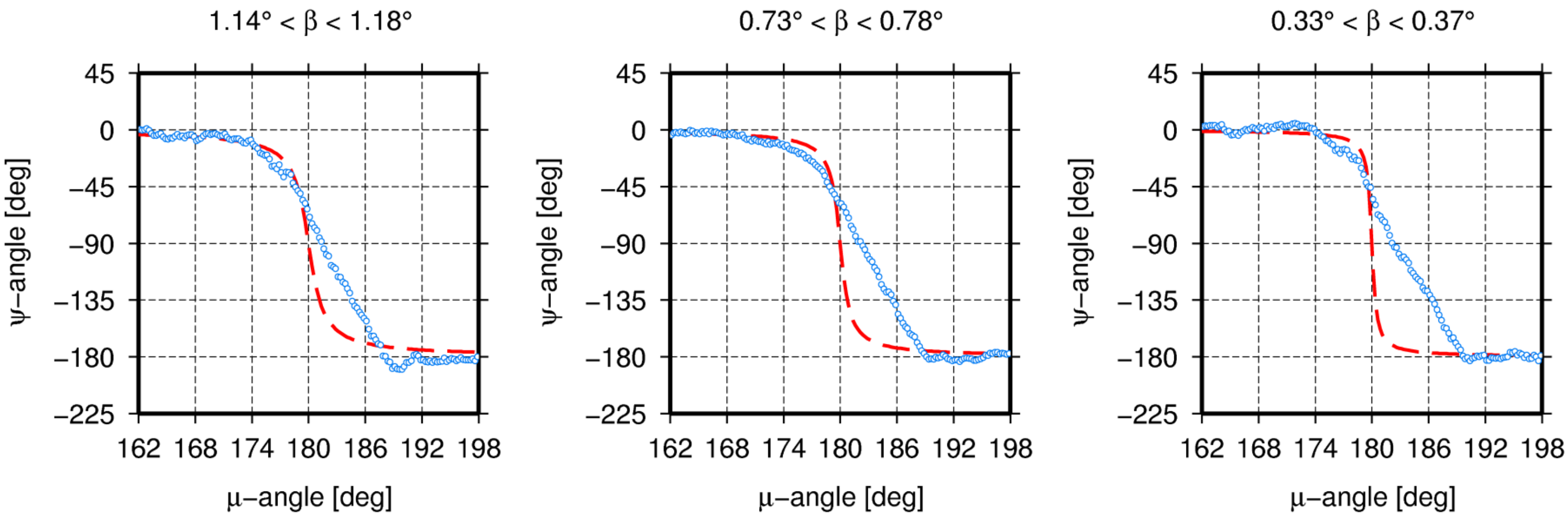
GPS IIF midnight-turn maneuver



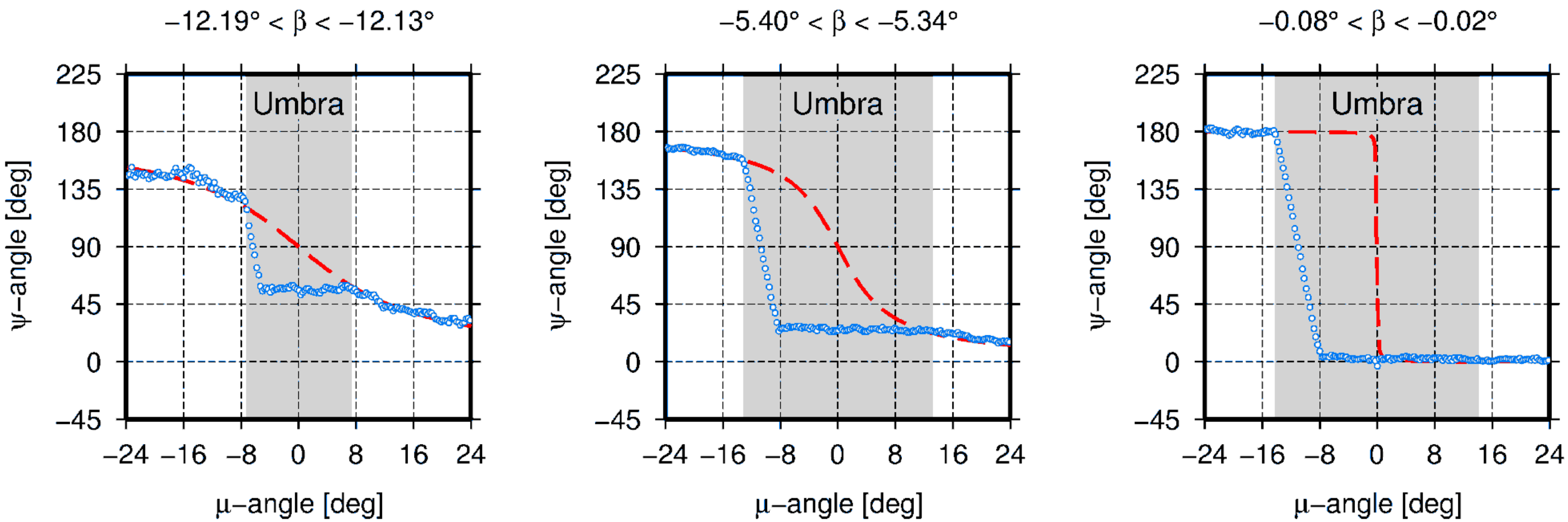
- Turn direction is kept due to yaw bias which is set to have same sign as β
- "Dynamical" yaw rate parameter; can be modeled using 2nd order polynomials
- Model reduces phase residual RMS from up to ±7 cm down to ±1 cm (→ Dilssner et al., AGU Fall Meeting 2011)

GPS IIF noon-turn maneuver



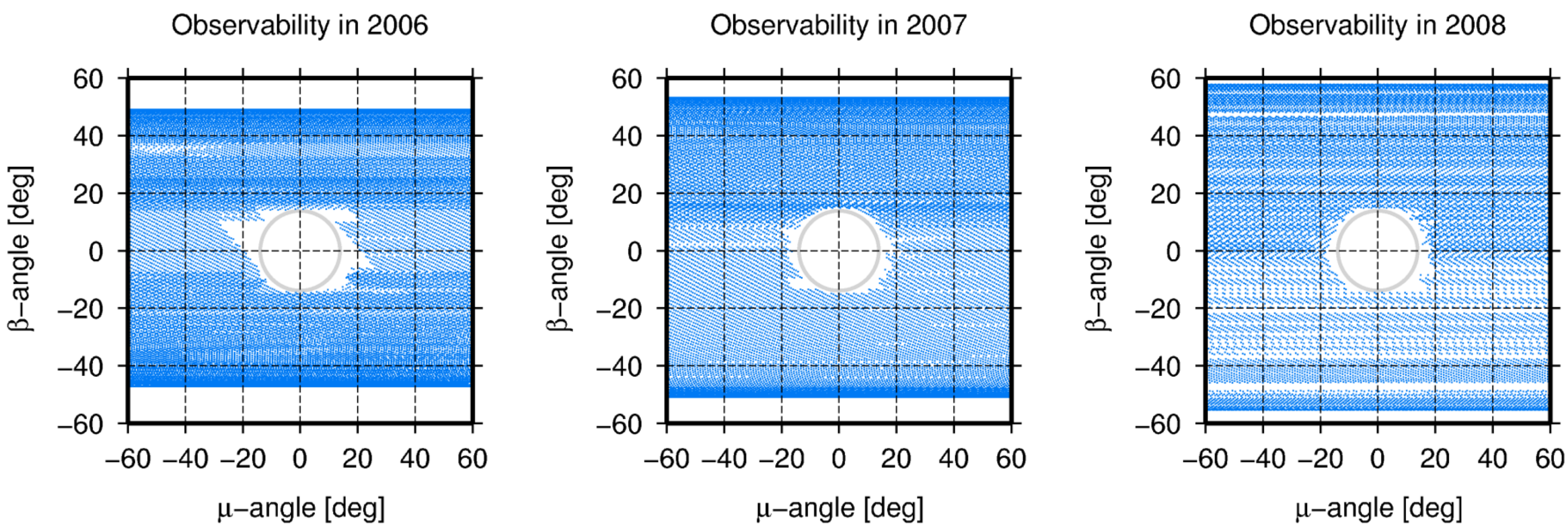
- Noon-turn manoeuvre must be taken into account for |ß| < 4.5º
- Maximum yaw rate similar to GPS IIA rate (R ≈ 0.11°/s)
- Discontinuity at β = -0.9°; delta of 0.01°/s between high and low rate values
- Model implemented into NAPEOS, but not tested thoroughly enough

GLONASS-M midnight-turn maneuver



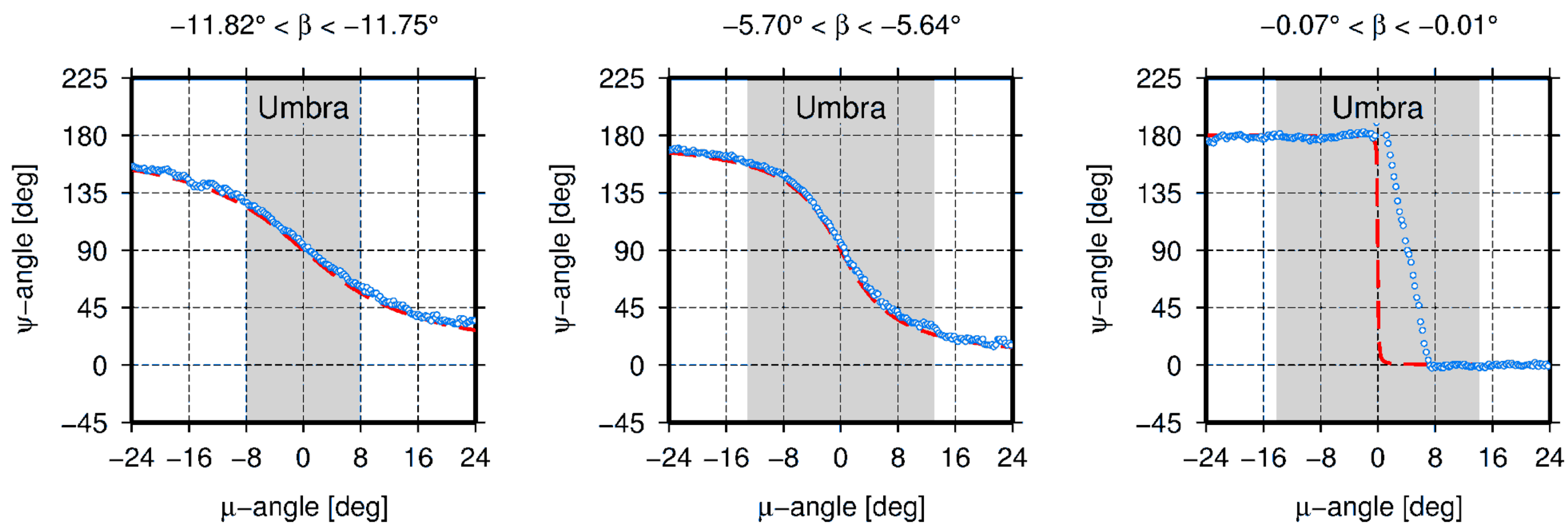
- S/C starts rotating around its z-axis with maximum rate (R ≈ 0.25°/s)
- Turn direction equivalent to nominal rotation direction
- S/C switches into fixed-yaw mode at the end of required midnight-turn
- Model applicable to all GLONASS-M S/C except for SVN 701 and SVN 713

GLONASS-M SVN 701



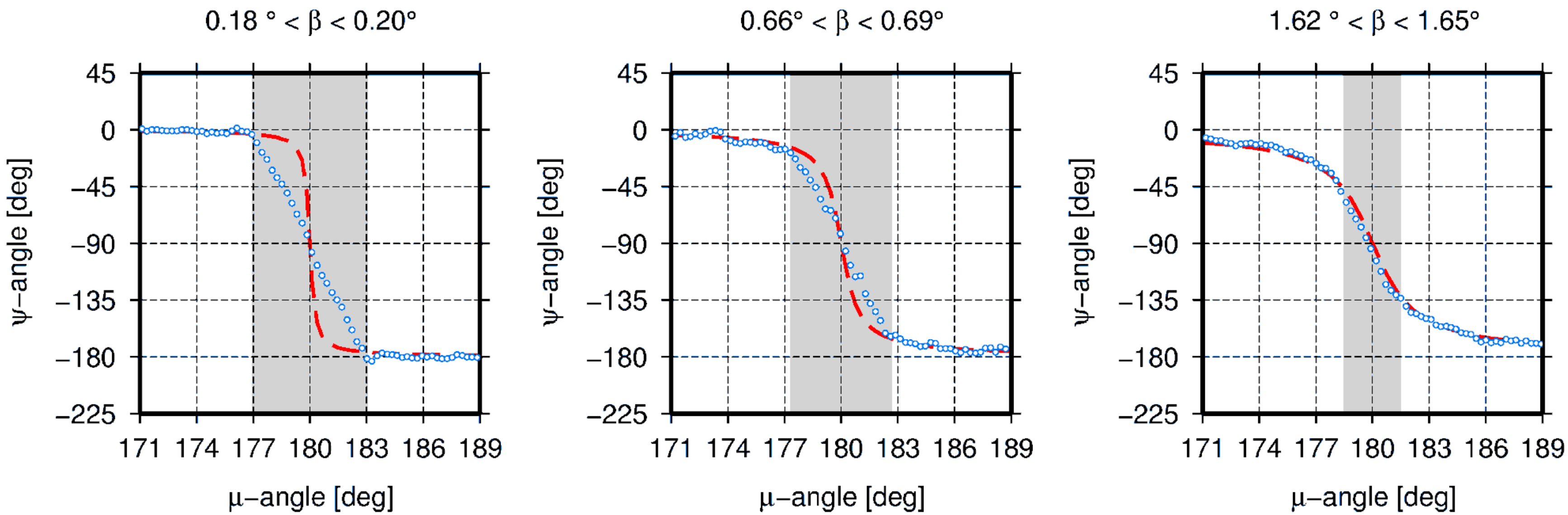
- Second-oldest S/C from GLONASS-M series; launched in Dec 2003
- No tracking data available from IGS network during shadow crossing
- L-band signal apparently turned off/on by system operators as soon as S/C enters/leaves penumbra

GLONASS-M SVN 713



- Satellite keeps nominal yaw attitude in the shadow (cf. GPS IIR)
- Noon- and midnight-turn problem due to limited yaw rate persists
- ACS solar sensors are malfunctioning
- Orbit quality significantly worse compared to other GLONASS-M S/C

GLONASS-M noon-turn maneuver



- Noon-turn manoeuvre must be taken into account for |ß| < 2.0º
- S/C is rotating around its z-axis with 0.25°/s for up to 12 min
- Maneuver starts well before nominal yaw rate exceeds R (≠ GPS) (→ Dilssner et al., Adv. Space Res. 2011)

Conclusions

- Reverse PPP has proven to be a reliable technique for characterizing the yaw attitude behaviour of GNSS satellites during eclipse season
- Technique takes advantage of horizontal antenna phase centre eccentricity; thus it can not be applied to GPS IIR and first-generation GLONASS S/C
- Evaluation of yaw-angle profiles estimated for different GPS S/C under different beta-angles indicates accuracy of ±3 deg
- Insights gained from studying the GPS IIA yaw attitude underline demand for a more reliable post-shadow maneuver model (→ Poster Weiss et al.)
- Consistent yaw attitude models along with consistent model parameters (yaw rates, eclipse angle) should be used by all ACs to avoid inconsistencies in IGS clock products (→ Kouba, GPS Solut 2009)