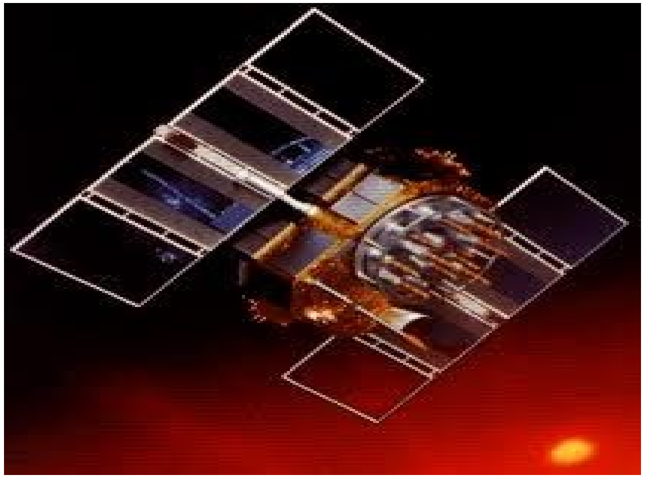
Review of Models for GNSS yaw attitude

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Review of Models for GNSS yaw attitude

Why yaw attitude modeling ?

For high precision GNSS positioning

- Orbit determination
- For correction of phase wind up due to RHCP in orientation of receiver
- Proper measurements (phase and pseudorange)
  due to antenna phase center eccentricity (GPS II/IIA and GLONASS-M)

It can cause 10 centimeters range error

Attitude constraints (in S/C fixed coordinate system):

- y-axis points towards the solar panels, perpendicular to the Sun
- z-axis (yaw) points towards the center of the Earth

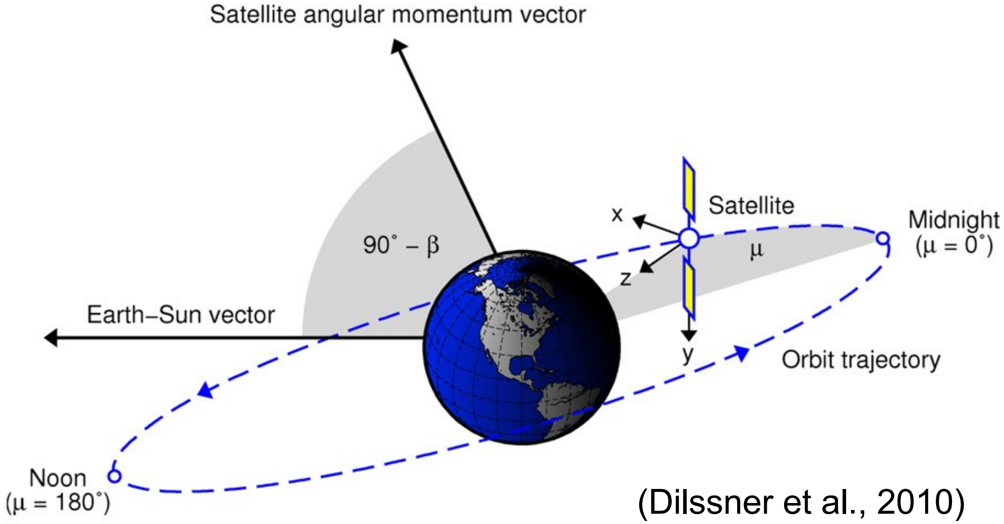
  ==> **satellites rotates around its z-axis (yaw steering)**

Review of Models for GNSS yaw attitude

Terminologies:

Beta (β) : Elevation (acute) angle above the orbital plane.
Rate of beta is about 1 deg/day. Eclipse occurs twice per year

Orbit Angle (μ) : Angle between S/C position vector and orbit midnight grows with the S/C motion and restricted to be [0, 360] deg
$\mu = 180°$ at orbit Noon, $\mu = 0°$ at orbit Midnight



(Dilssner et al., 2010)

Review of Models for GNSS yaw attitude

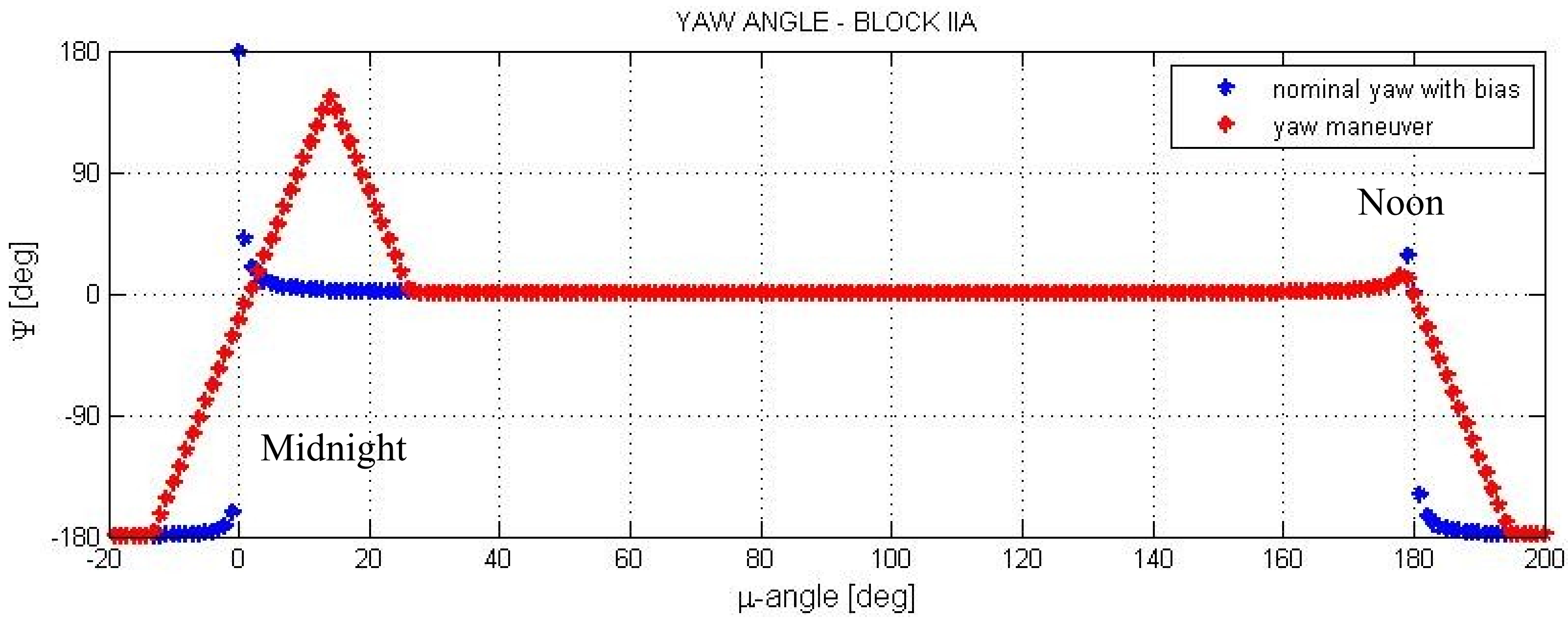
Yaw attitude is splited out into three regimes:

- **Nominal yaw [ψ = atan2(-tanβ, sinμ)]:** most of the time
- **Noon turn maneuver:** around $\mu = 180°$ and $|\beta| < 5°$ for all satellites
- **Midnight turn maneuver:** around $\mu = 0°$ and $|\beta| < 13.5°$
  - **- Shadow maneuver:** for all satellites
  - **- Post shadow recovery:** only for GPS block II/IIA satellites

Review of Models for GNSS yaw attitude

Models:

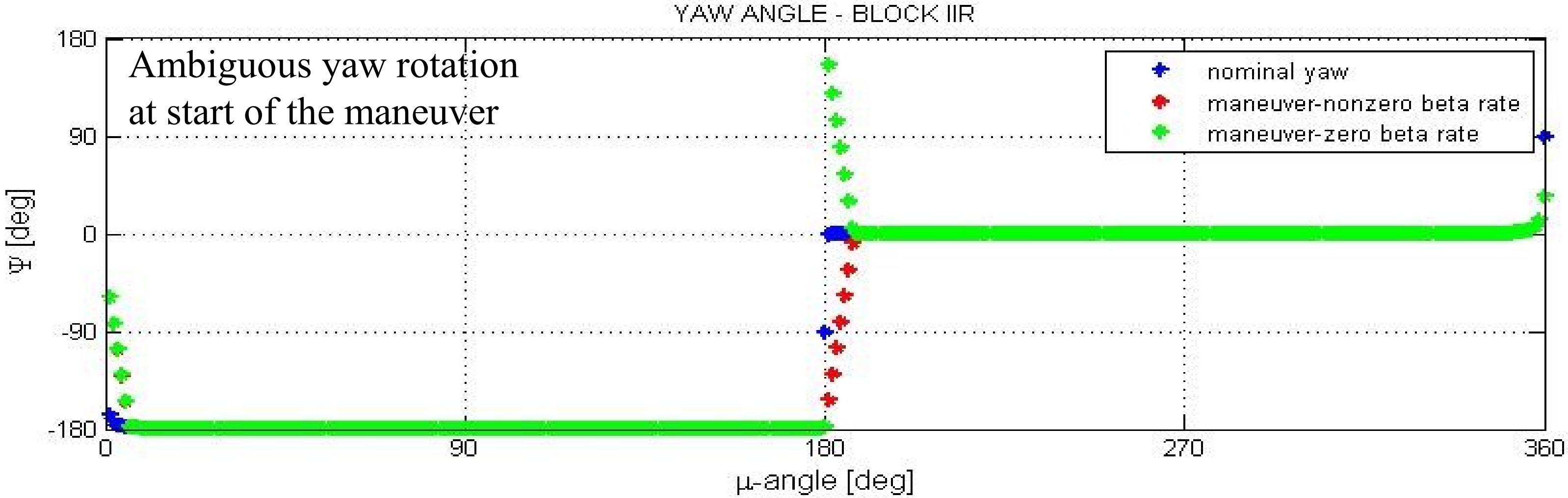
- Bar-Sever (1996) for GPS block II/IIA
- Kouba (2008) for GPS block IIR
- Dilssner et al (2010) for GLONASS-M

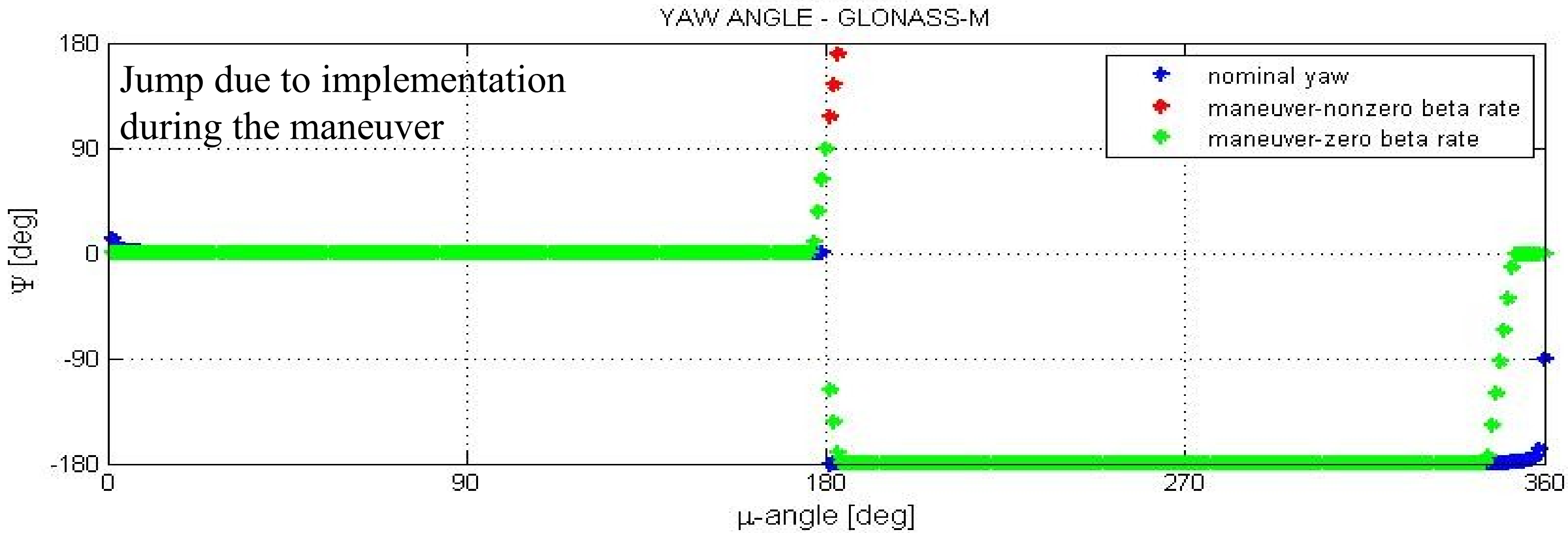


Impact of Assumptions of the Models

Problem at beta close to zero

Beta changes sign at μ = 180 deg (orbit noon)





Impact of Assumptions of the Models

Problem at beta close to zero

GPS block IIR and GLONASS-M

- Maximum **180 deg yaw error** during noon and midnight maneuvers
- **Jump in yaw angle** during the maneuvers while beta changes its sign
- Beta rate problem can be solved by using orbits (data) from the past

GPS block II/IIA

- Maximum **180 deg yaw error** during **noon maneuver**
- Almost **no yaw error** due to yaw bias as it drives the yaw angle during the **shadow crossing maneuver**

Impact of Assumptions of the Models

Problem at beta close to zero

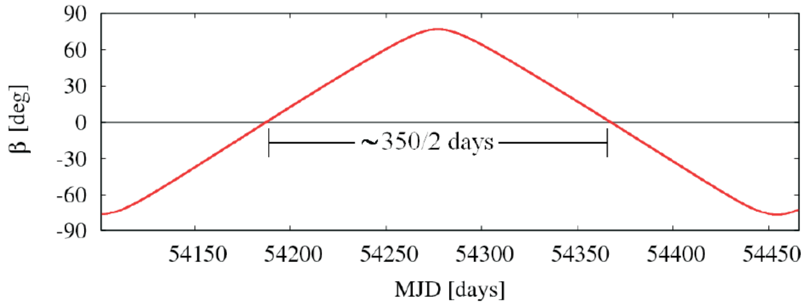
How often the jumps happen ?

- Max. duration of maneuvers:

  15 min for GPS IIR 1 hour/ day

  12 min for GLONASS-M 0.8 hour/day

- Beta changes sign approx. twice per year:



- Probability of a jump for one satellite:

  (2/365)*(1/24) = 2/24 per year for GPS IIR

  (2/365)*(0.8/24) = 1.6/24 per year for GLONASS-M

For example in 2010, there were around 20 GPS-IIR and 22 GLONASS-M satellites

In total 3.1 days with a jump in 2010

Impact of Assumptions of the Models

Uncertainty in hardware rate R

GPS block II/IIA (JPL estimated hardware rate)

- Average hardware rate R is 0.115 deg/sec
- 5% uncertainty in R among satellites → R = 0.115 ± 0.005 deg/sec
- 10 % variation between satellites of the same block

GPS block IIR

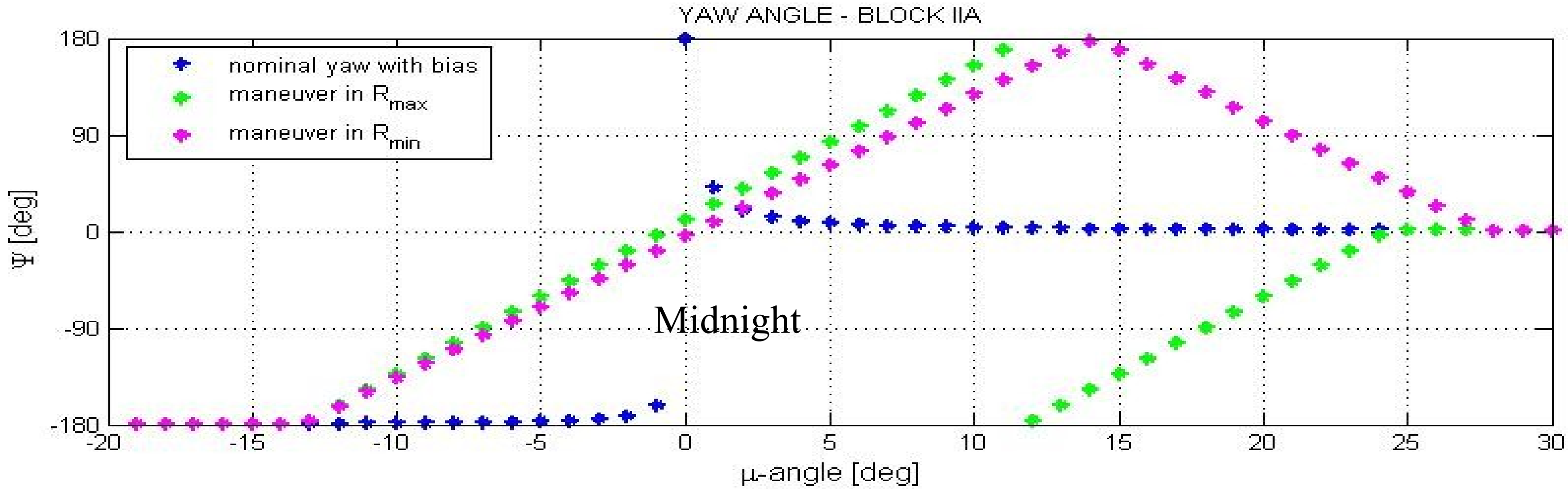
- No estimation but constant hardware rate R is 0.2 deg/sec
- 10% uncertainty in R → R = 0.2 ± 0.02 deg/sec

GlONASS-M

- Average hardware rate R is 0.25 deg/sec
- 10% uncertainty in R → R = 0.25 ± 0.025 deg/sec

Impact of Assumptions of the Models

Uncertainty in hardware rate R



GPS block II/IIA

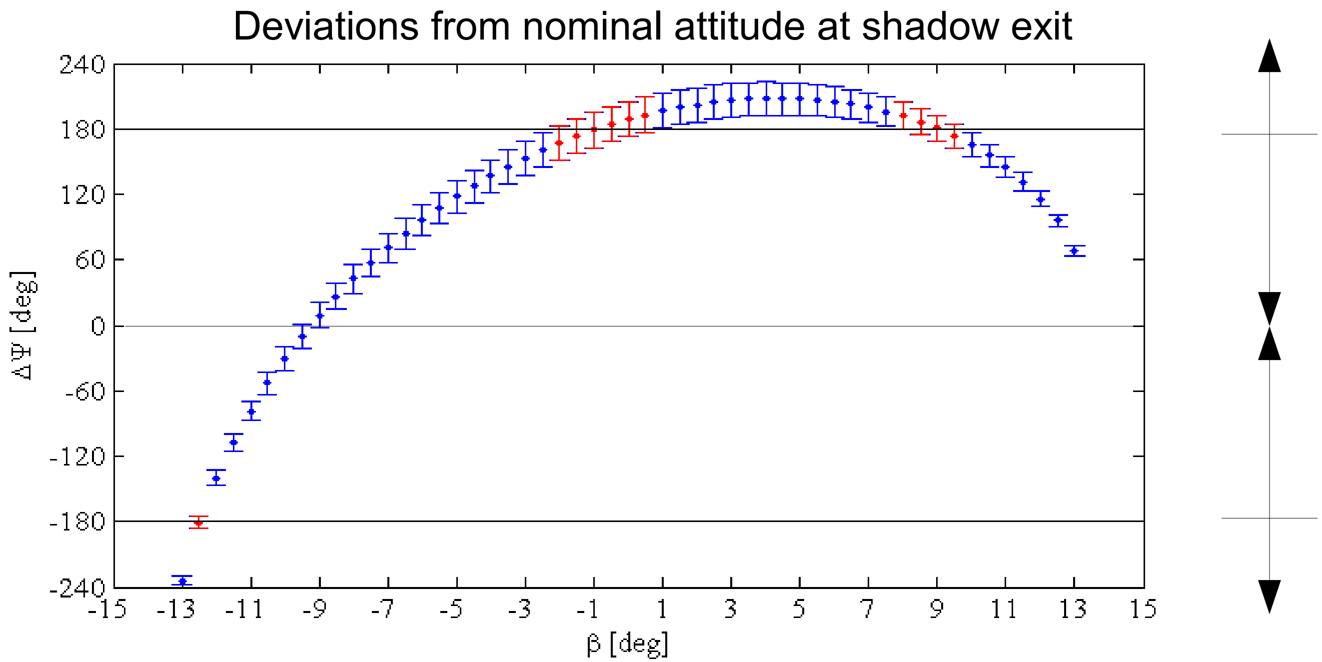
- Up to 15 deg and 30 deg yaw error during noon and midnight turns
- **Ambiguity in the direction of rotation of the post shadow maneuver**

GPS block IIR: Up to 36 deg yaw error in noon and midnight maneuvers

GLONASS-M: Up to 18 deg and 36 deg yaw error during noon and midnight turns

Impact of Assumptions of the Models

Post shadow recovery ambiguity for GPS block II/IIA



error bar = eclipse duration * uncertainty in hardware rate

Depending on ΔΨ ==> continue yawing at the same rate or yaw reversal
if ΔΨ is close to ± 180° ==> ambiguity

==> 21 % probability of ambiguity for one satellite in post shadow recovery

Impact of Assumptions of the Models

Conclusions

GNSS satellites perform yaw maneuvers during eclipse seasons

The key parameters of these models are:

- beta
- R, hardware rate
- b, yaw bias (GPS II/IIA)

If beta is close to zero during the maneuver a jump may occur:
==> problem can be solved by using the rate of beta

Uncertainty in nominal hardware rate, ambiguity in post-shadow maneuver may occur
==> problem can be solved by estimating R

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References

1. Bar-Sever Y., A new model for GPS yaw attitude, Journal of Geodesy (1996) 70:714-723. DOI 10.1007/BF00867149

2. Dilssner F., Springer T., Gienger G., Dow J., The GLONASS-M satellite yaw-attitude model, Advances in Space Research (2010) 47: 160-171. DOI 10.1016/j.asr.2010.09.007

3. Kouba J., A simplified yaw-attitude model for eclipsing GPS satellites, GPS Solutions (2008) 13:1-12. DOI 10.1007/s10291-008-0092-1