Observed features of GPS Block IIF satellites yaw attitude and corresponding modeling

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Da Kuang, Shailen Desai and Aurore Sibois (Contact: dakuang@jpl.nasa.gov)

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.

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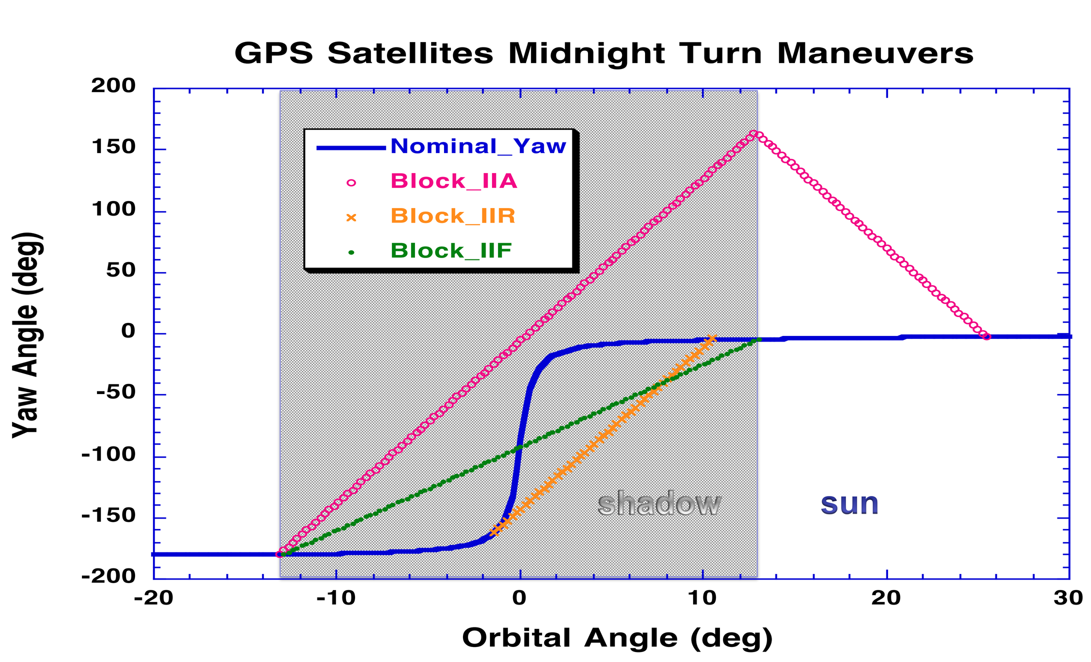
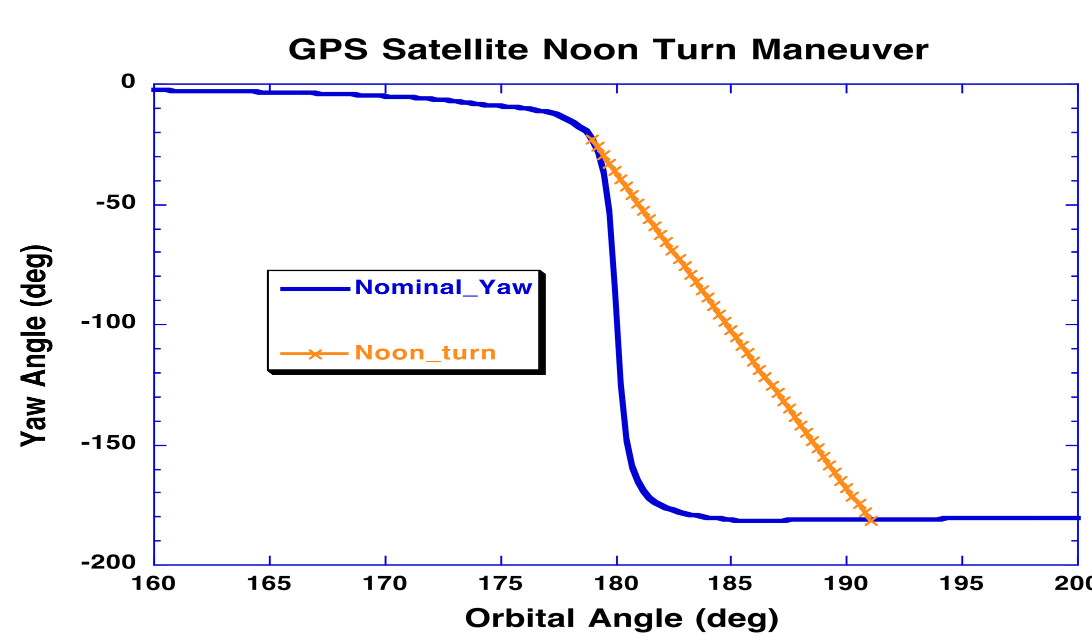
Abstract

The attitude of GPS satellites affects both modeling of their orbit dynamics and measurement geometry. For JPL's GPS orbit and clock products, the yaw attitude of block IIF satellites is modeled based on previous experience from other types of GPS satellites and new observations from IIF satellites (e.g., Dilsner et al. 2010). During eclipsing season, the noon turn is modeled similar to other satellites, i.e., yaw at the maximum rate when the nominal yaw rate reaches the physical limit of the satellite. For the midnight turn model, the maneuver is spread over the entire shadow crossing to reduce the yaw rate. We have an independent yaw attitude estimation process (Weiss et al. 2012) to monitor the actual yaw attitude. By comparing the modeled and the estimated yaw angles for 8 IIF satellites over one year, we observed discrepancies between the yaw directions in the vicinity of zero beta angle. Two features of the turn maneuvers are extracted after analysis of the observed differences: 1) the noon turns reverse yaw direction when the beta angle is between -0.7 and 0 degrees; 2) midnight turns always take the direction as if completing less than 180 degree of total yaw. An empirical beta angle bias is applied in the noon turn model to correct the yaw direction. A short-route constraint is applied in the midnight turn model for more robust performance.

Types of GPS turn maneuvers

- **Nominal (ideal) GPS attitude points the solar panel towards the Sun all the time;**
- **However, actual GPS satellites cannot keep up with the nominal yaw rate at small β angle during eclipsing season;**
- o **Block IIA satellites yaw at their maximum rate throughout the whole eclipse, then recover the nominal yaw after exiting the shadow;**
- x **Block IIR satellites start to yaw at their maximum rate when the nominal rate reaches the physical limit, till the nominal yaw is recovered;**
- **Block IIF satellites evenly spread the total yaw throughout the whole eclipse;**
- x **All GPS satellites perform noon turn in the same way as the Block IIR satellite midnight turn.**





Where orbital angle lies in the orbit plane, starting from the orbit midnight direction (opposite to the projection of the Earth-Sun vector onto orbit plane).

Modeled turns for Block IIF satellites

- **Midnight turn:**

$\Psi = (t - t_s)^*(\Psi(t_e) - \Psi(t_s))/(t_e - t_s)$

- **Noon turn:**

$\Psi = \Psi(t_s) - \text{SIGN}(R,\beta)^*(t - t_s)$ **(Bar-Sever, 1996)**

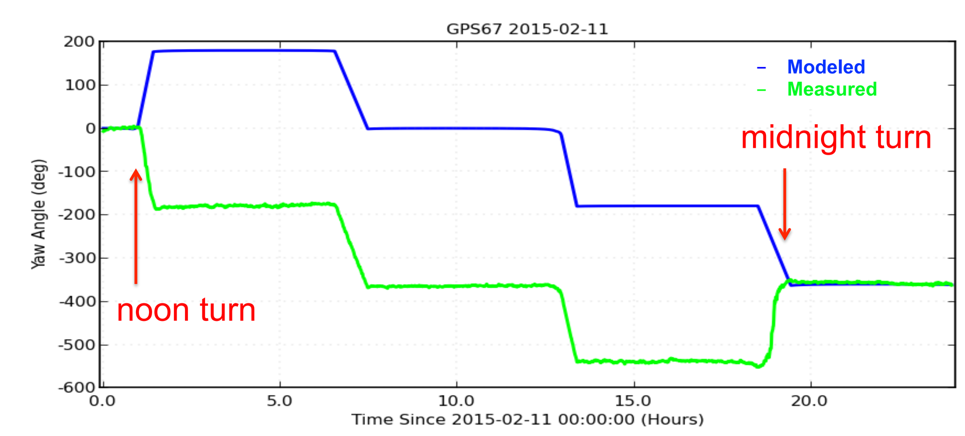
or

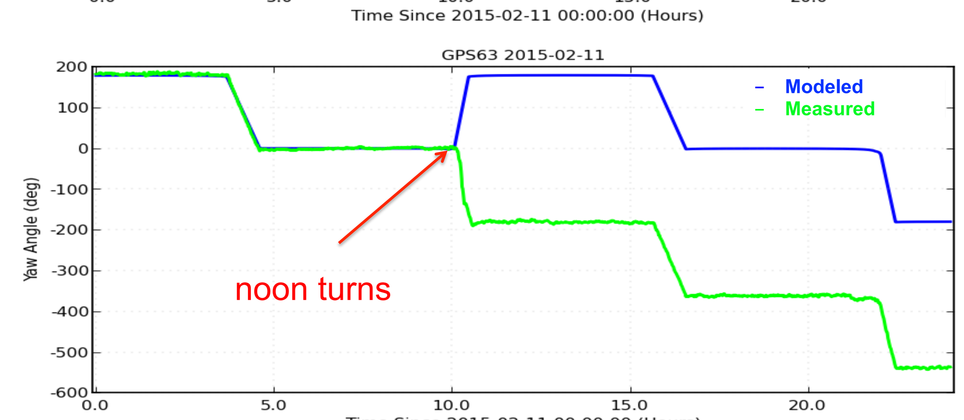
$\Psi = \Psi(t_s) + \text{SIGN}(R, \Psi'(t_s))^*(t - t_s)$ **(Kouba, 2009)**

Where Ψ is the yaw angle during the turn maneuver, t_s is the turn starting time, t_e is the turn ending time, Ψ' is the yaw rate, R is the satellite yaw rate limit. SIGN is the function taking value from R and sign from β (or Ψ').

Observed turns for Block IIF satellites

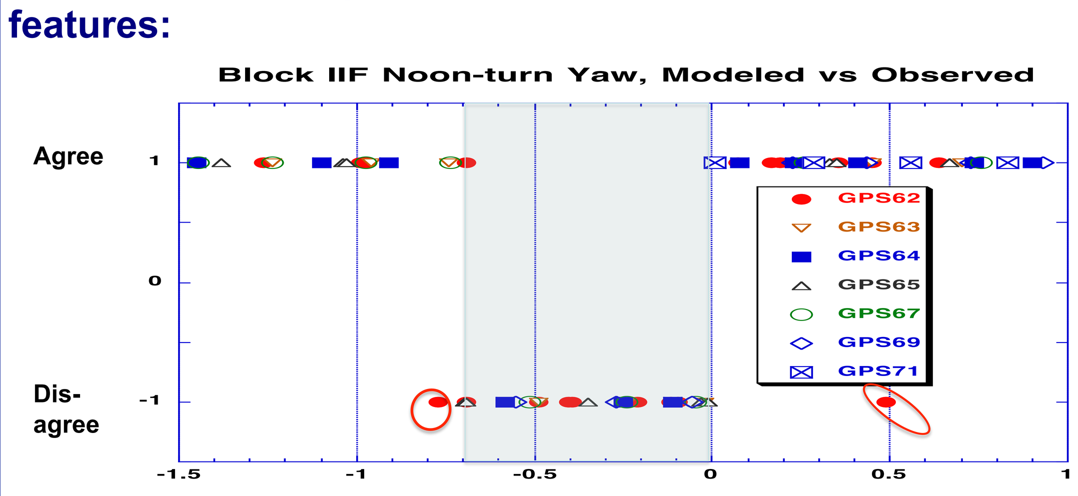
At JPL we have a routine Reversed Precise Point Positioning (RPP) process (Weiss, et al. 2012) to measure and monitor the actual attitude of GPS satellites. Occasional discrepancies are observed during eclipsing seasons.

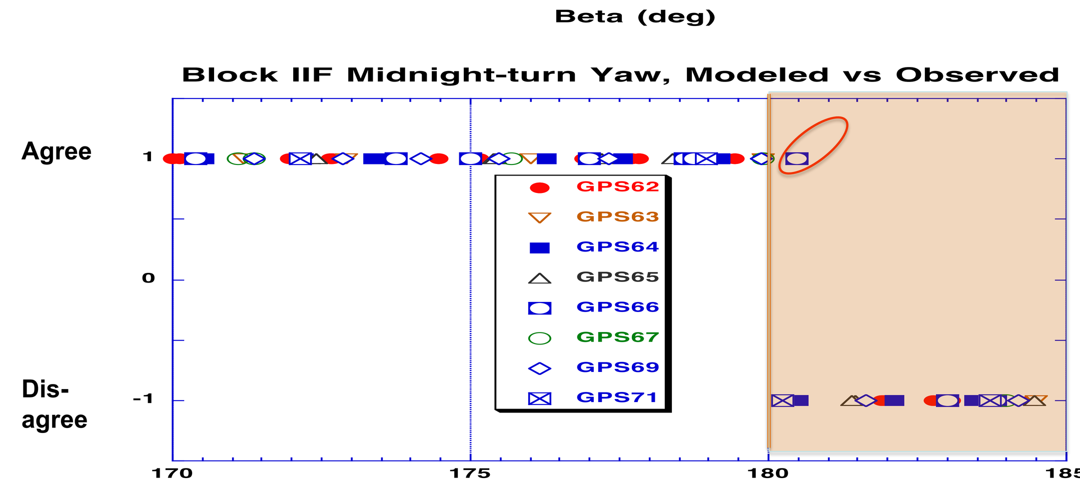




Features of the Discrepancies

Observed discrepancies can be summarized into two features:





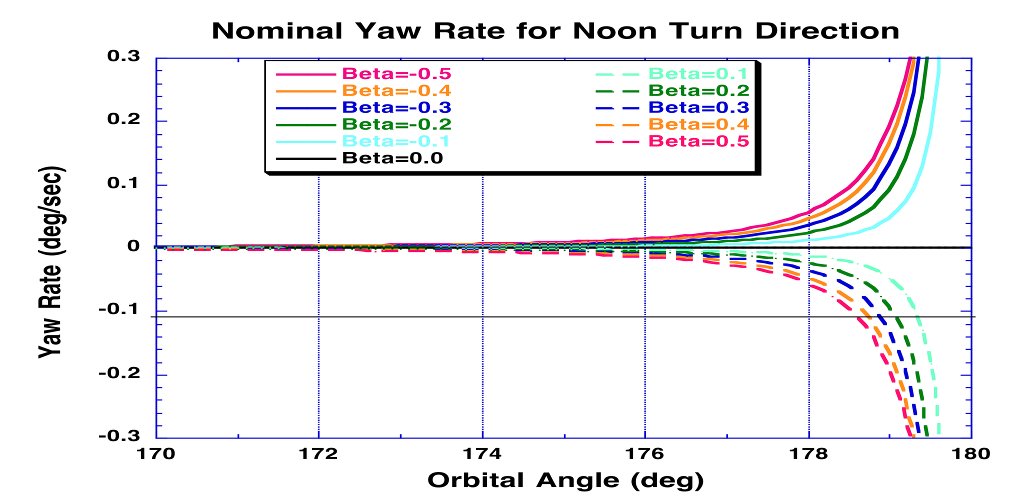
Empirical correction to the models

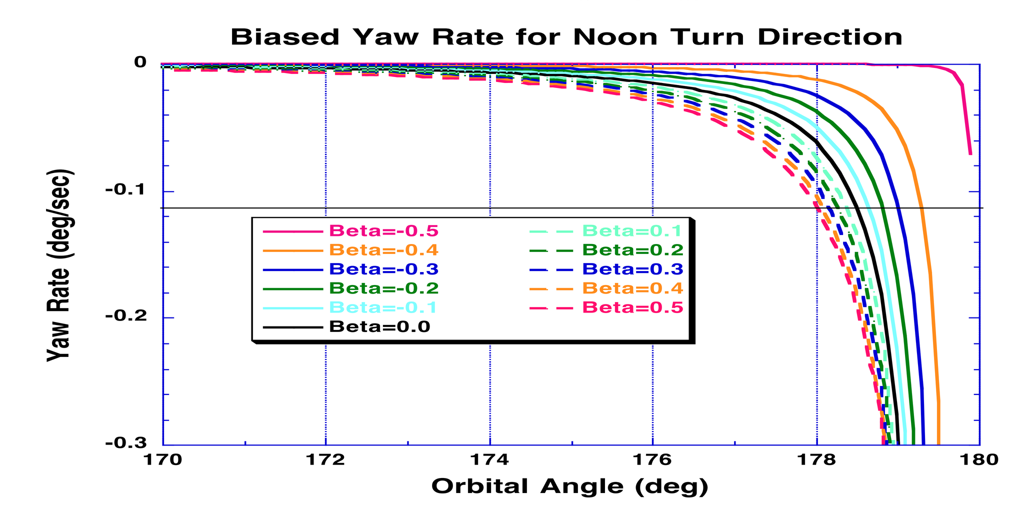
Based on the observed features, following empirical corrections are added to the IIF yaw model during eclipsing season:

- **A bias of 0.7° is applied to β angle in the noon turn direction decision making.**
- **A short-route constraint is applied in the midnight turn direction decision making to force it to turn less than 180°.**

Effect of yaw bias on turn direction

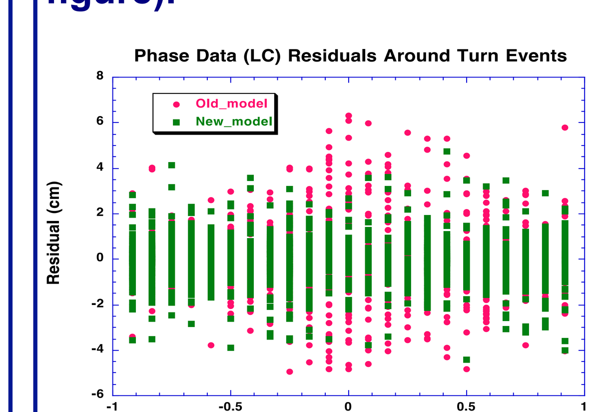
The equations by Bar-Sever (1996) and Kouba (2009) are equivalent without yaw bias. When yaw bias is implemented the effective β angle changes. However, with -0.5 yaw bias for Block IIF satellites, this only explains 0.5° of β shift.

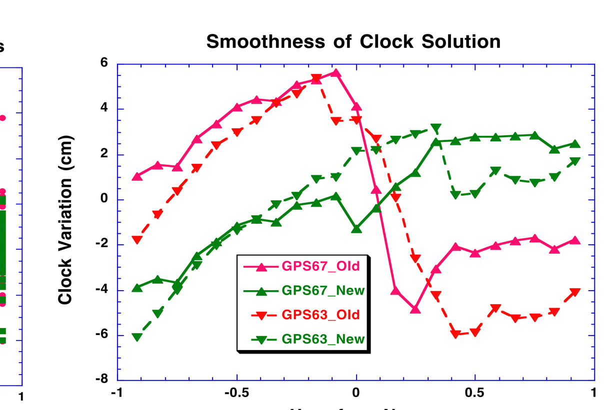


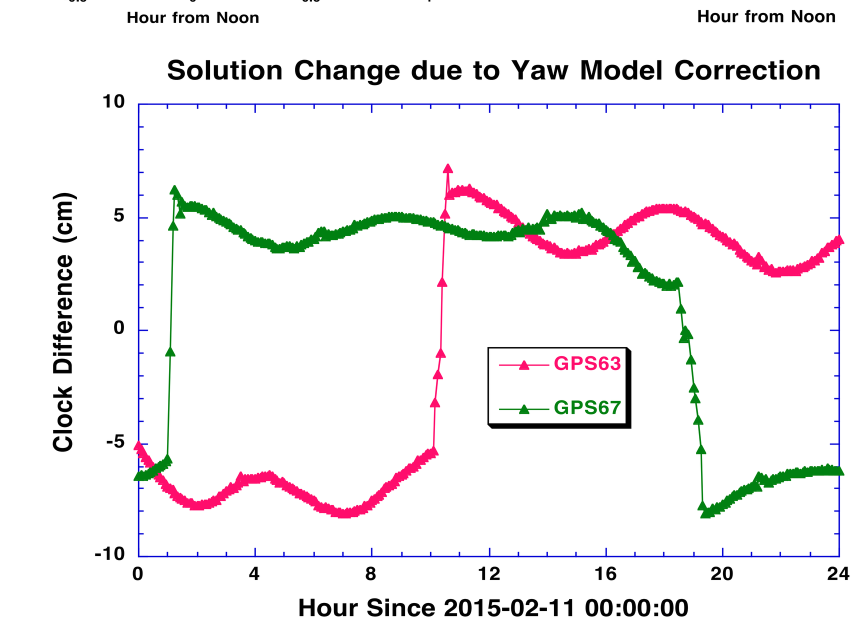


Corrected Solutions

With the revised yaw model for IIF satellites, most of the wrong turn directions are corrected, except those in the red circles on the central middle panel. Data residuals are smaller, orbits and clocks are smoother around turn events. Clock error due to turn direction error lasts much longer than the turn event, it stays over rest of the arc until an opposite turn direction error to unwind it (see the bottom figure).







Suggestion

GPS yaw modeling is an ongoing effort. Due to the binary nature of the direction switch in the model, smaller error such as in the orbital angle (for noon turn) or shadow boundary (for midnight turn) evaluation may result in wrong decision of the turn direction and cause phase measurement error of one wavelength. However, post-process (e.g., RPP process) can help this decision. The post-process corrected GPS attitude (quaternion) data should be fed back into POD process and added as an IGS product to improve customer application performance.

References

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Weiss J., Bar-Sever Y., Bertiger W., Desai S., Harvey N., and Sibthorpe A., Modeling and characterization of the GPS Block II/IIA/IIF attitude, IGS Workshop2012, Olsztyn, Poland, 2012.