Testing a Reverse Kinematic Point Positioning Technique for Possible Operational Use in GPS Data Analysis at NASA's Goddard Space Flight Center

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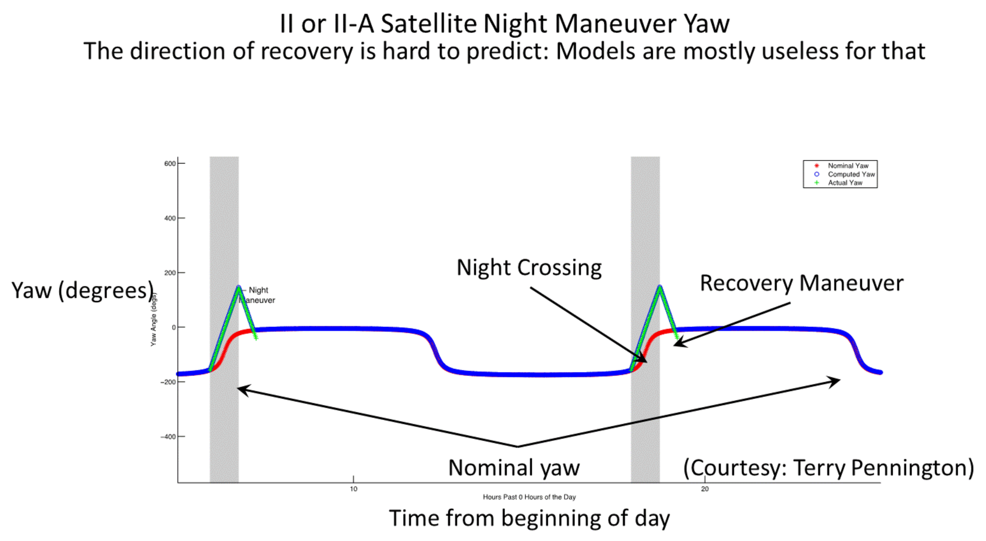
Satellite Orientation Models:

The orientations of GNSS satellites need to be known precisely for:
(1) Calculating the effect of radiation pressure (solar, thermal emission and albedo) on the satellite orbits.
(2) Calculating the correction of satellite antenna offsets and PCVs (in azimuth).

The orientation is defined by the yaw angle between the X body-axis of the satellite and (approximately) its velocity vector.
This angle can be obtained from one of several available orientation models.
The most recent and realistic model, adopted by the IGS as its standard model, is Jan Koubas' model [1], implemented by him in the Fortran subroutine "eclips."

All models, including Kouba's, are known to be subject to occasional errors that can be quite large sometimes. In general, they all are unreliable for calculating the yaw of GPS satellites:
(a) During the Block II and IIA recovery maneuvers after crossing the Earth's shadow (**Fig. 1**).
The IGS recommends not to use the data during those 20 to 30-minute maneuvers.
(b) When the elevation of the Sun on the orbit plane (the beta angle) is small (Blocks II, IIA , IIF) (**Figs. 2 and 3.)**
(c) During unannounced tests carried out by the USAF (could be any Block, in rare occasions.)



The IGS-recommended procedure is: NOT to use the data for ~ 30 minutes after every Night Crossing.

Figure 1: Yaw, Block II, IIA satellite according to IGS model (J. Kouba 2008) -- Recovery maneuver issue.

Here the Rev-Kin Solution and IGS Model Agree …

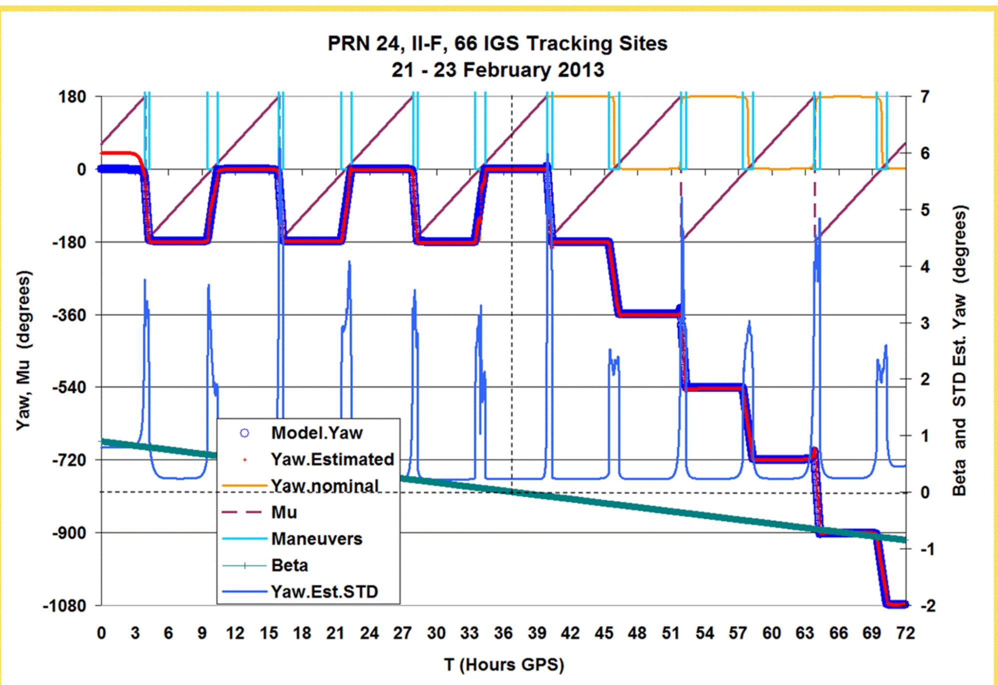


Figure 2: The reverse-kinematic estimated yaw (red) agrees with the IGS Model (blue)

Here ALL Night-Crossing Maneuvers Are Different!

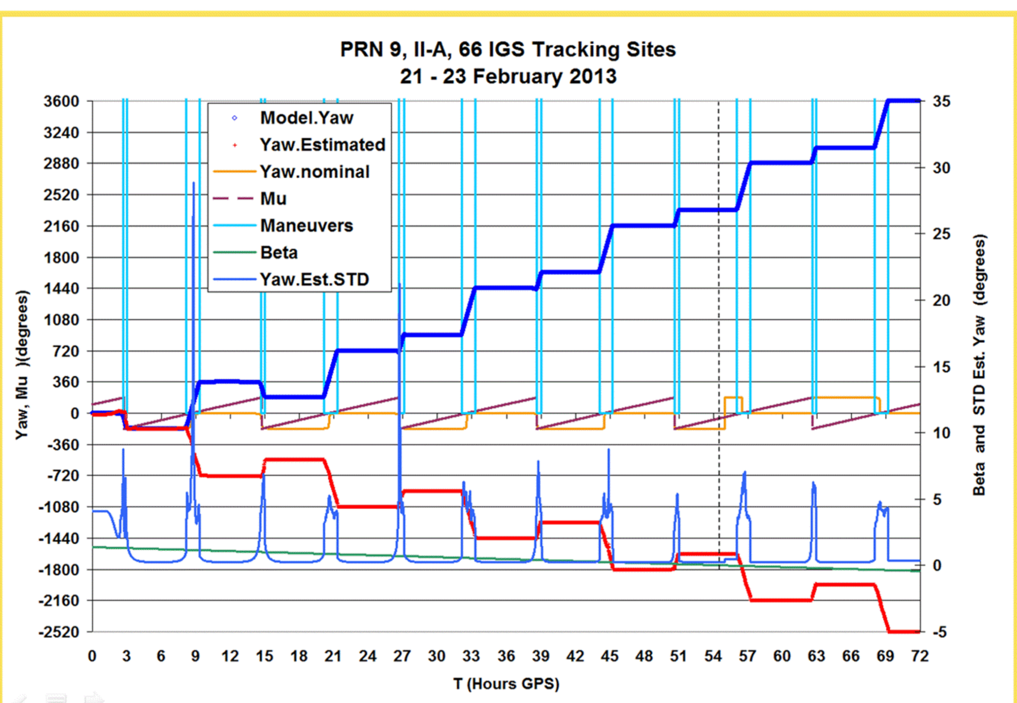


Figure 3: The reverse-kinematic model and IGS Model do not always agree.

Implementing a Reverse-Kinematic Technique at Goddard:

A technique known as **reverse kinematic point positioning** has been developed in recent years, e.g. [2], to obtain the orientation of GNSS satellites (yaw angle) with **significant horizontal antenna offsets**, using the data from a global network of receivers.
This technique, sometimes described as "upside down kinematic point positioning" **(Fig.4)**, usually involves assimilating data from some hundreds of receivers -- because of the intrinsically poor observing geometry and also the need to observe a satellite, at all epochs, simultaneously from at least four sites. This is not in line with the orbit determination operations carried out at Goddard, often using data from some 40 globally distributed IGS receivers.
An effort is under way to implement reverse kinematic modified to work with less than 70 stations, in better agreement with current practice at Goddard.

The Modified Reverse-Kinematic Technique:

The main difference between this modified technique and the usual one is the introduction of dynamic constraints in the estimated x, y body-frame coordinates of the satellite antenna phase center: modelling them as random walks instead of as white noise processes (the usual practice). This is justified by the slow-varying and rather predictable changes in those coordinates.
In addition to the center of phase coordinates, ion-free combination biases are estimated as part of the reverse-kinematic solution. **Data:** both phase and code ion-free combinations, single-differenced between satellites to eliminate receiver clocks.

Current Status of the Implementation:

A system is being developed to download, clean and process the data and then transfer the yaw estimated with the reverse-kinematic technique to GEODYN for its use in precise orbit estimation and other geodetic applications of GPS data.
A series of end-to-end tests of the software has concluded and now preparations are under way for the next stage: testing with several months worth of data from altimeter-satellites, including GPS, SLR and Doris tracking, to compare results using the orientation calculated with the reverse-kinematic technique vs. the one calculated with the one currently in GEODYN (the IGS/Kouba model).

Data Processing Steps:

(1) Data and IGS products are downloaded from the CDDIS: RINEX, SP3 orbits and clocks (the orbits and the clocks are from CODE), and SINEX from the IGS as well as from several ACs, to get the receiver data, coordinates and antenna corrections for all sites needed for the reverse-kinematic solution.
(2) Data is pre-processed, editing out bad points, correcting cycle-slips, P1-C1 biases, etc.
(3) The pre-processed data is used, along with the sites' IGS coordinates and the CODE precise orbits and clocks, in point-positioning solutions, one per site, to estimate the zenith delay (zd) at each site. The data from Block II, IIA and IIF satellites in eclipse season are not used, but they are corrected for tropospheric delay using the estimated zd while applying the other usual corrections, except for the antenna offset correction. The antenna center offset and phase windup corrections are applied (with the exception just noted) and they are the same as those used in the making of the orbits and satellite clock corrections. These products are taken from an AC using a known orientation model in the solutions, in this case CODE.
(4) The a priori residuals of all the RINEX data from the global network for the eclipsing satellites is used in the reverse-kinematic solution.
(5) The estimated yaw is likely to have gaps and other irregularities because of the uneven data coverage and data quality. So, during the maneuvers a model is built by fitting straight lines, joined by cubics and quartics, to the reverse-kinematic time series; while the estimated yaw for periods between eclipse maneuvers is set equal to the nominal yaw according to the Bar-Sever equations. This fitted model is then used in GEODYN to calculate the yaw. **(Figs. 5 and 6)**

Data Editing:

At every stage of the process a number of statistic tests are made (chi-squared and null-hypothesis), including the fitting of a model to the yaw estimated in the reverse-kinematic solution.
When tests are failed, data get deleted, including whole midnight or noon eclipse maneuvers. (Under certain special circumstances, the Kouba model is used to fill the gaps)
As a result, in a test involving 71 days of continuous solutions, there was a number of hours when reliable reverse-kinematic yaw estimates could not be made and the RINEX data had to be deleted.
Comparing those to the number of hours that would have been deleted following the IGS recommended practice of not using data from Block II and IIA recovery maneuvers, in that 71-day period the total percentages of data not used for lack of a reliable yaw model were:

Reverse-kinematic procedure: 6%
IGS recommended procedure: 20%

Reverse-Kinematic Point Positioning in a Nutshell

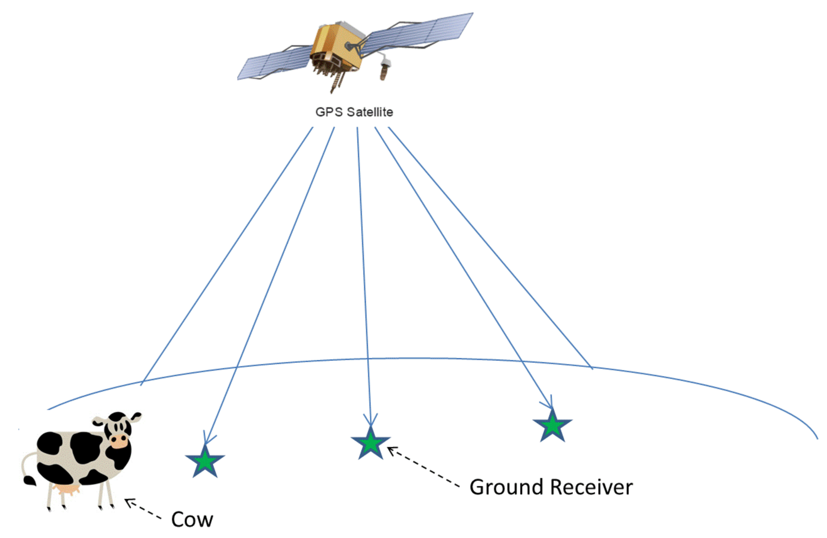


Figure 4: Instead of fixing satellite positions and finding those of the receivers' antenna phase centers, as in kinematic, here one fixes the receivers' to find the satellites' phase centers.

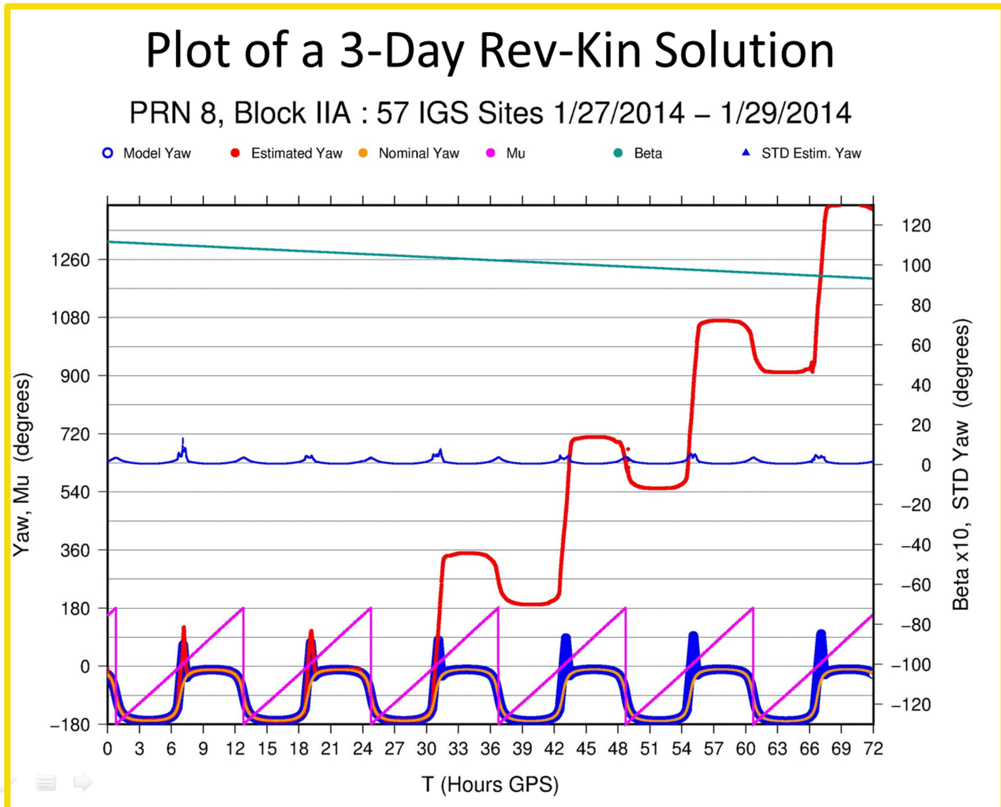


Figure 5: Yaw, from a 3-day reverse kinematic solution.

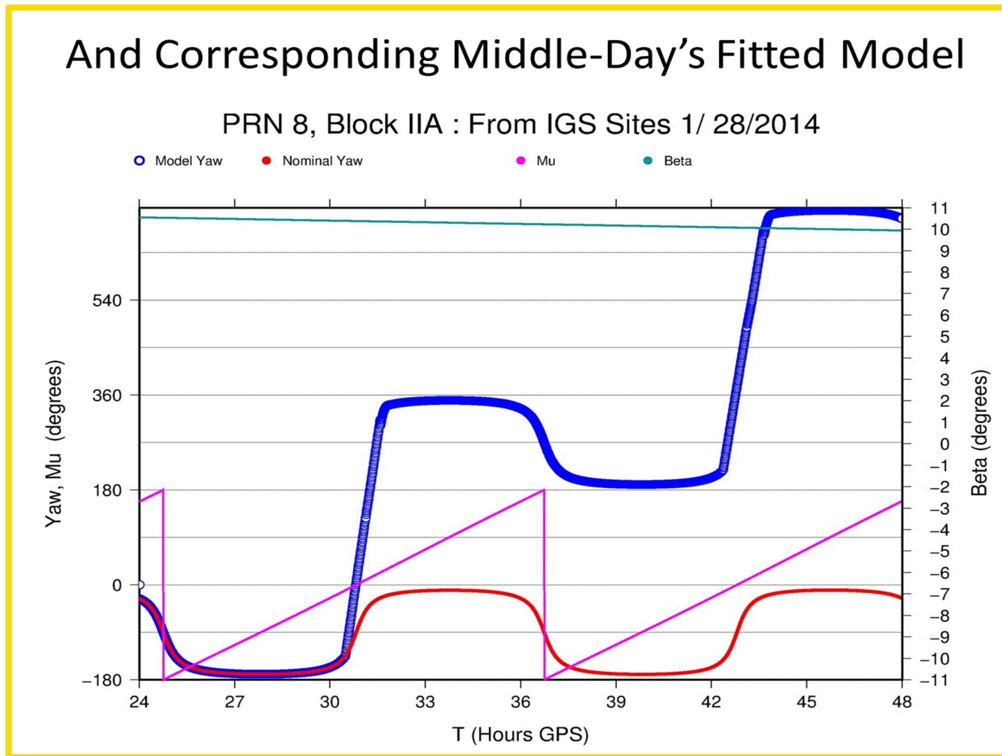


Figure 6: The model fitted to yaw of middle day in Fig. 5

References:

[1] J. Kouba, "A simplified yaw-attitude model for eclipsing GPS satellites", GPS Solutions 2008: DOI: 10.1007/s10291-008-0092-1.

[2] F. Dilssner, T. Springer, G. Gienger, J. Dow, "The GLONASS-M satellite yaw-attitude model", Advances in Space Research, Elsevier, doi:10.1016/j.asr.2010.09.007

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