GPS IIF yaw attitude control during eclipse season

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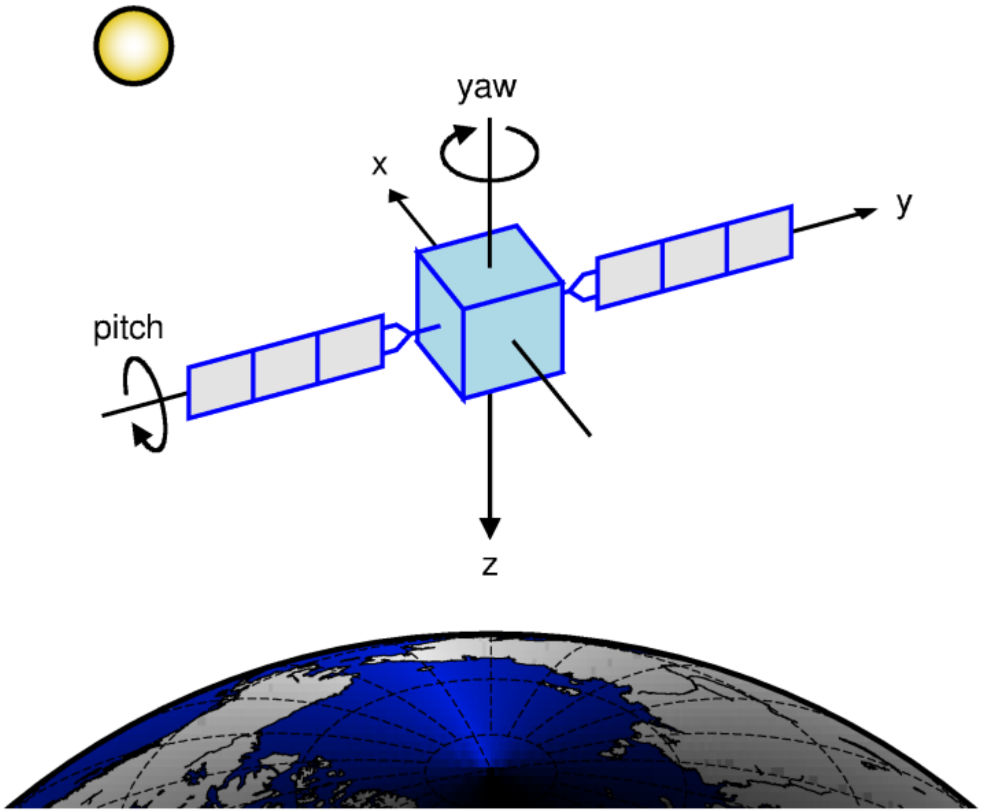
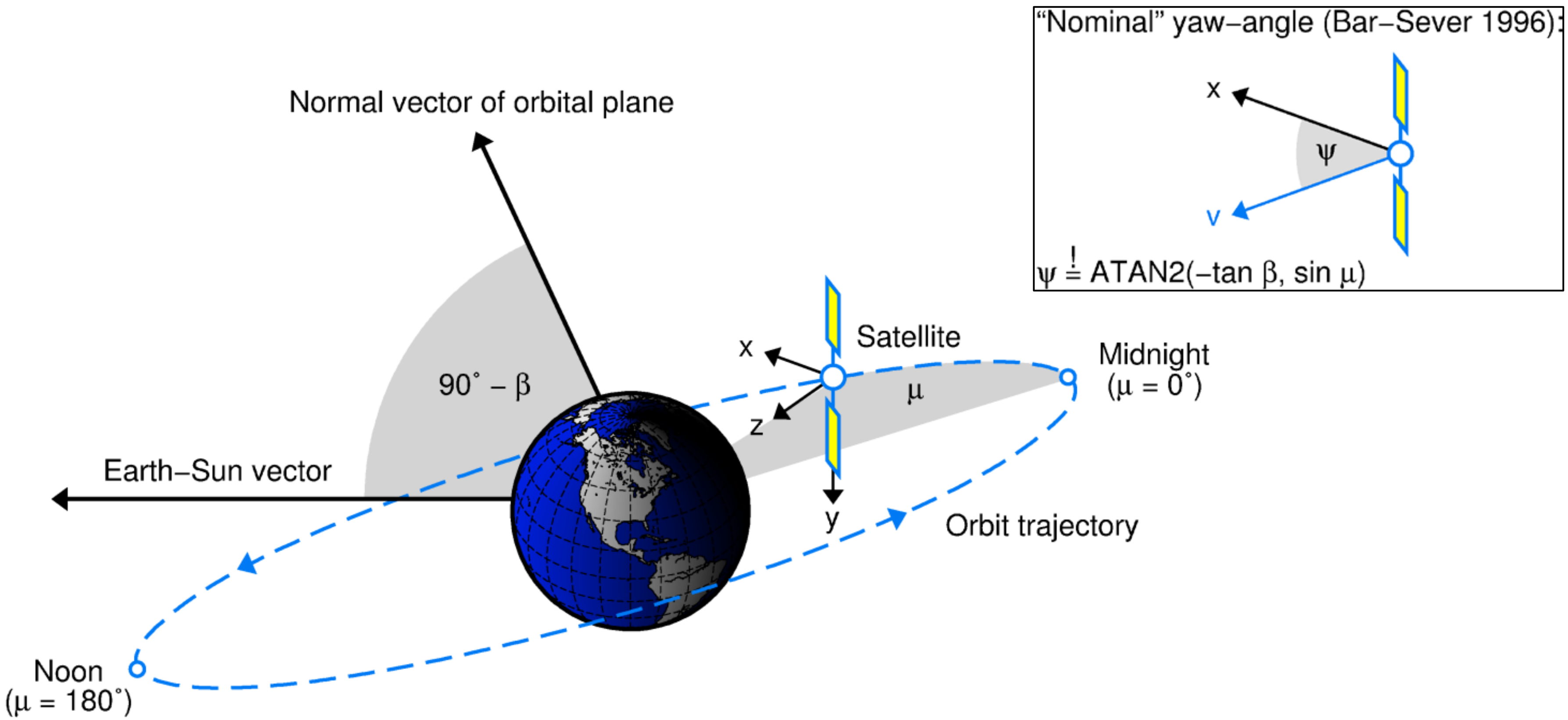
Sun-nadir-steering (1/2)

- L-band antenna needs to be pointed toward geocenter; solar panels have to be perpendicular to Sun direction
- Orientation (“attitude”) needs to be continuously adjusted through yaw and pitch control
- ADCS provides sensors (Earth, Sun, Gyro) and effectors (reaction wheels, torque rods)



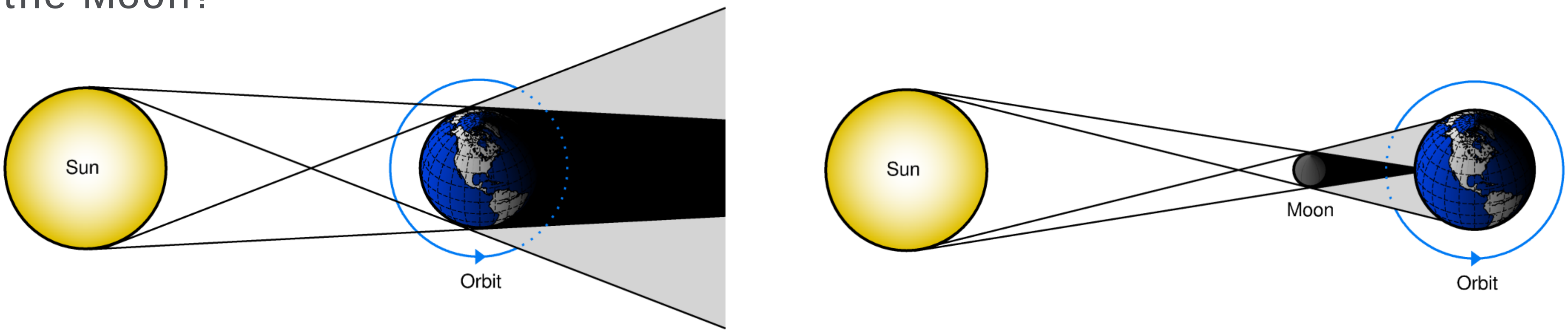
Sun-nadir-steering (2/2)



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

Today's focus

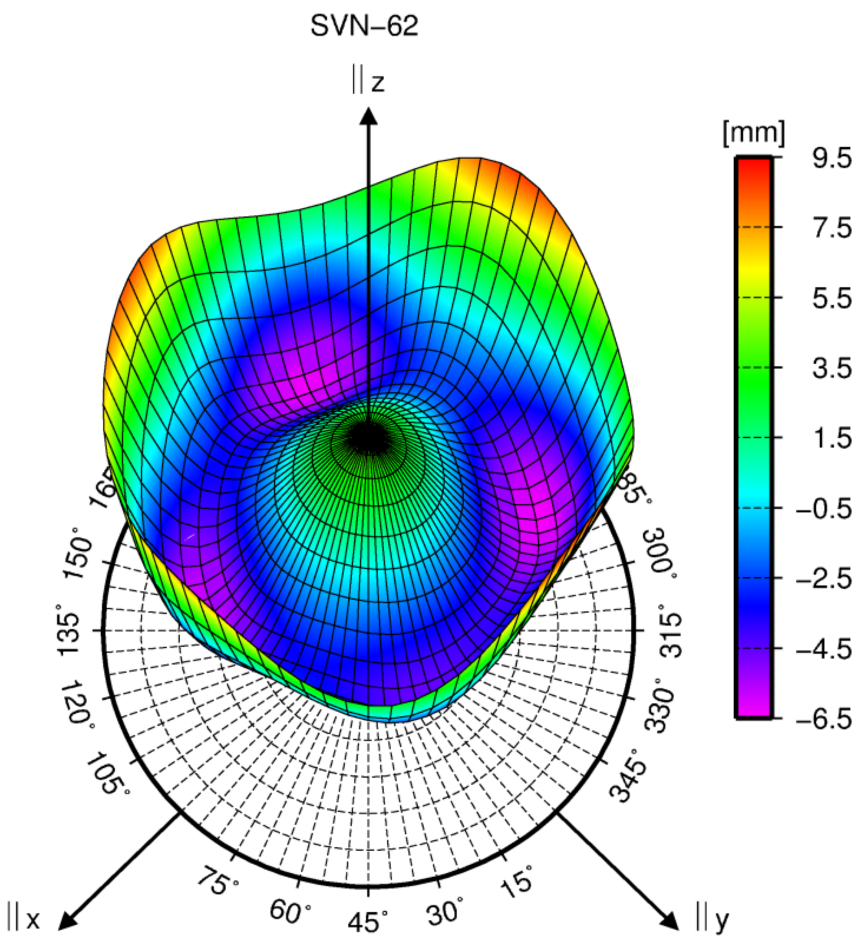
- *Shadow-crossing maneuvers*: How does GPS Block IIF S/C control its yaw attitude when solar sensors' view of the Sun is obstructed by the Earth / the Moon?



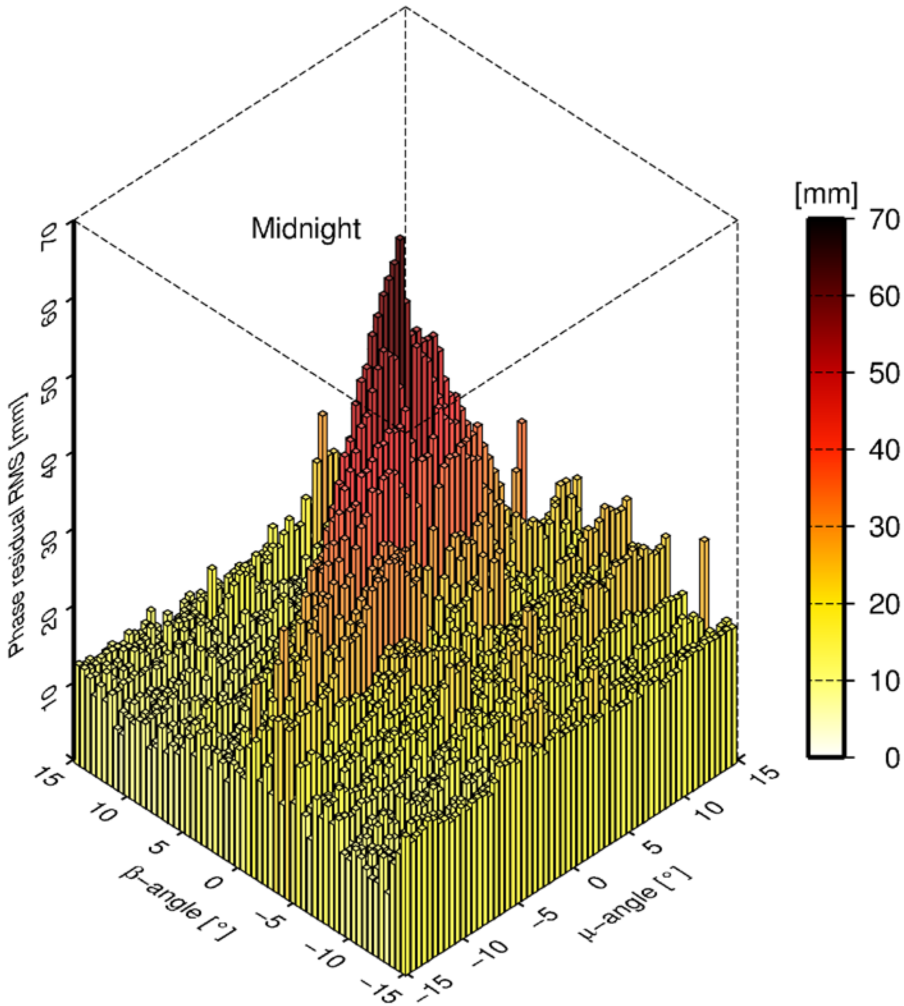
- *Noon-turn maneuver*: How does S/C perform its noon-turn to keep +X side facing the Sun?

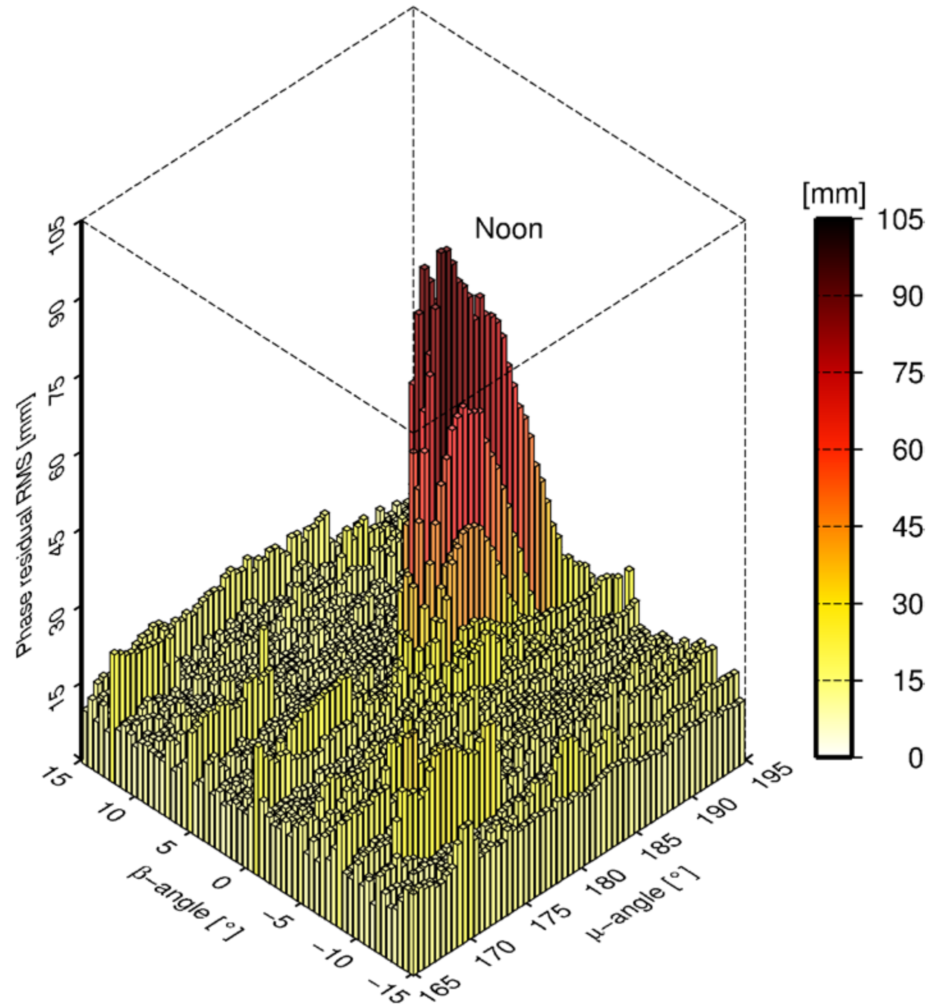
Yaw angle is crucial for precise satellite antenna phase centre and clock modeling

Estimated GPS IIF satellite antenna PCVs



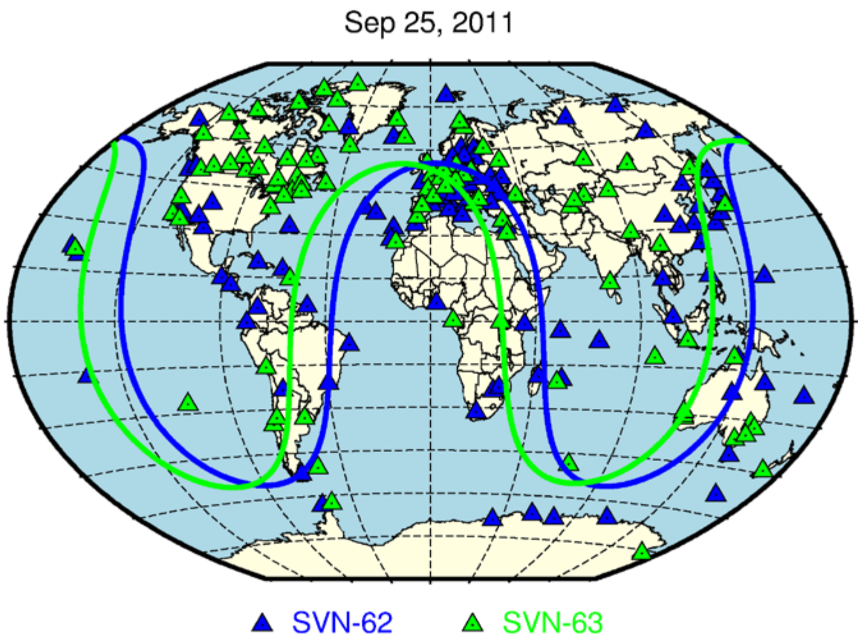
Evidence for GPS IIF yaw attitude modeling issues





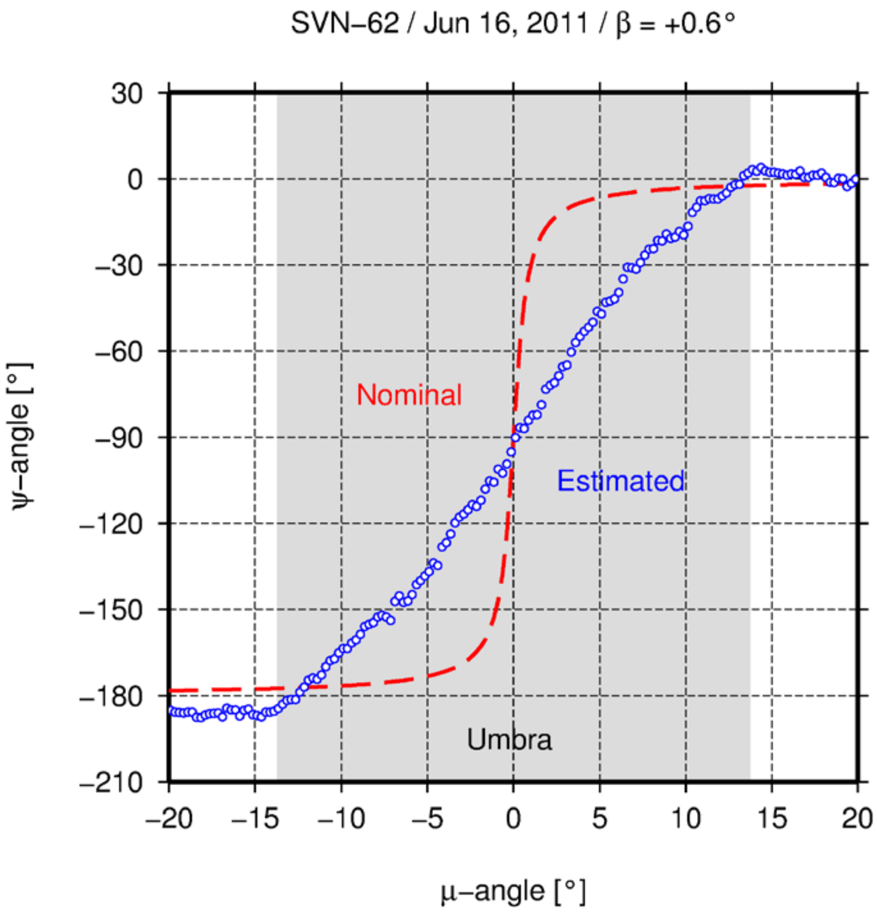
Epoch-wise yaw angle estimation

- 30-sec code & phase measurements from global IGS tracking network
- 1st step: IGS-like GNSS analysis
- 2nd step: Resolving satellite clocks & phase centre positions epoch-by-epoch ("reverse kinematic point positioning")
- "Nominal" yaw attitude model employed
- Yaw error reflected in horizontal PCOs



Midnight-turn regime (1/2)

- Linear drift in yaw angle estimates as soon as S/C enters umbra
- S/C is rotating around its z-axis with nearly constant rate (here: ≈ 0.06º/s)
- S/C keeps “natural” sense of rotation due to yaw bias which is set to have the same sign as β-angle
- Yaw angle upon shadow exit may be off from “nominal” value forcing S/C to perform short post-shadow recovery maneuver (< 5 min)



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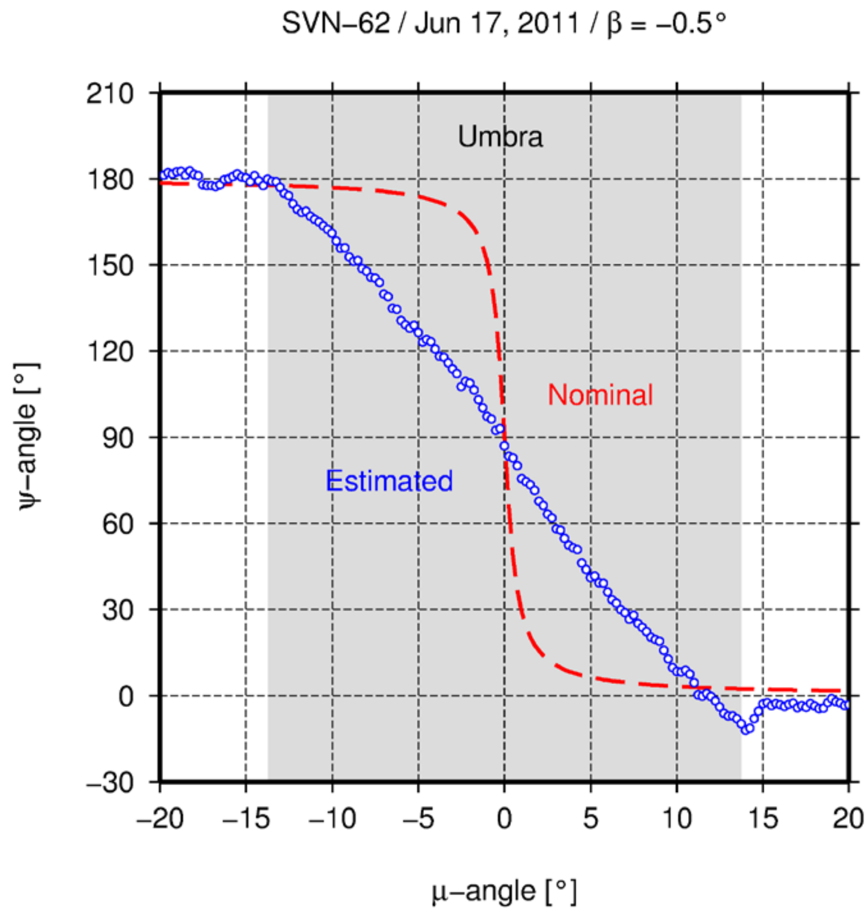
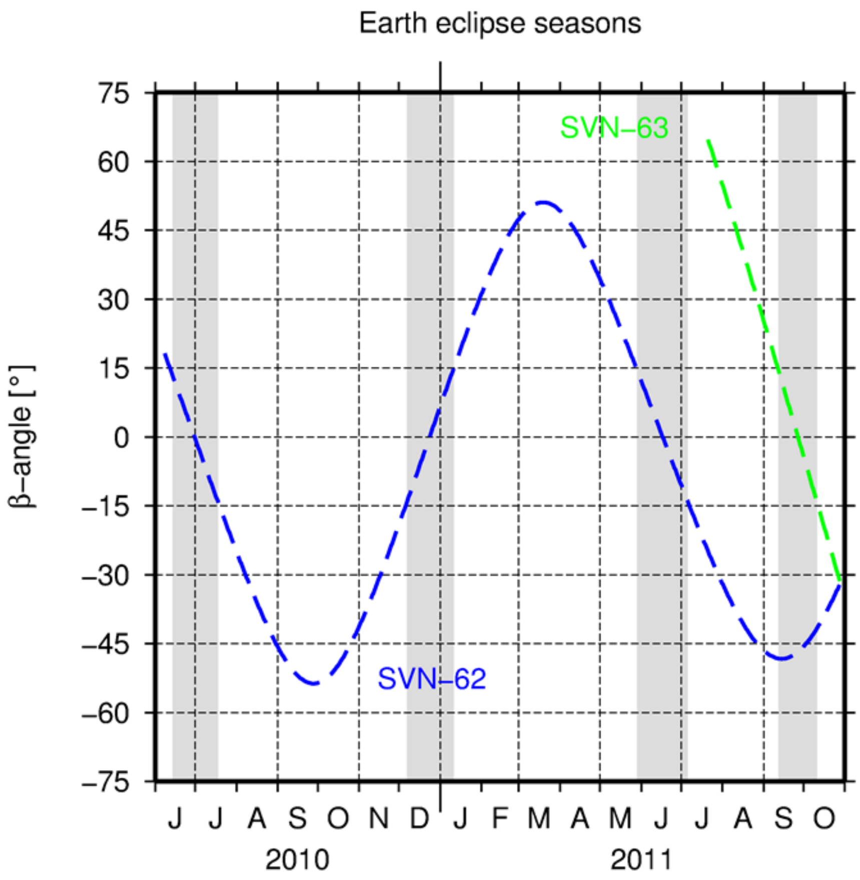


Midnight-turn yaw-rate estimates (1/2)

- Yaw-rate estimates for 228 eclipse events (SVN-62: #176, SVN-63: #52)
- Yaw-rate varies through the eclipse season; the lower the β-angle, the higher the rate
- Estimates for β > 0° closely match thereoretical expectations; values for β < 0° tend to be higher as expected
- Difference between high rate (β < 0°) and low rate (β > 0°) values of 0.005°/s



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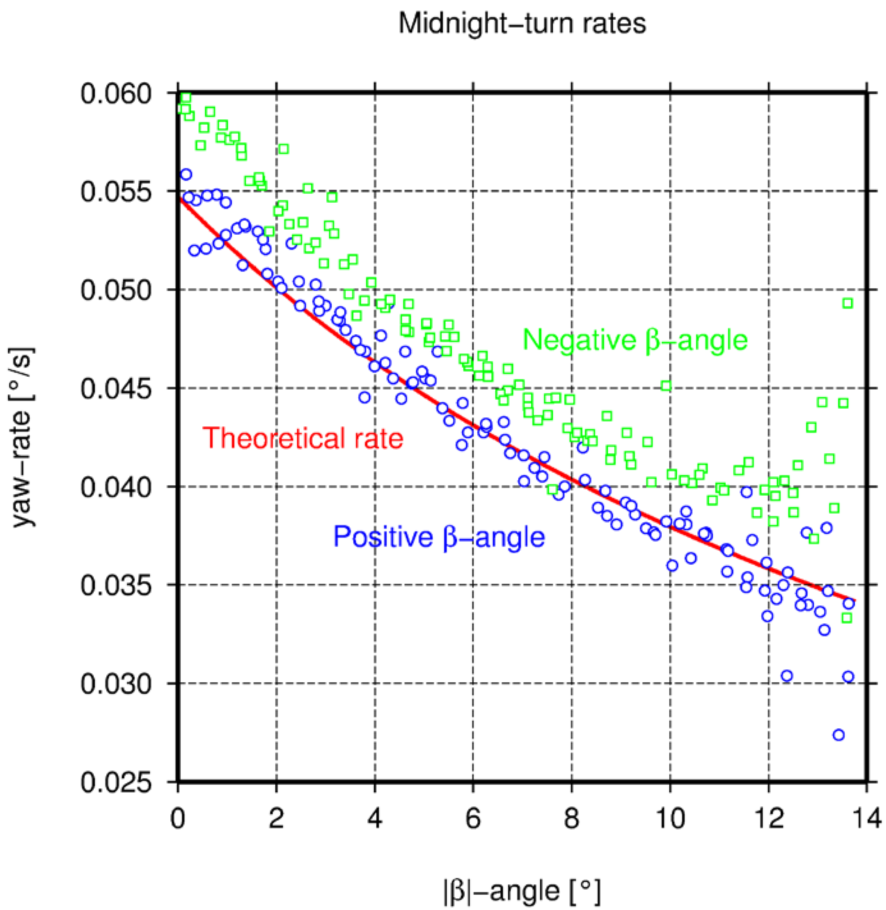
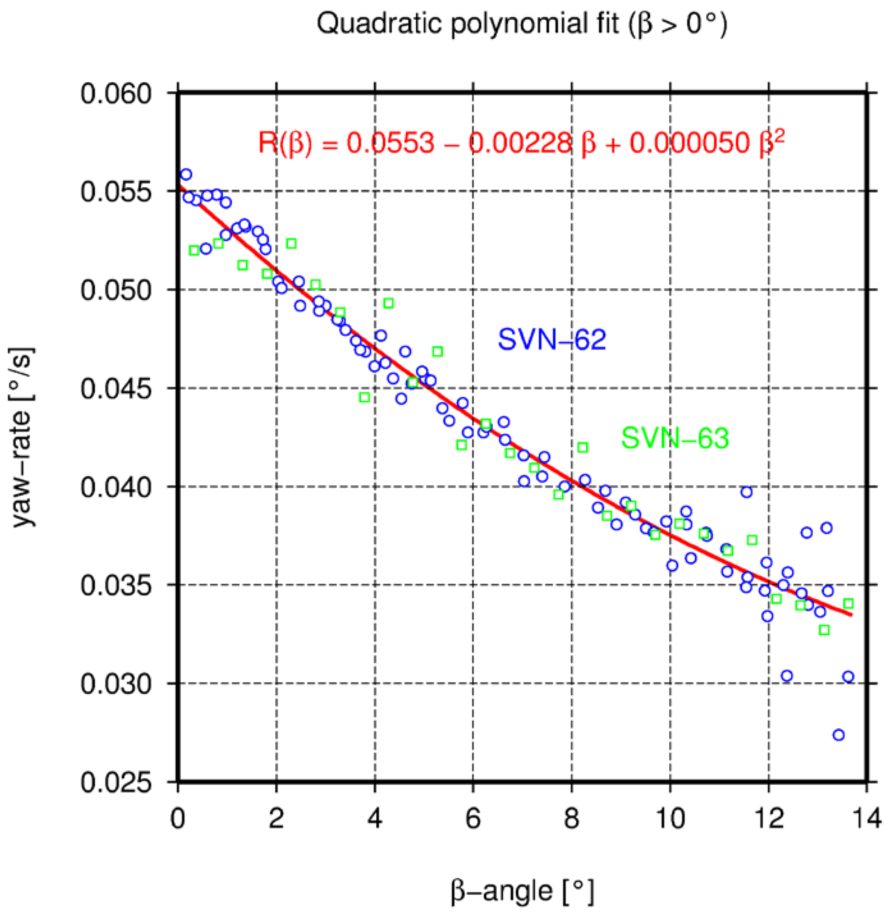


Midnight-turn yaw-rate estimates (2/2)

- Yaw-rate parameter can be well described by two “block-specific” 2nd order polynomials
- De-trended rate estimates exhibit RMS of ±0.0014°/s
- Yaw rate uncertainty translates into uncertainty in yaw angle of ±5° at the end of a 55-min eclipse event



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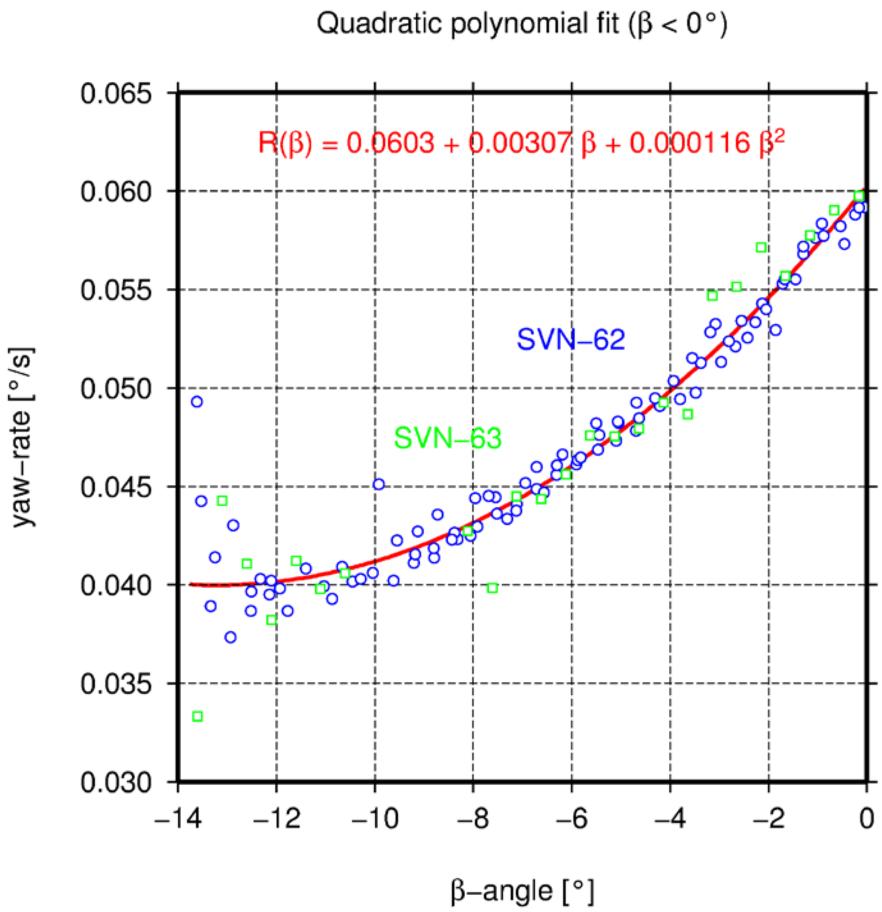

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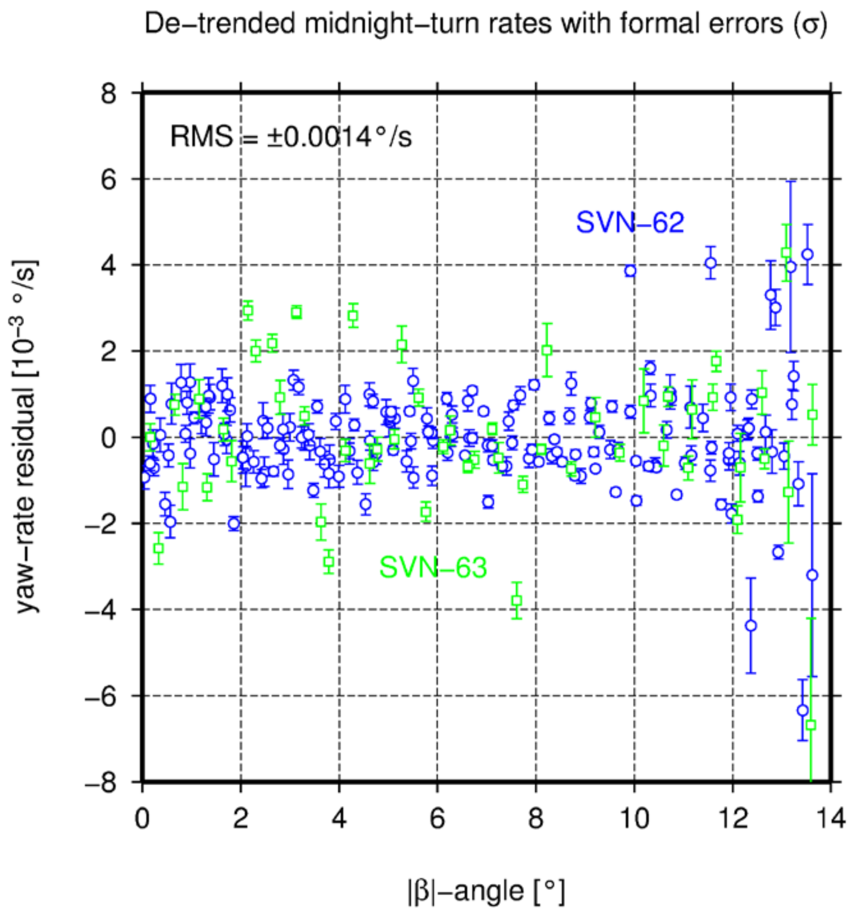
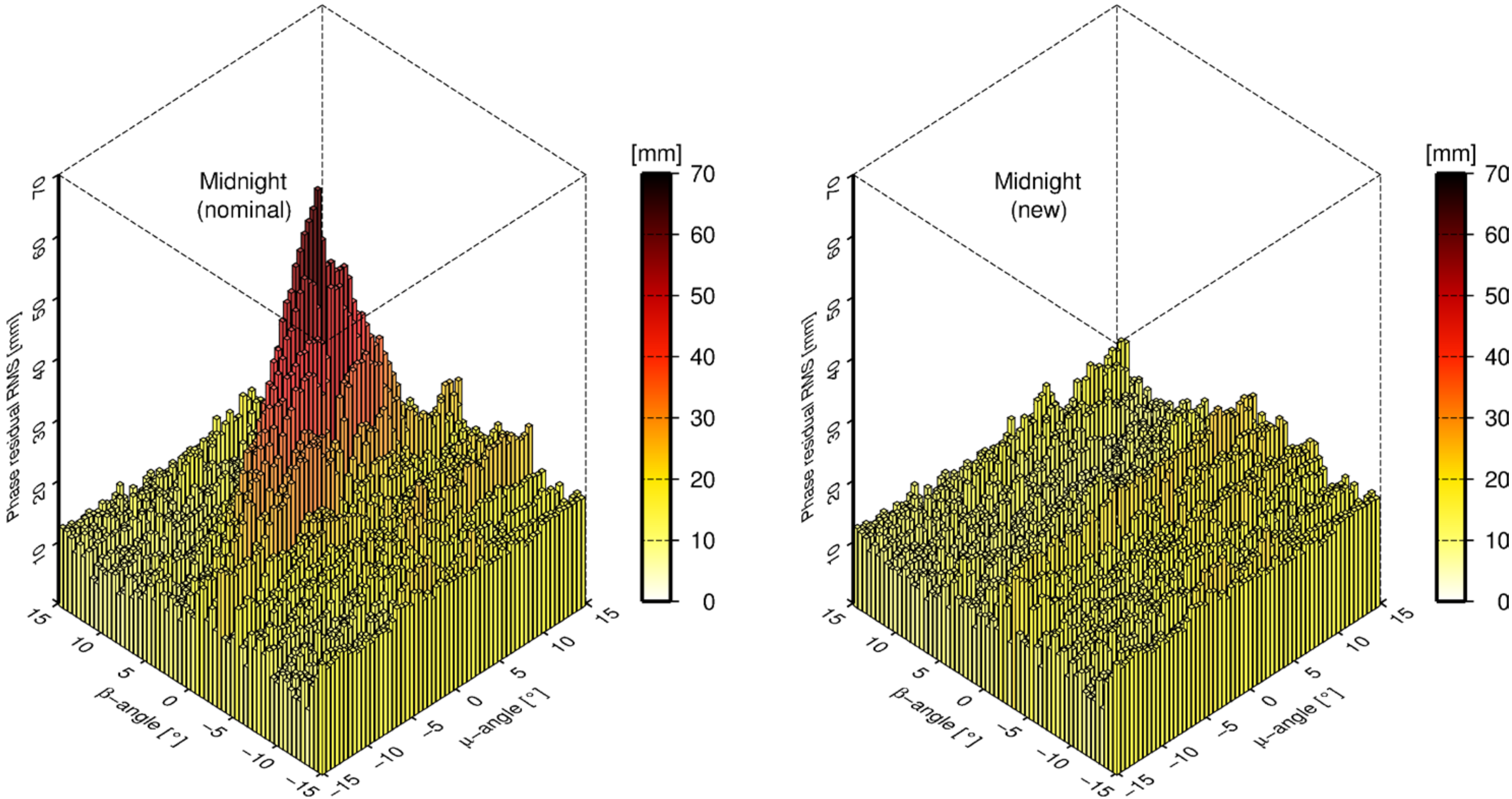
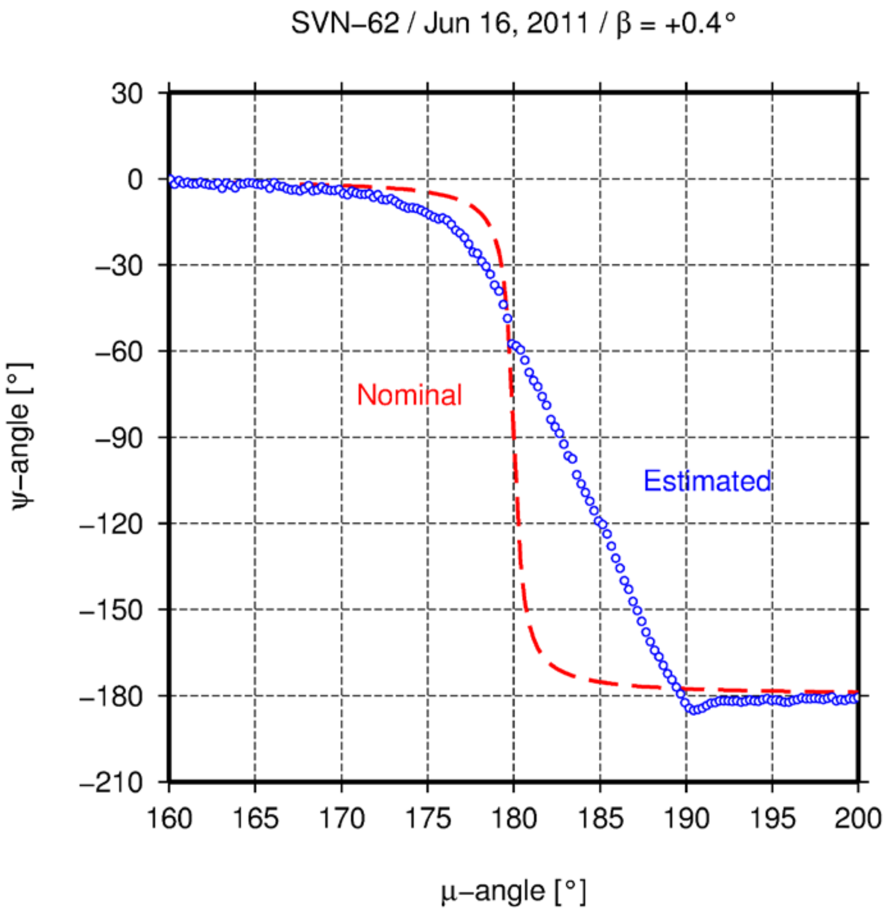


“Nominal” attitude model vs. new attitude model



Noon-turn regime

- S/C cannot keep up with required yaw rate, if |β| < 4.5°
- Estimated and "nominal" yaw angle diverge under small negative β-angle (-0.9° < β < 0°); Δψ adds up to 360°
- Linear drift in IGS clock solutions in the range of 0.4 ns (0.12 m) due to phase wind-up mismodeling



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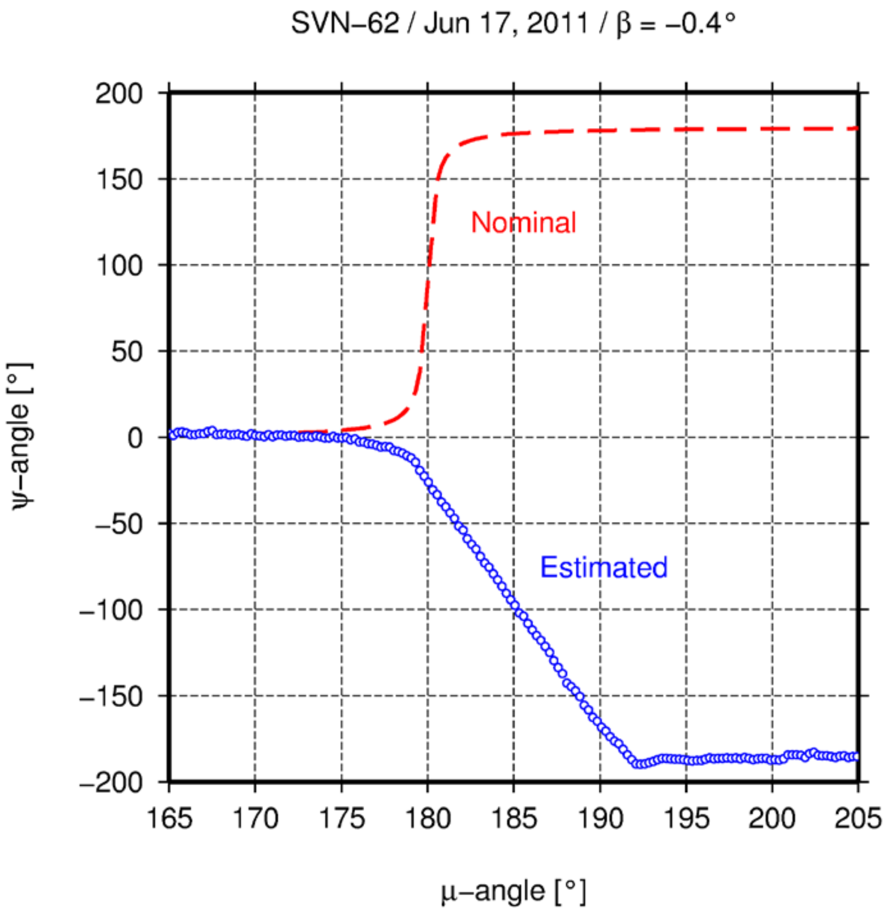

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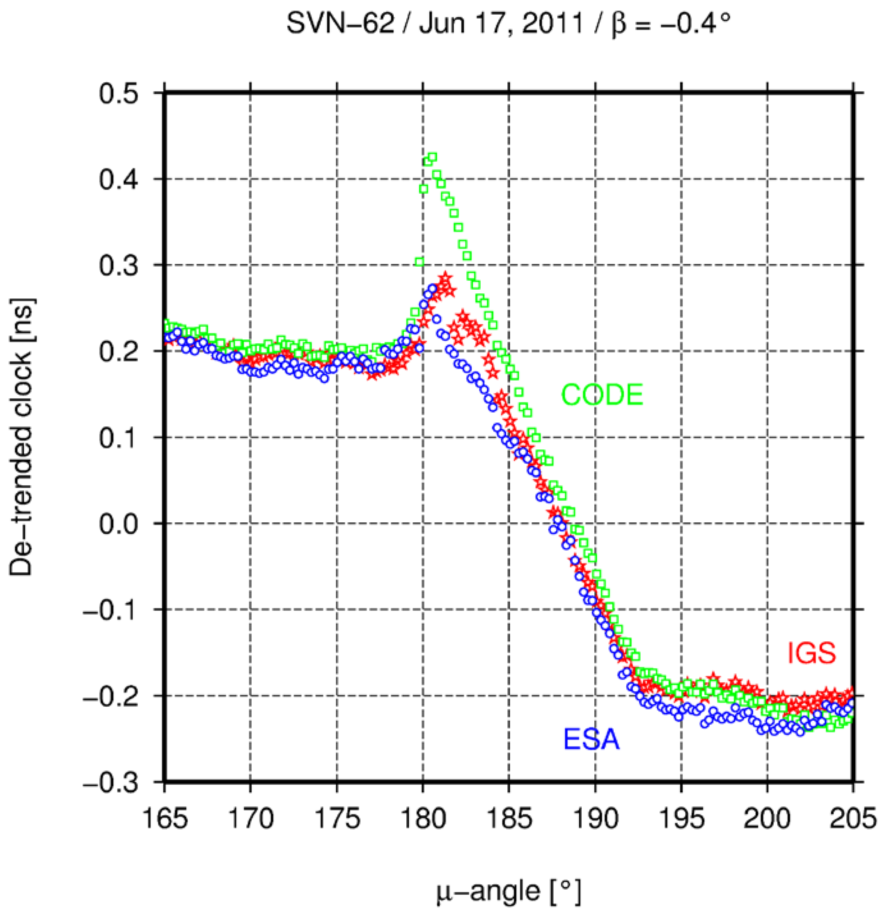
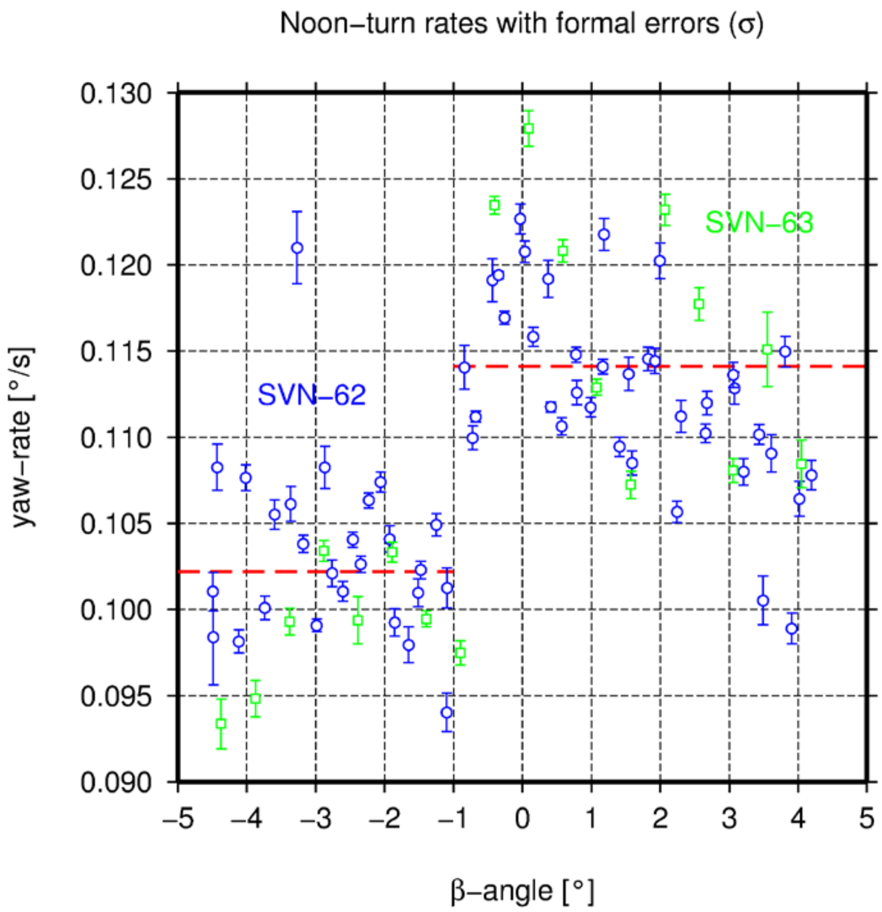


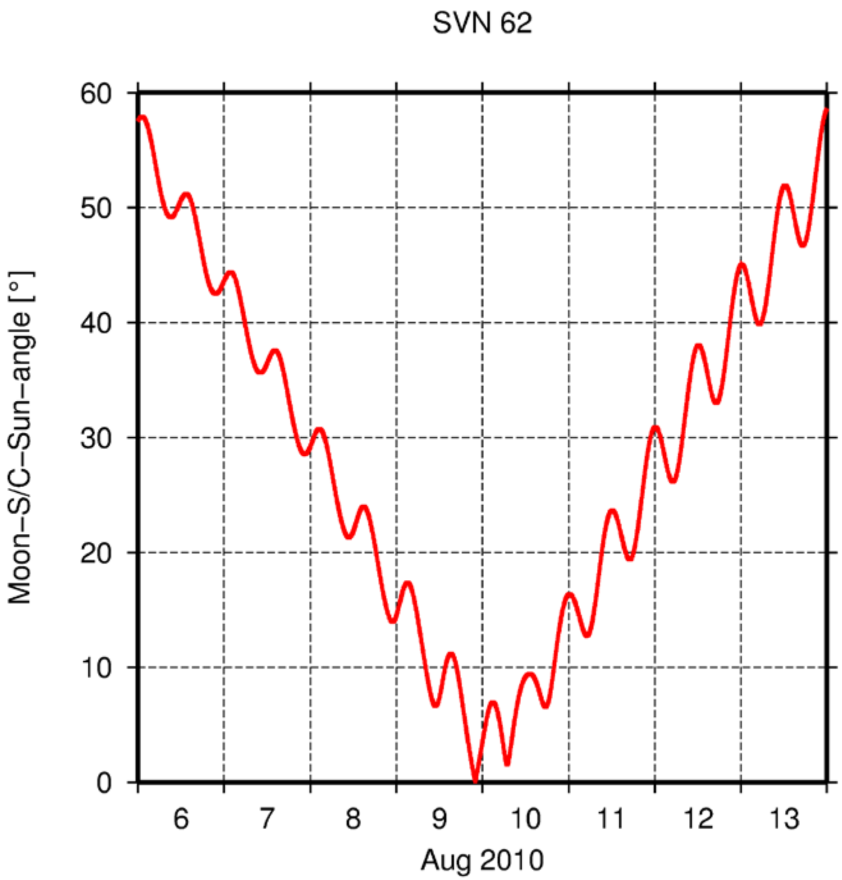
Noon-turn yaw-rate estimates

- Yaw-rate estimates for 81 noon-turn events (SVN-62: #63, SVN-63: #18)
- S/C yaws about twice as fast as during shadow crossing
- Discontinuity at β = -0.9°; difference between high and low rate values of 0.01°/s
- Estimates vary by 5%; repeatability four times worse than midnight rates



Moon eclipse

- Analysis of eight partial Moon eclipses
- No yaw anomalies detected, except for 40-min eclipse event on Aug 9, 2010
- S/C reached darkest point on its eclipse passage at 21:58 UTC; angle between S/C-Moon and S/C-Sun is 0.07°
- S/C starts yawing with -0.08°/s; yaw reversal after 20 min; rotation at full rate until “nominal” attitude is resumed



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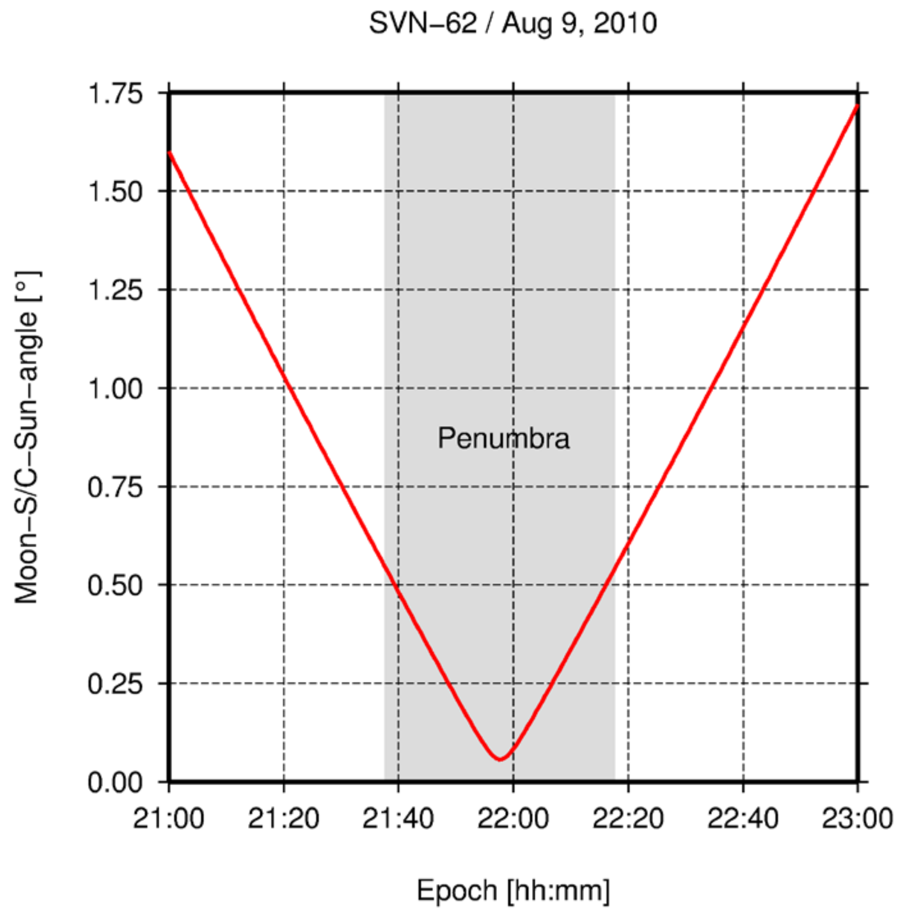

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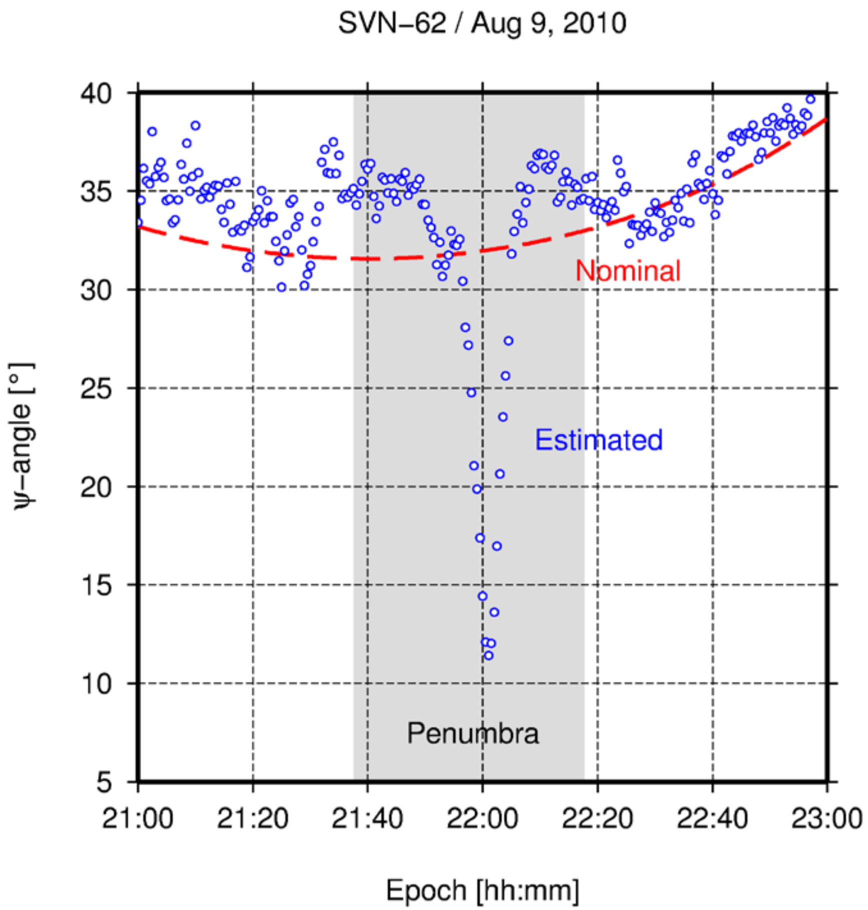

Conclusions

- Block IIF satellites follow a completely different yaw attitude scheme, when passing through the Earth's shadow, as the Block IIA and IIR S/C
- Midnight-turn yaw rate is kept constant to the value needed to get the S/C near to its nominal attitude when leaving the Earth's shadow
- S/C crossing shadow during middle of the eclipse season ($\beta = 0°$) needs to yaw almost two times faster as towards the edges of the eclipse season
- Yaw angle can be precisely modeled using 2nd order yaw rate polynomial; model reduces phase residual RMS from up to ±7 cm down to ±1 cm
- Noon-turn model still under development
- Moon eclipses rarely affect attitude control