Extended Abstract for 19th International Symposium on Space Flight Dynamics
Title: TRMM On-Orbit Performance Re-Accessed After Control Change
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The Tropical Rainfall Measuring Mission (TRMM) spacecraft, a joint mission between the U.S. and Japan, launched onboard an HII rocket on November 27, 1997 and transitioned in August, 2001 from an average operating altitude of 350 kilometers to 402.5 kilometers. Due to problems using the Earth Sensor Assembly (ESA) at the higher altitude, TRMM switched to a backup attitude control mode. Prior to the orbit boost TRMM controlled pitch and roll to the local vertical using ESA measurements while using gyro data to propagate yaw attitude between yaw updates from the Sun sensors[1]. After the orbit boost, a Kalman filter used 3-axis gyro data with Sun sensor and magnetometers to estimate onboard attitude[2]. While originally intended to meet a degraded attitude accuracy of 0.7 degrees, the new control mode met the original 0.2 degree attitude accuracy requirement after improving onboard ephemeris prediction and adjusting the magnetometer calibration onboard.

Independent roll attitude checks using a science instrument[3], the Precipitation Radar (PR) which was built in Japan, provided a novel insight into the pointing performance. The PR data helped identify the pointing errors after the orbit boost, track the performance improvements, and show subtle effects from ephemeris errors and gyro bias errors[4]. It also helped identify average bias trends throughout the mission.

Roll errors tracked by the PR from sample orbits pre-boost and post-boost are shown in Figure 1. Prior to the orbit boost the largest attitude errors were due to occasional interference in the ESA. These errors were sometime larger than 0.2 degrees in pitch and roll, but usually less, as estimated from a comprehensive review of the attitude excursions using gyro data. Sudden jumps in the onboard roll show up as spikes in the reported attitude since the control responds within tens of seconds to null the pointing error. The PR estimated roll tracks well with an estimate of the roll history propagated using gyro data. After the orbit boost, the attitude errors shown by the PR roll have a smooth sine-wave type signal because of the way that attitude errors propagate with the use of gyro data. Yaw errors couple at orbit period to roll with ¼ orbit lag.

By tracking the amplitude, phase, and bias of the sinusoidal PR roll error signal, it was shown that the average pitch rotation axis tends to be offset from orbit normal in a direction perpendicular to the Sun direction, as shown in Figure 2 for a 200 day period following the orbit boost. This is a result of the higher accuracy and stability of the Sun sensor measurements relative to the magnetometer measurements used in the Kalman filter. In November, 2001 a magnetometer calibration adjustment was uploaded which improved the pointing performance, keeping the roll and yaw amplitudes within about 0.1 degrees.

After the boost, onboard ephemeris errors had a direct effect on the pitch pointing, being used to compute the Earth pointing reference frame. Improvements after the orbit boost have kept the the onboard ephemeris errors generally below 20 kilometers. Ephemeris errors have secondary effects on roll and yaw, especially during high beta angle when pitch effects can couple into roll and yaw. This is illustrated in figure 3.

The onboard roll bias trends as measured by PR data show correlations with the Kalman filter's gyro bias error. This particularly shows up after yaw turns (every 2 to 4 weeks) as shown in Figure 3, when a slight roll bias is observed while the onboard computed gyro biases settle to new values. As for longer term trends, the PR data shows that the roll bias was influenced by Earth horizon radiance effects prior to the boost, changing values at yaw turns, and indicated a long term drift as shown in Figure 4. After the boost, the bias variations were smaller and showed some possible correlation with solar beta angle, probably due to sun sensor misalignment effects.

References

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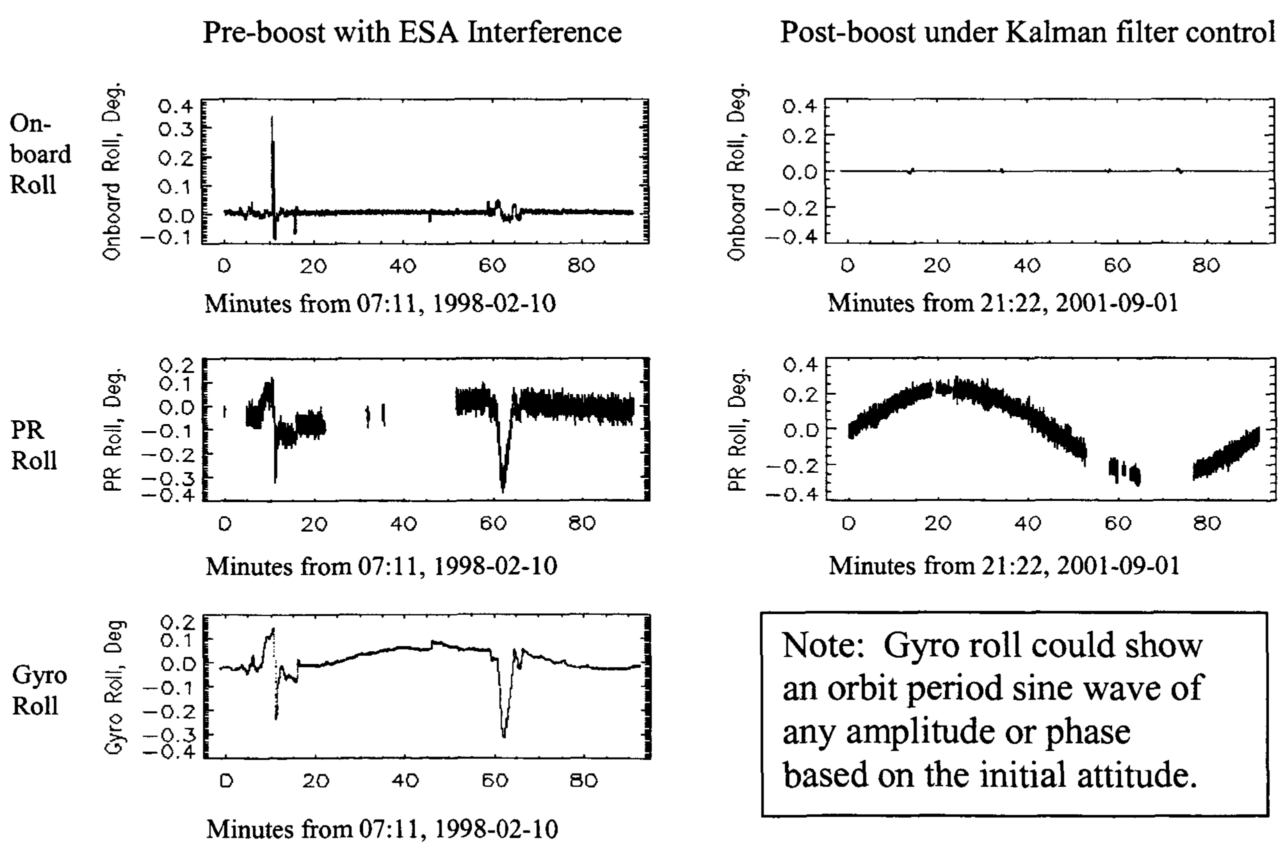

Figure 1. Sample roll data for orbit spans under ESA roll control, and Kalman filter control

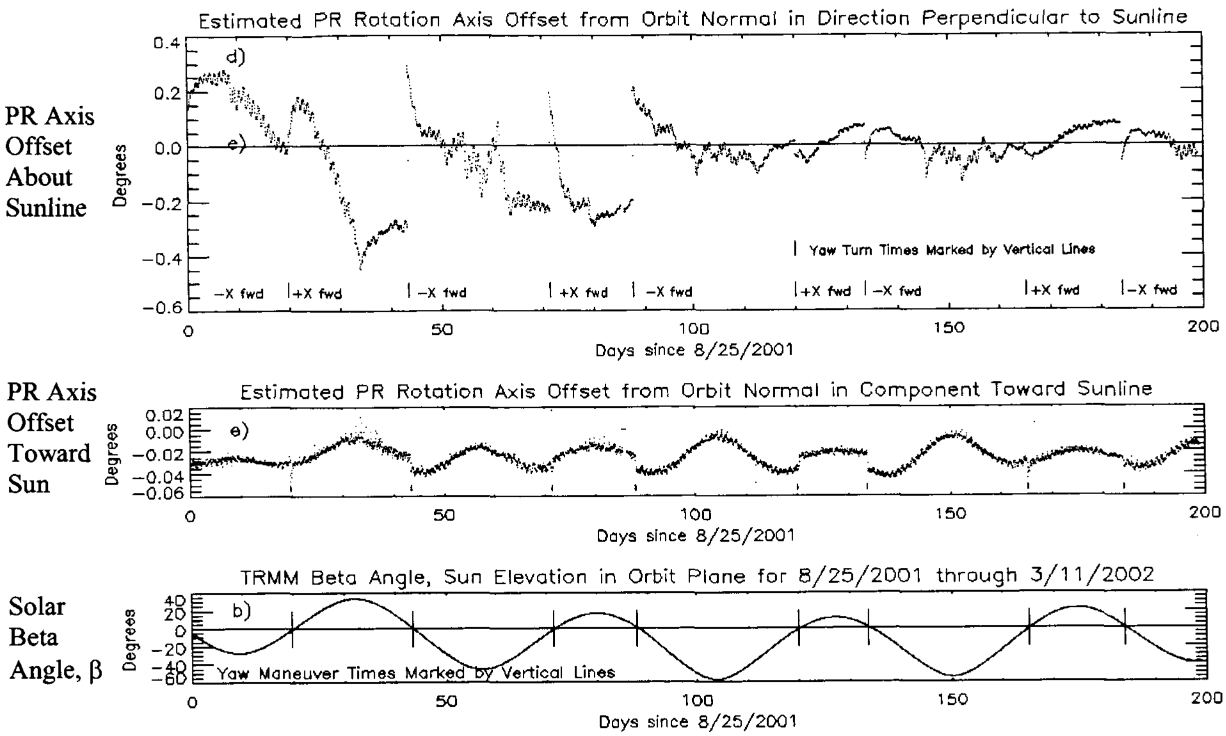

Figure 2. Average offset in PR average rotation axis from orbit normal relative to Sun direction

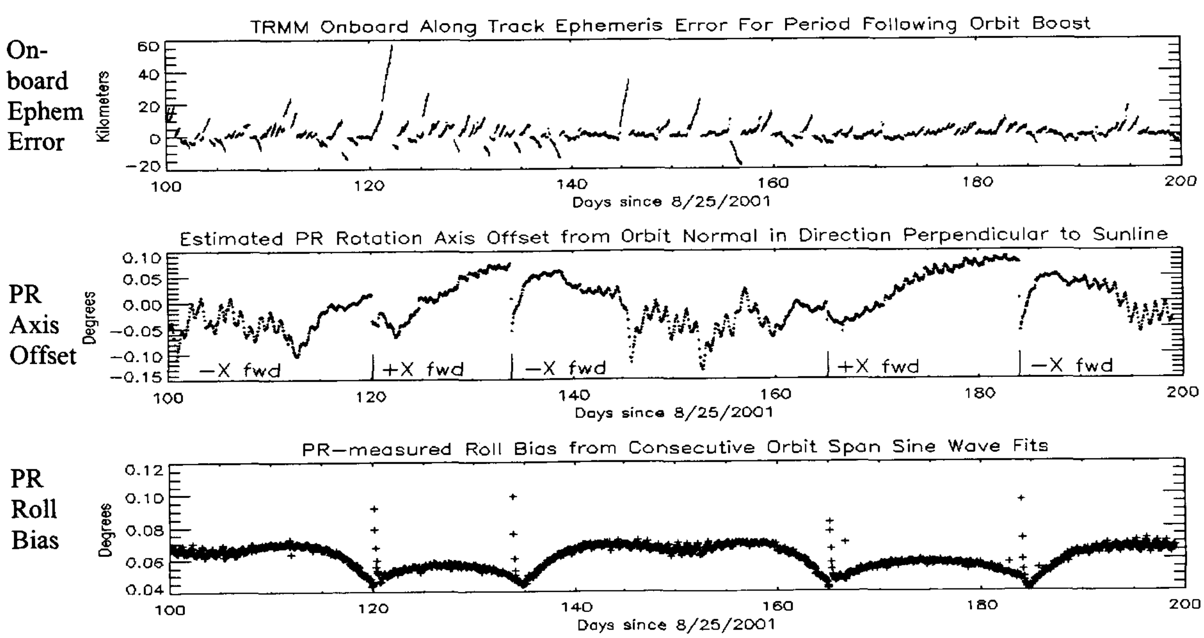

Figure 3 Roll/yaw attitude excursions associated with ephemeris errors, and roll bias effects at yau turns.

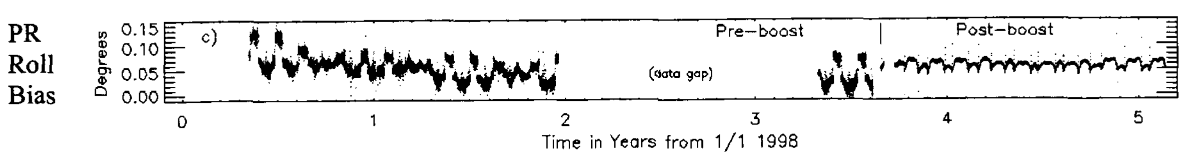

Figure 4. Long-term trends in PR estimated roll bias, showing bias shifts before and after the orbit boost