Evaluation of the KBR Simulation Model with Flight Data

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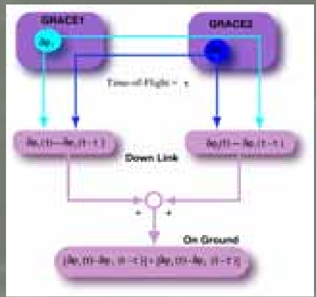
Abstract

The K-band inter-satellite ranging (KBR) system is the primary measurement system of the GRACE mission. During the preliminary design and ground test period of the GRACE satellites, comprehensive KBR simulations were performed to evaluate the accuracy level of the KBR and to predict the overall GRACE mission performance. Comparison between the simulated KBR measurements and real flight measurements can improve the fidelity of the simulation models and may contribute to the calibration of the KBR measurements. This paper describes the pre-flight simulation models and ongoing status of the comparison process.

Concept of KBR System

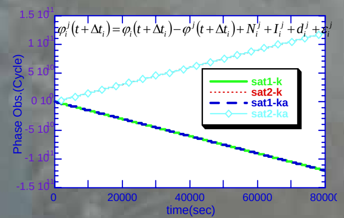
With identical transmission and reception subsystems, each satellite transmits a carrier phase signal to the other satellite. The received signal at each of the two satellites is recorded and later transmitted to a ground station. The frequency fluctuations due to oscillator instability have nearly equal and opposite effects on each satellite's measurement and summation of these two phases cancels most of the oscillator noise.



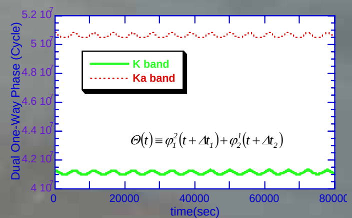
KBR Measurement Simulation

The measurement simulation part begins with generating truth orbits and GPS observations by using truth dynamic models. Time-tag errors are generated and added to the nominal time to yield the actual observation (signal reception) time. The phase error time-series are generated from the oscillator specification. With these error sources four one-way phase measurements for each epoch are generated.

The measurement processing part computes the inter-satellite range from the one-way phases. Several corrections are applied to yield an instantaneous range at each epoch.



Simulated one-way phases



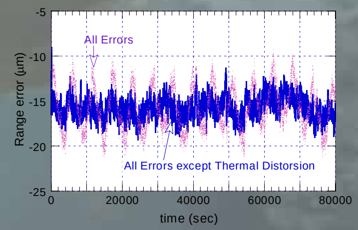
Simulated dual one-way phases

Error Sources

Applied error sources are as follows:

- Oscillator noise due to the USO instability
- Time-tag error due to measurement time-tag determination error after ground time-tag correction
- System noise
- Multipath noise
- AM/PM conversion error
- Attitude knowledge error from the star cameras
- Thermal distortion (CM-to-PC distance change)

Among those error sources, the thermal distortion has not been fully modeled yet. The total error level is within 10 micron.



Simulated KBR Range Error

Other Possible KBR Error Sources

There are several error sources not included in the simulations.

- Data gap - Mitigated by measurement Interpolation
- Thermal distortion -Modeled but its size and behavior are not fully known
  - Possible correlation with the orbit
- Multipath - Its characteristic is very complicated and not fully known
  - Possible correlation with the attitude and gravity signal (routine maneuver)
- Interpolation error due to time-tag offset - Caused by large onboard clock offset

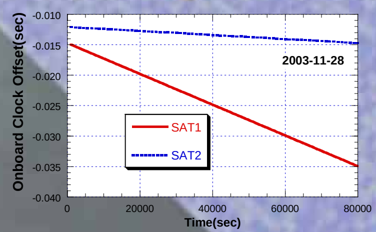
Measurement Time-tag Offset

Due to the noise cancellation process of the KBR, one-way phase measurement time from the two satellites should be synchronized. Difference between the one-way phase measurement time-tags for common epoch degrades the oscillator noise cancellation efficiency and increases the range error. In order to minimize this effect, GRACE uses GPS measurements to correct the measurement time-tags. The correction process in ground involves two steps:

- Determines true measurement time using GPS data
- Interpolates KBR one-way phase data toward a common nominal time

The onboard clock driven by the USO determines the measurement time-tag and the clock offset grows with the USO drift. In order to limit the clock error level, the onboard GPS receiver provides the clock offset and performs routine clock resets when the clock offset becomes larger than a specific limits.

The figure shows the clock offset on November 28, 2003, and the offset rates are -250ns/s (SAT1) and -100ns/s (SAT2).



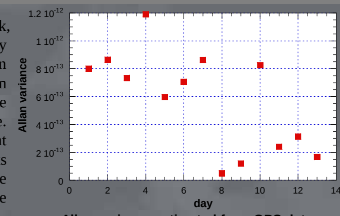
Onboard Clock Offsets

Measurement Interpolation Error

The interpolation error on the KBR one-way phase measurements grows as the time-tag offset becomes larger. Smaller time-tag offset is preferable but it requires much more onboard clock reset. The interpolation error level depends on the USO variability during short time interval (interpolation interval) and interpolation method. Preliminary simulation analysis shows a high level of interpolation error but the conclusion is reserved until the USO error model is fully updated with the flight data and the same interpolation algorithm as with the GRACE Level 1B process is implemented.

USO Stability Analysis by using GPS Measurements

Since the USO drives the onboard clock, analysis of the time-tag error may computes the USO stability, e.g. Allan variance. The Allan variance from several days of CLK1B data were computed as shown in the figure. However, another analysis shows that the GPS measurement accuracy limits the USO stability analysis and the results may not be directly used for the USO analysis.



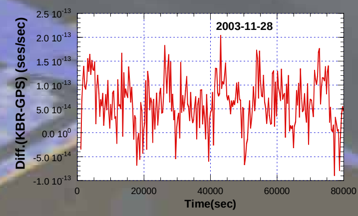
Allan variance estimated from GPS data

KBR Phase Difference Rate

JPL GRACE team evaluated the CLK1B clock offset estimates, which is from the GPS measurements, by comparing with the KBR measurements. The rate of the difference between the two satellites' phase can be approximated with a function of the clock offset estimates and the signal time-of-flights, the later are driven from the orbit solution using the GPS measurements.

JPL's analysis shows a certain level of discrepancy as much as 0.06ps/s bias while the KBR simulation shows no bias. This implies that there is un-modeled error source in the KBR or certain systematic bias in the clock offset estimates from the GPS data.

Comparison with another independent clock offset estimates may help the analysis



Difference between KBR and GPS rates

Future Works

Improvement of GRACE instrument calibration technique is one of the key factors to improve the gravity solution accuracy and resolution. Comprehensive analysis on the GRACE instruments, especially the KBR, is required. Updating the pre-flight simulation model with the flight data may explain the discrepancy between the baseline gravity accuracy and the current gravity accuracy and may improve the instrument calibration methods.

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