Improving Near Real-Time and Predicted Earth Orientation Parameters Using IGS Ultra-Rapid Polar Motion and Length-of-Day Measurements

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Abstract. It has been recognized since the early days of interplanetary spacecraft that accurate navigation requires taking into account changes in the Earth's rotation. In the 1960s, tracking anomalies during the Ranger VII and VIII lunar missions were traced to errors in the Earth orientation parameters. As a result, Earth orientation calibration methods were improved to support the Mariner IV and V planetary missions. Today, accurate Earth orientation parameters are used to track and navigate every interplanetary spacecraft mission. The approach taken at JPL to provide the interplanetary spacecraft tracking and navigation teams with the Earth orientation parameters that they need is based upon the use of a Kalman filter to combine past measurements of the Earth orientation parameters and predict their future evolution. Changes in the Earth's orientation can be described as a randomly excited stochastic process; consequently, between measurements, the uncertainty in our knowledge of the Earth's orientation grows and rapidly becomes much larger than the uncertainty in the measurements. Thus, measurements of the Earth's orientation must be taken frequently and processed rapidly in order to meet the demand accuracy requirements of the spacecraft navigation teams. Here, the improvement in the accuracy of JPL's near real-time and predicted EOPs when the IGS Ultra-Rapid polar motion and length-of-day measurements are included in the Kalman filter is discussed. A 30% improvement in the accuracy of the short-term predicted PMX, PMY, and UT1 estimates delivered to the interplanetary spacecraft navigation teams at JPL is obtained when the IGS Ultra-Rapid polar motion and length-of-day measurements are included in the solution.

Kalman Earth Orientation Filter

- **Introduction**
  - Accurate navigation of interplanetary spacecraft requires accurate knowledge of Earth's orientation.
  - Must know Earth's orientation in space to know spacecraft's position in space from Earth-based tracking measurements.

- **Earth Orientation Data**
  - EOP prediction accuracy controlled by timeliness and accuracy of most recent measurement.
  - UT1 varies rapidly and randomly.
  - UT1 orientation varies rapidly and randomly.

- **Kalman Filter Theory**
  - The Kalman filter is an optimal estimator in a sense which is made precise under assumptions about the statistical properties of the system being estimated.

Impact of IGS Ultra-Rapid

- **Control Run (No IGS Ultra-Rapids)**
  - PMX, PMY, UT1 estimates. This improvement is achieved because the IGS Ultra-Rapid polar motion and length-of-day measurements are more timely than the Rapids, but are still quite accurate.

- **With IGS Ultra-Rapid Polar Motion and Length-of-Day**
  - PMX, PMY, UT1 delivered to the navigation teams during the last half of 2014 was 0.39, 0.31, 1.6 cm, respectively. This grow to 17.8, 5.4, 10.1 cm at prediction day 5.

Measurements of the Earth's changing orientation in space acquired by the space-geodetic techniques of very long baseline interferometry (VLBI), satellite and laser ranging (SLR and LLR), and global navigation satellite systems (GNSS) including the IGS Final and Rapid combined series are merged using a Kalman filter to provide the interplanetary spacecraft navigation teams at JPL with the near real-time and short-term predicted EOPs that they need. The accuracy of the near real-time and predicted EOPs is determined by comparing them to a more accurate reference series. The rate over the last 6 months of 2014 of the difference of the daily operational solutions with a more accurate reference series is shown above. During this time period, the most timely EOP measurements included in our solutions were the IGS Rapid polar motion and length-of-day measurements. The near-real-time (prediction day 0) accuracy of PMX, PMY, UT1 delivered to the navigation teams during the last half of 2014 was 0.39, 0.31, 1.6 cm, respectively. This grow to 17.8, 5.4, 10.1 cm at prediction day 5.

Kalman Earth Orientation Filter

- **Introduction, cont.**
  - UT1 orientation varies rapidly and unpredictably.

- **Earth Orientation Data, cont.**
  - External data.

- **Kalman Filter Theory, cont.**
  - The measurement model provides a relationship of the system state with the measurements. The state transition model gives the relationship of the system state with the time.

- **Impact of IGS Ultra-Rapids**
  - Precision statistics using IGS Ultra-Rapid polar motion and length-of-day measurements.