GNSS Activities at the U.S. Naval Observatory

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Abstract: The Earth Orientation Department at the U.S. Naval Observatory (USNO) produces precise Earth orientation parameters on a daily basis. As part of this activity, we contribute to the international GNSS community as an IGS Associate Analysis Center, producing Rapid and Ultra-Rapid products on a daily and sub-daily basis. The accuracies of these products have improved significantly by the implementation of modified processing strategies and the addition of modernized software. This paper describes our method of orbit determination and prediction, the improvements to our products, and relevant research currently being pursued at USNO.

Methods

USNO continues to contribute rapid and ultra-rapid products to the IGS. Descriptions of the methods used for each product are given below.

Rapid Products

The GIPSY/OASIS (GOA) orbit processing software is used for generating our Rapid products. A new computer running RedHat Linux, with the latest version of GOA, has been added to the Rapid processing effort. Three computers now contribute to the Rapid solution, each using a different version of GOA (versions 4, 2.6 and 2.5). Each computer is assigned different IGS stations to process (with some redundancy), and the individual results are merged, so a large number of stations contribute to the overall solution without processing all the stations within the same program run. The merging of individual solutions is weighted based on comparison to the IGS Ultra solution. The steps involved for a typical Rapid processing run are given below.

Procedure:
- Select 34 – 44 well distributed stations.
- Quality check the observations.
- Execute 2 passes maximum through filter/smoother.
- Execute 4 passes maximum through outlier editor/smoother.
- Resolve integer ambiguities.
- Compute additional clock solutions with Precise Point Positioning (PPP) using new orbits, satellite clocks, and Earth Rotation Parameters (ERPs).

Particulars:
- Processing length: 3+24 hours
- Elevation cutoff: 15 degrees
- Sample rate: 5 minutes

Ultra-rapid Products

The Bernese GPS software (version 5.0) is used for generating our Ultra products. Currently, we produce 0-hour and 12-hour Ultra-rapid orbits, satellite clocks and Earth rotation parameters, generating determined values for the previous 24 hours, and predicted values for the next 24 hours. Since double-differencing is employed, satellite clock solutions are determined using the new orbits and ERPs. The steps involved for a typical Ultra-rapid processing run are given below.

Procedure:
- Select ~35 well distributed stations.
- Quality check the observations.
- Form the double-differences.
- Resolve integer ambiguities.
- Perform main parameter estimation of determined orbits and ERPs.
- Solve for satellite clocks using estimated orbits, ERPs.
- Predict orbits, clocks and ERPs for next 24 hours.

Particulars:
- Processing Length: 3+24 hours.
- Elevation cutoff: 3 degrees
- Sample rate: 3 minutes

Performance

The precision of the USNO Rapid and Ultra-rapid products continues to improve. Figure 1 shows the smoothed orbit precisions for both products, compared against the IGS Rapid orbits, for January 2002 through March 2006. Note the sudden improvement in the Ultra-rapid performance in the summer of 2005, which corresponds to our implementation of the Bernese GPS Software for that product. Figure 2 shows the RMS and number of station clocks solved for in our Rapid products for January 2002 through March 2006.

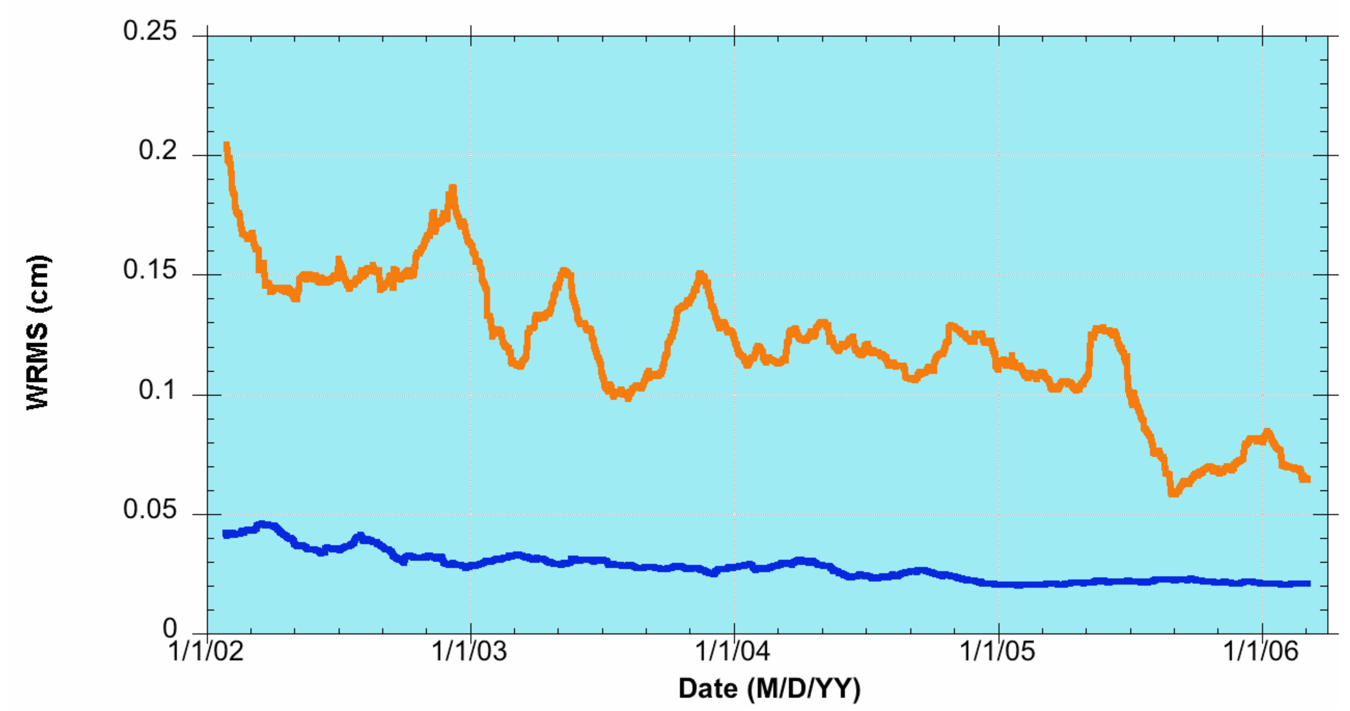

Figure 1. Rapid and Ultra-rapid Orbit Performance

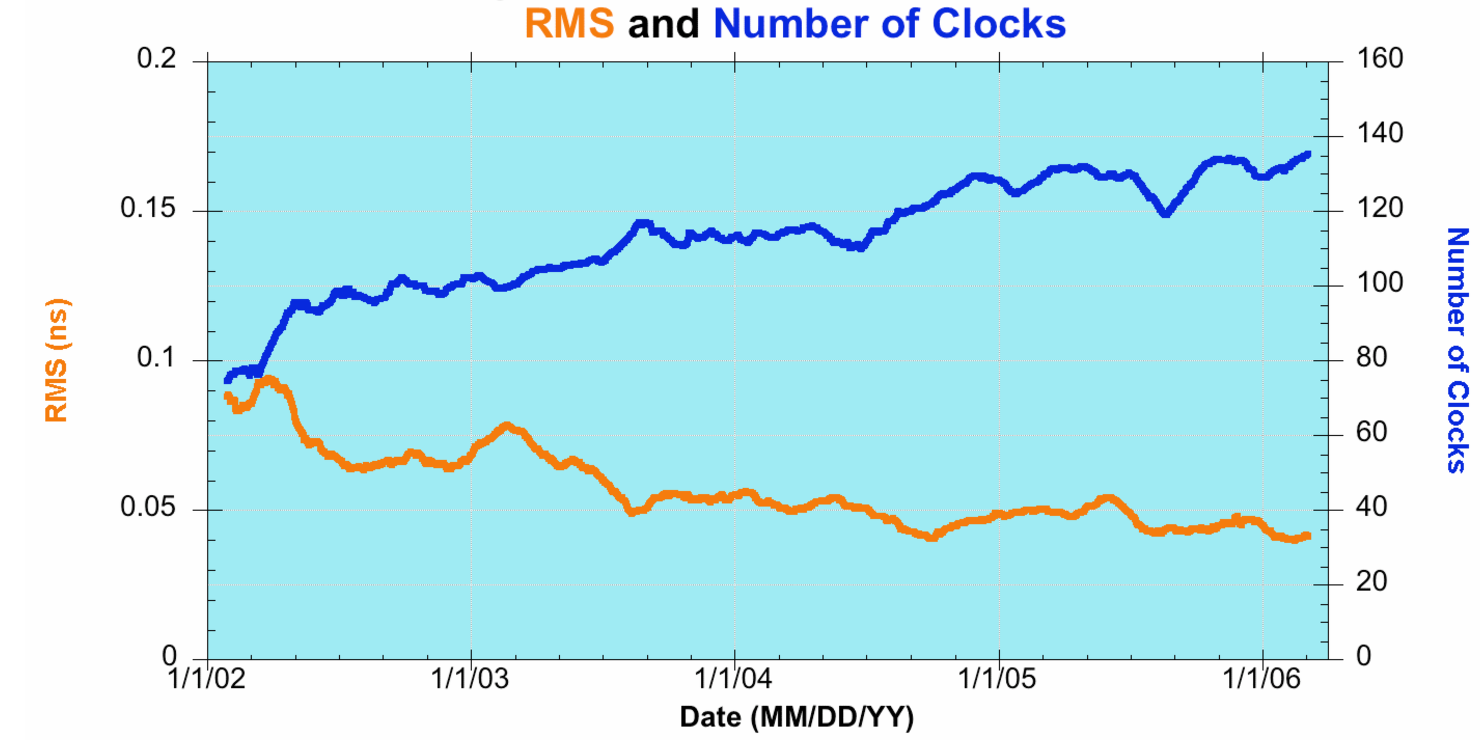

Figure 2. Rapid Clock Performance RMS and Number of Clocks

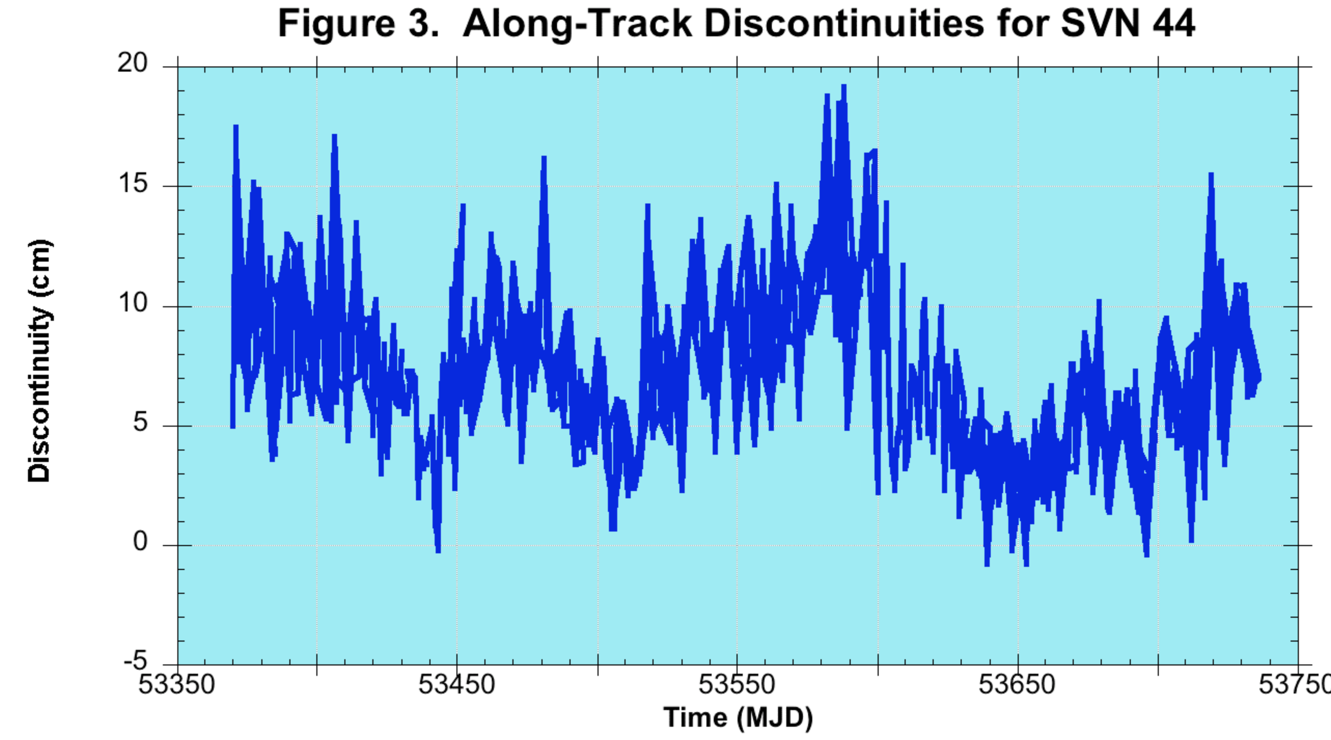

Figure 3. Along-Track Discontinuities for SVN 44

Research

Several areas of GNSS research are being pursued by the USNO, both for the improvement of our current products and for new applications. The research described below includes orbital day-boundary discontinuities, a UT1-like product from GPS (UTGPS), and carrier-phase time transfer.

Orbital Day-boundary Discontinuities

When we fit a GPS spacecraft trajectory through several days of orbit positions from IGS Rapid orbit SP3 files, the orbit position residuals show discontinuities at the day boundaries between SP3 files. Figure 3 shows the along-track component of the discontinuity through the year 2005 for SVN 44 (PRN28), a GPS Block II-R spacecraft. The discontinuities for this spacecraft are particularly large and always positive, with a weekly mean varying between +2 and +13 cm. Other spacecraft show similar discontinuity values that have the same sign for several months, that is, the variation is not random.

The 9 cm mean of the Figure 3 discontinuity values indicates a change in the determined orbit error at the day boundaries which is much larger than the 2 cm RMS difference between orbits from different Analysis Centers. V. Slabinski is investigating possible sources of the systematic error.

UT1-like GPS Product (UTGPS)

P. Kammeyer has developed the UTGPS product, which uses GPS satellite orbit information to estimate UT1. For each satellite used in the product, the observed relation between the satellite's IGS orbit and a model of its orbit plane in inertial space is used to estimate UT1. Standard gravitational force models and an empirical model representing orbit-normal radiation pressure (over several years) are applied. UTGPS results are currently used as input to the USNO Bulletin-A process, and are especially useful when VLBI data are unavailable. Kammeyer is currently working toward making improvements to the UTGPS software.

Carrier-phase Time Transfer

M. Lee and D. Matsakis (USNO) are working with R. Dach and U. Hugentobler (AIUB), and Z. Jiang (BIPM) comparing multi-day time transfer results using GIPSY and the Bernese GPS Software. Methods using GIPSY include independent daily clock solutions and also continuous (multi-day) solutions, both using code and phase data. The Bernese methods include continuous code+phase solutions and also continuous phase-only solutions. The Bernese continuous solutions are obtained using ambiguity stacking across day boundaries, while the GIPSY continuous solutions use a continuous Kalman filter. Figure 4 compares results of a 17-day period from these four methods against a "common clock" fiber-optic measurement between stations USNO and USN3, which is used as truth.

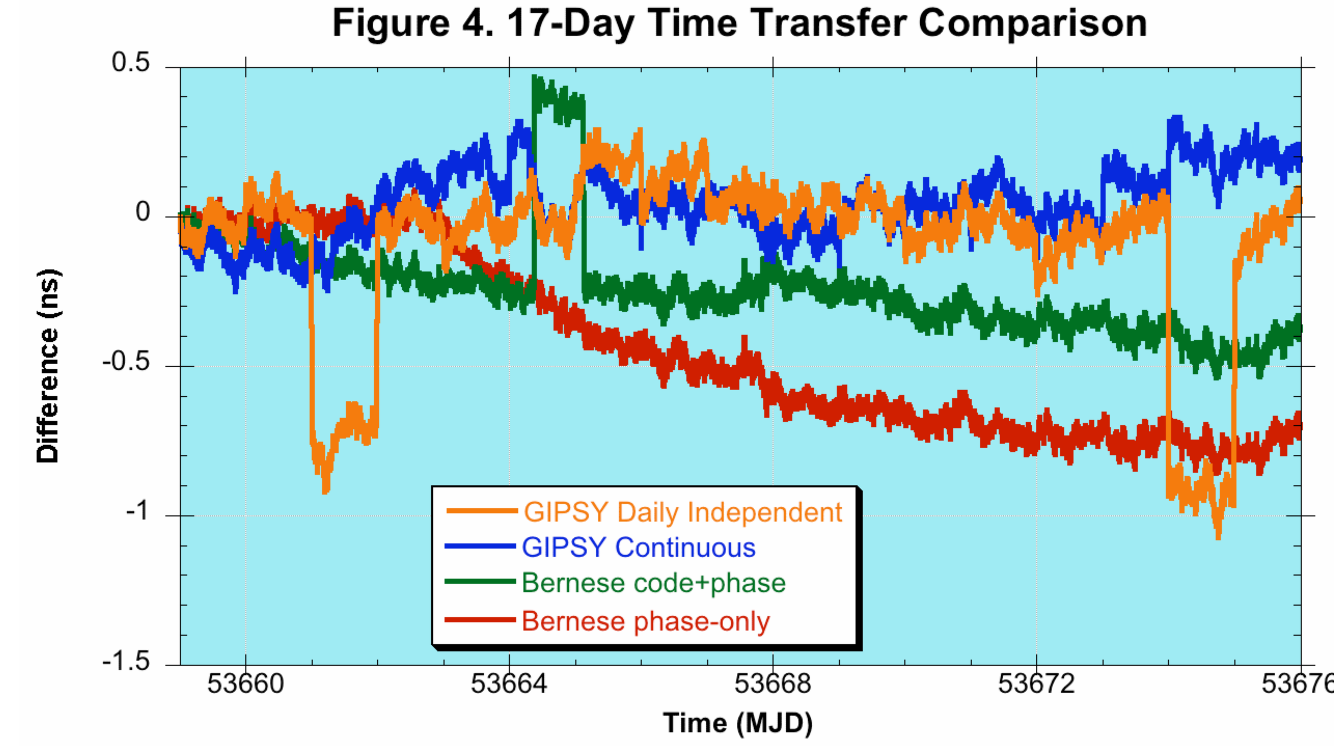

Figure 4. 17-Day Time Transfer Comparison