Usage of the UT1-like Quantity UTGPS at the United States Naval Observatory

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Introduction

The rate at which the Earth rotates and the position of its rotation axis undergo small, unpredictable irregularities which are observable as fluctuations in the axial-rotation angle UT1. These irregularities must be determined on a regular basis to facilitate coordinate transformations between the terrestrial frame and inertial space. We estimate an approximation of the axial-rotation angle UT1 by comparing numerically-propagated model GPS satellite orbits, referenced to inertial space, to observed orbits referenced to the Earth's surface. The comparison is converted into a UT1-like quantity from which the quantity UTGPS is determined over the entire constellation of GPS satellites. UTGPS is calculated daily and is used to extrapolate and interpolate between UT1 values determined by Very Long Baseline Interferometry (VLBI).

UTGPS at USNO

The U.S. Naval Observatory (USNO) fulfills the role of the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC). On a daily basis, USNO publishes a UT1-UTC value that is typically for 0^{h}UTC of the current day. Determinations of UT1 from VLBI, excess length of day (LOD) measurements from GPS satellite orbits, Atmospheric Angular Momentum (AAM) and UTGPS are combined to determine the value for UT1. On days when VLBI estimates are not available, UTGPS is the primary contributor to the value of UT1.

The IERS RS/PC also produces predicted values for UT1-UTC beyond the final combined value. AAM values are the primary component in determining these predicted values. UTGPS plays a vital role in keeping these predictions accurate since the AAM values rely on combined values of UT1 for calibration. Oftentimes, UTGPS values are the most recent UT data before AAM values are used to create predictions. More accurate combinations with UTGPS make more accurate predictions.

UTGPS is the median solution over the entire GPS constellation of UT1 values on a per satellite basis. The more satellites that are used in its determination, the less susceptible the daily solution will be to an occasional bad satellite. For instance, a satellite orbit might occasionally be modeled poorly during its eclipse season.

A new version of UTGPS is being tested with more than twice as many satelllites as the current version. Preliminary results are shown in Figure 1. The smoother the curves and the less drift from zero, the more useful UTGPS data are for accuracy of the combination. The current operational version will be replaced by the new one in the near future.

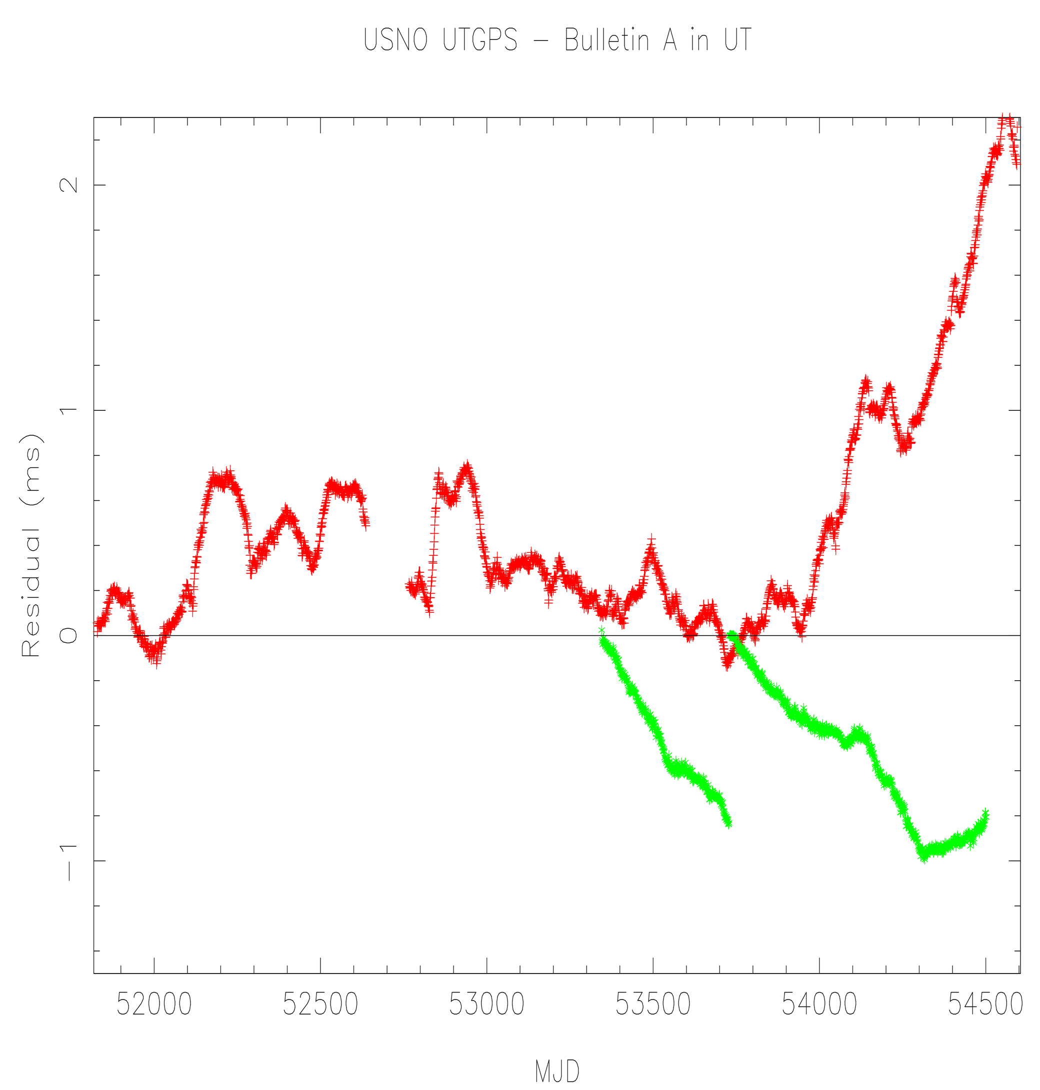

FIGURE 1: Graph showing the comparison of *Bulletin A* and UTGPS values for UT1. The red curve is the current operational version of UTGPS; the green curve is the new version. (Graph courtesy of Brian Luzum, USNO.)

Calculating UTGPS

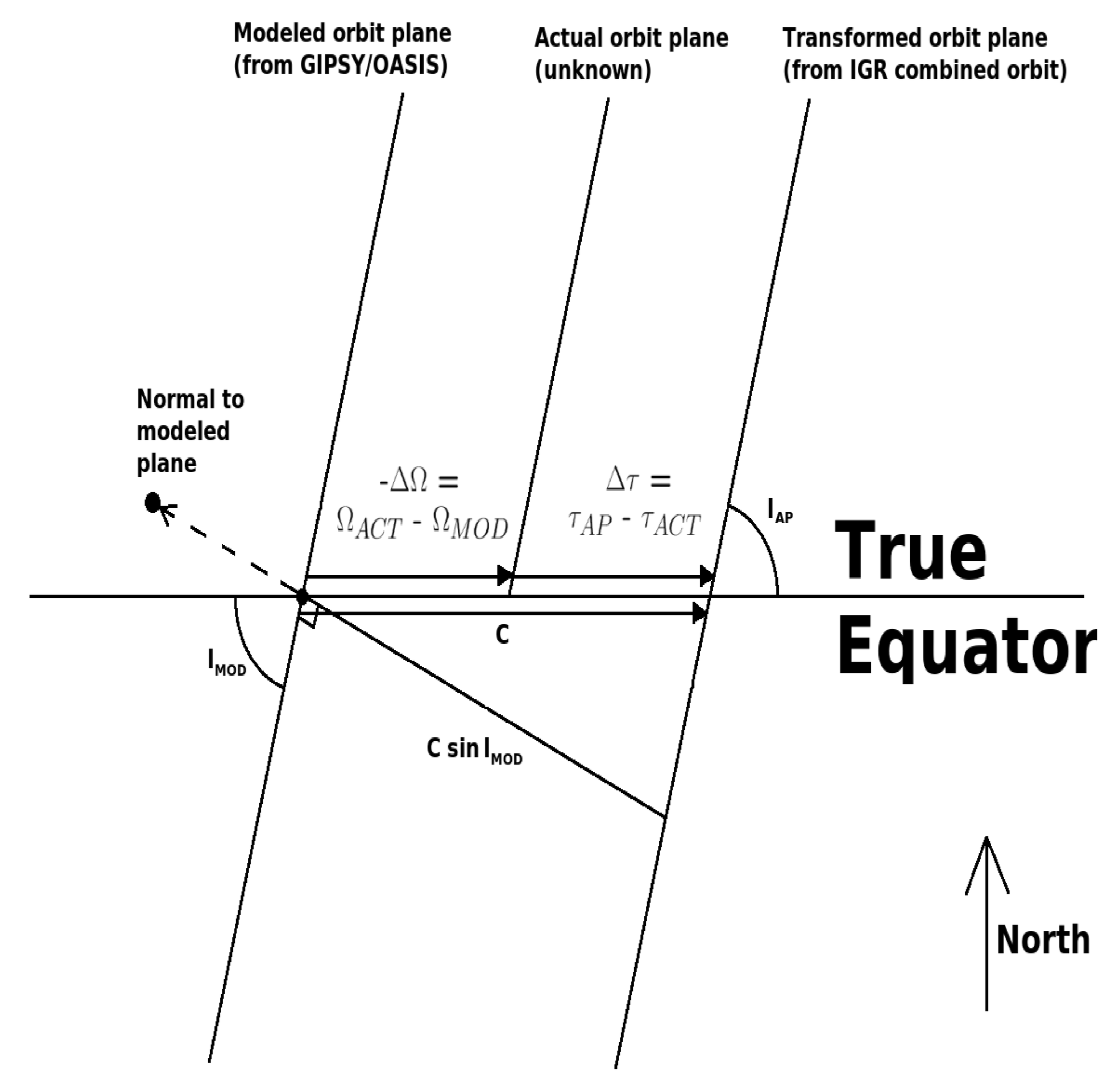

FIGURE 2: An illustration of how the region of the ascending nodes of the orbits used to determine UTGPS appear from outside the celestial sphere looking inward. The orbit planes are the modeled orbit, the actual orbit, and the transformed orbit, where Ω is right ascension and τ is Greenwich Apparent Sidereal Time (GAST).

The right ascension for the actual and modeled orbit planes on the True Equator are denoted as Ω_{ACT} and Ω_{MOD}. The quantity of the unknown offset between the actual orbit and the modeled orbit is expressed as the difference between these two right ascension values:

$$\Delta\Omega = \Omega_{MOD} - \Omega_{ACT} \tag{1}$$

Consider the observable angle, $C = \Omega_{AP} - \Omega_{MOD}$ which is the arc of the true equator from the ascending node of the modeled orbit to the ascending node of the transformed (a-priori) orbit. Figure 2 and equation (1) illustrate that:

$$C = (\Omega_{AP} - \Omega_{ACT}) - (\Omega_{MOD} - \Omega_{ACT}) = (\tau_{AP} - \tau_{ACT}) - \Delta\Omega \tag{2}$$

Multiplying equation (2) by the UT1 interval u required for the earth to rotate through one radian $(86164s/2\pi)$ yields:

$$uC = (UT1_{AP} - UT1_{ACT}) - u\Delta\Omega \tag{3}$$

If the value of $u\Delta\Omega$ were known then equation (3) could be used to solve for an exact value of UT1$_{ACT}$. Rather, $\Delta\Omega$ is modeled and steered so that it remains close to UT1$_{AP}$. The modeled value of $\Delta\Omega$, the a-priori value UT1$_{AP}$, and the quantity C that was determined from the comparison of the transformed orbit and the modeled orbit are used to solve for a UT1-like quantity UT1$_{SAT}$ on a per satellite basis in place of UT1$_{ACT}$. The median of these UT1$_{SAT}$ values over the entire GPS constellation is the value UTGPS.

Orbit Planes

We compare the modeled to the observed orbit in order to solve for the quantity UTGPS.

Modeled Orbit: The model orbit plane in inertial space is initialized with EOP (Earth-orientation parameters) from the IERS and International GNSS (Global Navigation Satellite System) Service (IGS) Rapid orbit positions. The goal is to create a model plane that is close to the observed plane of the satellite on the day of initialization. In propagating the model orbit plane, gravitational models provided with the GIPSY-OASIS II software (Webb and Zumberge, 1993) are used along with models of the effect of solar radiation pressure on movement of the orbit plane. The model for solar radiation pressure is determined after the satellite has been launched (see next section). The model orbit plane is propagated in 24h arcs using the position and velocity from the previous day. After initialization, current values (neither EOP nor IGS Rapid orbit positions) are no longer used in determining the model orbit for subsequent days. No model is perfect so the modeled orbit will be offset from the actual orbit by a changing unknown quantity every day, equation (1).

Observed Orbit: For each UTC day, the IGS produces for each GPS satellite a combined Rapid orbit, in the form of position vectors expressed in the International Terrestrial Reference Frame (ITRF). These vectors are transformed with polar motion and Greenwich Apparent Sidereal Time (GAST) to a rough approximation of inertial space. The transformation is not exact and if the actual GAST matrix could be applied to determine true-of-date coordinates, then UT1 could be determined exactly. GAST is assumed a-priori in the transformation.

The transformed orbit is in close proximity to the modeled orbit. Since the compared orbits are so close, small-angle approximations can be used. These orbits are discussed extensively by Kammeyer (2000).

Modeling Solar Radiation Pressure

In addition to the gravitational models used in propagating the modeled orbit planes, forces from solar radiation pressure also affect movement of the orbit plane and must be taken into account. As the orientation in inertial space of the GPS satellite orbit plane changes with respect to the sun throughout the course of about a year, the angle of the sun to the orbit plane will be at a maximum once, a minimum once, and edge-on twice, coinciding with the eclipse seasons of the satellite. The movement of the orbit plane due to solar radiation pressure is a function of this sun angle.

Comparisons are made of observed positions of the satellite, taken from IGS Rapid orbit products, which include the effect of the solar radiation force and modeled positions of the satellite in which a very general model for solar radiation forces is used. These comparisons are made independent of any calculation of UTGPS and are on a per satellite basis as each satellite is unique in construction, orbit plane orientation with respect to inertial space and orbit plane slot. From these comparisons, a more accurate model can be made of the effect of solar radiation pressure on the satellite orbit for a given angle of the sun to the orbit plane. These models are put into table format and then subsequently used in the propagation of model orbits for determination of UTGPS.

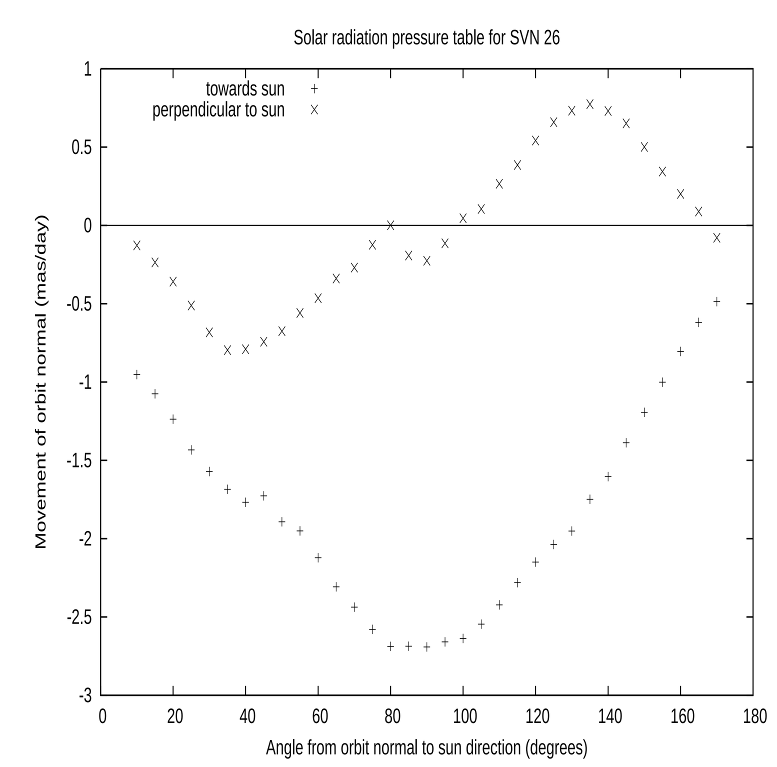

FIGURE 3: An example of a solar radiation pressure table showing movement of the orbit plane characterized by movement of the orbit normal as a function of the angle from the orbit normal to the sun.

References

[1] Kammeyer, P. *Celestial Mechanics and Dynamical Astronomy 77: 241-272.* 2000

[2] Webb, F.H. and Zumberge, J.F. (eds): 1993, *An introduction to GIPSY/OASIS II,* Jet Propulsion Laboratory, Pasadena, CA.