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ACCURACY ASSESSMENT OF GEOSTATIONARY-EARTH-ORBIT WITH SIMPLIFIED PERTURBATIONS MODELS

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ABSTRACT. A two-line element set (TLE) is a data format encoding orbital elements of an Earth-orbiting object for a given epoch. Using suitable prediction formula, the motion state of the object can be obtained at any time. The TLE data representation is specific to the simplified perturbations models, so any algorithm using a TLE as a data source must implement one of these models to correctly compute the state at a specific time. Accurately adjustment of antenna direction on the earth station is the key to satellite communications. With the TLE set topocentric elevation and azimuth direction angles can be calculated. The accuracy of perturbations models directly affect communication signal quality. Therefore, finding the error variations of the satellite orbits is really meaningful. In this present paper, the authors investigate the accuracy of the Geostationary-Earth- Orbit (GEO) with simplified perturbations models. The coordinate residuals of the simplified perturbations models in this paper can give references for engineers to predict the satellite orbits with TLE.

Keywords: Geostationary-Earth-Orbit; simplified perturbations models; two-line element set

1. INTRODUCTION

A Geostationary-Earth-Orbit (GEO) is a circular orbit 35786 kilometers above Earth's equator and following the direction of Earth's rotation. A satellite in such an orbit has an orbital period equal to Earth's rotational period, and appears motionless at a fixed position in the sky to ground observers. Communications satellites are usually placed in GEO orbit, so that the satellite antennas which communicate with them do not have to real-time rotate to track them, but can be pointed at the position in the sky where the satellites are located. A two-line element set (TLE) is a data format encoding orbital elements of an Earth-orbiting object for a given epoch (Kelso, 1998; Ma et al, 2016). With the simplified perturbations models, orbital state vectors of satellites relative to Earth can be calculated (Vallado et al., 2006; Wei & Zhao, 2009). An earth station plays a vital role in the satellite communications. Accurately adjustment of the antenna angle of direction on the earth station is the key to satellite communications (Roddy, 2006). The direction angle including azimuth and elevation angles can be calculated with the TLE set. The accuracy of perturbations models directly affect communication signal quality. To ensure that the Earth station works reliable the antenna should accurately aim at the target communications satellite. In this present paper, using the Systems Tool Kit (STK) software, the authors investigate the accuracy of the Geostationary-Earth-Orbit (GEO) satellites with simplified perturbations models.

2. SIMPLIFIED PERTURBATIONS MODELS

Simplified perturbations models are a set of five mathematical models (SGP, SGP4, SDP4, SGP8 and SDP8) (Vallado et al., 2006; Wei & Zhao, 2009). This set of models is often referred to collectively as SGP4 due to the frequency of use of that model particularly with TLE sets produced by the North American Aerospace Defense Command (NORAD) and National Aeronautics and Space Administration (NASA). Based on these models, the effect of perturbations caused by the Earth's shape, drag, radiation, and gravitation effects from other bodies such as the sun and the moon can be predicted. Simplified General Perturbations (SGP) models apply to near Earth objects with an orbital period of less than 225 minutes. Simplified Deep Space Perturbations (SDP) models apply to objects with an orbital period greater than 225 minutes.

The original SGP model was developed by Kozai in 1959, refined by Hilton & Kuhlman in 1966 and was originally used by the National Space Surveillance Control Center (and later the United States Space Surveillance Network) for tracking of objects in orbit. SGP8/SDP8 introduced additional improvements for handling orbital decay. Deep space models SDP4 and SDP8 use only 'simplified drag' equations. Accuracy is not a great concern here as high drag satellite cases do not remain in "deep space" for very long as the orbit quickly becomes lower and near circular. SDP4 also adds Lunar-Solar gravity perturbations to all orbits, and Earth resonance terms specifically for 24-hour geostationary and 12-hour Molniya orbits.

3. TLE SET DESCRIPTION

As mentioned above, the TLE data representation is specific to the above simplified perturbations models, so any algorithm using a TLE as a data source must implement one of the SGP models to correctly compute the state at a specific time. The TLE sets contain 69-character lines that can be used with NORAD's SGP4/SDP4 orbital model used to determine the position and velocity at a given time. An example TLE for the International Space Station is displayed in Fig. 1.

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ISS (ZARYA)
1 25544U 98067A   08264.51782528 -.00002182  00000-0 -11606-4 0  2927
2 25544  51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537
```

Fig. 1. An example TLE

The definitions of fields at first TLE line are given in the following Table. 1.

Table 1. TLE first line fields

Field	Columns	Content	Example
1	01–01	Line number	1
2	03–07	Satellite number	25544
3	08–08	Classification (U=Unclassified)	U
4	10–11	International Designator (Last two digits of launch year)	98
5	12–14	International Designator (Launch number of the year)	067
6	15–17	International Designator (piece of the launch)	A
7	19–20	Epoch Year (last two digits of year)	08
8	21–32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34–43	First Time Derivative of the Mean Motion divided by two	−.00002182
10	45–52	Second Time Derivative of Mean Motion divided by six (decimal point assumed)	00000-0
11	54–61	BSTAR drag term (decimal point assumed)	-11606-4
12	63–63	The number 0 (originally this should have been "Ephemeris type")	0
13	65–68	Element set number. Incremented when a new TLE is generated for this object.	292
14	69–69	Checksum (modulo 10)	7

The definitions of fields at second TLE line are given in the following Table. 2.

Table 2. TLE second line fields

Field	Columns	Content	Example
1	01–01	Line number	2
2	03–07	Satellite number	25544
3	09–16	Inclination (*i*, degrees)	51.6416
4	18–25	Right ascension of the ascending node (*RAAN*, degrees)	247.4627
5	27–33	Eccentricity (*e*, decimal point assumed)	0006703
6	35–42	Argument of perigee (degrees)	130.5360
7	44–51	Mean Anomaly (degrees)	325.0288
8	53–63	Mean Motion (revolutions per day)	15.72125391
9	64–68	Revolution number at epoch (revolutions)	56353
10	69–69	Checksum (modulo 10)	7

4. ACCURACY ANALYSIS

4.1 Simulation software

Systems Tool Kit (formerly Satellite Tool Kit) used in this work, is a physics-based software package from Analytical Graphics Inc. It is a suite of software that allows engineers and scientists to design and develop complex dynamic simulations of real-world problems, and allows engineers and scientists to perform complex analyses of ground, sea, air, and space assets, and share results in one integrated solution (Yang, 2005; Ma et al., 2011). The core of STK is a geometry engine for determining the time-dynamic position and attitude of assets, and the spatial relationships among the objects under consideration including their relationships or accesses given a number of complex, simultaneous constraining conditions. Originally created to solve problems involving Earth-orbiting satellites, the software has been used in both the aerospace and defense communities for many other applications. Its common application fields include space exploration, geo-spatial intelligence, spacecraft mission design, missile defense, spacecraft operations, etc. The STK software used in this work was released edition 10.0 in November, 2012.

4.2 Accuracy analysis

Actually, orbit elements of a GEO orbit change with time under the spatial perturbation force, thus the GEO satellite does not appear motionless. Refer to present communication satellites CHINASAT-12, ASIASAT-3S and MEASAT-2 with different orbit inclination, the Keplerian orbital elements of three virtual satellites, SAT-1, SAT-2 and SAT-3, are given in this work, respectively.

Table 3. Keplerian orbital elements

Sat No	Epoch year	Epoch	Semi-major axis (km)	*e*	*i* (°)	*RAAN* (°)	Argument of periapsis (°)	True anomaly (°)
SAT-1	2015	285.73248328	42164.2801	0.0002867	0.0211	280.870	281.754	169.587
SAT-2	2015	285.87345544	42164.8676	0.0003806	1.2600	81.092	124.896	280.048
SAT-3	2015	285.49450542	42164.2498	0.0009107	6.4969	54.527	155.767	136.603

With the simplified perturbations models the TLE sets of the orbit elements provided in Table 3 are obtained. The information contained in a TLE is a set of mean orbital elements that are specific to the SGP4 propagator, which considers secular and periodic variations due to Earth oblateness, solar and lunar gravitational effects, gravitational resonance effects, and orbital decay using a drag model. Daily coordinate time series are calculated once with the original orbit and also with the TLE sets under the true equator mean equinox (TEME) coordinate system, respectively. Finally, the coordinate residuals of the simplified perturbations models for the three satellites are drawn in the following Figs. 2-4.

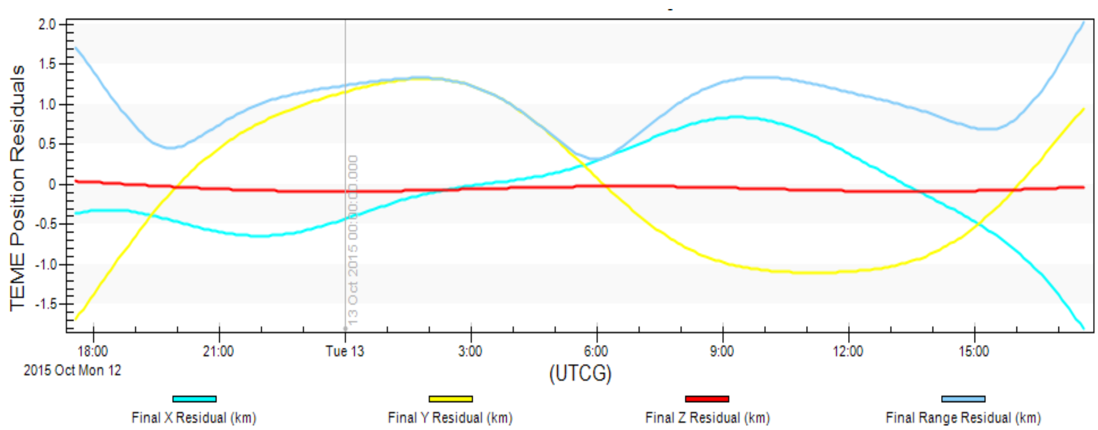

Fig. 2. Model residuals of SAT-1

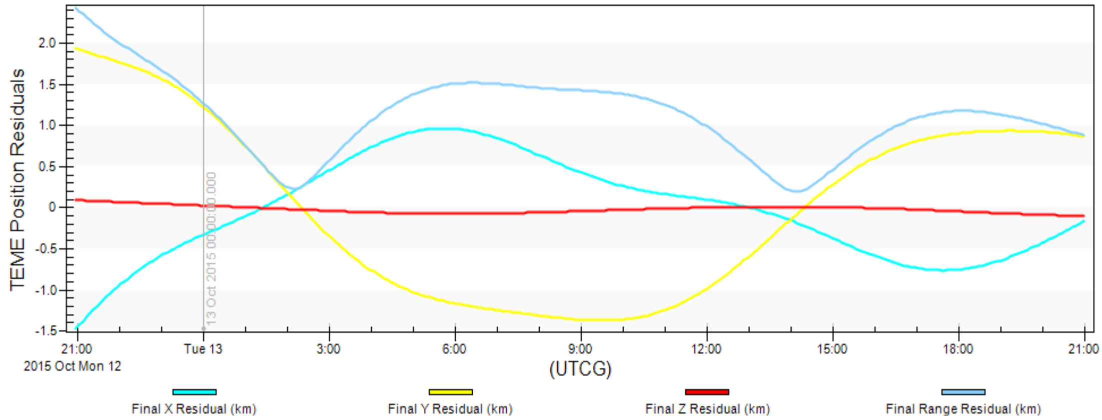

Fig. 3. Model residuals of SAT-2

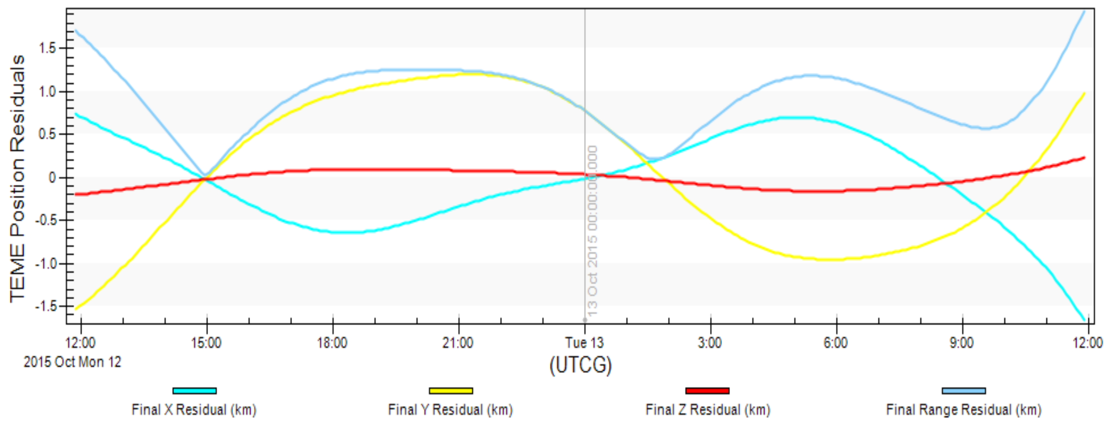

Fig. 4. Model residuals of SAT-3

5. SUMMARY

With the STK software, the accuracy of GEO orbits calculated with the simplified perturbations models is investigated. The results show that the model introduces an error of 1.5 kilometers within the whole analysis period. This data is updated frequently in NASA and NORAD sources to limit this error. The coordinate residuals of the simplified perturbations models can give references for engineers to predict the satellite orbits with TLE.

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