

# Sun ephemeris comparison

*The author presents various programs available on the internet, on PCs or smartphones to compute the solar astronomical parameters useful to gnomonists and compares the results with those obtained from authoritative sources, concluding that all of them can be considered satisfactory to gnomonic purposes, at least for general applications.*

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## Introduction

The instantaneous position of the Sun in the sky is a useful if not essential parameter for gnomonists in order to verify the time precision of a sundial. The purpose of this article is to list the available programs and data-bases that can provide this kind of information and to compare their results.

Only freeware or cheap programs have been here considered. Each one is shortly described together with instructions for the download.

All the results come from PC based programs with the following exceptions: *Horizons*, a web based program, that has been considered as the reference in the comparison of the results; *Astronomical Almanac*, a publication that is well known to astronomers all over the world, used as a confirmation source; *Almanacco UAI*, the publication of the Italian Amateur Astronomers Union (UAI) as a second confirmation source.

This is the list of data sources:

1. *Horizons* (reference values)
2. *Astronomical Almanac* (confirmation values)
3. *Almanacco UAI* (confirmation values)
4. *Geffem*
5. *The Dialist's Companion*
6. *Solex*
7. *Stellarium*
8. *AlmSun*
9. *Sun Ephemeris*<sup>1</sup>

This list is not claimed to be complete and it is based on the author's experience, his friends suggestions and several investigations on the web.

The comparison is based on results obtained for year 2015: it cannot be guaranteed, although it looks credible, that similar results can be obtained for previous or following years.

## Algorithms

There are two numerical methods to compute Sun ephemeris:

1. VSOP87 theory by P. Bretagnon and G. Francou [ref. 1]  
This theory consists of a long series of periodic terms that allow the calculation of the heliocentric coordinates of each planet from Mercury to Neptune (about 2500 terms for the Earth); the heliocentric coordinates of the Earth provide, when reversed, the geocentric coordinates of the Sun. The algorithm is well described in the book *Astronomical Algorithms* [ref. 2].

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<sup>1</sup> *Sun Ephemeris* results are exactly equivalent to the results that can be obtained from *Orologi Solari* and *Sol Et Umbra*

- models DE<sub>xxx</sub> developed by the Jet Propulsion Laboratory [ref. 3 - 4]  
 These models represent the positions, velocities and accelerations of the main bodies of the solar system, computed at constant intervals of time by means of numerical integration of the equations of motion. Data are distributed in the form of numerical coefficients of Chebyshev polynomials. The figures that follow the acronym DE (Development Ephemeris) differentiate the model according to the year of issue, the accuracy, the time covered etc.

## The programs

- Horizons* (version September 28, 2012)

This program uses the DE431 model. It was developed by the Solar System Dynamics Group at JPL (Jet Propulsion Laboratory) and it is able to provide accurate ephemeris of the solar system objects.

It is only available through the internet via a web, email or telnet interface. The web interface is available at <http://ssd.jpl.nasa.gov/horizons.cgi>.

The output of the program consists of a table in html or text format.

In this article *Horizons* results, being originated by the same organization that develops the DE<sub>xxx</sub> models that are the most accurate models currently available, have been considered as the absolute reference to which compare all the other data.

- Astronomical Almanac*<sup>2</sup>

This is an almanac published by the US Naval Observatory (USNO). Universally considered the ultimate source for all kinds of astronomical data, the almanac contains for the most part the ephemeris of the solar system as well as a catalog of stars and selected extragalactic objects. It uses the DE430 model.

In the context of this article it has been used as an additional element of verification for the data that has been possible to extract: right ascension, declination and equation of time.

- UAI Almanac*<sup>3</sup>

This is an almanac published by the Italian Amateur Astronomers Union and it is available for download from the UAI website [ref. 5]. The almanac contains mainly the ephemeris of the solar system (Sun, Moon, planets, asteroids, meteors). It uses the VSOP87 theory.

Also these data (right ascension, declination and equation of time) have been used in the context of this article as an additional element of verification.

- GEFFEM* (version 01/2003)

This program, that is well known to Italian as well as foreign gnomonists, was written by Gianni Ferrari and is available for download

from [http://www.gnomonicaitaliana.it/public/prg/G\\_EFFEM.zip](http://www.gnomonicaitaliana.it/public/prg/G_EFFEM.zip)

It implements the VSOP87 theory and makes use of the J. Meeus algorithms [ref. 2]. Being developed for MS DOS, starting from Windows 7 it cannot be anymore run

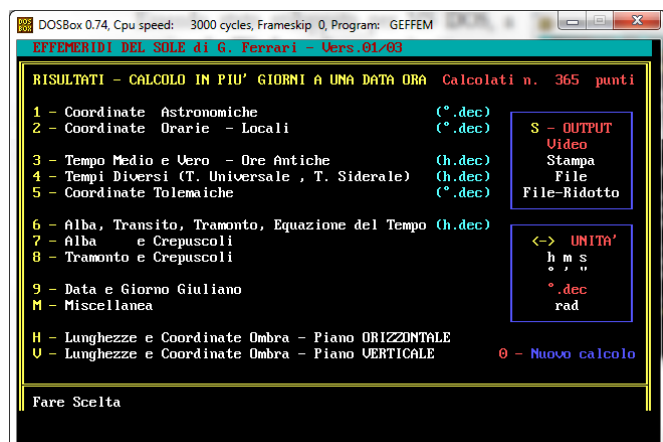


Fig. 1 - GEFFEM

<sup>2</sup> *Astronomical Almanac* data were kindly provided and properly interpolated by Giuseppe De Donà.

<sup>3</sup> These data too were kindly provided by Giuseppe De Donà although they can be obtained by interpolation from published data.

directly but it requires a dedicated simulation environment: virtual machine (eg. VirtualBox) or DOS emulator (eg. DOSBox). Program interface is shown in fig. 1.

The program allows to create tables of ephemeris for constant time steps (maximum 400) or arbitrary time values (up to 20). The allowed dates are between 9999 BC and 9999 AD.

5. *The Dialist's Companion* (version 1.1b)

Written by Robert Terwilliger and Frederick Sawyer from the North Atlantic Sundial Society (NASS), it is as *GEFFEM* written for MS DOS and therefore it suffers from the same compatibility problems.

It is no longer distributed by NASS but it can be easily found in the gnomonic community.

The program uses the theory VSOP87 and it implements the algorithms described in [ref. 2].

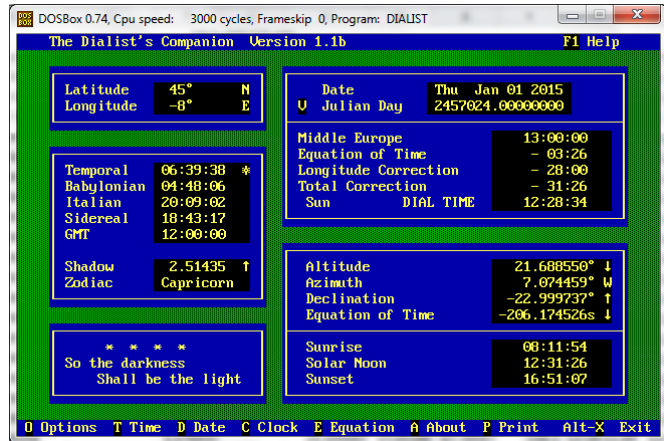


Fig. 2 – *The Dialist's Companion*

The program interface is shown in Fig. 2. Input date may range between year 1 and year 2999.

6. *Solex 11.0 Light* (revision 05, October 15, 2010)

This program was developed by Aldo Vitagliano and it uses the DE406 or the DE421 models.

The program can be downloaded from the site <http://www.solexorb.it/> where a 12.0 beta version is also available.

The interface is DOS style (fig. 3) but the program is fully compatible with Windows 7 (and presumably with later versions).

It is the author's opinion that the time setting for the calculation is not particularly easy and requires a bit of practice.

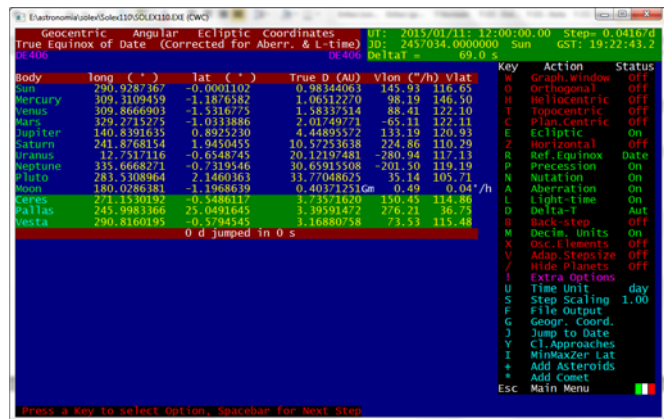


Fig. 3 - *Solex*

7. *Stellarium* (version 0.14.1β 64 bit)

It can be downloaded from the official website <http://www.stellarium.org/it/>.

It is an open source planetarium software that is very much loved by amateur astronomers because it includes a graphical interface that is very appealing and realistic, showing any sector of the sky at any moment and from any location.

The clock is evolving in real time or at the desired speed or it can be locked to the desired date/time.

Clicking on a celestial object, such as the Sun, the corresponding ephemeris are listed on the screen.



Fig. 4 - Stellarium

8. *AlmSun - Astronomical compedium* (version 4.63m 845)

Actually this program, developed by Rafal Tomasik, is not freeware but it requires the payment of a small \$ 19 donation that can be considered acceptable for the useful features it offers.

The program uses the DE431 or the DE406 models at the user's choice.

The web page <http://almsun.pl/en/> contains a detailed description of its many features together with the instructions for the purchase.

The program interface, fully compatible with Windows, is shown in fig. 5.

It is possible to graphically display many of the calculated quantities. The following original commands

$$time = f(b) \qquad time = f(a) \qquad time = f(b, a)$$

allow to compute the time instant at which the Sun reaches the azimuth  $a$  and/or the height  $b$ .

The command "Ephemeris" allows to get a table with the values of the desired ephemeris calculated at predetermined time intervals.

AlmSun is not exclusively dedicated to the Sun and it also provides information about the planets of the solar system, stars, asteroids and comets.

9. *Sun Ephemeris* (version 1.0)

This program has been developed by the author in order to make accessible on a PC all the data that are already supplied by his Android app *Sol Et Umbra* (and in part also by *Orologi Solaris*) and moreover to allow the calculation of entire data tables.

The program, which implements the VSOP87 theory, can be downloaded from the author's website <http://www.sundials.eu>.

Fig. 6 shows the main interface of the program that is developed natively for the Windows environment.

Computation time covers the period from 1/1/1900 to 1/1/3000<sup>4</sup>.

<sup>4</sup> This limitation may be overcome in the future as it is not due to the program itself, which might actually accept any date, but comes from the libraries that provide the control for date selection.

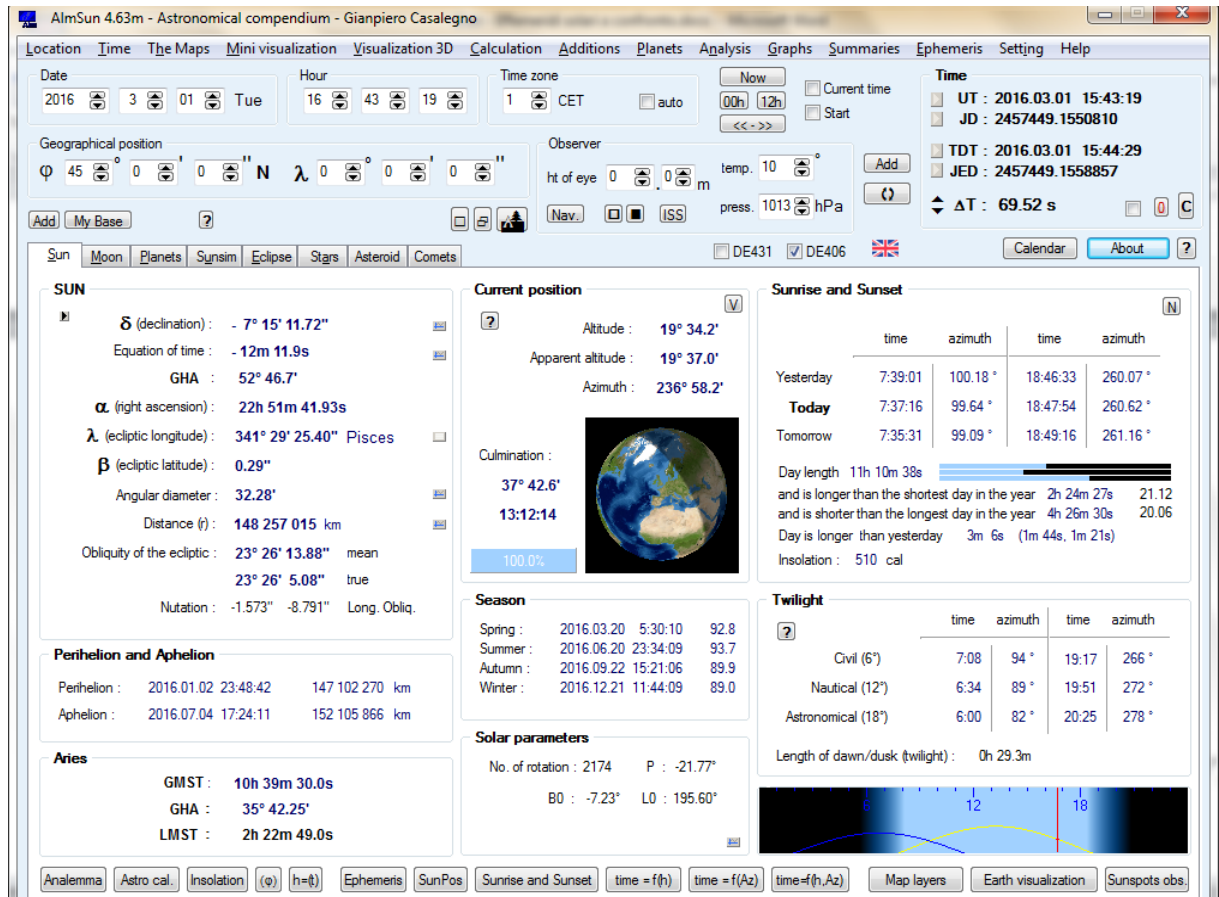


Fig. 5 - *AlmSun*

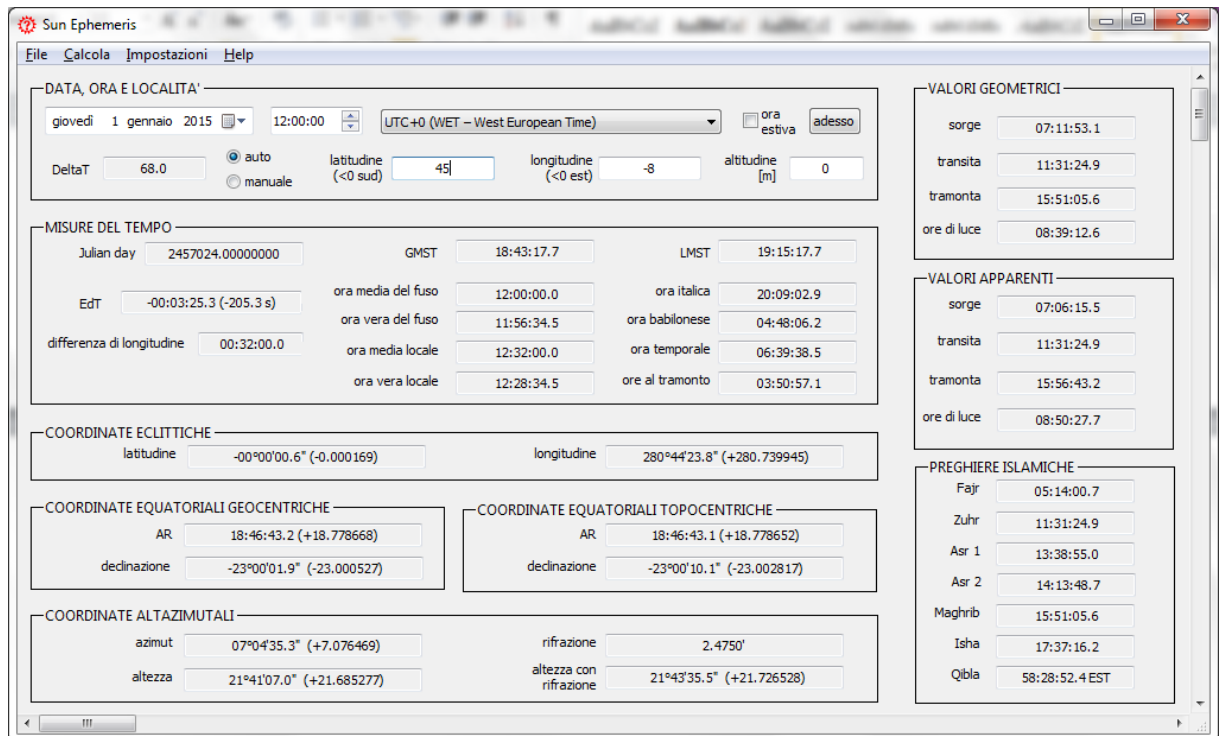


Fig. 6 - *Sun Ephemeris*

Between the calculated values it should be noted the presence of the times of Islamic prayers and the direction of Mecca, parameters quite unusual but useful for some types of sundials.

The command "Compute" → "Table" allows to compute and to save in many ways a table containing the ephemeris values in the desired time range at equally spaced instants.

## The comparison

The comparison was made by calculating solar parameters considered the most important in gnomonics, namely:

- apparent ecliptic longitude
- geocentric right ascension
- geocentric declination
- azimuth
- height
- equation of time

at 12 UT <sup>5</sup> on days 1, 11, 21 of each month in the year 2015. Topocentric parameters (azimuth and height) were computed for geographic coordinates 45° North and 8° East. Atmospheric refraction was not taken into account. Results were then compared to those obtained by the *Horizons* program and the resulting errors are shown in a series of graphs which allow to easily evaluate the performance of each program.

Table 1 shows for each program/almanac the acronym used in the graphs and the data that could be used in the comparison.

<i>source of data</i>	<i>acronym</i>	<i>longitude</i>	<i>AR</i>	<i>declination</i>	<i>azimuth</i>	<i>height</i>	<i>EoT</i>
<i>Astronomical Almanac</i>	<i>AA</i>		✓	✓			✓
<i>UAI Almanac</i>	<i>AU</i>		✓	✓			✓
<i>Geffem</i>	<i>GF</i>	✓	✓	✓	✓	✓	✓
<i>The Dialist's Companion</i>	<i>DC</i>			✓	✓	✓	✓
<i>Solex</i>	<i>SO</i>	✓	✓	✓	✓	✓	
<i>Stellarium</i>	<i>ST</i>	✓	✓	✓	✓	✓	✓
<i>AlmSun</i>	<i>AS</i>	✓	✓	✓	✓	✓	✓
<i>Sun Ephemeris</i>	<i>SE</i>	✓	✓	✓	✓	✓	✓

Tab. 1 – List of available data

<sup>5</sup> For other aspects related to the instant of calculation, see the appendix "On the time scales used" at the end of this article.

### 1. Apparent Ecliptic Longitude

The solar longitude is the parameter that defines the entry of the Sun in the zodiac signs, each 30° wide, and it is essential to assess the correctness of the day lines in a sundial.

Graphs of fig. 7 and 8 show, with different vertical scales, the errors obtained.

All the programs show an error lower than one arcsecond with the exception of *Stellarium* which presents an error greater than 20 arcseconds. In particular *Solex*, *AlmSun* and *Sun Ephemeris* are virtually coincident.

Note that one arcsecond in longitude corresponds to nearly 25 seconds in time: a 20 arcseconds error thus involves an error of about 8 minutes in the calculation of the instant of an equinox or a solstice!

### 2. Geocentric Right Ascension

Right ascension has been included in the comparison for completeness although it is generally not used in gnomonics.

The two graphs in fig. 9 and 10 show the results (expressed in arcseconds although right ascension is usually measured in hours, minutes and seconds) with two different vertical scales.

Again, error is contained in about one arcsecond except for *Stellarium*.

### 3. Geocentric Declination

Sun declination is another key parameter in gnomonics.

Comparison results are shown in fig. 11 and 12.

Resulting error is less than half arcsecond except for *Stellarium* (about 10 arcseconds) and *The Dialist's Companion* (more than 20 arcseconds).

Note the coincidence of the results for the *Astronomical Almanac*, *Solex*, *AlmSun* and *Sun Ephemeris*.

### 4. Azimuth

With azimuth we start considering topocentric parameters.

Comparison results are shown in fig. 13 and 14.

Error increases up to more than 40 arcseconds for *The Dialist's Companion* and *Stellarium* while it remains within 4 arcseconds for all the other programs.

*Sun Ephemeris* especially outperforms with a maximum error of about 0.5 arcseconds.

### 5. Height

Comparison results are shown in fig. 15 and 16.

Apart from *The Dialist's Companion* with more than 30 arcseconds, for all the other programs error is contained within 10 arcseconds.

Notably *Geffem* and *Sun Ephemeris* show a maximum error of about 0.5 seconds.

### 6. Equation of time

Comparison results are shown in fig. 17 and 18.

All the programs excluding *Stellarium* and *The Dialist's Companion* provide almost coincident results with a maximum error of about 0.15 seconds.



Fig. 7 – Ecliptic longitude error

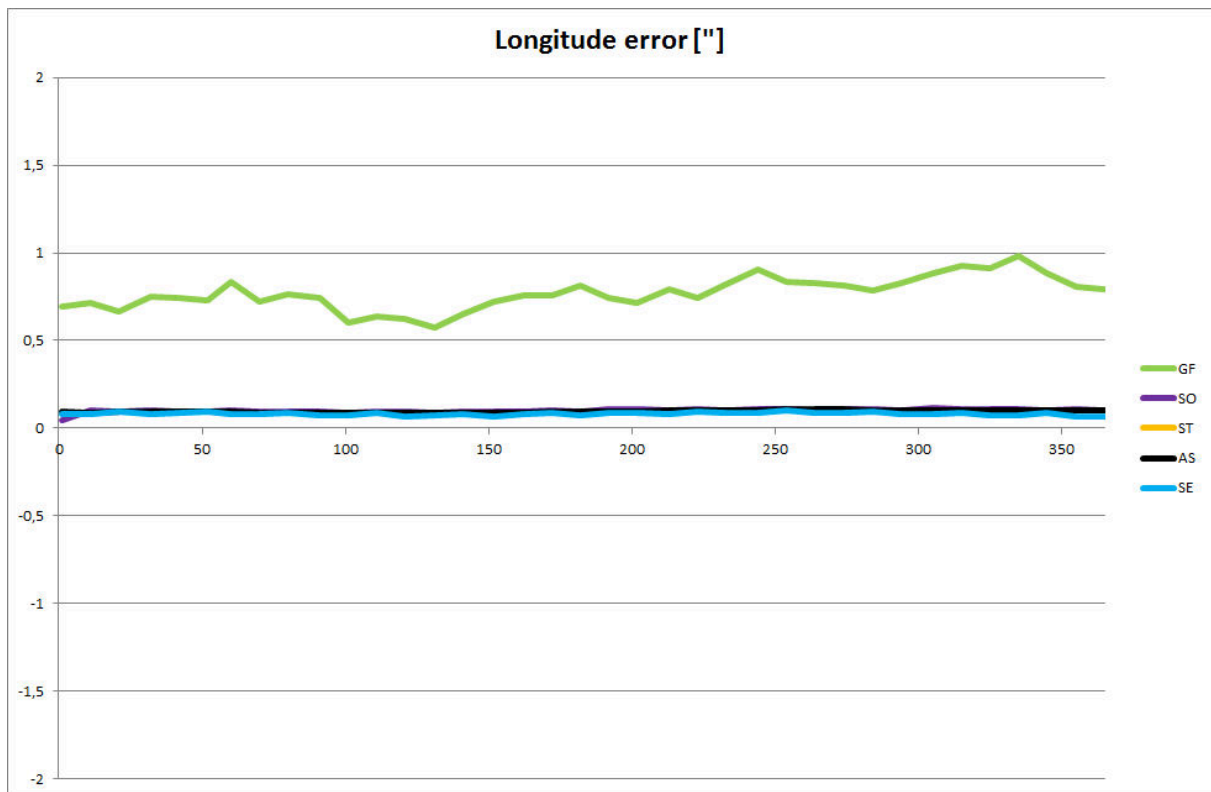


Fig. 8 – Ecliptic longitude error (magnification)



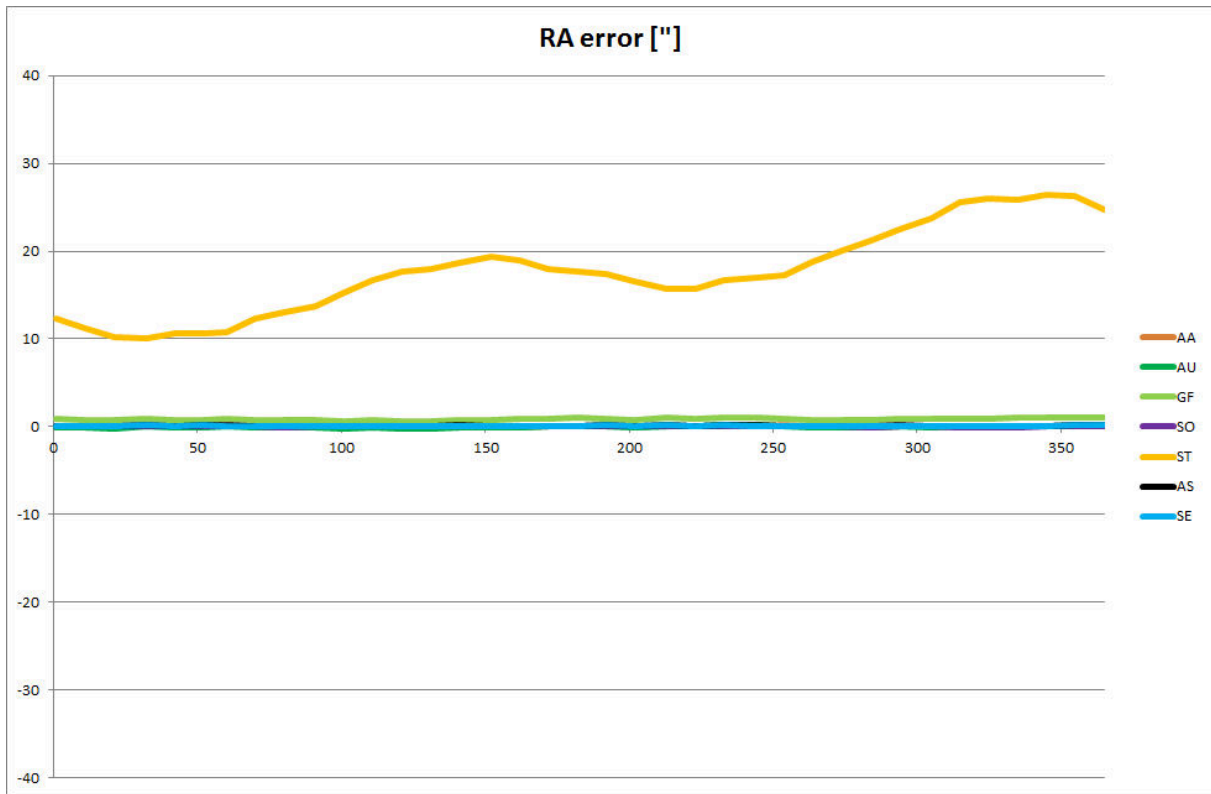


Fig. 9 – Right ascension error

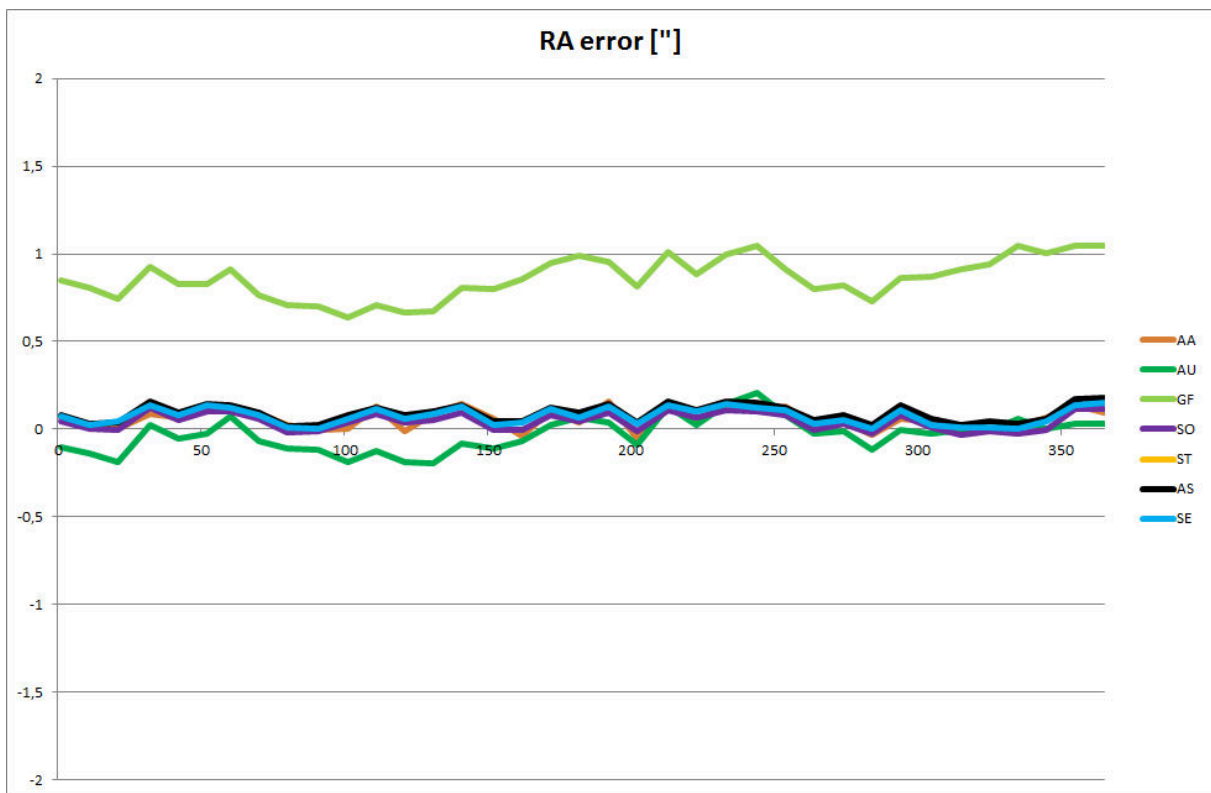


Fig. 10 – Right ascension error (magnification)

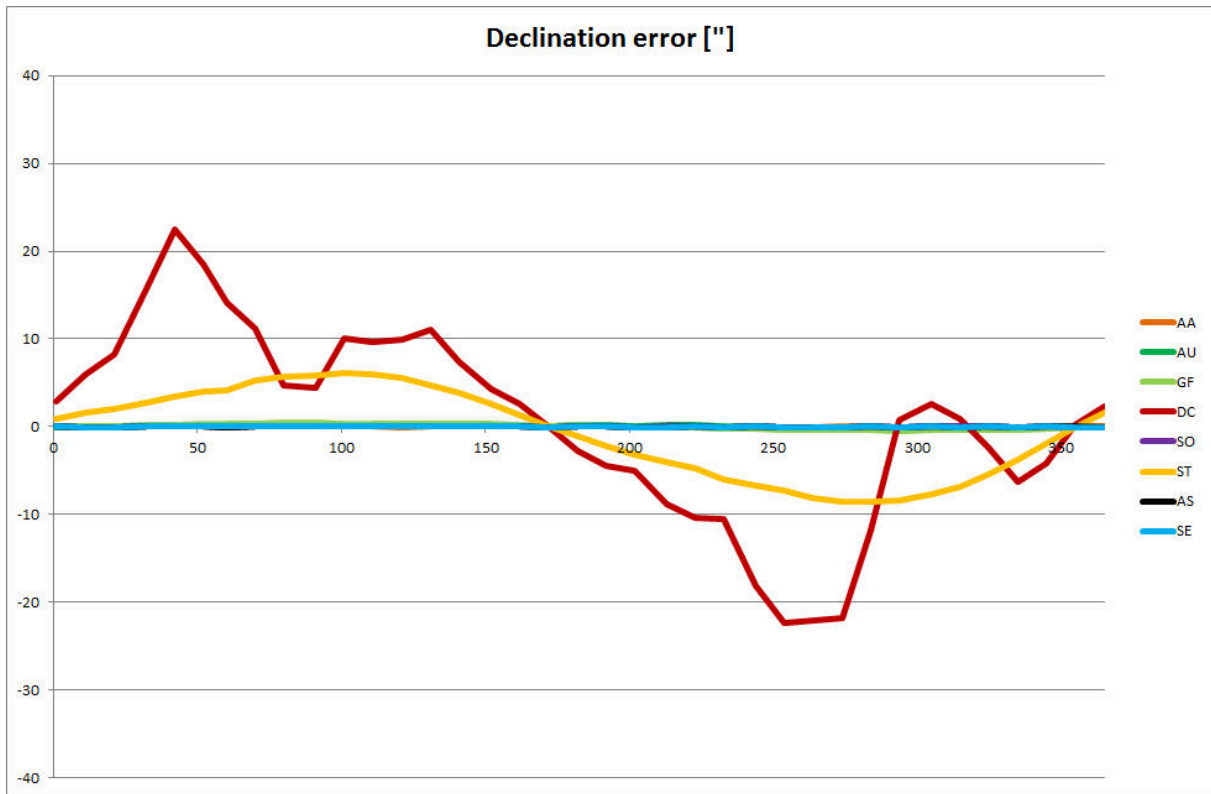


Fig. 11 – Declination error

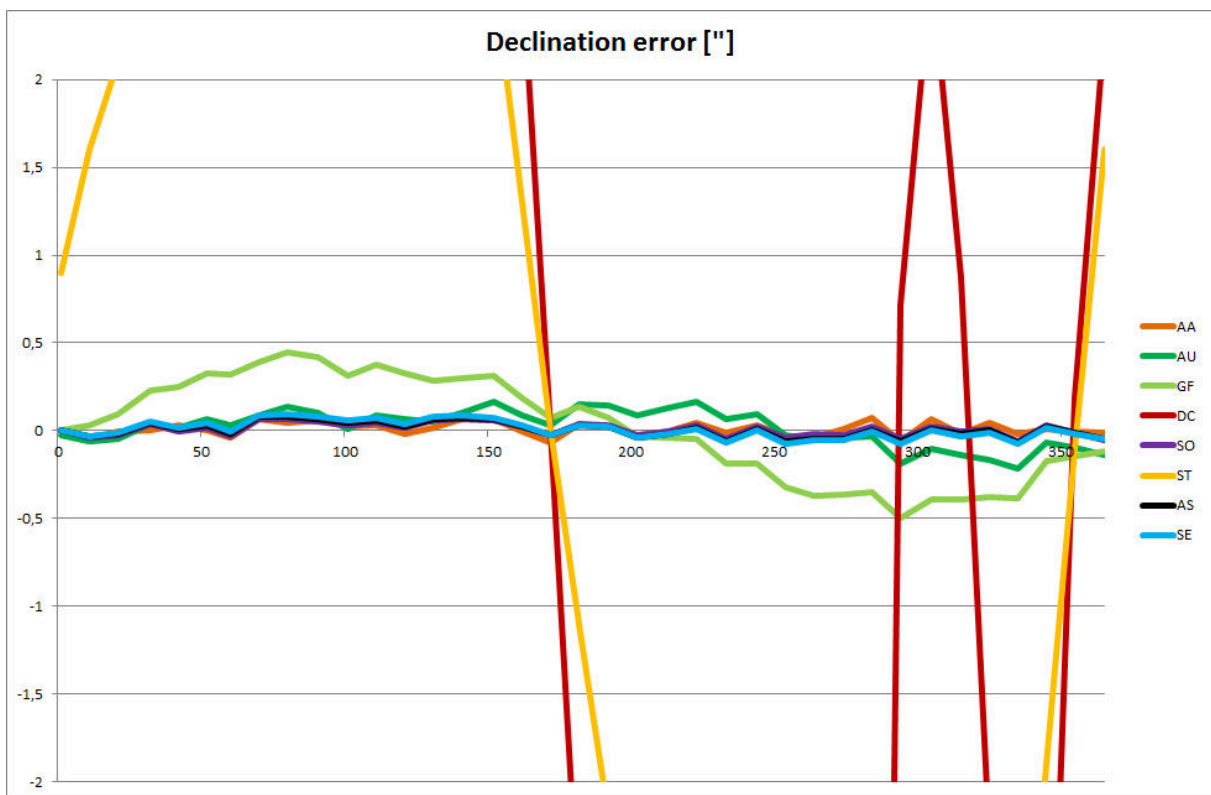


Fig. 12 - Declination error (magnification)

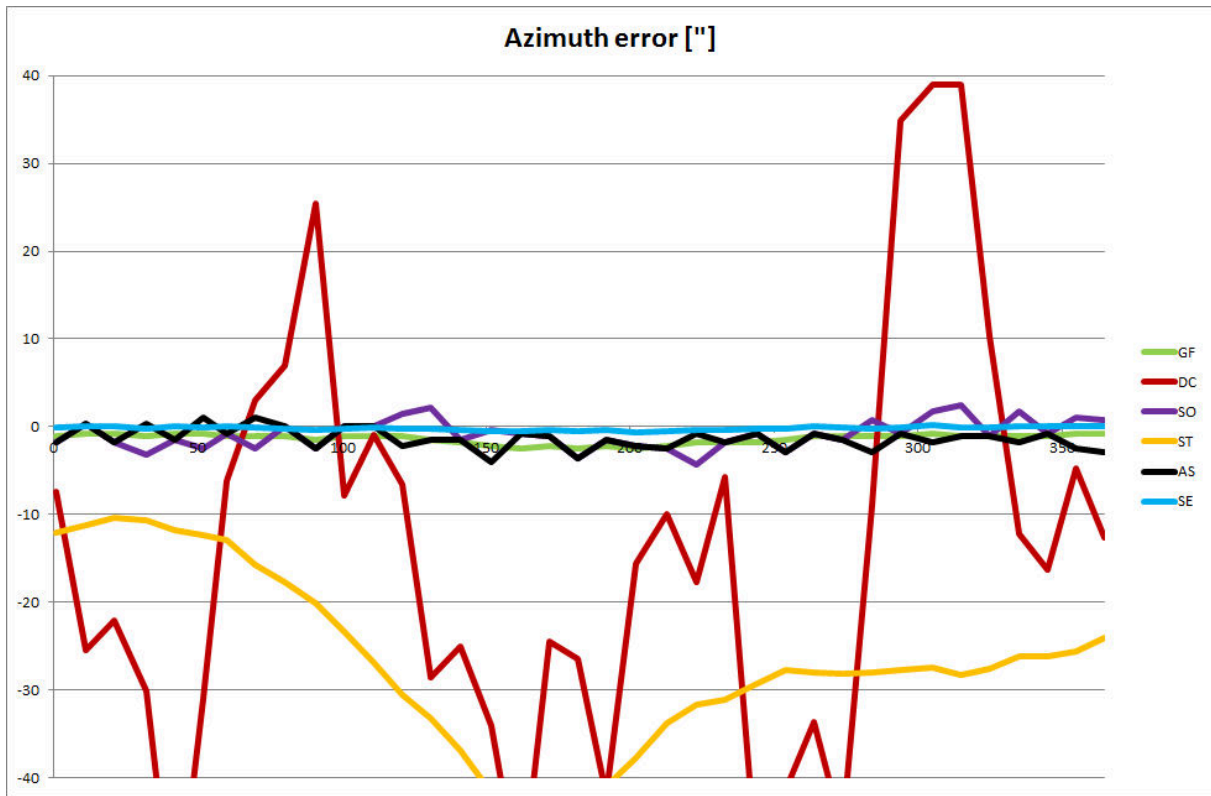


Fig. 13 – Azimuth error

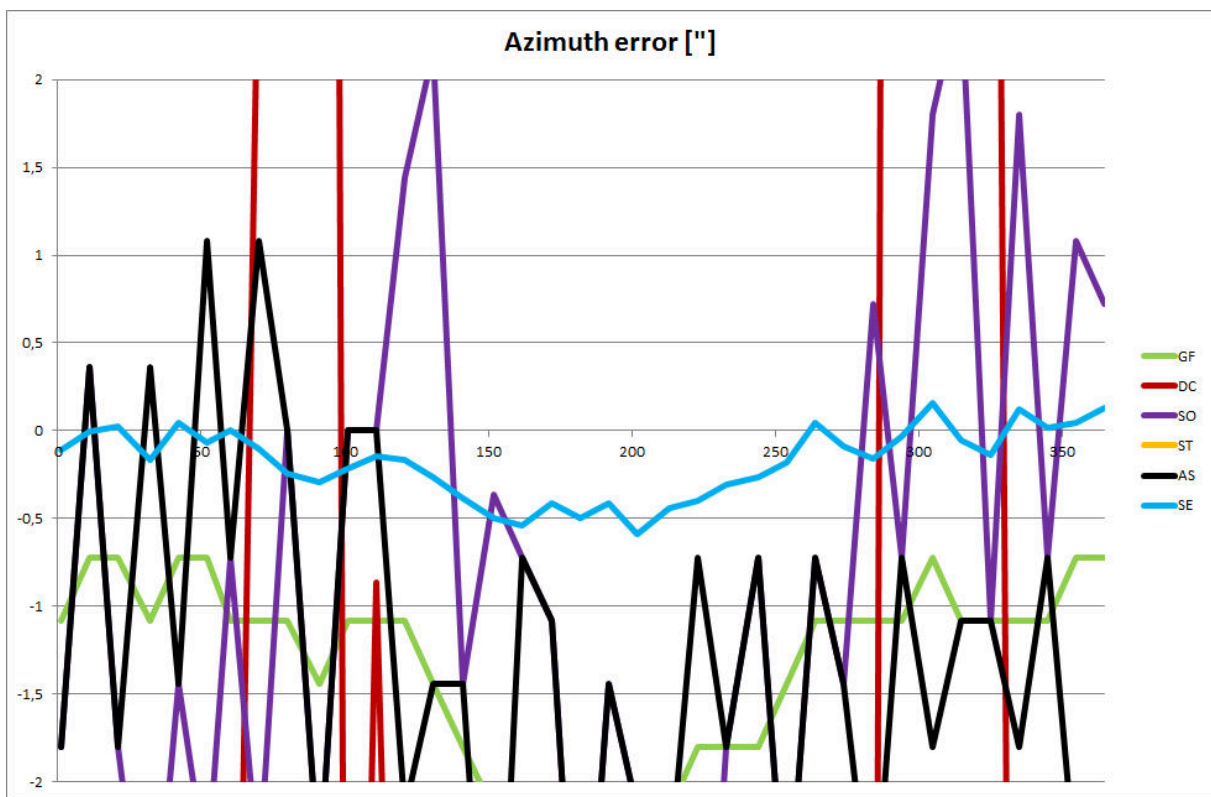


Fig. 14 - Azimuth error (magnification)

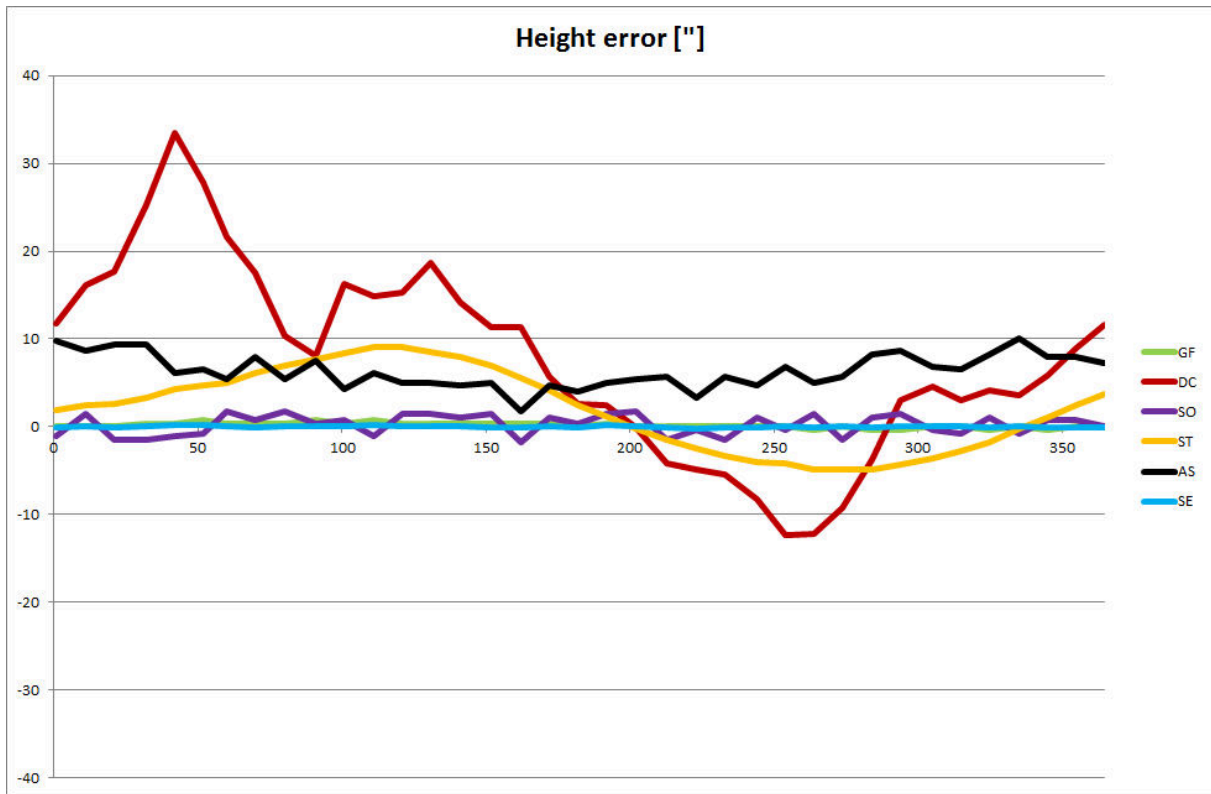


Fig. 15 – Height error

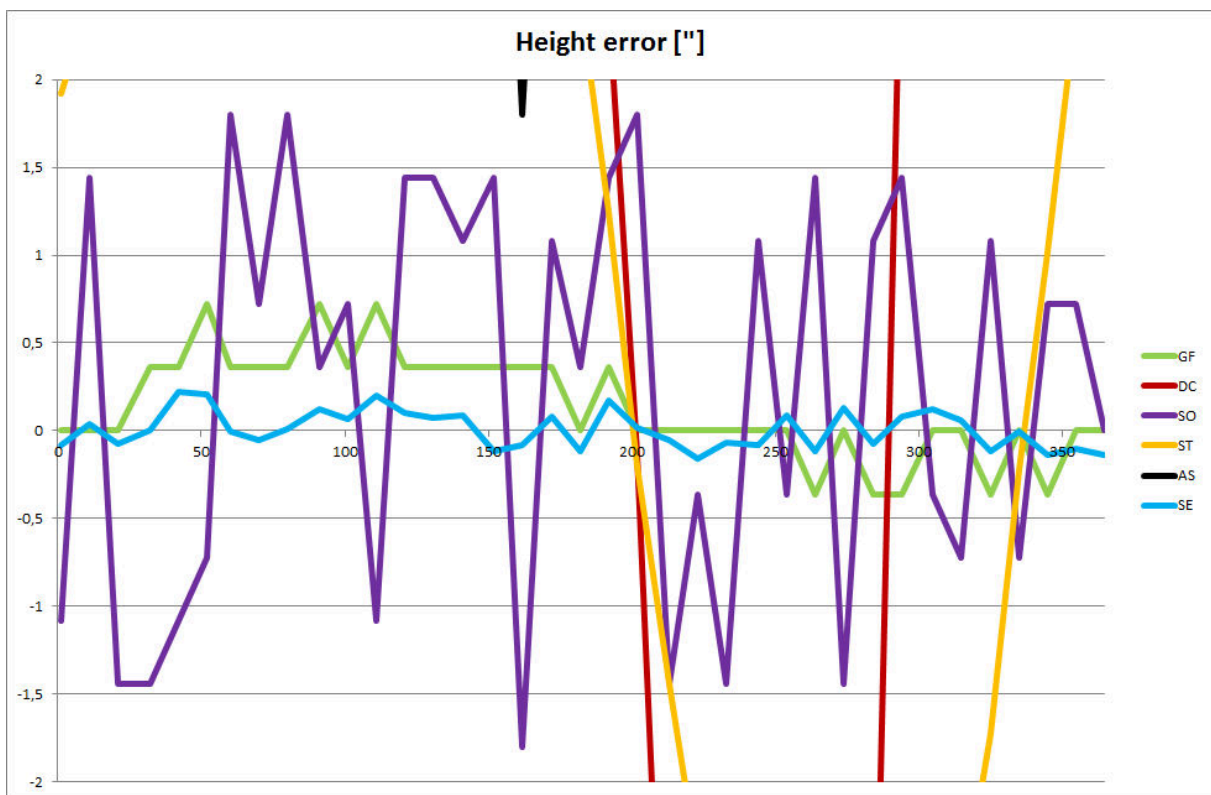


Fig. 16 - Height error (magnification)

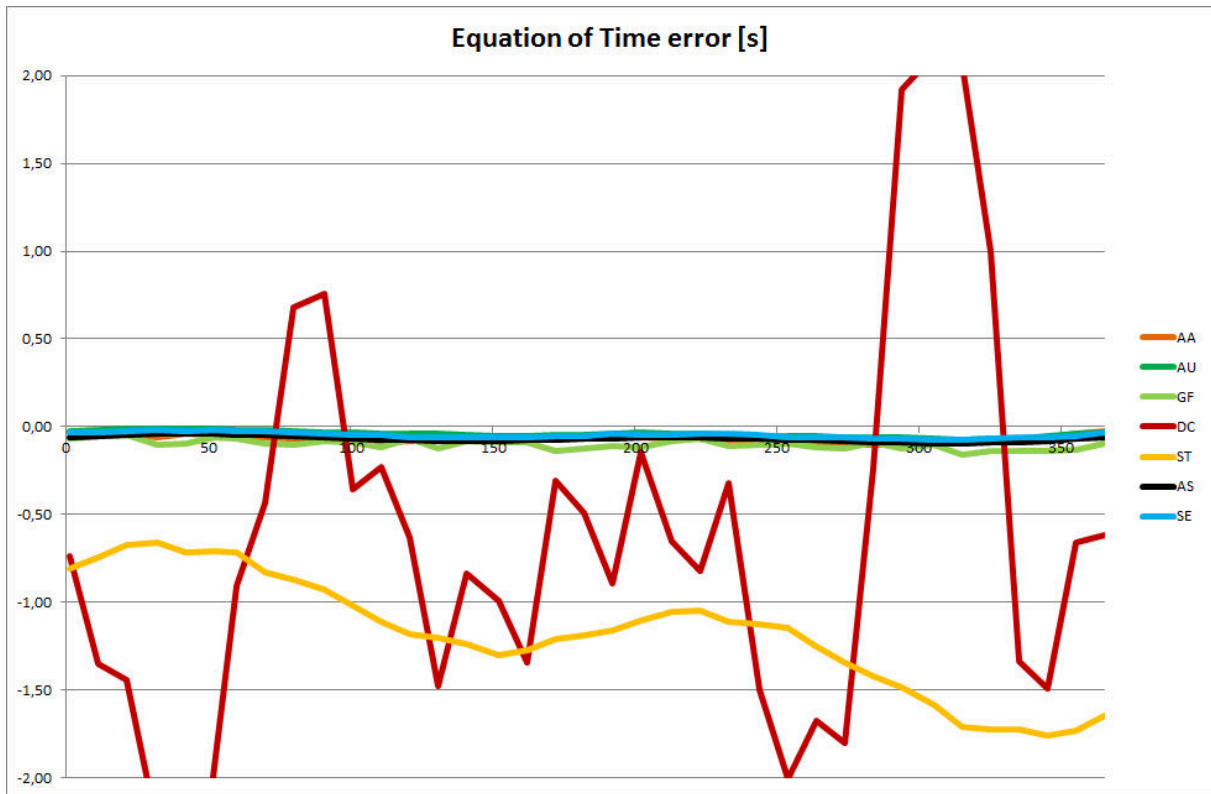


Fig. 17 – Equation of time

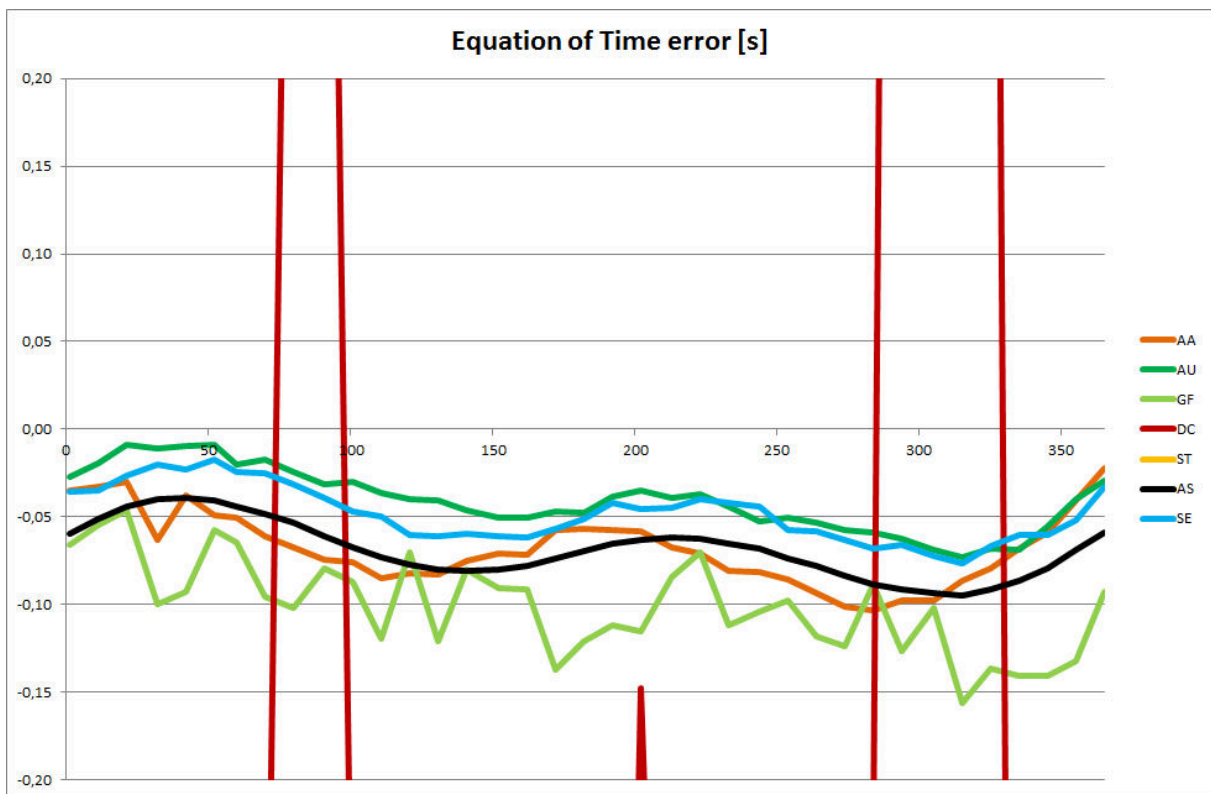


Fig. 18 – Equation of time (magnification)

## Conclusion

Results obtained in this test suggest that for a general gnomonic use all the evaluated tools are equally valid, except for the calculation of the ecliptic longitude where *Stellarium* error is a bit too high.

However when greater accuracy is required, for example in the case of monumental sundials, then *Stellarium* and *The Dialist's Companion* would be in the opinion of the author to be discarded.

## Appendix

### On the time scales used

It may be helpful to mention briefly the time scales used in astronomy and especially those used in this article.

It is well known that the rotation period of the Earth, which historically originated our 24 hour clock system, is not constant in time and tends to slow down mainly because of the friction of tides.

Astronomical calculations however require a constant and precise time system: this has been until 1967 the Ephemeris Time (**ET**), replaced in 1984 by the Terrestrial Dynamic Time (**TDT**) and in 2001 by Terrestrial Time (**TT**).

Terrestrial Time is equal to the International Atomic Time (**TAI**), the average of about 200 atomic clocks located in about 50 laboratories around the world, apart from a constant difference of 32.184 seconds.

The clock that is bound to the Earth's rotation is called Universal Time (**UT**) (various definitions exist but the difference is always less than approximately 0.03 secs) and it is related to **TT** through a value which varies in time and that is named  $\Delta T = TT - UT$ .

The exact value of  $\Delta T$  can only be known retrospectively and it is measured and distributed by the *IERS* (*International Earth Rotation and Reference Systems Service*); for the future it is only possible to carry out an estimate by extrapolating current trends.

In the normal civil life however there is the need of a clock that remains linked to the rotation of the earth (in order to avoid, after a long time, large deviations between measured time and position of the Sun in the sky) but that is simultaneously also constant in time (to avoid having to constantly adjust watches to adapt them to Earth slowing).

This apparently conflicting requirement is satisfied by the Coordinated Universal Time (**UTC**).

**UTC** is equal to **TAI** apart from an integer number of seconds: when it becomes necessary, a so called *leap second* is added to or removed from **UTC** in such a way that the difference between **UT** and **UTC** (that is called  $\Delta UT$ ) is maintained less than 0.9 seconds<sup>6</sup>.

Fig. 19 shows the values of  $\Delta T$  and  $\Delta UT$  in the period 1973 – 2010.

The programs used in this article require that time is expressed in the **UT** system with the only exception of *Horizons* that requires time to be input in the **UTC** system. In order to properly compare the results it was so necessary to compute the value of **UTC** at 12 o'clock **UT** for each date considered in the comparison.

To this purpose *IERS Bulletins B 324 – 336* were used [ref. 6].

For a discussion on time scales in use today and in the past see [ref. 7] and [ref. 8].

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<sup>6</sup> The last leap second was introduced on June 30, 2015

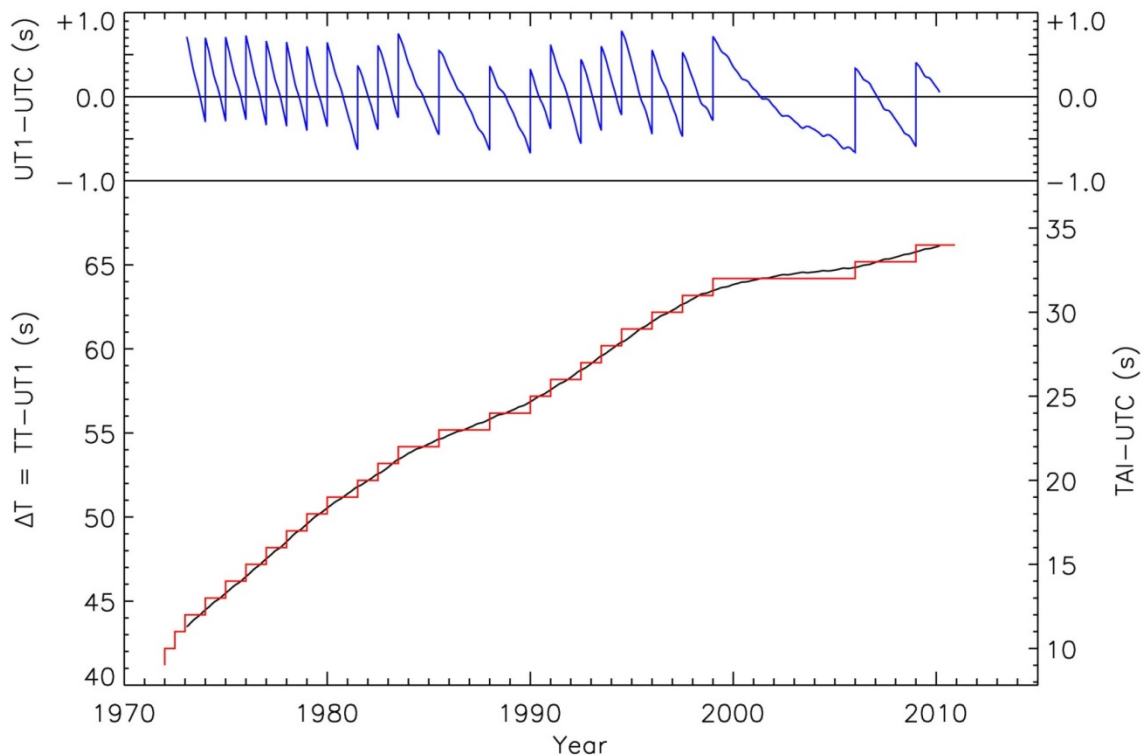


Fig. 19 – Historical values of  $\Delta T = TT-UT1$  (black line), difference between TAI and UTC (red line) and values of  $\Delta UT = UT-UTC$  (blue line) since 1973 to 2010  
 (from “Delta T: Terrestrial Time, Universal Time and Algorithms for Historical Periods”  
<https://www.staff.science.uu.nl/~gent0113/deltat/deltat.htm>)

## References

- [1] P. Bretagnon and G. Francou, “Planetary theories in rectangular and spherical variables. VSOP87 solutions”, *Astronomy and Astrophysics* 202, pag. 309-315, 1988
- [2] Jean Meeus, “*Astronomical algorithms*”, Willmann-Bell Inc., Richmond, Virginia, Second Edition, 1998
- [3] Wikipedia, “*Jet Propulsion Laboratory Development Ephemeris*”,  
[https://en.wikipedia.org/wiki/Jet\\_Propulsion\\_Laboratory\\_Development\\_Ephemeris](https://en.wikipedia.org/wiki/Jet_Propulsion_Laboratory_Development_Ephemeris)
- [4] “*JPL Planetary and Lunar Ephemerides*”, [http://ssd.jpl.nasa.gov/?planet\\_eph\\_export](http://ssd.jpl.nasa.gov/?planet_eph_export)
- [5] “*UAI – Unione Astrofili Italiani*”, <http://www.uai.it/>
- [6] “*IERS – Earth orientation data*”,  
<https://www.iers.org/IERS/EN/DataProducts/EarthOrientationData/eop.html>
- [7] Paul Schlyter, “*Timescales*”, <http://stjarnhimlen.se/comp/time.html>
- [8] Steve Allen, “*Time Scales*”, <http://www.ucolick.org/~sla/leapsecs/timescales.html>

An Excel file containing all the data and graphs used in this article can be downloaded from the web site of Orologi Solari [www.orelogisolari.eu](http://www.orelogisolari.eu) in the bonus section associated to n. 11.