

## STELA V2.6.1 release note

**STELA V2.6.1** is a major release of the STELA software, following STELA V2.5.2 available since May 2014. The main evolutions from earlier release are listed below as well as the previous release notes. STELA Notice and User's Guide contains more information.

### 1) GTO dynamical model used also for LEO and GEO

Up to 2.5.2 version the integration frame was the Celestial Mean of Date frame (MOD). The MOD was also the "reference frame". As it is quasi-inertial, some slight effects were not accounted for.

In this new STELA version the dynamical model (used through GUI and batch mode for LEO, GEO and GTO simulations) is now using the Celestial Intermediate Reference Frame (CIRF) as integration frame and a complementary acceleration (due to inertial forces) is added depending on the choice of the reference frame that is considered inertial. The reference frame can be MOD, ICRF or CIRF, as selected in the advanced parameters files. International Celestial Reference Frame (ICRF) is the default value since it is really inertial.

The following table shows the order of magnitude of slight effect of the inertial forces on 4 typical orbits over 50 years (effect on semi major axis and eccentricity is not given because it is negligible):

	<b><math>\Delta</math> Inclination (deg)</b>	<b><math>\Delta</math> RAAN (deg)</b>	<b><math>\Delta</math> Arg of perigee (deg)</b>
LEO (600km/800km/98deg)	$2 \cdot 10^{-3}$	1	0.6
MEO (19000km/21000km/55deg)	$5 \cdot 10^{-2}$	0.5	1.5
GEO (35000km/36000km/2deg)	0.15	2	2
GTO (200km/36000km/5deg)	$5 \cdot 10^{-3}$	$5 \cdot 10^{-2}$	0.15

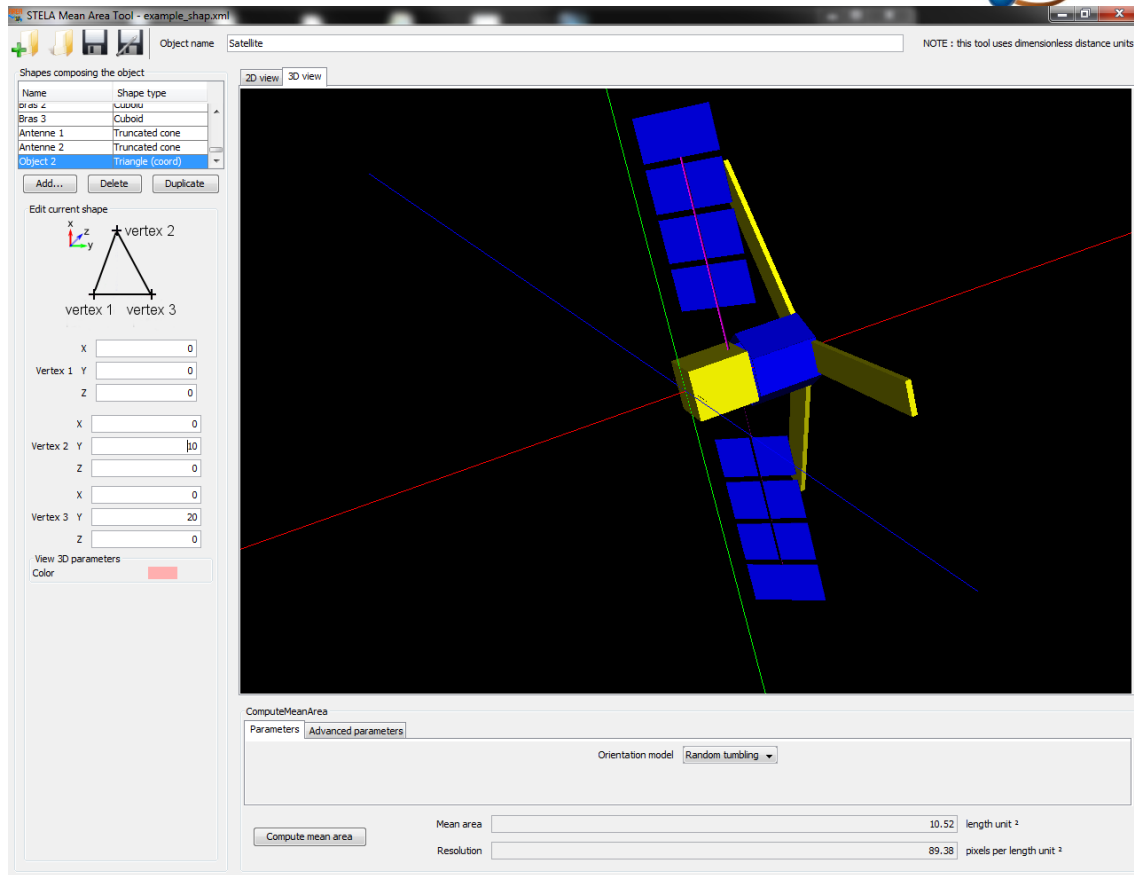
Note that all plots of orbital elements produced by STELA are now in CIRF (as it is the integration frame).

### 2) Area computation tool

A JAVA3D based visualization possibility has been added: see "3D view" tab.

To benefit from 3D functionalities, OpenGL libraries must be available on the computer:

- opengl32.dll for Windows
- libGL.so for Linux



A new “triangle” shape has been added. It allows defining triangles by the position of their vertex.

The algorithm for the cross sectional area computation has been improved, so that the computing time is reduced and the result is more precise.

A new file with extension \*\_shap.txt is saved. This file contains the matrix of computed cross sectional areas (used in the mean area computation) following the pattern: azimuth, elevation, area.

## **2) Other modifications and improvements**

### **Files:**

- It is now possible to choose the output frame when saving an ephemeris file: it can take some time if the output frame is not the integration frame, since accurate conversions are used.
- When running a statistical analysis, the user has the possibility to save the ephemeris files and xml simulation files of every run by modifying the associated parameter in the stela\_advanced\_parameters file. Output path, nature, type and frame of the parameters can also be chosen through this file.
- The solar activity file has been updated. If the DAS file is directly used instead of this stela\_solar\_activity file, the geomagnetic index AP required by the MSIS atmospheric model is set to 9 instead of 15 in the previous STELA version (9 is a better constant equivalent value). This default value is tunable through the stela\_advanced\_parameters file.

**Library mode:**

- The Example.java file (in STELA example directory) has been updated to provide the user with concrete examples of the use of the library mode
- It is possible to access to each perturbation effect on the transition matrix computation (transition matrix derivatives)
- It is possible to get through a dedicated function the maximum order and degree of the Earth gravity field available in STELA dynamical model
- It is possible to access to solar activity statistical computation
- It is possible to set the reference frame in GTO model (see Example.java file)
- Some methods have been deprecated: see Javadoc. A list of the deprecated java methods can be delivered just asking [stela@cnes.fr](mailto:stela@cnes.fr)

**Java COTS** have been upgraded.

**Any question? Contact STELA hotline: [stela@cnes.fr](mailto:stela@cnes.fr)**

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**End of STELA V2.5.1 release Note**

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## **STELA V2.5.2 release note**

**STELA V2.5.2** is a minor release of the STELA software, following the 2.5.1 version available since February 2014.

This version is released in order to fix a V2.5.1 problem in C4 criterion computation for GEO simulations (computation of perigee or apogee distance from protected region B for GEO simulations only).

Any question? Contact STELA hotline: [stela@cnes.fr](mailto:stela@cnes.fr)

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**End of STELA V2.5.1 release Note**

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## STELA V2.5.1 Release note

**STELA V2.5.1** is a major release of the STELA software, following the V2.4.2 available since February 2013. The main evolutions from earlier release are listed below as well as the previous release notes. STELA Notice and User's Guide contains more information.

### 1) GTO dynamical model used also for LEO and GEO

Since the first STELA version in 2010, three dynamical models (referred to as LEO, GEO and GTO model) have been developed and tuned for an efficient propagation of LEO, GEO and GTO orbit types.

**Since this new STELA version only the so-called "GTO dynamical model" is used through the GUI.** Then, whatever **simulation** you choose (LEO, GEO, GTO), the GTO dynamical model will be used to propagate the orbit since it is the most generic, complete and precise one. It is indeed more generic because it is able to deal with eccentric orbits (LEO and GEO models are written for quasi-circular orbits). As a counterpart the computations are more time-consuming. It can be used through GUI parameters with different settings for the dynamics depending on the orbit type, for example a 4x4 earth gravity model for GEO propagation, or a 7x0 earth gravity model for most of the LEO propagations and a 7x7 earth gravity model for the GTO propagations (STELA default settings for these orbit types).

Note that the dedicated LEO and GEO dynamical models remain in the STELA software and can be used through the library mode.

Among that, the GTO dynamical model has been improved to be able to account the Earth gravity model up to 15x15.

The default drag recomputed step has been tuned to 1 (instead of 2) to increase STELA precision and warnings have been added to the integration time step if it is chosen above the following values: 24h for any orbit type, 12h if orbit inclination is bigger than 120 deg for LEO and GTO orbits.

Indeed, it can be tempting to think of increasing it to save computation time but it must be done very carefully (to be tested case by case) since it can lead to bad precision depending mainly on the inclination. Figure 1 shows the difference in % of orbit lifetimes between STELA and a CNES reference numerical propagator (PSIMU) for a LEO with 0.125 initial eccentricity.

One can see that the precision is decreasing for a higher integration step size when inclination is bigger than about 120 deg. This is due to the increasing evolution rate of  $\omega+\Omega$  at high inclination (red curve Figure 2) that leads to less precision in the eccentricity vector computation by the 6<sup>th</sup> order Runge-Kutta ( $e_x=e.\cos(\omega+\Omega)$  ;  $e_y=e.\sin(\omega+\Omega)$ ). This is also the case to a lesser extent when inclination is less than about 20deg.

GTO model, relative difference (%) wrt numerical propagation

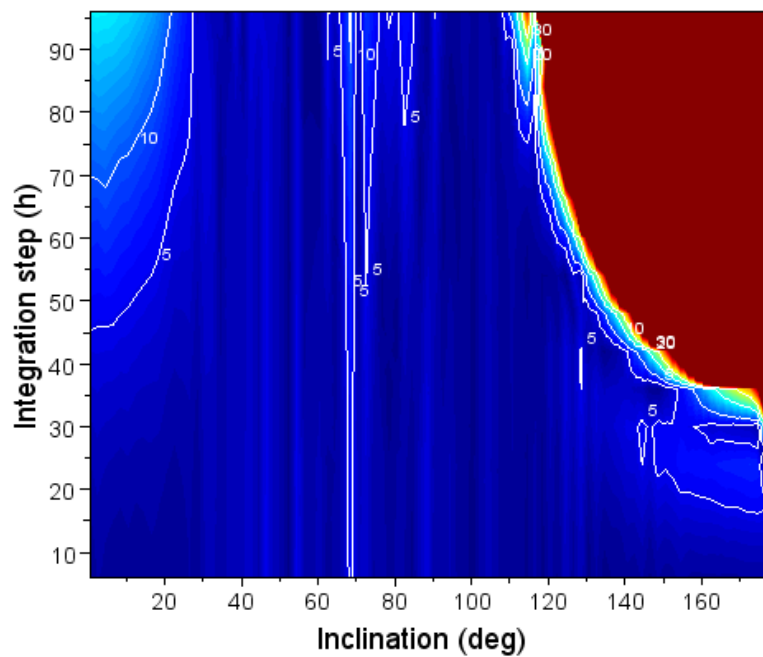


Figure 1: influence of STELA integration step size on the orbit life time computation for a LEO ( $e=0.125$ )

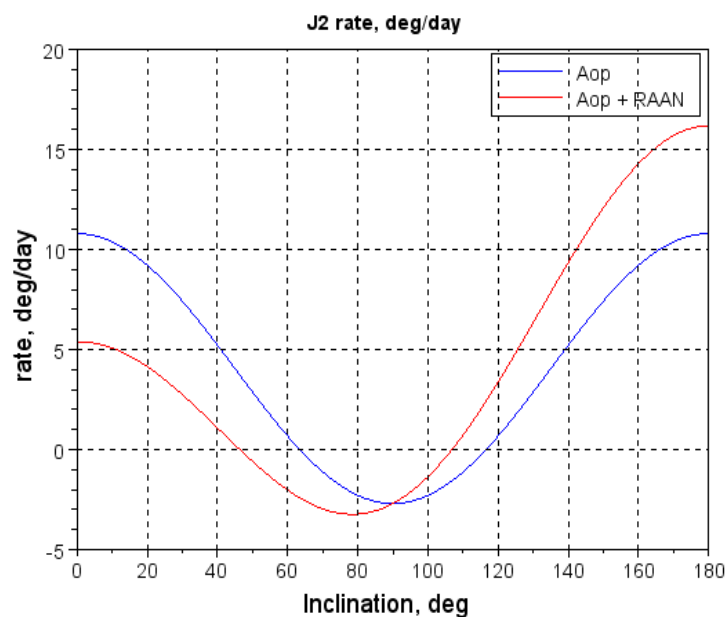


Figure 2: evolution rate of  $\omega + \Omega$  depending on inclination

## 2) Other modifications and improvements

### **Drag coefficient computation:**

- Among “ $C_d=f(\text{altitude})$  file” and “constant value”, it is now possible compute the  $C_d$  coefficient using Cook formula.

### **GTO statistical mode:**

- Addition of a new “mixed dispersion method” for solar activity

**GUI:**

- Addition of plots for Right Ascension of Ascending Node and “RAAN + Argument of Perigee + Mean anomaly” versus time.
- More settings to tune the dynamical model (see previous §)

**Files:**

- Solar Activity File has been updated and its format has slightly evolved. The mean solar flux parameter is now automatically computed by STELA using the daily values, in line with what is expected by the atmospheric model. Hence the corresponding column has been removed. Older files including this parameter are readable by the software but the mean flux is not used. Moreover for the date parameter a new column containing the number of seconds from the beginning of the Julian day has been added. Older files not including this parameter are readable by the software. Then a value of 0 sec is considered.
- STELA can now read DAS solar activity file.

**Two Line Elements tool:**

- When converting the TLE elements to mean elements, the computation of the semi major axis has been modified. As Kozai mean motion is the standard for TLE orbital products, the mean motion is now converted to a Brower formulation before computing the mean semi-major axis to be used by STELA.

**Java COTS** have been upgraded.

**Note that:**

Simulation files (\*\_sim.xml) from the previous versions can be loaded by the new STELA version (upward compatibility): additional parameters are set to a default value.

**Any question? Contact STELA hotline: [stela@cnes.fr](mailto:stela@cnes.fr)**

--- **End of STELA V2.5.1 release Note** ---

## **STELA V2.4.2 Release note**

**STELA V2.4.2** is a major release of the STELA software, following the V2.2.1 available since April 2012. It offers the possibility to perform statistical analysis for Geostationary Transfer Orbits. The computation of the partial derivatives of the orbital parameters is also available for GTO only.

The main evolutions from earlier release are listed below as well as the previous release notes. STELA Notice and User's Guide contains more information.

### **1) New Geostationary Transfer Orbit statistical mode**

As explained in the STELA V2.2.1 release note GTO extrapolation results may be very sensitive. A tiny modification in the initial conditions or the computation parameters (area to mass ratio, drag and SRP coefficients, solar activity ...) might end up with very different results. This sensitive behaviour is due to resonance phenomena linked to the sun-moon and Earth perturbations and cannot be avoided. Theoretical explanations and more details can be found in the following paper: *Morand et al, «Dynamical properties of Geostationary Transfer Orbit over long time scales: consequences for mission analysis and lifetime estimation», AIAA- ASC 2012.*

As a consequence a reliable status regarding the criteria validation cannot be achieved by performing a single STELA extrapolation. Statistical approaches are recommended to obtain relevant results and statistical criteria have been established for GTO.

STELA statistical mode for GTO helps the user to perform such a statistical analysis. All the input parameters (orbit parameters, date, object characteristics, solar activity hypothesis...) can be dispersed in a uniform or Gaussian way. Solar activity can also be dispersed based on past data: random realisation of a future cycle sequence based on the five last cycles plus a random initial day in the first cycle.

In order to decrease the computation time for GTO statistical mode, STELA can run the extrapolations in multiprocessing mode (enabled by default). The results of each extrapolation are then used to compute the statistical criteria. The criteria compliances are based on a 0.9 probability level and a 95% confidence interval. More details on the way the statistical results are computed can be found in the following paper: *Le Fèvre et al, «Compliance of disposal orbits with the French space act: the good practices and the STELA tool », IAC 2012.*

A file example for GTO statistical mode is provided (example\_GTO\_sim.xml).

### **2) Other main functionalities**

#### **GTO propagation:**

- Partial derivatives computation for Geostationary Transfer Orbit.  
When using GTO single propagation mode (i.e. statistical mode disable) STELA can propagate the orbital elements and their sensitivity at the same time through a set of variational equations. The state transition matrix is propagated using a semi analytical method; a very complete dynamical model is available. The partial derivatives are saved in an ephemeris file.
- Tesseral terms are taken into account in GTO force model. The GTO perturbation model for Earth gravity field is then a complete 7x7 model including J2<sup>2</sup>
- Third body effects (Sun and Moon) are taken into account for the short periods computation. The GTO model for short periods then includes J2 and third body effects.

#### **LEO propagation:**



- Addition of a warning for particular inclination ranges in LEO. Some resonances phenomena may occur in LEO; in this case extrapolation results may be more sensitive to initial conditions than outside this inclination range. Theoretical explanations and more details can be found in the following paper: *Lamy et al. «Resonance Effects on Lifetime of Low Earth Orbit Satellites», 23rd ISSFD, 2012.*

### **Two Line Elements tool:**

STELA provides users with a Two-Line Elements conversion tool, based on the SGP4/SDP4 theory

- The user can convert one or several TLE at once into a format compatible with STELA.
- Conversion can be performed in osculating parameters or in mean parameters according to SGP/SDP theory. Note that the conversion to osculating parameters is not valid for high eccentricities due to limitations in the SGP4-SDP4 short period model

### **Library mode:**

- Language and files path variables management in library mode have been improved
- The derivatives of orbital elements with respect to time can be obtained in library mode for each integration step

### **Frame conversions:**

- TEME Frame is now available in the GUI. The True Equator Mean Equinox frame is the frame in which TLE are defined.

## **3) Other modifications and improvements**

### **GUI:**

- Addition of plots for semi-major axis, argument of perigee and inclination vector coordinates

### **Files:**

- Resources and Configuration folders/files have been rearranged.
- Solar Activity File has been updated and made longer

### **Time Scale:**

- Update of default TT-UT1 value (01/07/2012 leap second)

**Java COTS** have been upgraded.

**JVM server mode** is enabled by default

### **Note that:**

Simulation files (\*\_sim.xml) from the previous versions can be loaded by the new STELA version (upward compatibility): additional parameters are set to a default value.

**Any question? Contact STELA hotline: [stela@cnes.fr](mailto:stela@cnes.fr)**

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**End of STELA V2.4.2 release Note**

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## STELA V2.2.1 release note

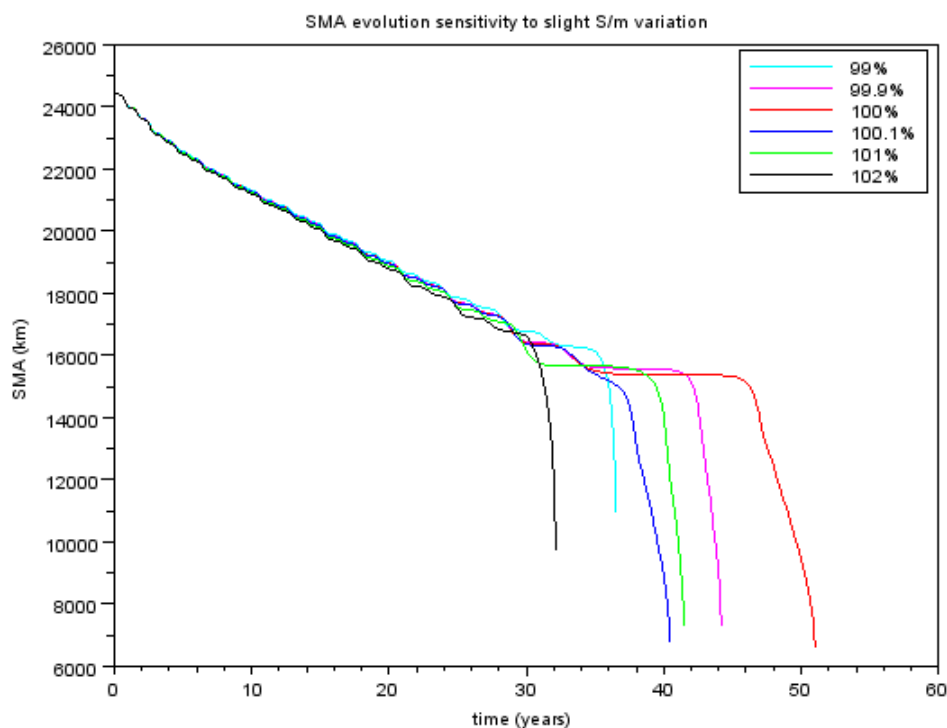
**STELA V2.2.1** is a major release of the STELA software, following the V1.4.2 available since July 2011. It offers the possibility to propagate Geostationary Transfer Orbits. The main evolutions from the previous release are listed below. STELA Notice and User's Guide contains more information.

### 1) New Geostationary Transfer Orbit propagation functionality

**This new STELA release includes a semi-analytical modelization adapted to GTO:**

- Equations adapted to highly eccentric orbits.
- Earth potential model includes first order terms up to J7 and second order term for J2. No tesseral terms are included in this version.
- Drag effect is computed through Simpson's quadrature on the orbit part below 2,500 km of altitude.
- The Solar Radiation Pressure perturbation computation is done the same way as in LEO mode (Simpson's quadrature taking into account the Earth shadowing).
- The effect of Sun and Moon perturbations are developed up to the fourth degree of Legendre polynomials.
- Short period analytical model (used to compute osculating parameters) includes J2 perturbation.

**Warning:** note that for GTO the extrapolation results may be very sensitive. A tiny modification in the initial conditions or the computation parameters (area to mass ratio, drag and SRP coefficients, solar activity ...) might end up with very different results (similar to chaotic behaviour). The following plot shows an example of the evolution of the semi-major axis of a low inclination GTO orbit and the difference in re-entry durations for the same initial conditions, only slightly changing the S/m ratio:



One can see that a modification of less than one percent of the ballistic coefficient can change the re-entry date by almost 20 years. This sensitive behaviour is due to resonance phenomena linked to the sun-moon and Earth J2 perturbations. For this orbit the resonance phenomena occurs when the semi-major axis (decreasing due to the drag force) is close to about 15,000 km. Theoretical explanations and more details can be found in the following paper: *Lamy et al, «Analysis of Geostationary Transfer Orbit long term evolution and lifetime»*, 22<sup>nd</sup> ISSFD, 2011.

Then, in order to get a reliable status regarding the criteria validation, **one should not perform a single STELA extrapolation**. Sensitivity analyses or statistical approaches are strongly recommended in order to obtain relevant results : the STELA batch mode is well suited for this kind of study.

This is the reason why for GTO simulations, the **"Not Reliable"** status replaces both "Compliant" and "Not Compliant" status for criteria compliancy. It indicates that one single orbit propagation can not give a reliable criterion status due to resonance phenomena.

## **2) Main functionalities**

### **General :**

- Before starting a simulation, it is now possible to disable any perturbation except the Earth gravity field which is always taken into account (Drag, Sun, Moon and SRP can be selected or not in the “advanced parameters” tab; all of them are taken into account as the standard option).

### **LEO propagation :**

- Some minor modifications of the drag effect computation may generate very small differences with respect to previous versions results.

### **Iterative mode :**

- The algorithm used in the LEO iterative modes (search of an initial orbit that fits a user defined lifetime in LEO) has been improved.

### **Criteria :**

- A margin has been added to C2 criterion computation in order to take into account the model precision.
- C3 criterion computation has been implemented and C4 criterion computation has been modified so that it can be used with highly inclined and highly elliptical orbits. Both of them use the same algorithm.
- For GTO simulations, a "Not Reliable" status replaces both "Compliant" and "Not Compliant" status (see §1).

### **Frame conversions :**

- Frame conversions have been improved and are fully compliant with the IERS 2010 conventions.
- EME2000 Frame (very close to ICRF) is now available in the GUI.

## **3) Other modifications and improvements**

**GUI :**

- A new eccentricity plot is available in the Ephemeris tab.
- A new ephemeris output file is accessible (“STELA\_OEM”). This file displays the date in Modified Julian Days and Seconds in the day instead of the calendar format used in the CCSDS\_OEM file.

**Files :**

- Resources and Configuration folders/files have been rearranged.
- Solar Activity File has been updated and made longer. Last date of this file is now in year 2225.

**Batch mode:**

- The Batch mode has been simplified and is now based on the information available in the simulation file (\*\_sim.xml). Please have a look at the examples written in “python” and “ksh” in the User’s Guide.

**Java COTS** have been upgraded.

**Note that :**

Due to algorithm enhancements, computation times have slightly decreased for LEO and GEO computations.

Simulation files (\*\_sim.xml) from the previous versions can be loaded by the new STELA version : additional parameters are set to a default value.

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**End of STELA V2.2.1 release Note**

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## **STELA V1.4.2 release note**

**STELA V1.4.2** is the second release of the STELA software, following the V1.2.1 available since December 2010. The main evolutions from the previous release are listed below.

### **Note that :**

- Due to the algorithm evolutions computation times have slightly increased
- Simulation files (\*\_sim.xml) from the previous version can be loaded by the new STELA version : additional parameters are set to a default value

### **1) Algorithms**

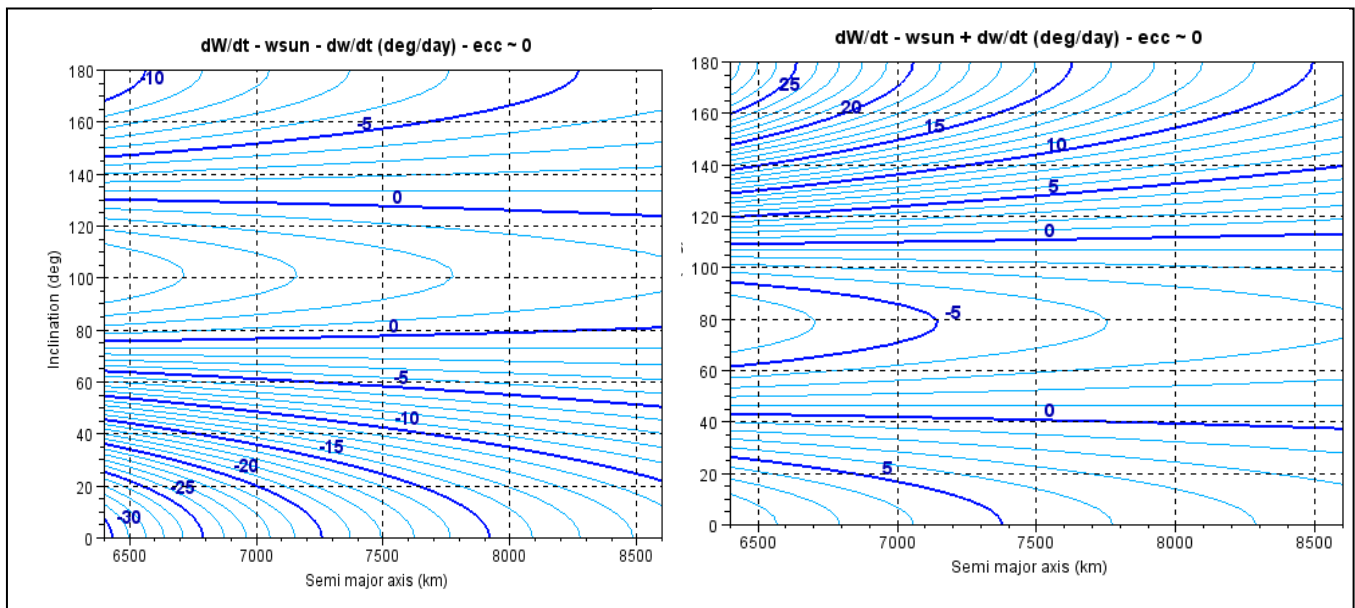
#### **GEO orbits :**

- The earth shadow is taken into account for the solar radiation pressure (SRP) computation through a multiplicative coefficient (lighted part of the orbit) applied to the perturbation
- Short period variations due to third body (sun and moon) and SRP are considered into the mean/osculating transformation. Be careful, the computation of the short period relies on the object characteristic (reflectivity coefficient) and the date of orbital parameters
- Thank is to these changes the STELA precision evaluated through comparison with CNES reference high precision numerical propagators has improved from about 5km to less than 3 km on the minimum orbit altitude for a 100 years GEO extrapolation

#### **LEO orbits :**

- Solar radiation pressure is now taken into account in the physical model. SRP is computed through a Simpson quadrature so that the eclipse duration and its position on the orbit are considered (see user manual for more precisions).
- The user shall provide reflecting area and reflectivity coefficient values before running the extrapolation
- The STELA precision evaluated through comparison with CNES reference numerical propagators is about 1% on a computed lifetime of 25 years for LEO extrapolation

Note that the SRP perturbation does not have a significant effect on the computed lifetime except for some particular orbits that show high sensitivity to initial value of right ascension of ascending node, argument of perigee and sun right ascension. For example resonant orbits occur when the J2 drift of the angular parameters follows the relationship  $\dot{\Omega} - \alpha \pm \dot{\omega} = 0$  where  $\alpha$  is the mean apparent rotation rate of the sun around the Earth. Fig 1. show couples of semi major axis and inclination that lead to the resonance (zero-level curves, low dependency wrt the eccentricity value) : in these cases the SRP leads to a secular evolution of the eccentricity whose sign depends on the initial conditions.



**Figure 1 : Resonant orbit : semi major axis and inclination**

### Iterative mode :

The algorithm used in the iterative modes (search of an initial orbit that fits a user defined lifetime in LEO or an exclusion duration in GEO) has been improved to reduce the number of iterations.

## 2) New functionalities

- Three new frames are available to express the initial and final position and velocity : the Celestial Intermediate Reference Frame (CIRF), the Terrestrial Intermediate Reference Frame (TIRF) and the Terrestrial Frozen at Epoch. See user manual for more information.
- Tooltips are available in the GUI to clarify the term's signification
- A batch mode (without GUI) best suited to perform a big amount of extrapolations is available on Windows and Linux. See user manual for more information.

Any question? Contact STELA hotline : [stela@cnes.fr](mailto:stela@cnes.fr)

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**End of STELA V1.4.2 release Note**

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