SAT-LAB: A MATLAB Graphical User Interface for simulating and visualizing Keplerian satellite orbits

D. Piretzidis and M.G. Sideris

Department of Geomatics Engineering, University of Calgary

dimitrios.piretzidis@ucalgary.ca

INTRODUCTION

SAT-LAB is a MATLAB-based Graphical User Interface (GUI), developed for simulating and visualizing satellite orbits. The primary purpose of SAT-LAB is to provide a software with a user-friendly interface that can be used for both academic and scientific purposes. The calculation of the satellite state vector (position and velocity) is done using a Keplerian propagator. After selecting the six Keplerian elements, the computation and visualization of the satellite orbit is performed simultaneously and in real time. Both the satellite orbit and the state vector at each epoch are given in two reference frames, i.e., the Inertial Reference Frame (IRF) and the Earth-Fixed Reference Frame (EFRF). For the EFRF, both the 3D Cartesian coordinates and the ground tracks of the orbit are provided. Other visualization options include selecting the appearance of the coastline, topography/bathymetry, satellite orbit, position, velocity and radial distance, and IRF and EFRF axes. SAT-LAB is also capable of visualizing orbits of operational satellites and real-time tracking of their position.

CURRENT LIMITATIONS

SAT-LAB users should use the current version only for educational purposes or for low-accuracy simulations of satellite orbits. Scientific usage is not yet advised. Satellite positions are calculated with an accuracy of several kilometers due to the following limitations:

- A Keplerian propagator is used, which cannot accurately describe the motion of a satellite orbiting a planet, especially in a low orbit. In low orbital altitudes, planet flattening and non-gravitational forces highly affect the satellite orbit.
- Two-line element (TLE) ephemerides are used for the computation and real-time tracking of operational satellites. Although TLE ephemerides provide the six Keplerian elements, they are suitable for use only with simplified perturbation models (e.g., SGP, SGP4, SDP4, etc.) and not with a Keplerian propagator. Even using simplified perturbation models, the accuracy of the satellite position using TLE ephemerides can reach several kilometers per day.
- Only the Earth's rotation is taken into account for the transformation of satellite position and velocity from IRF to EFRF. Formally, precession, nutation and polar motion effects should be taken into account as well.

SOFTWARE DESCRIPTION

The SAT-LAB GUI is presented in Figure 1. The main form consists of the 9 elements provided below, following the same numbering as in Figure 1:

1) Menu bar, which contains the "Satellite Data" menu and two submenus that allow the user to download orbital data from operational satellites and access their orbital elements, as well as other information.
2) "Inertial Reference Frame" panel, which shows the satellite orbit in the IRF.
3) "Earth Fixed Reference Frame" panel, which shows the satellite orbit in the EFRF.
4) "Earth Fixed Reference Frame (Ground Tracks)" panel, which shows the satellite orbit in the EFRF after converting the 3D Cartesian coordinates of the satellite to geodetic coordinates.
5) "Select Keplerian elements" panel. When the user selects or changes the Keplerian elements, SAT-LAB produces and simulates the orbit in real time.
6) "Select appearance" panel. The user can control which orbital and geometric components should be shown and can select their color. The changes are implemented in real time.
7) "Select resolution" panel. The user can define the spatial resolution of the topography/bathymetry (terrain), coastline and day/night map (for real-time positioning of operational satellites). For optimal performance, a medium resolution is recommended.
8) "Select satellite" panel. The user can select the orbit and real-time position of selected operational satellites.
9) "Animation" panel. Selecting at least one reference frame and clicking on the "Animate orbit" button, SAT-LAB produces an animation of the current satellite orbit.

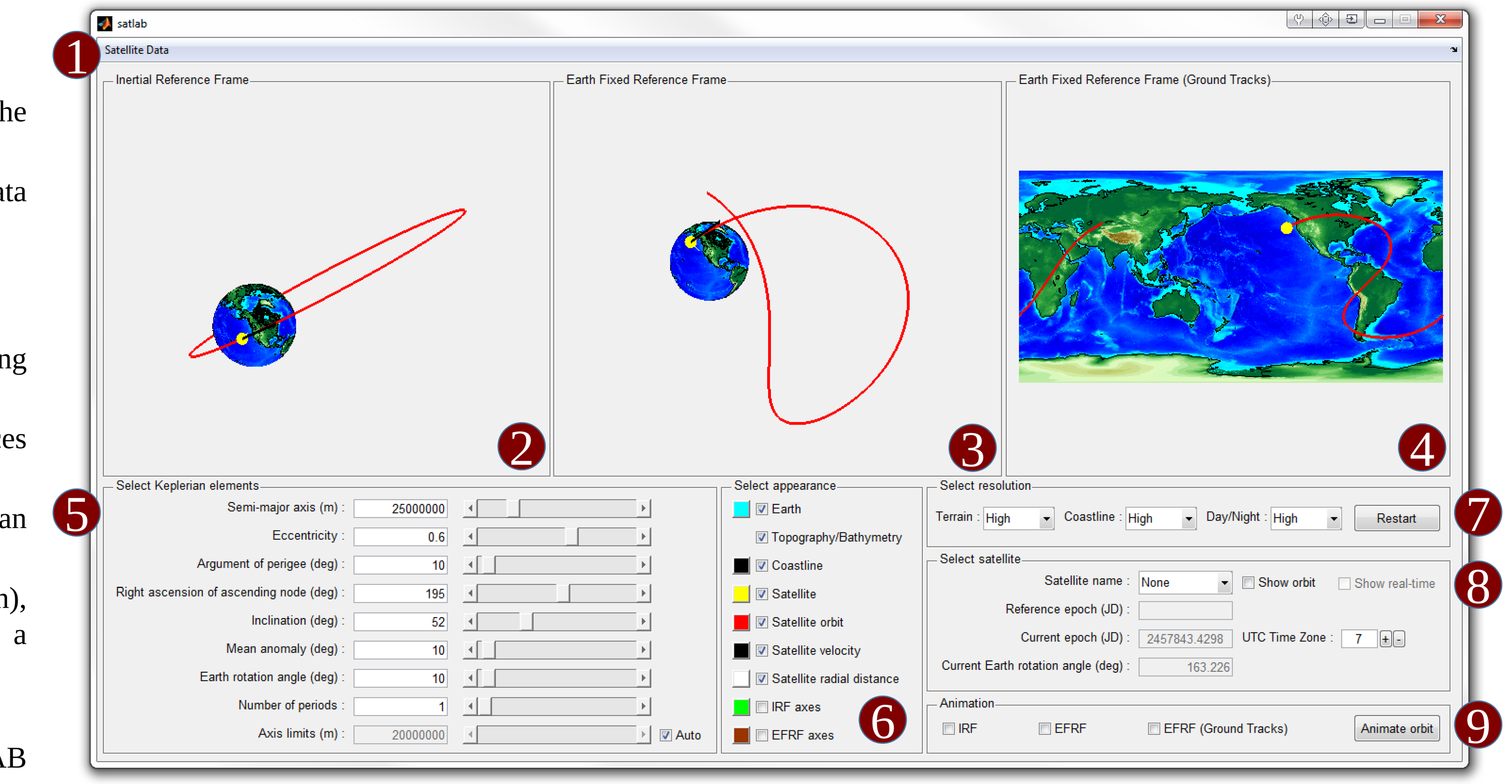

Figure 1 – SAT-LAB main form

ORBIT SIMULATION AND VISUALIZATION

Orbit simulation and visualization examples using SAT-LAB are given in Figures 2 to 5. The following types of orbits are presented:

- Geostationary orbit. A geostationary orbit is considered a special case of geosynchronous orbit. A satellite in geostationary orbit has a period of 1 sidereal day, an inclination of 0° (equatorial orbit) and an angular velocity equal to the Earth's angular rate.
- Tundra orbit. Tundra orbit is a geosynchronous, elliptical orbit with an inclination of 63.4°.
- Molniya orbit. Molniya orbit is an elliptical orbit with an inclination of 63.4°, an argument of perigee of 270° and a period of 0.5 sidereal days. A satellite in Molniya orbit spends the majority of its orbit in the northern hemisphere and, therefore, Molniya orbit is suitable for satellite observations over North America, Russia and northern Europe.
- Low Earth orbit. Low Earth orbit is any satellite orbit with an altitude of 200-2000 km. Earth observation satellites, such as altimetry and gravimetry satellites, are orbiting in low Earth orbits.

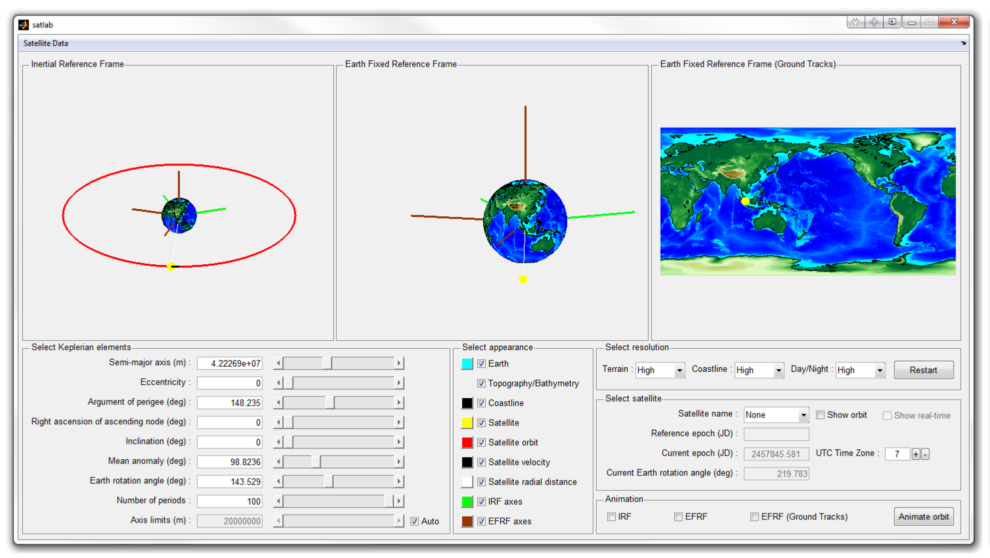

Figure 2 – Geostationary orbit

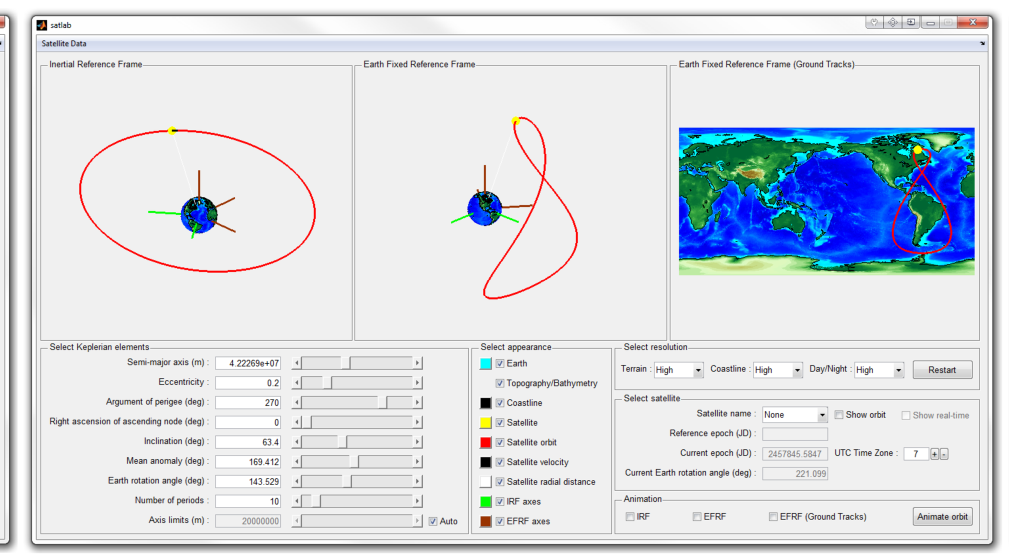

Figure 3 – Tundra orbit

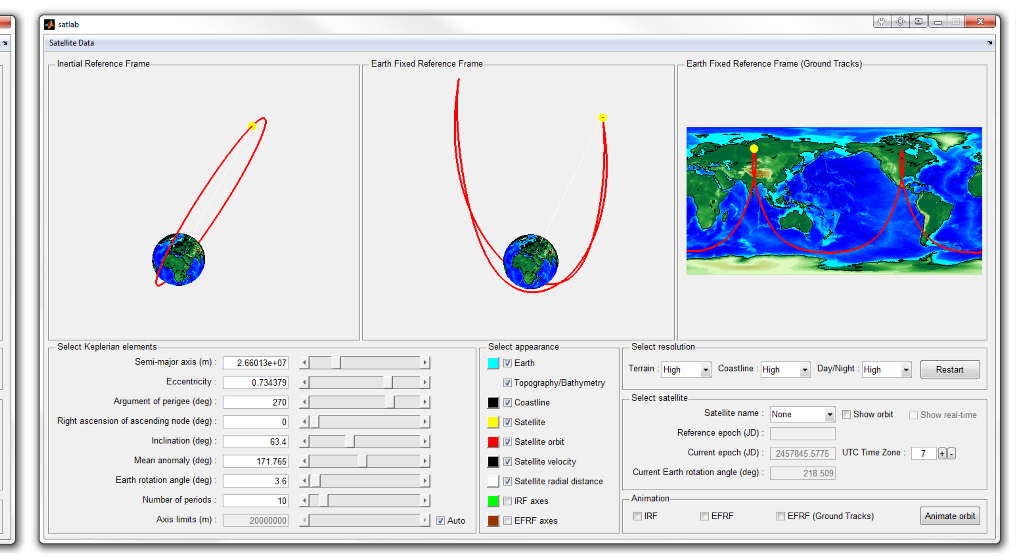

Figure 4 – Molniya orbit

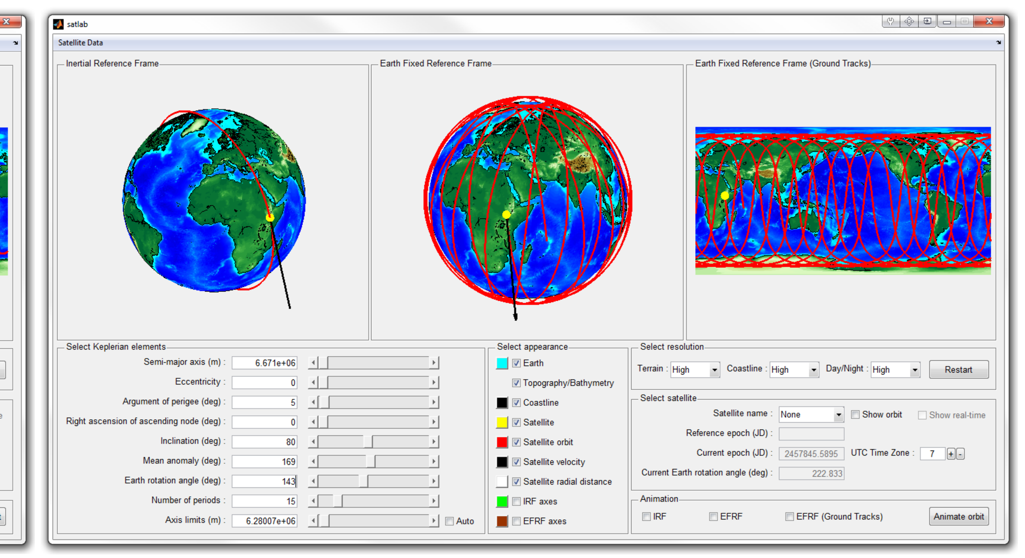

Figure 5 – Low Earth orbit

ORBIT VISUALIZATION OF OPERATIONAL SATELLITES

SAT-LAB provides the ability to download Keplerian elements and other information of operational satellites in the form of TLE ephemerides from https://celestrak.com/. The user can choose among the 41 satellite categories presented in Figure 6. Figure 9 provides the TLE information for GRACE-1 satellite. Here, the orbit of the following satellites is chosen to be visualized using SAT-LAB:

- LAGEOS 1 (Figure 7). LAGEOS is a satellite mission dedicated to providing geodetic and geodynamic data using the method of satellite laser ranging. The LAGEOS 1 satellite is a sphere of 60 cm diameter with 426 reflectors on its surface. LAGEOS 1 was launched in 1976 and has an orbital altitude of 5860 km and an inclination of 109.84°.
- BEIDOU IGSO 2 (Figure 8). BEIDOU is the navigation satellite system of China, currently consisting of 21 operational satellites. The BEIDOU IGSO 2 satellite was launched in 2010 and operates at an altitude of 35700 km with an inclination of 55°.
- GPS BIIF-1 (Figure 10). GPS is a navigation satellite system operated by the U.S Department of Defense and currently consists of 31 operational satellites. The GPS BIIF-1 (PRN 25) satellite was launched in 2010 and has an altitude of 20000 km, an inclination of 55° and a period of approximately 12 hours.
- GRACE-1 (Figure 11). The GRACE satellite mission is designed to observe the temporal variations of the Earth's gravity field. GRACE-1 was launched in 2002 in a low Earth, circular and near-polar orbit.

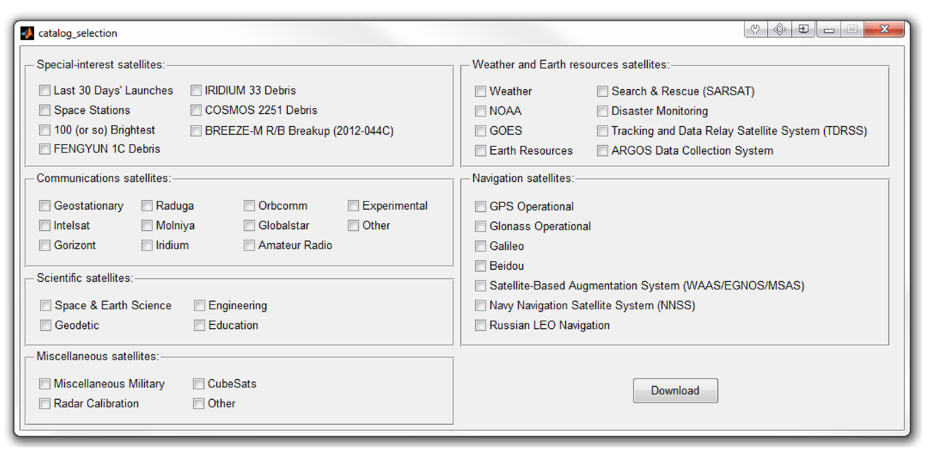

Figure 6 – Satellite catalogs

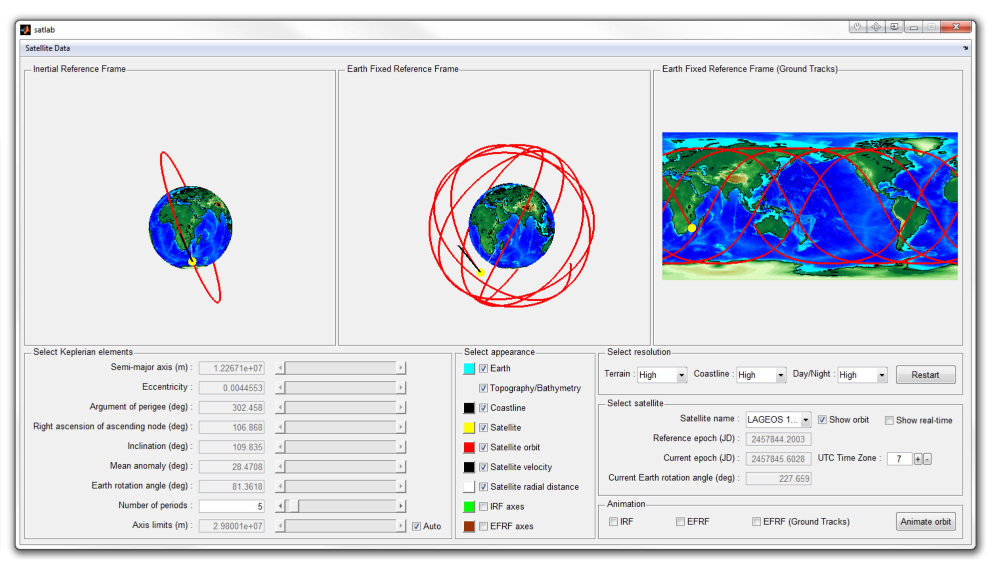

Figure 7 – Visualization of LAGEOS 1 satellite orbit

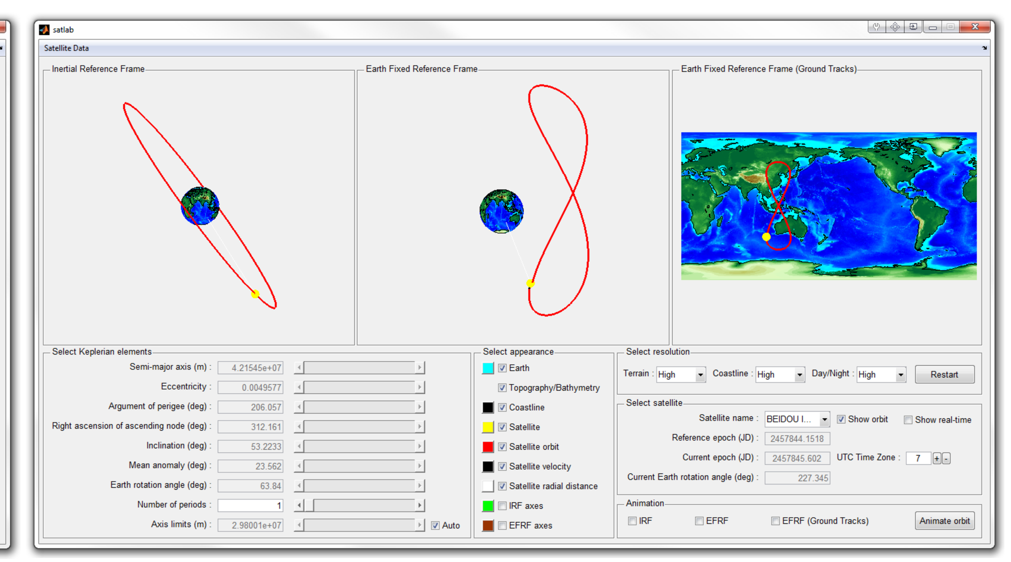

Figure 8 – Visualization of BEIDOU IGSO 2 satellite orbit

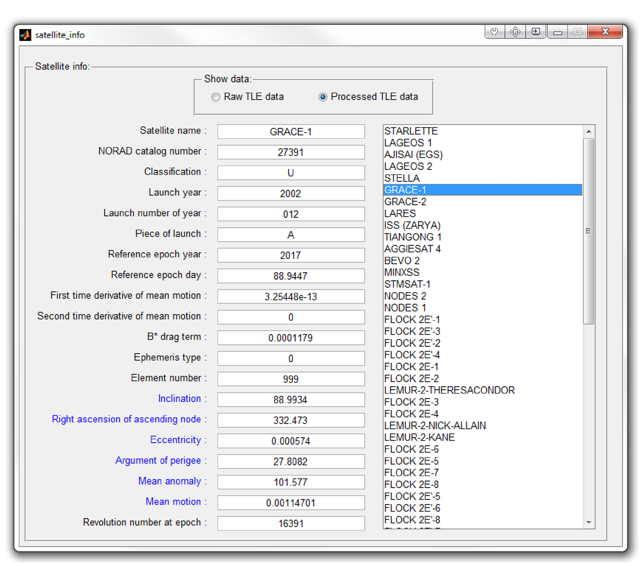

Figure 9 – Satellite information

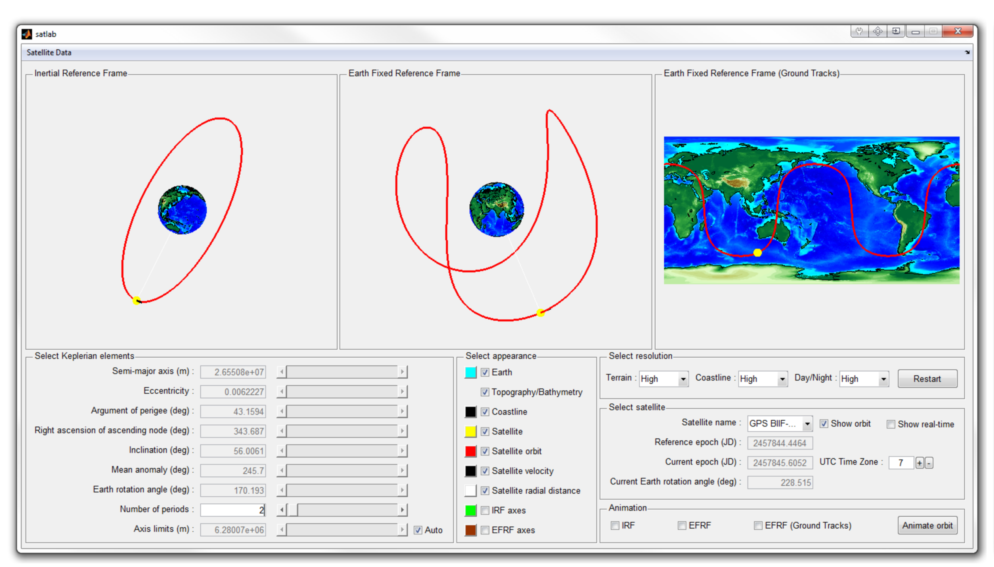

Figure 10 – Visualization of GPS BIIF-1 satellite orbit

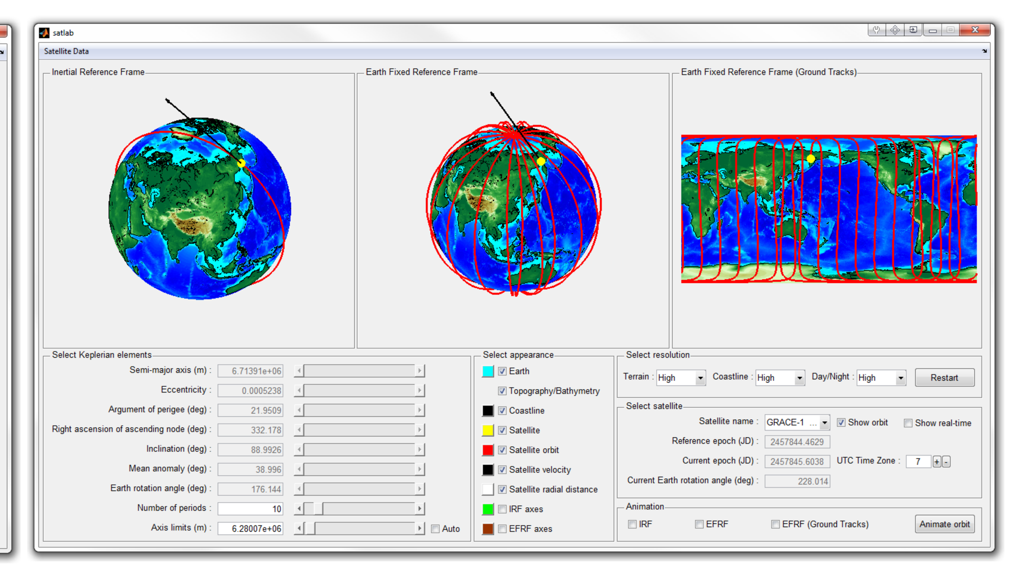

Figure 11 – Visualization of GRACE-1 satellite orbit

REAL-TIME SATELLITE TRACKING

The capability of real-time tracking of operational satellites is also implemented in SAT-LAB. Accurate real-time satellite tracking is possible only when the correct date/time settings and UTC time zone are selected by the user, depending on their location. A day and night map is also calculated and superimposed only for real-time satellite tracking. Examples of real-time tracking of GRACE-1 and International Space Station (ISS) satellites are given in Figures 12 and 13, respectively. The satellite position can be visually compared with results obtained from http://www.heavens-above.com/ , for both cases.

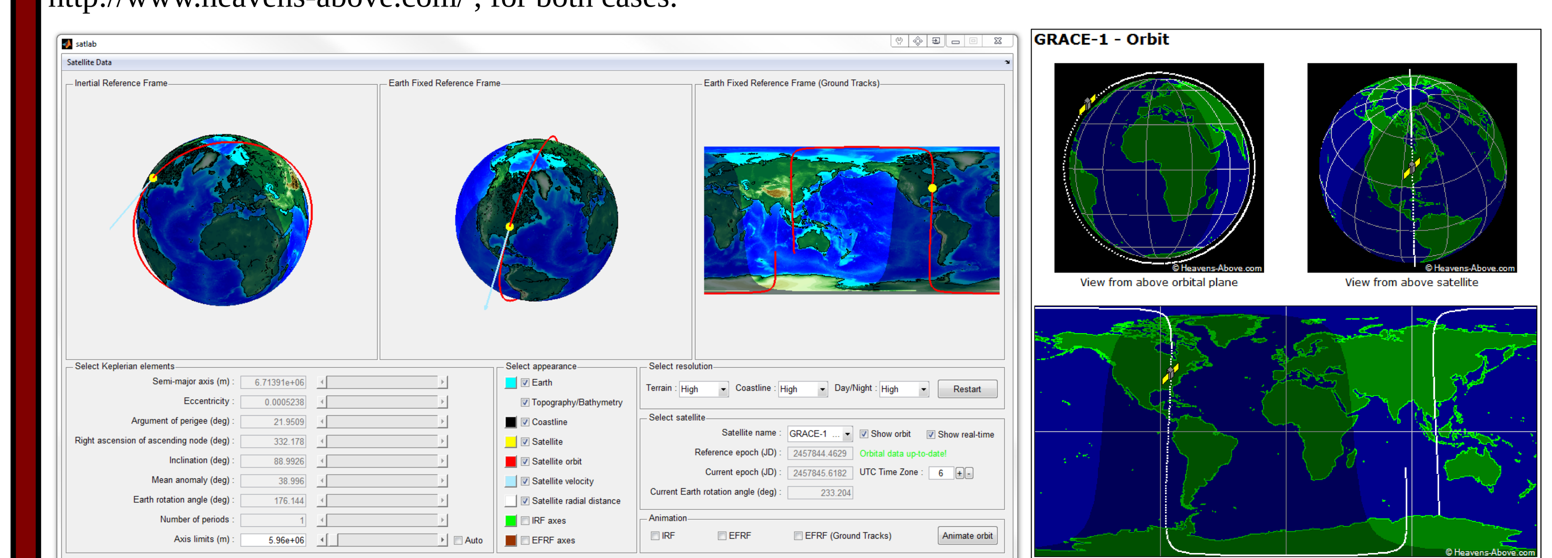

Figure 12 – Real-time tracking of GRACE-1 by SAT-LAB (left) and heavens-above.com (right)

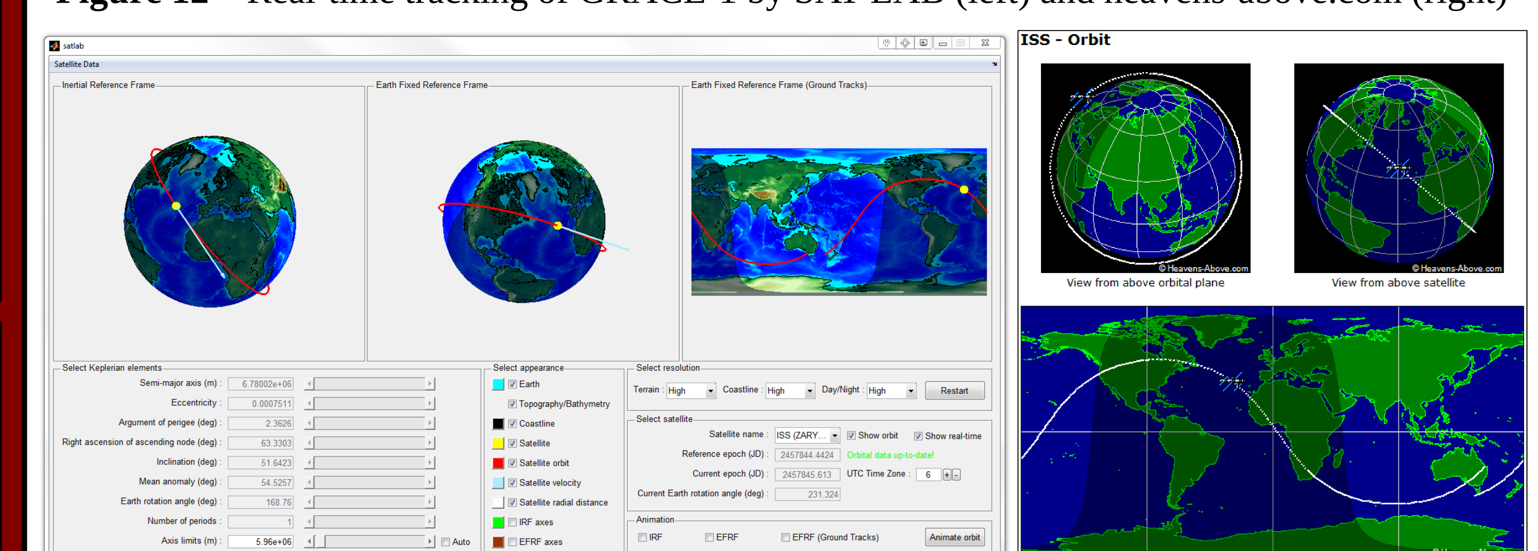

Figure 13 – Real-time tracking of ISS by SAT-LAB (left) and heavens-above.com (right)

SUMMARY

- The SAT-LAB software provides a friendly and easy-to-use GUI for orbit simulation, orbit visualization and real-time tracking of operational satellites.
- SAT-LAB is developed using MATLAB R2012 and tested in later releases (i.e., R2013a) in both 32- and 64-bit operating systems. Overall, SAT-LAB consists of 20 .m files (17 functions and 3 script files).
- The current version of SAT-LAB is suitable for educational purposes and low-accuracy orbit simulations only.
- More rigorous approaches to satellite orbit simulation and, possibly, more visualization options will be implemented in future releases of SAT-LAB.
- SAT-LAB is freely available for download at http://www.dimitriospiretzidis.com/satlab_home.html .

REFERENCES

Heavens-Above. http://heavens-above.com/. Accessed 3 Apr 2017a

CelesTrak. https://celestrak.com/. Accessed 3 Apr 2017b