ISSN 1330-3651
UDC/UDK 521.3:629.783.014.8

SATELLITE ORBITS OPTIMIZED FOR SATELLITE SUPPORTED SERVICES ON THE TERRITORY OF CROATIA

Ante Barišić, Andrea Crnković, Željko Hećimović

Original scientific paper

Modeling of satellite orbits that are used to design satellite supported services on the territory of Croatia is presented in this paper. Modeling of the Kepler's orbit elements is used to optimize satellite orbits considering the territory of Croatia. The paper describes the process of designing the usage of the modeled satellite orbits i.e. Meteorological (CROMETEO) and fire protection (CROFIRE) satellite supported services designed for the territory of Croatia. Meteorological service is designed to use two satellites. One is in optimal orbit over the territory of Croatia for periodical measurements of the atmosphere parameters and the cloudiness in higher spatial resolution, while the other is in the geostationary orbit to continuously monitor the atmosphere and the cloudiness. Fire protection satellite supported service uses a satellite optimized to monitor fire risk, detect fire early, support fire extinguishing and assess fire damage.

Keywords: *Kepler's parameters, satellite orbit, satellite services*

Putanje satelita optimirane za satelitski podržane servise na teritoriju Hrvatske

Izvorni znanstveni članak

Ovaj rad obrađuje problematiku modeliranja putanja satelita optimiranih za teritorij Hrvatske. Modeliranjem Keplerovih elemenata su dobivene putanje satelita optimirane za teritorij Hrvatske. Na osnovu dobivenih satelitskih putanja dizajnirani su meteorološki (CROMETEO) i protupožarni (CROFIRE) satelitski podržani servisi za teritorij Hrvatske. Meteorološki servis se sastoji od geostacionarnog i satelita s optimiranom putanjama za teritorij Hrvatske. Geostacionarni satelit kontinuirano prikuplja podatke o atmosferi i naoblaci u grubljoj prostornoj rezoluciji, a drugi satelit periodično prikuplja podatke o atmosferi i naoblaci iznad teritorije Hrvatske u većoj prostornoj rezoluciji. Protupožarni satelitski podržan servis se sastoji od satelita koji u dnevnoj vremenskoj rezoluciji daje procjenu opasnosti od požara, otkriva požar u ranoj fazi, daje podršku pri gašenju požara i daje procjenu štete nakon gašenja požara.

Ključne riječi*: Keplerovi elementi, putanja satelita, satelitski servisi*

1 Introduction
Uvod

There are many satellite-supported services covering global, regional or local area of interest. The usage of satellite-supported services is widely spread. They are used in solving everyday problems appearing in different branches and with individual users. They are used in navigation, communication, natural resource management, rescue missions, ecology, economy and other. In this work the satellite orbits optimized considering the territory of Croatia are described. Orbit optimization is made considering the Kepler's orbit elements. The repeatability of satellites flying over the territory of Croatia, satellite altitude and inclination and satellite paths on the Earth surface is optimized. The satellite orbits optimized for the territory of Croatia are used to design the meteorological (CROMETEO) and fire protection (CROFIRE) services. CROMETEO service should continuously collect meteorological data necessary for weather forecasting. CROFIRE satellite supported service should contribute in monitoring the risk of fire, earlier detection, localization and reaction to fire and supporting fire-extinguishing and fire damage assessment.

2 Kepler's laws and satellites' orbit elements
Keplerovi zakoni i elementi putanje satelita

Johannes Kepler (1571-1630) defined the laws of planet motions. The Kepler's laws can be seen as two bodies problems of classical celestial mechanics [10]. Kepler developed his laws using the planets' motion data, but the laws are also valid for the satellite motion. One of two bodies has a significantly bigger mass and the other body moves around it. Six Kepler's orbit elements are used to determine the position of the satellites (Fig. 1 and Fig. 2) [27].

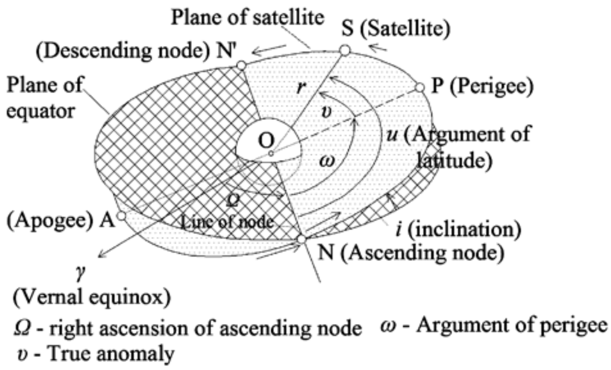

Figure 1 *Kepler's satellite orbit elements*
Slika 1. *Keplerovi elementi putanje satelita*

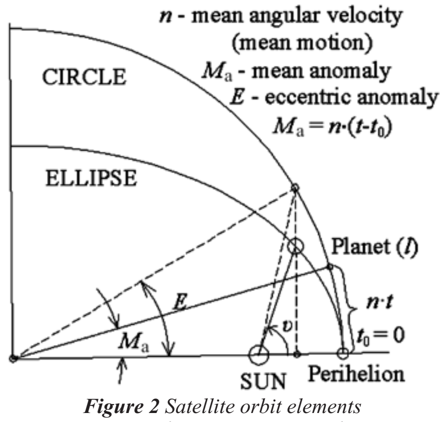

Figure 2 *Satellite orbit elements*
Slika 2. *Elementi putanje satelita*

Orbit period is the time a satellite needs to make one revolution around the Earth. One revolution is defined by 24 sidereal hours, i.e. a sidereal day. One sidereal day is 1-1/366,2422 mean solar days i.e. 0,99726956633 mean solar days, because 24 hours of sidereal days are 23 h 56 min 4,09053 sec of the mean solar time. In one solar day (e.g. the Sun culminates again in a local meridian) the Earth moves 360° and a small additional angle around the Sun. The mean solar day is 3 min 56,6 sec longer than the sidereal day [11].

Satellite orbits can be classified according to several criteria. The most common criteria are developed according to the Kepler's orbit elements [16]. The orbit of special interest for this work is the Sun–synchronous orbit. It includes altitude, velocity and inclination in the way that the satellite flies over the same part of the Earth at the same local time [17, 19].

3
Calculating Kepler's satellite orbit elements
Računanje Keplerovih elemenata putanje satelita

Kepler's orbit elements can be calculated using satellite position in inertial reference frame on the assumption that the satellite position (geocentric position vector $\vec{r}$) and the associated velocity are [9]

$$r = |\vec{r}|; \quad v = |\dot{\vec{r}}|. \tag{1}$$

Radial satellite velocity can be calculated using the formula

$$v_{\mathrm{r}} = \frac{\vec{r}\cdot\dot{\vec{r}}}{r}, \tag{2}$$

and angular momentum per unit mass is defined by

$$\vec{h} = \vec{r}\times\dot{\vec{r}} = \begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix}, \tag{3}$$

$$h = |\vec{h}|. \tag{4}$$

Using these equations, orbit right ascension of ascending node and inclination can be calculated

$$\Omega = \tan^{-1}\frac{h_1}{-h_2}, \tag{5}$$

$$i = \tan^{-1}\frac{\sqrt{h_1^2 + h_2^2}}{h_3}. \tag{6}$$

Semi-mayor axis and eccentricity are defined by

$$a = \frac{GM\cdot r}{2\cdot GM - r\cdot v^2}, \tag{7}$$

$$e = \sqrt{1 - \frac{h^2}{a\cdot GM}}. \tag{8}$$

Here, GM is geocentric gravitational constant, e.g. the product of universal gravitational constant and mass of the Earth. These expressions are used for calculating eccentric and true anomaly.

$$\sin E = \frac{r\cdot v_{\mathrm{r}}}{e\sqrt{a\cdot GM}}, \tag{9}$$

$$\cos E = \frac{a - r}{a\cdot e}, \tag{10}$$

$$\nu = \tan^{-1}\frac{\sqrt{1-e^2}\,\sin E}{\cos E - e}. \tag{11}$$

Argument of perigee can be calculated by

$$\omega = u - \upsilon. \tag{12}$$

The equation for the mean angular motion and the distance from the Earth's centre to the satellite can be obtained using the third Kepler's law [1]

$$n = \sqrt{\frac{GM}{r^3}}, \quad n = \frac{2\pi}{T}, \tag{13}$$

$$r = \sqrt[3]{\frac{GM\cdot T^2}{4\pi^2}}. \tag{14}$$

Here, T is the mean satellite orbital period, GM=3986004,418×10^8 m^3/s^2 and r distance from the Earth center to the satellite. It is calculated using the equation.

The mean anomaly can be calculated using Kepler's equation

$$M_{\mathrm{a}} = E - e\cdot\sin E. \tag{15}$$

Circular orbits are special types of orbits. Circular orbits have eccentricity equal to zero. The origin of circular orbit and ellipse center are the same points, and semi-mayor and semi-minor axes have the same length. Using these assumptions in the equations above, the eccentric anomaly of circular orbits is

$$E = \tan^{-1}\frac{\sin\nu}{0+\cos\nu} = \tan^{-1}(\tan\nu) \rightarrow E = \nu \tag{16}$$

and it is

$$M_{\mathrm{a}} = E - 0\cdot\sin E \rightarrow M_{\mathrm{a}} = E. \tag{17}$$

The circular orbit has identical true anomaly, eccentric anomaly and mean anomaly ($\upsilon = E = M_{\mathrm{a}}$). The position and velocity of the satellite can be calculated using the equation

$$|\vec{r}_{\mathrm{B}}|_{e=0} = \begin{pmatrix} \cos\tau \\ \sin\tau \\ 0 \end{pmatrix}\cdot r; \quad |\dot{\vec{r}}_{\mathrm{B}}| = \begin{pmatrix} -\sin\tau \\ \cos\tau \\ 0 \end{pmatrix}\cdot n\cdot r. \tag{18}$$

Kepler's ellipse is a non perturbed satellite orbit. Satellites would move on the Kepler's ellipse if the Earth were a homogeneous ball or if the Earth had concentric homogeneous shells of different density. However, the satellite motion is influenced by various disturbances, like the following: the Earth's gravity field anomalies, the Moon's and the Sun's gravity, atmospheric frictions, the Sun's radiations, reflection of the Sun's radiations from the Earth and the Moon (albedo), the Earth's magnetic fields and so on. The satellite is therefore moving on trajectories of the Kepler's ellipses. The sources of orbit perturbations are variables of time, and it is not easy to predict the satellite orbit for a longer period of time with a higher accuracy. In this work classical orbit perturbation models are used: Simplified General and Deep-space Perturbations [4].

4 Elements influencing the modeling of the optimal satellite orbits for the territory of Croatia

Elementi koji utječu na modeliranje optimalne putanje satelita za teritorij Hrvatske

There are more elements influencing optimal satellite orbit in the area of interest [3]. Some of the most important Kepler's satellite orbit elements for designing satellite-supported services on the territory of Croatia are considered.

4.1 Position and shape of Croatia

Položaj i oblik Hrvatske

Croatia is situated in the northern Earth hemisphere at the latitude of 45°. Its central meridian is 16,5° from Greenwich. It is spreading about 500 km in the east-west direction, and a little bit less than 400 km in the northeast-southwest direction. Croatia has the shape of a horseshoe. This direction is important because of the satellite orbit used to cover the territory of Croatia. The position and the shape of Croatia prevent the satellite orbits with inclinations bigger than 130° to be used. In order to cover Croatia with satellite orbit paths, the orbits with altitudes of about 3500 km and lower inclinations should be used.

4.2 Cloudiness and atmosphere above the territory of Croatia

Naoblaka i atmosfera iznad teritorija Hrvatske

Clouds, humidity and atmospheric conditions affect the satellite acquisition quality. The analysis of cloudiness can be done using the comparison of the number of clear and cloudy days. Clear days do not have clouds coverage greater than 2/10 of the sky, and cloudy days have cloudiness bigger than 8/10 [15, 18, 24].

Croatia has three climate zones. They have different atmospheric conditions. If we observe annual cloudiness on the territory of Croatia, the clearest months are July and August, and the biggest cloudiness is in December [22]. The biggest trend of reduced cloudiness is from June to July, and the highest from August to September. The cloudiness in Croatia has the tendency of being reduced as we move towards the south. It is lowest on the open sea. The cloudiness needs to be considered with respect to the time when the satellite moves over the territory of interest. It is not the same whether the satellite moves over the territory of interest for 10, 12 or 17 hours. In order to meet the criteria of the lowest daily cloudiness, and the criteria of the shortest shadows, we should use the orbits with satellites flying over Croatia 13 hours ±0,5 h in local time.

4.3 Satellite acquisition resolutions

Rezolucije satelitske snimke

The acquisition resolutions are the main characteristics defining the acquisition quality [13]. Four resolution types define the main acquisition characteristics:

- spatial – the dimensions of the smallest spatial element (pixel),
- spectral - the number of wavelengths that a sensor can detect,
- radiometric – the level of radiation registered in one spectral channel,
- temporal – the time difference between acquisitions of the same area.

Satellite sensor resolutions are one of the main characteristics of satellite missions. It defines the quality and usability of satellite acquisitions data [20, 8, 14, 2]. It is a very complex problem to optimize the sensor resolution of the satellite. For most of the satellite missions, sensors are designed in scientific laboratories.

5 Satellite orbit modeling considering the territory of Croatia

Modeliranje putanje satelita s obzirom na teritorij Hrvatske

The modeling of satellite orbits considering the territory of Croatia is made by taking the optimization of the Kepler's orbit elements into account. Not all Kepler's elements are important for the orbit optimization in a certain area. The satellite orbit modeling for the territory of Croatia considering the main Kepler's orbit elements is further designed.

The orbits are modeled using the Satellite Tool Kit (STK) software of the Analytical Graphics, Inc. (AGI). The STK software accurately displays and analyzes the land, sea, air, and space assets in real or simulated time.

5.1 Modeling of satellite orbit period

Modeliranje perioda obilaska putanje satelita

The satellites have to make a full number of revolutions. The biggest number of satellite revolutions around the Earth in the Sun-synchronous orbit in one day is sixteen (Tab. 1) because it is not possible to use lower altitudes. The lowest number of satellite revolutions in the Sun-synchronous orbit on the territory of Croatia is eight. It means that sixteen to eight revolutions can be used for Croatia. In Tab. 2 the Kepler's orbit elements are given for all orbit periods.

5.1.1 Orbit with the period of 1,5 hour

Putanja s periodom od 1,5 sata

The shortest orbit period is 1,5 hours. The satellite has the altitude of 270 km. It is a very low orbit. The satellite at that altitude has a significantly shorter lifetime because of higher atmosphere frictions. The satellites at lower altitudes are also exposed to the higher Earth gravity anomalies.

Table 1 *Satellite orbits with different orbit periods*
Tablica 1. *Putanje satelita s različitim periodima putanje*

Orbit period sidereal	Revolution numbers in one day	Altitude km	Satellite passing through perigee hh:mm:ss
1,500	16	268,15	12:15:00
1,600	15	561,00	13:52:00
1,714	14	888,30	13:56:00
1,846	13	1257,15	14:05:00
2,000	12	1676,50	14:16:00
2,182	11	2158,50	14:30:00
2,400	10	2719,80	14:52:00
2,667	9	3383,50	15:26:00
3,000	8	4183,50	16:40:00

Table 2 *Kepler's elements for all orbit periods*
Tablica 2. *Keplerovi elementi za sve periode putanje*

Period / h	Ω / °	i / °	ω / °	a / km	e	T_0 / hh:mm:ss
1,500	344,225	97,648	335,564	6649,45	0,0010493	11:45:02
1,600	345,965	97,646	334,308	6942,15	0,0010340	11:42:45
1,714	346,716	98,992	335,751	7269,25	0,0009944	11:40:12
1,846	348,468	100,708	335,453	7637,87	0,0009492	11:32:39
2,000	350,720	102,942	330,363	8056,96	0,0008978	11:34:07
2,182	353,973	105,926	325,401	8538,63	0,0008394	11:30:18
2,400	359,476	110,048	319,453	9099,60	0,0007714	11:25:47
2,667	6,479	116,007	322,335	9762,59	0,0006885	11:20:06
3,000	21,984	125,275	327,737	10561,60	0,0005776	11:12:51

5.1.2
Orbit with the period of 2,0 hour
Putanja s periodom od 2,0 sata

The orbit with the period of 2,0 hours has higher inclination and altitude. The satellite should fly over Croatia at 13 o'clock of local time. Its orbit parameters are given in Tables 1 and 2. It is more suitable than the orbit with the period of 1,5 hours. However, it is not good enough to make the acquisition on the territory of Croatia.

5.1.3
Orbit with the period of 2,7 hour
Putanja s periodom od 2,7 sata

The satellite orbit with the revolution period of 2,7 hours is the most suitable for covering the territory of Croatia (Fig. 3). This orbit is more appropriate with respect to the geographical shape and position of Croatia than the orbits with lower revolution period, lower altitude and inclination. Kepler's orbit elements for 2,7 hours orbit period are given in Tables 1 and 2.

5.1.4
Orbit with the period of 3,0 hours
Putanja s periodom od 3,0 sata

The satellite orbit with the period of 3,0 hours is obtained using higher satellite altitude and bigger inclinations. For Croatia, the biggest inclination of 125° can be used. The orbits using higher inclinations are closer to the Equator and do not cover the territory of Croatia. The satellite using the orbit period of 3,0 hours flies over Croatia every day at 13 o'clock of local time (Tables 1 and 2). This orbit is on the edge of covering Croatia. It could be used on the territory of Croatia, but it is not optimal.

The satellite orbit using the period of 2,7 hours is the most optimal for the territory of Croatia, and it is used in further modeling.

Figure 3 *Satellite orbit for period of 2,7 hours*
Slika 3. *Putanja satelita za period od 2,7 sata*

5.2
Orbit modeling considering orbit inclination
Modeliranje putanje s obzirom na inklinaciju putanje

The orbit modeling that takes into account optimal inclination is connected to the latitude of the area of interest. Due to the latitude of Croatia, the satellite orbits with bigger inclinations do not fly over Croatia, but closer to the Equator. Using lower inclination (below 90°) the satellites fly over Croatia during the night in direction from the northeast to the southwest. Small inclination variations prevent the satellite from flying over the area of interest every day. The best inclinations for the territory of Croatia are between 110° i 120°. The flight direction is from the southeast to the northwest (Fig. 4).

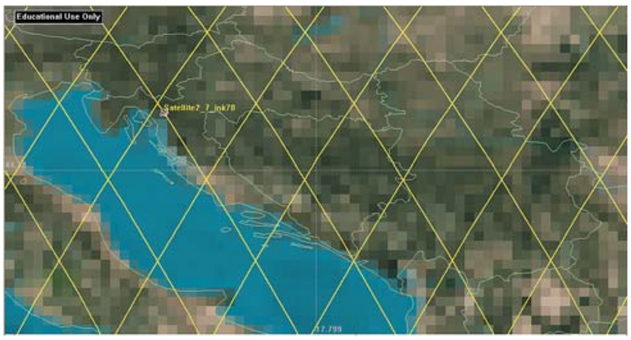

Figure 4 *Satellite orbit using inclination of 70°*
Slika 4. *Putanja satelita s inklinacijom od 70°*

The inclination presented in this work varies with regard to the purpose and services developed; e.g. CROFIRE satellite is optimized with regard to the passage over the Croatian coastal region.

5.3
Satellite orbit modeling considering the Earth covering period
Modeliranje putanje satelita s obzirom na period prekrivanja Zemlje

Because of the Earth rotation, the satellite paths provide obtaining of a grid on the Earth surface. The usage of more satellite revolutions makes it possible to obtain a better grid.

5.3.1
Orbit with the Earth covering period of 15 days
Putanja s periodom prekrivanja Zemlje od 15 dana

The application of the orbit period of 2,7 hours makes it possible to obtain the satellite orbit with three paths over Croatia. The period of repeating the first orbit is 15 days (Fig. 5).

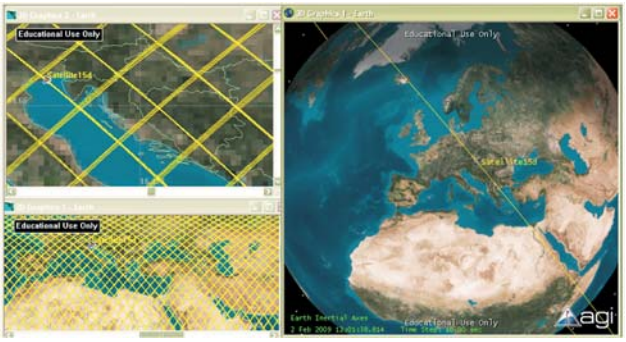

Figure 5 *Satellite orbit covering the Earth 15 days*
Slika 5. *Putanja satelita s periodom prekrivanja Zemlje od 15 dana*

Kepler's orbit elements that use the orbit period of covering the whole Earth in 15 days are given in Tables 3 and 4.

Table 3 *Kepler's orbit elements with period of 15 days*
Tablica 3. *Keplerovi elementi za putanju s periodom od 15 dana*

Period / h	Ω / °	i / °	ω / °	a / km	e	T_0 / hh:mm:ss
2,628	35,500	115,091	274,849	9667,34	0,0006999	11:01:05

Table 4 *Flights over Croatia using the orbit period of 15 days*
Tablica 4. *Prolasci iznad teritorija Hrvatske satelita s periodom od 15 dana*

Date	Time [hh:mm]	Area of overflight
6.2.2009	13:00	Slavonija and north Croatia
13.2.2009	13:10	Central Croatia, part along western border with BiH
14.2.2009	12:50	Istra and Adriatic sea
21.2.2009	13:00	Slavonija and north Croatia

This orbit provides the obtaining of a denser path grid and better coverage of Croatia.

5.3.2
Orbit with the Earth covering period of 16 days
Putanja s periodom prekrivanja Zemlje od 16 dana

The satellite orbit having the flight period over the whole Earth lasting 16 days is given in Table 5. This orbit is the modification of the orbit that needs the period of 1,7 hours.

Tab. 6 presents the time and data about the flight over Croatia.

Table 5 *Kepler's orbit elements for satellite with the period of 16 days*
Tablica 5. *Keplerovi elementi za putanju s periodom od 16 dana*

Period / h	Ω / °	i / °	ω / °	a / km	e	T_0 / hh:mm:ss
1,722	37,700	99,0895	270,00	7288,21	0,0007207	11:34:11

Table 6 *The flight over Croatia using the orbit period of 16 days*
Tablica 6. *Prolasci satelita s periodom od 16 dana*

Date	Time / hh:mm	Area of overflight
1.3.2009	12:13	South of Adriatic basin, Dalmatia, central and north Croatia
2.3.2009	12:19	South and central Adriatic basin, north Dalmatia, Lika and Gorski kotar
3.3.2009	12:25	North Adriatic basin, Istria and Kvarner
16.3.2009	12:06	Eastern Slavonia
17.3.2009	12:13	South of Adriatic basin, Dalmatia, central and north Croatia

Up to now, the satellite orbit modeling has yielded more satellite orbits with more elements. Every satellite orbit has its own advantage and disadvantage. The orbit having the period of 2,7 hours and the repeatability resolution of one day is the most appropriate for the territory of Croatia. The reason for that is its inclination being the most appropriate for the position and shape of Croatia. The orbits with bigger period of returning into the same starting orbit of 15 and 16 days are very good for the acquisition over the Croatian territory. However, they have small flight over time resolution.

6
Sensor modeling
Modeliranje senzora

Satellite sensors are very important elements of satellite systems [7, 26]. The characteristics of simple cones, complex cones, SAR and half power sensors are modeled here. In the tables from 7 to 11 the data about the main sensor modeling are given. In Figures 6 and 7 complex cones and rectangular sensors are shown.

Table 7 *Simple cones sensor*
Tablica 7. *Jednostavni konusni senzor*

Sensor	Cones angle / °	Diameter / km
Simple cones sensor	5	600

Table 8 *Complex cones sensor*
Tablica 8. *Kompleksni konusni senzor*

Sensor	Cones angle / °		Hour angle / °		Diameter / km
	outside sensor	inside sensor	minimal	maximal	inside circle
Complex cones	5	6	0	360	600

***Table 9** SAR sensor*
***Tablica 9.** SAR senzor*

Sensor	Elevation angle / °		Outside angle / °	
	minimal	maximal	forward	backwards
SAR	83	90	10	10

***Table 10** Half power sensor*
***Tablica 10.** Half power senzor*

Sensor	Frequency / GHz	Diameter / m	Angle / °	Acquisition width / km
Half power	11,5	0,25	3,6521	440
Half power	11,5	0,20	4,5652	550
Half power	9,0	0,25	4,6666	550
Half power	9,0	0,20	5,8333	700

***Table 11** Rectangular sensor*
***Tablica 11.** Pravokutni senzor*

Sensor	Vertical angle / °	Horizontal angle / °	Diameter / km
Rectangular	10	10	1200 × 1200
Rectangular	4	5	470 × 600

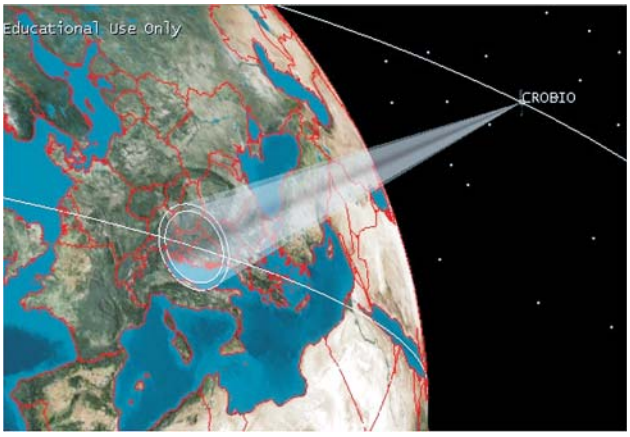

***Figure 6** Complex cones sensor*
***Slika 6.** Kompleksni konusni senzor*

***Figure 7** Rectangular sensor*
***Slika 7.** Pravokutni senzor*

Considering the meteorological and fire protection systems, complex cones sensor with outside footprint of 600 km should satisfy the purposes of satellite-supported services.

7 Meteorological service optimized for the territory of Croatia - CROMETEO

Meteorološki servis optimiran za teritorij Hrvatske – CROMETEO

There are more meteorological satellite supported services in the world. They are optimized for global and regional territory. One of the most famous meteorological satellite supported services is the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). It uses Meteosat satellites of European Space Agency [23]. It is a part of the World Weather Watch geostationary satellite project of the World meteorological organization. The project includes five satellites at the altitude of 36 000 km. Meteosat performs the acquisition in three channels (0,4-1,1 μm, 5,7-7,1 μm and 10,5-12,5 μm) every 15 minutes. Nadir resolution in a visible part of spectrum is 2,4 km, and for infrared part it is 5 km [5]. Besides the Meteosat there are also the U.S.A. Geostationary Operational Environmental Satellites (GOES), Japanese Himawari (GMS), Indian INSAT and others.

CROMETEO service should ensure continuous acquisition of meteorological parameters on the local territory of Croatia. They should have better resolutions and better judgment of meteorological parameters. It is particularly important for Croatia, because there are tree climate zones on the relatively small territory: Mediterranean climate in the Croatian part of the Adriatic coast, continental climate in the mountain ranges and Pannonian climate in the plane area of Slavonia.

CROMETEO service has two satellites. A geostationary satellite flies periodically over Croatia. CROMETEO service is designed to have geostationary satellite at the longitude of 16,30° and the height of 35 800 km. It continuously collects the data about the atmosphere and clouds in a wider area. The second satellite flies periodically over Croatia in the orbit appropriate for Croatia. It collects meteorological parameters over Croatia in high resolution (Fig. 8 and Tab. 12 and 13).

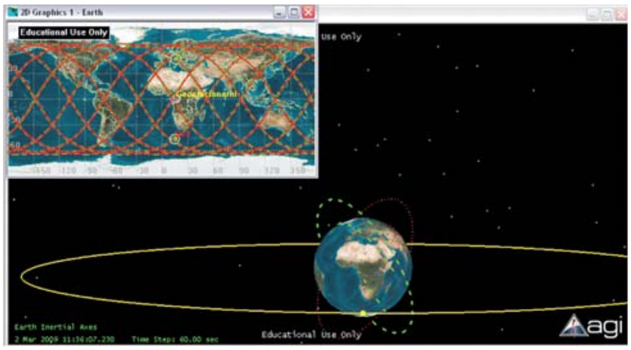

***Figure 8** CROMETEO system*
***Slika 8.** CROMETEO sustav*

***Table 12** Elements of the CROMETEO service*
***Tablica 12.** Elementi CROMETEO servisa*

Satellite	Satellite altitude / km	Repeatability	Coverage
Geostationary	35 800	Continuously	Croatia and 40 % of the Earth
Periodic orbit	3 500	Every 24 h in 11:36 h	Croatia

Table 13 *Kepler's orbit elements for CROMETEO satellites*
Tablica 13. *Keplerovi elementi za putanje CROMETEO satelita*

Satellite	Period / h	Ω / °	i / °	ω / °	a / km	e	T_0 / hh:mm:ss
Geostationary	23,936	13,7626	0,014	314,847	42166,3	1,2e-006	-
Circular	2,667	195,627	116,005	270,268	9759,81	0,000689	13:25:52

Geostationary satellite flies at a constant altitude. It continuously collects the atmosphere data above Croatia. It gives an overview of cloudiness. The disadvantage of geostationary satellite is high flight altitude and small spatial acquisition resolution. Low altitude satellite will collect high spatial resolution meteorological data over Croatia in time resolution of one day.

8 Fire protection satellite supported service on the territory of Croatia – CROFIRE
Protupožarni satelitski podržani servis za teritorij Hrvatske – CROFIRE

One of the satellite supported fire protection services known world-wide is EUMETSAT. This service uses geostationary satellite data. The data are in small spatial resolution; e.g. pixel has 3 × 3 km [23]. This service is not good for discovering and tracing fire occurrence in the local area.

In Croatia the fire protection system is based on monitoring the terrain. Its goal is to detect fire as soon as possible. The system is using human observers or cameras. They are observing the terrain from important locations [21]. Croatian meteorological and hydrological service forms judgments about the fire risks in the coastal area of the Adriatic sea using Fire Weather Index [12].

CROFIRE is the extension of the existing fire protection system in Croatia. The main goals of the CROFIRE systems are: judgment of fire risk, early detection of fire, support to fire extinguishing and fire damage assessment. CROFIRE satellite orbit is optimized for coastal area of Croatia because the greatest number of fires occurs there (Fig. 9). It is defined by the Kepler's orbit elements given in Tab. 14. The satellite has the period of revolution of 2,667 hours and the altitude of 3 500 km.

Table 14 *Kepler's orbit elements for CROFIRE satellite*
Tablica 14. *Keplerovi elementi za CROFIRE satelit*

Period / h	Ω / °	i / °	ω / °	a / km	e	T_0 / hh:mm:ss
2,667	21,479	116,007	322,335	9762,59	0,0006885	11:20:06

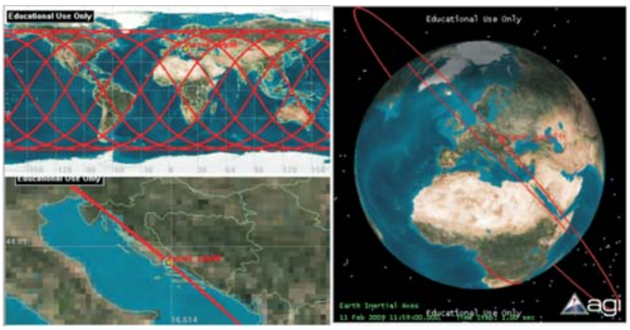

Figure 9 *CROFIRE satellite*
Slika 9. *CROFIRE satelit*

The satellite of the CROFIRE system appears above Croatia at 13 o'clock every day. It is the time with the highest possibility for the fire to occur. The disadvantage of the CROFIRE satellite is in its short flight time over Croatia, lasting only a few minutes. This disadvantage can be eliminated by using additional airborne, ship borne sensors, or the sensors in an unmanned aerial vehicle. They have lower time resolution. They should be connected in one information-communication system.

CROFIRE satellite uses sensors in a visible, but also in an infrared spectrum. The acquisition in infrared spectrum enables the detection of temperature differences in high resolutions and in the night conditions [25].

Fig. 10 displays the CROFIRE service using satellite, ship, helicopter and unmanned aerial vehicle for simulation of the fire on the island of Korčula.

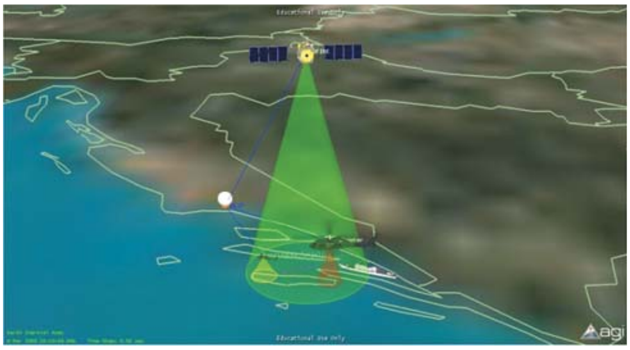

Figure 10 *CROFIRE service for fire simulation on the island of Korčula*
Slika 10. *CROFIRE servis za simulaciju požara na otoku Korčuli*

9 Conclusion
Zaključak

This work deals with the modeling of optimal satellite orbits on the territory of Croatia. They are used in satellite-supported services on the territory of Croatia. Satellite orbits are optimized considering the Kepler's satellite orbit elements. The orbit with the period of 2,7 hours has been chosen. The satellite flies over Croatia every day at 13 o'clock. Taking modeled optimal satellite orbits for the territory of Croatia in consideration, the meteorological (CROMETEO) and fire protection (CROFIRE) satellite supported services are designed. CROMETEO system has two satellites. One of them is geostationary. It continuously collects data about atmosphere and clouds above Croatia and of wider area in small spatial resolution. The second CROMETEO satellite has the orbit optimized for the territory of Croatia. It collects atmospheric data above Croatia in bigger spatial resolution, but also bigger time resolution. CROFIRE service can be used to assess fire risk, to detect fire early, to support extinguishing the fire and to assess fire damage. The orbit of CROFIRE satellite is optimized to fly over the Croatian part of the Adriatic coast. It is the area in Croatia with the greatest number of fires. Due to the low temporal resolution of CROFIRE satellite flying over Croatia, its data could optimally be used in combination with airborne, ship borne sensors and the sensors born by an unmanned aerial vehicle.

Acknowledgement
Zahvala

The authors thank Analytical Graphic Inc. (AGI) for the license for using Satellite Tool Kit (STK) software.

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Authors' Addresses:
Adrese autora:

Ante Barišić
Andrea Crnković
Sveučilište u Zagrebu, Geodetski fakultet
Kačićeva 26, 10000 Zagreb
e-mail:abarisic@geof.hr

Željko Hećimović, dr. sc.
Državna geodetska uprava
Savska 41/XVI
10144 Zagreb, P.P. 19
e-mail:zeljko.hecimovic@cgi.hr