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EARTH MAPPING – AERIAL OR SATELLITE IMAGERY COMPARATIVE ANALYSIS

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Abstract

Nowadays, solving the tasks for revision of existing map products and creation of new maps requires making a choice of the land cover image source. The issue of the effectiveness and cost of the usage of aerial mapping systems versus the efficiency and cost of very-high resolution satellite imagery is topical [1, 2, 3, 4]. The price of any remotely sensed image depends on the product (panchromatic or multispectral), resolution, processing level, scale, urgency of task and on whether the needed image is available in the archive or has to be requested. The purpose of the present work is

- *to make a comparative analysis between the two approaches for mapping the Earth having in mind two parameters: quality and cost.*
- *to suggest an approach for selection of the map information sources – airplane-based or spacecraft-based imaging systems with very-high spatial resolution.*

Two cases are considered: area that equals approximately one satellite scene and area that equals approximately the territory of Bulgaria.

1. Introduction and purpose of the research

Launching into orbit the new generation of commercial satellite systems like IKONOS-2, EROS A1, SPOT 5, QuickBird and OrbView-3, opened a new era into Earth observation from open space. The optic sensors of these systems made it possible to combine very high-resolution (VHR) abilities with reduced revisit time. On the other hand, their navigation systems, GPS, gyro platforms and star trackers provide for precise geometrical modelling of the image assessment system. This allows extracting of geoproduct from raw data without using ground control points (GCP). This is possible at limited precision of the georectification. For example, the precision of the Standard product without GCP and 3D relief model for IKONOS is 50 CE90 ± 25 m RMS [7]. *Table 1* contains the basic parameters of the currently active commercial satellites with VHR. It can be seen that the revisit time is between 1.5 and 5 days.

Now, the issue of the effectiveness and cost of the usage of aerial mapping systems versus the effectiveness and cost of VHR satellite imagery is topical. The price of any remotely sensed image depends on the product, resolution, processing level, scale, urgency of task, and on whether the needed image is available in the archive or has to be requested.

The aim of the present work is to make a comparative analysis between these two approaches for mapping the Earth having in mind two parameters: quality and cost. Two cases will be considered:

- Area that equals approximately to one satellite scene;
- Area that equals approximately to the territory of Bulgaria

2. Very High Resolution Satellite Imagery (VHRSI): products and prices

The prices of the satellite imagery we are received from the price lists of the distributor companies. As data for the analysis, we will use the prices of VHRSI for the four of the five commercial satellites (OrbView-3, of ORBIMAGE does not offer price list up to now). The data is presented on *Table 2*. The whole set of products offered by the companies is not presented on the table. Only two products are shown - radiometrically corrected and orthorectified. *Table 3* presents the prices for one scene and the estimated price for scenes covering the whole territory of Bulgaria (~ 111,000 km^2). The "losses" from scenes recovering will be compensated by price discounts for quantity. More information is available in the web sites [7, 8, 9, 10].

On *Table 2* and *Table 3*, the type of the product is shown with its original name from the price lists as follow:

For IKONOS [7]:

- *Geo Ortho Kit* – raw image that includes the camera geometry obtained at the time of image collection;
- *Precision* – the most positionally-accurate product, provides the spatial accuracy necessary for most urban planning applications, as well as cadastral and infrastructure mapping requirements (4.1 m CE90 ±1.9 m RMSE, require customer supplied GCPs and DEM);
- *Precision Plus* – the same as above (2.0 m CE90 ± 0.9 m RMSE, require customer supplied GCPs and DEM).

For EROS A1 [8]:

- *Archive* – product from archive

- *New* – product with coordinates and time required by the client

For QuickBird [9]:

- *Basic Imagery* – same as with the product *Geo Ortho Kit* of Space Imaging;
- *Standard Imagery* – radiometric, sensor and geometric correction, map projection with accuracy 23 m CE90 ±14 m RMSE;
- *Orthorectified Imagery* – same as above, but map projection accuracy is 12.7 m CE90 ±7.7 m RMSE, require customer supplied GCPs and DEM.

For SPOT-5 [10]:

- *Level 1A* – radiometric correction only;
- *Level 3* – orthorectified, requires customer supplied GCPs and DEM.

3. Aerial Imagery: products and prices

We review aerial imaging systems from the type Wild RC10 and Zaiss RMK-TOP. The finest spatial resolution of the processed negative film is around 40 line pairs per mm (40 lp/mm). At scale 1:40,000, the finest resolution of 11 pl/mm on the film is equivalent to 1 m in terrain ground resolution. With the newer types of aerial cameras, such as Leica RC30 and Zaiss RMK-TOP, equipped with forward motion compensation (fmc) and gyro-controlled mounts, and utilising fine-grained film emulsions, the image resolution is 60 lp/mm. At scale1:60,000, the finest resolution on the film is again equivalent to a ground resolution of 1 m. It is important to note that for the newest commercial VHRSI the spatial resolution of 1m is equivalent to 2 m in terms of their actual ground resolution. In this context, the Kell factor gives the relationship that 1 line pair (lp) is roughly equivalent to 2 pixels [5]. The following international standard rates can be used to assess the cost of the digital photogrammetric mapping [2]:

- Aerial photography – 4,000 $ mobilization + 10 $ per image
- Scanning of photos – 15 $ per image
- Aerial triangulation – 25 $ per image
- Digital elevation model – 120 $ per image
- Digital orthophoto – 30 $ per image
- Mosaicking – 20 $ per image

The following strategy will be used for the price analysis (*Figure 1*),[11]:

1) At scale 1:40,000, the standard aerial photos sized 23x23 cm cover an area of 9.2x9.2 km and, at scale 1:60,000 - area of 13.8x13.8 km.
2) The photos are usually flown with overlap as follows:
   - Longitudinal – 60% ;
   - Lateral – 30%.

The neat area decreases by 72%, i.e. 0.40x0.70 = 0.28. At scale 1:40,000, the effective area is 23.6992 km^2 and, at scale 1:60,000 - 53.3232 km^2.

3) Longitude sampling:

   $a_{1:40000} = 0.4 \cdot 9.2\ km = 3.68\ km$

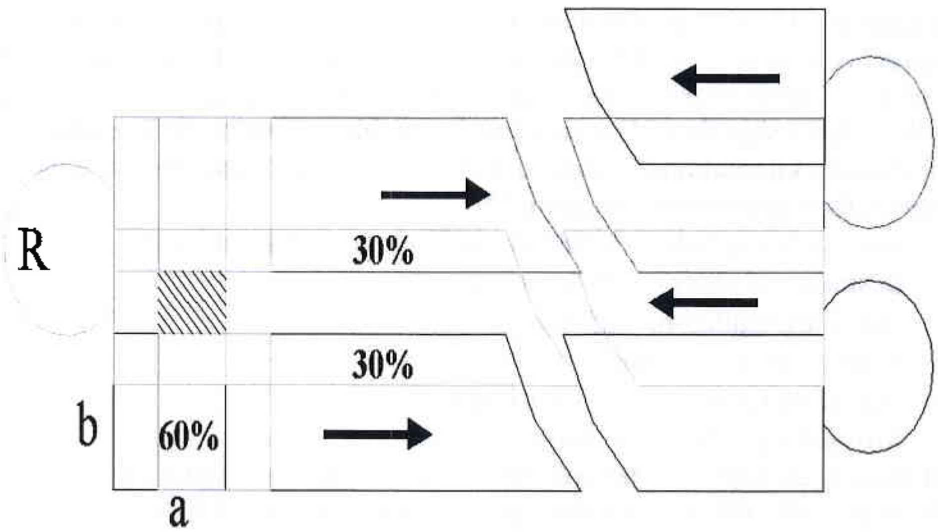
   $a_{1:60000} = 0.4 \cdot 13.8\ km = 5.52\ km$

4) Latitude sampling, b = 0.7 x 9.2 km = 6.44 km / 0.7 x 13.8 km = 9.66 km

   $b_{1:40000} = 0.7 \cdot 9.2\ km = 6.44\ km$

   $b_{1:60000} = 0.7 \cdot 13.8\ km = 9.66\ km$

5) Aerial span length (for one fuel charging), L=2,000 km,
6) Turnover, R~50 km [12].
7) For rough cost estimation of the area equalling approximately to one satellite scene we will use the square:
   A x B = 11 km x 11 km
   for IKONOS-2, EROS A1, QuickBird and
   A x B = 60 km x 60 km
   for SPOT-5.
8) For the territory of Bulgaria we will approximate using the square:
   A x B = 430 km x 255 km.



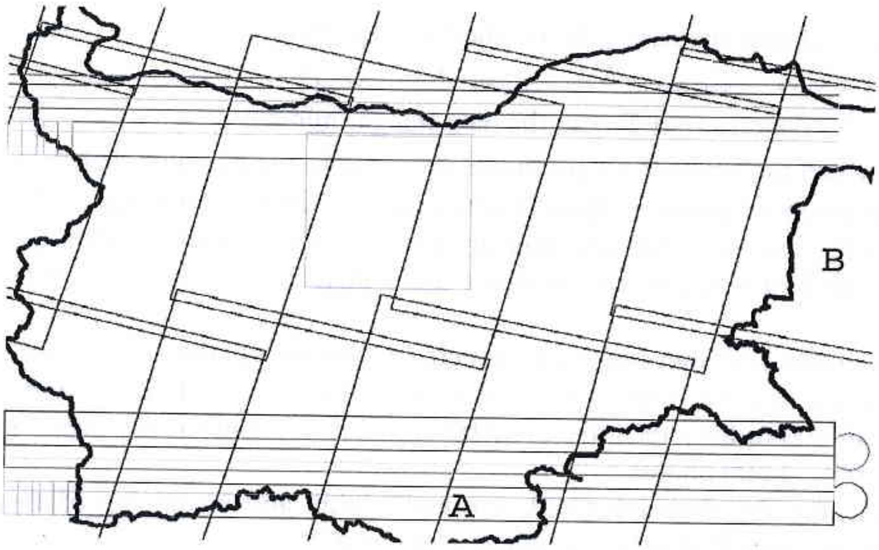


Fig. 1 Simplified model for fly all over the territory of Bulgaria – cost assessment

9) The number of the photos in one-track n_1:
   $n_1 = \text{int}\{A/a\}$
10) The number of the tracks N:
   $N = \text{int}\{B/b\}$
11) The number of the tracks for one take-off N_1:
   $N_1 = \text{int}\{L/(A+R)\}$
12) The number of the photos n:
   $n = n_1 \cdot N$
13) The number of the take-offs M:
   $M = N / N_1$
14) Expenses for mobilizations C_a:
   $C_a = M \cdot 4000\$$
15) Expenses for photo processing until photogrammetric processing C_i - they are determined by the total number of photos, the price of one photo and the price of scanning:
   $C_i = n \cdot (\, C_{image} + C_{scanning\ of\ photos}\,)$
16) Finally we can write down for the expenses on airplane and photos until photometric processing C_{raw}:
   $C_{raw} = C_a + C_i$

17) The value of airplane triangulation and the mosaicing:

$$C_{ph} = n \cdot (C_{aerial\ triangulation} + C_{digitalorthophoto} + C_{mosaicking})$$

Note. int{...} - denotes rounding to the next integer number

The results from the analysis are presented on Table 4. We can note that:

- The price of aerial images depends mainly on the territory of the analyzed area. The price for analysis organization and implementation for areas between 100 and 500 km^2 is times more than the one for areas over 3,000 km^2.
- The time and the expenses related to converting the photos into digital type are also of importance. While for a territory of 121 km^2 their number is around 6, for a territory of 3,600 km^2 it is 170 and for the territory of the country – 4,800 photos.
- The time for choosing GCP, georectification and mosaicing of the different photos should also be taken into consideration.

4. Compatible analysis and conclusions

Taking into consideration the results presented on *Tables 2, 3, 4,* we shall make a compatible assessment between aerial images and VHRSI aiming at large scale mapping. While comparing costs, we shall use the price of different analyzed areas that equal 1 km^2 .We shall compare digital raw images (*Table 5*) and images that are georeferenced with defined precision (*Table 6*).

Conclusions relating to area-price factors:

- When the area that has to be photoed and analyzed equals one or several satellite scenes, it is better in terms of price to use satellites.
- When the area that has to be photoed and analyzed is times more than one or several satellite scenes, it is better in terms of price to use aerial imagery. At the same time, it is necessary to take into account the deadlines for fulfilling the task versus the volume of work into man months.
- The cost of the geoproduct from SPOT-5 satellite with pixel 2.5 m is comparable to the one of aerial imagery even for areas over 50,000 km^2;
- It is important to make very careful analysis of the necessary special resolution of the imagery that will be used. *Tables 6* and *7* show that a change-over in special resolution from ~ (0.61– 1) m to 1.8 m reduces the cost price 4-5 times and from ~ (0.61–1) m to 2.5 m - 9-10 times;

• The price of the product will increase 5-6 times to receive a georeferenced product with precision compatible with the pixel of the raw image. At the same time, it is necessary to present to the client the CGP and the 3D model of the relief.

Conclusions relating to time for execution factor:

• Thanks to the precise navigation systems, the new generation satellites allow obtaining rectified-to-a-datum and map-projected product ready for integration in GIS. The accuracy is much less than the pixel size of the scanning system, but for map scales like 1:50,000 it is completely satisfying [8]. This product could be obtained within less than 48 hours.

• Apart from the panchromatic channel, the new generation satellites have several multispectral channels with lower special resolution. Data fusion techniques allow express change detection and estimation of the land cover;

• To obtain the image throughout the territory of interest, aerial photos need in addition digital scanning, triangulation and mosaicing (overlapping - longitudinal – 60%, lateral – 30%); in relation with this, the processing of large number of aerial photos requires greater operation time and human resources.

Appendix

Таблица 1. **Satellites and Sensors – very-high resolution satellite imagery**

Satellite	Company Country Launching	Sensor	Pixel size, m	FOV along/across swatch, km	H_{orb}, км Revisit time, days
IKONOS-2	**Space Imaging EOSAT, USA 24.09.1999**	**Pan/MSI (13816/3454) Pushbroom,11 bit f=10000mm**	**0.82*/1 pan 3.2*/4 sp**	**±45°/±45° 11**	**680 2.9 (1m)/ 1.5 (1.5m)**
EROS A1	**ImageSat Internat. N.V. Cyprus/Israel 05.12.2000**	**Pan (7000) Pushbroom**	**1.8 pan**	**±50°/±50° 13.5**	**480 3**
QuickBird	**Earth Watch USA 18.10.2001**	**Pan/MSI (27000/6700) Pushbroom,11 bit**	**0.61 pan 2.44 sp**	**±30°/±30° 16.5**	**450 1 - 3.5**
OrbView-3	**ORBIMAGE USA 26.06.2003**	**Pan/MSI (8000/2000) Pushbroom,**	**1 pan 4 sp**	**±50°/±50° 8**	**470/3**
SPOT-5	**SPOTIMAGE France 02.05.2002**	**HRVIR (12000/6000) Pushbroom,**	**2.5, 5, 10, 20**	**±20°/±27° 60-120**	**822 24 nadir/5**

Таблица 2. **Price list - IKONOS-2, EROS A1, QuickBird and SPOT-5, at 20. Jan 2004, [8,9,10,11].**
The prices are based on an area of 1 km^2.

Product, USD[*1]/km$_2$	IKONOS – 2 **1 m**		EROS A1 **1.8 m**	
	B&W	***All***	***B&W***	***All***
Radiometric correction	**21.50 Geo Ortho Kit**	**24.75 Geo Ortho Kit**	**5.00 Archive 8.25 New**	**N/A**
Radiometric correction & Georectified	**100 Precision 120 Precision Plus**	**110 Precision 125 Precision Plus**	**N/A**	**N/A**

Product, USD[*1]/km$_2$	QuickBird **0.61 m**		SPOT-5 **2.5 m**	
	B&W	***All***	***B&W***	***All***
Radiometric correction	**22.50 Basic Imagery 23m CE90 ±14 RMSE**	**30.00 Basic Imagery 23m CE90 ±14 RMSE**	**1.875 Level 1A 2.15[*2] Level 1A**	**N/A**
Radiometric correction & Georectified	**90 Ortho Imagery 12.7m CE90 ±7.7 RMSE**	**117 Ortho Imagery 12.7m CE90 ±7.7 RMSE**	**2.125 Level 3 2.40[*2] Level 3**	**N/A**

[*1] – The prices for SPOT - in USD (rate of exchange at 20.01.2004 EURO/USD – 1.25)
[*2] – require additional satellite programming = 3900$
B&W **– panchromatic**
All **– panchromatic + all multispectral**

Table 3. **Approximate prices for VHRSI (0.61 – 2.5 m), radiometrically corrected, georectified.**
The prices are based on the territory of Bulgaria

Based on an area of 111000 km²	IKONOS – 2[*1] **1 m**		EROS A1 **1.8 m**	
	B&W	**All**	**B&W**	**All**
Raw product, per scene	**2600** Geo Ortho Kit	**3540** Geo Ortho Kit	910 Archive **1500** New	N/A
Raw product, all territory	**2 386500** Geo Ortho Kit	**3 246750** Geo Ortho Kit	**555 000** Archive **915 750** New	N/A
Rectified per scene	**12100** Precision **14520** Precision Plus	**13310** Precision **15125** Precision Plus	N/A	N/A
Rectified all territory	**11 100000** Precision **13 320000** Precision Plus	**11 655000** Precision **13 875000** Precision Plus	N/A	N/A

Based on an area of 111000 km²	QuickBird[*1] **0.61 m**		SPOT-5 **2.5 m**	
	B&W	**All**	**B&W**	**All**
Raw product, per scene	**6120 Standard Imagery 23m CE90 ±14 RMSE**	**8160 Standard Imagery 23m CE90 ±14 RMSE**	**6 750 Level 1A** **7 750 Level 3**	N/A
Raw product, all territory	**2 500 000 Standard Imagery 23m CE90 ±14 RMSE**	**3 330 500 Standard Imagery 23m CE90 ±14 RMSE**	**208 000 Level 1A** **240 000 Level 3**	N/A
Rectified per scene	**24 000 Standard Imagery 12.7m CE90 ±7.7 RMSE**	**32 000 Standard Imagery 12.7m CE90 ±7.7 RMSE**	**7 700 Level 1A** **8 700 Level 3**	N/A
Rectified all territory	**9 990000 Standard Imagery 12.7m CE90 ±7.7 RMSE**	**12 987000 Standard Imagery 12.7m CE90 ±7.7 RMSE**	**236 000 Level 1A** **266 000 Level 3**	N/A

Table 4. **Rough estimation of an aerial photos price - GIS compatible data.**

Parameters		Photo 1:40 000 9.2 km x 9.2 km 1 m			Photo 1:60 000 13.8 km x 13.8 km 1 m		
		121 km²	**3600 km²**	**111 000 km²**	**121 km²**	**3600 km²**	**111 000 km²**
Photos per track, n_t		**3**	**17**	**117**	**2**	**11**	**78**
Number of the track, N		**2**	**10**	**40**	**2**	**7**	**27**
The number of the tracks for one takeoff, N_t		**34**	**19**	**4**	**34**	**19**	**4**
Total number of the photos, n		**6**	**170**	**4680**	**4**	**77**	**2106**
The number of takeoff, M		**1**	**1**	**10**	**1**	**1**	**7**
Airplane mobilization, C_a, $		**4000**	**4000**	**40 000**	**4000**	**4000**	**28 000**
Price of the photos , C_f, $		**150**	**4250**	**117 000**	**100**	**1925**	**52 650**
Raw data price $C_{raw} = C_f + C_a$, $		**4150 34.20/km²**	**8250 2.30/km²**	**157 000 1.40/km²**	**4100 34.20/km²**	**5925 1.65/km²**	**80 650 0.75/km²**
Processing price, C_{photo}, $	**Triang + Mosaic**	**450 3.70/km²**	**4250 1.20/km²**	**351 000 3.20/km²**	**300 2.50/km²**	**5775 1.60/km²**	**158 000 1.40/km²**
	DEM	**720 5.60/km²**	**20 400 5.70/km²**	**562 000 5.10/km²**	**480 4.00/km²**	**9240 2.60/km²**	**252 000 2.30/km²**
C [$], +Triang + Mosaic		**~ 4 600 38.00/km²**	**~ 12 500 3.50/km²**	**~ 510 000 4.60/km²**	**~ 4 400 36.40/km²**	**~ 11 700 3.25/km²**	**~ 240 000 2.15/km²**
C [$], +DEM		**~ 5 320 44.00/km²**	**~32 900 9.10/km²**	**~1 072 000 9.70/km²**	**~ 4 880 40.30/km²**	**~ 20 940 5.80/km²**	**~ 492 000 4.45/km²**
C_1 [$/km²], Raw		**34.30**	**2.30**	**1.40**	**33.90**	**1.65**	**0.70**
C_1 [$/km²], +Triang + Mosaic		**38.00**	**3.50**	**5.60**	**36.40**	**3.25**	**2.20**
C_1 [$/km²], +DEM		**44.00**	**9.10**	**9.70**	**40.30**	**5.80**	**4.45**

Table 5. **Comparison cost assessment between aerial photos and VHRSI, raw digital data.**
The prices are based on tested area of 121 km², 3600 km², 111 000 km² reduced to 1 km².

	Продукт	**Пиксел**	**121 km²**	**3600 km²**	**111000 km²**
Aerial photo	**9.2 x 9.2 km 1:40 000**	**1 m**	**34.20**	**2.30**	**1.40**
Aerial photo	**13.8 x 13.8 km 1:60 000**	**1 m**	**34.15**	**1.65**	**0.75**
IKONOS – 2	**B&W**	**1 m**	**22.50**	**22.50**	**22.50**
EROS A1 - Archive/New	**B&W**	**1.8 m**	**5.00 / 8.25**	**5.00 / 8.25**	**5.00 / 8.25**
QuickBird	**B&W**	**0.61 m**	**22.00**	**22.00**	**22.00**
SPOT-5 – Archive/New	**B&W**	**2.5 m**	**1.90 / 8.70 + 2.10[*1]**	**1.90 / 1.10 + 2.20**	**1.90 / 2.20**

***Table 6.* Comparison cost assessment between aerial photos and VHRSI, rectification, mosaicing, DEM.**
Prices are based on tested area of 121 km^2, 3600 km^2, 111 000 km^2, reduced to 1 km^2.

	Продукт	Пиксел	Точност	121 km^2	3600 km^2	111000 km^2
Aerial photo	9.2 x 9.2 km 1:40 000	1 m	1m	38.00	3.50	5.60
Aerial photo	13.8 x 13.8 km 1:60 000	1 m	1m	36.40	3.25	2.15
IKONOS – 2 Precision &Precision Plus	B&W	1 m	4.1 m CE90 2.0 m CE90	100.00 120.00	100.00 120.00	100.00 120.00
EROS A1	B&W	1.8 m	N/A	N/A	N/A	N/A
QuickBird Standard Imagery	B&W	0.61 m	23.0 m CE90 12.7 m CE90	22.50 90.00	22.50 90.00	22.50 90.00
SPOT-5 – Archive Level 3	B&W	2.5 m	5m	2.10	2.10	2.10
SPOT-5 – New Level 3	B&W	2.5 m	5m	8.70 + 2.40[*1]	1.10 + 2.40	2.40

[*1] – The price increases as a result of satellite programming – 3900$. Sum total normalizes to the area (121 km^2 - to 450 km^2 – 1/8 scene, minimum required area)

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КАРТИРАНЕ НА ЗЕМНАТА ПОВЪРХНОСТ - АЕРО- ИЛИ САТЕЛИТНИ ИЗОБРАЖЕНИЯ СРАВНИТЕЛЕН АНАЛИЗ

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Резюме

Бързите промени в заобикалящата ни среда и навлизането на новите технологии намали изключително времевия интервал за актуализиране на съществуващите карти – топографски, тематични и други. Актуализацията на картната информация в момента е един от главните проблеми на картографията в световен мащаб [1,2,3,4]. Особено актуален в тази връзка става въпроса за ефективността и себестойността на използваните за тази цел аеро- и/или сателитни изображения. Цената на всяко изображение на земната повърхност, получено чрез дистанционни методи, зависи от спектралния тип на продукта, пространствената разделителна способност, нивото на обработка, мащаба, сроковете за решаване на задачата и, дали исканото изображение присъства в архива или тепърва трябва да бъде получено. Целта на представената работа е

- да направи сравнителен анализ между тези два подхода за картиране на земната повърхност, вземайки пред вид два параметъра – качество и цена;
- да предложи подход за избор на източника на картна информация – аеро- или сателитно изображение - в зависимост от типа на решаваната задача.

Разгледани са два случая: площ, съизмерима с площта на една или няколко сателитни сцени и площ, съизмерима с територията на България.