Optimal Conditions for Satellite Derived Bathymetry (SDB) - Case Study of the Adriatic Sea

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Key words: Satellite Derived Bathymetry, Hydrography, Adriatic Sea

SUMMARY

Sea depth data was by far the most expensive spatial data. Traditional hydrographic surveys performed using large and expensive research vessels have resulted in fact that at least 50% of the total global area of the continental shelf (shelf depth is shallower than 200 m) was unsurveyed or surveyed with horizontal and vertical inadequate accuracy defined according to IHO S-44 standards.

Therefore we need to find new methods of bathymetric survey. One of these methods is relatively new method called "Satellite Derived Bathymetry" (SDB), similar or sub variant to the LIDAR bathymetry survey method. SDB uses satellite or other remote multispectral imagery for depth determination. This method is founded on analytical modelling of light penetration through the water column in visible and infrared bands.

In this research SDB will be used in the middle Adriatic Sea, which has the specificity of the shallow archipelago sea. The research of optical characteristics in the coastal area of the middle Adriatic Sea, which cover channel areas and semi-enclosed bays which are far from the river mouths, indicated that oceanic optical water type II was observed (according to Jerlov classification) where euphotic zone (1% PAR) reaches below 45 m.

In this paper SENTINEL 2 satellites free of charge data are used to estimate the sea depths in the wider area of Murterski Kanal channel in the middle Adriatic Sea. It is concluded that the depth gradients and coastline are actually very well surveyed by using SDB method, while individual shoals are not revealed because of the low spatial resolution of SDB method.

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1. INTRODUCTION

It is very well known fact in the world hydrographic community that the Moon's surface is better mapped than the Earth's seabed. We can assume that at least 50% of the total global area of the continental shelf (shelf depth is shallower than 200 m) was unsurveyed or surveyed with inadequate horizontal and vertical accuracy, defined according to IHO S-44 standards (IHO, 2008). Continental shelves make up about 8% of the entire area covered by oceans and seas and the remaining parts have a poorly defined sea bottom. Therefore, it is necessary to find efficient and preferably coast effective methods of bathymetry determination. One of the most efficient and the least expensive method is satellite derived bathymetry (SDB) (Pe'eri et al., 2013).

Satellite Derived Bathymetry technique (SDB) is relatively new survey remote sensing acquisition technique method, which uses high-resolution multispectral satellite imagery or other remote multispectral imagery for depth determination. Method has been recently considered as a new promising technology in the hydrographic surveying industry, especially for shallow water area acquisition. SDB is a survey method founded on analytical modelling of light penetration through the water column in visible and infrared bands. SDB data has potential to become most important low cost source of a large number of spatial data including hydrographic data also. Satellite-derived bathymetry procedure provides a simple reconnaissance tool for hydrographic offices around the world. The procedure is already in commercial use and its steps are documented in public literature (Pe'eri et al., 2013). The satellite imagery provides repeatable coverage of remote areas.

It should be pointed out that SDB method is suitable for bathymetric survey of shallow coastal areas with clear water (approximately to the depth of 2 secchi disc depth; e.g. Duplančić Leder et al., 2019), and that accuracy of this method does not meet current IHO Standards for Hydrographic Surveys (IHO, 2008).

The research of optical characteristics of the eastern Adriatic Sea (Morović et al., 2008) indicated that offshore waters of the middle and southern Adriatic mostly are the open-sea optical water type I according to Jerlov classification (Jerlov, 1968) where euphotic zone (1% PAR) reaches below 80 m. In the coastal area which cover channel areas and semi-enclosed bays which are far from the river mouths, oceanic type II was observed (Morović et al., 2008) where euphotic zone (1% PAR) reaches below 45 m. Furthermore, annual coarse of monthly mean transparencies (Secchi disk depth) for the middle Adriatic area demonstrate the range between 8 and 13 m with maximum in early autumn (September) and minimum in winter (January and February) (Morović, 2002).

It can be concluded that the coastal area of the middle and southern Adriatic is convenient for the application of airborne/space-borne techniques for the purpose of the bathymetric survey.

In this article we deal with Satellite Derived Bathymetry technique (SDB), as relatively new survey remote sensing acquisition technique method, which uses high-resolution multispectral satellite imagery for depth determination in the coastal area of the middle Adriatic. Sentinel-2 ESA observation mission was applied in the wider area of the Murterski Kanal channel, situated in the middle of the Adriatic Sea.

2. SATELLITE DERIVED BATHYMETRY (SDB)

Satellite Derived Bathymetry (SDB) is a relatively new bathymetry or seabed topography survey method, which first usage begins in the late 1970s. The frequency of its use has increased considerably in the last few years (UKHO, 2015) with significant achievements of satellite technology. Method uses satellite or other remote multispectral imagery (unmanned aerial vehicles - UAVs, drones) for depth determination (Marks, 2018). The method is especially effective for measuring shallow areas, which represent a problem for the use of classical ultrasonic acoustic (single beam and multibeam echo sounder) methods.

It should be mentioned that accuracy of SDB does not meet current International Hydrographic Organization (IHO) S-44 standards (IHO, 2008). However, according to Pe'eri et al. (2013), it can be used when planning hydrographic surveying of marine areas not surveyed or areas with old data.

Since the data of some satellite missions is free or available for a relatively small price, it can be said that this is almost the cheapest source of spatial data in general. In particular, the rapid development of this method has been accelerated using a relatively inexpensive and effective unmanned autonomous vehicle (UAV) or drones. Sub variant method so-called Airborne Derived Bathymetry (ADB) uses the same methodology but the same restrictions apply as with SDB method.

Similar or second sub variant of SDB is LiDAR (Light Detection And Ranging) bathymetry survey method. All of these techniques for bathymetry survey (LiDAR, SDB or ADB) use a combination of two waves (shortwave visible – blue or green and shortwave infrared), the first one that penetrates well into the water column and the other which reflects off the water surface. By measuring the difference between the two returning waves, we can measure the depth of the sea.

2.1 SDB Limitations

The limitations of the SDB method are related to several significant factors:

1. Resolution of satellite or aerial images;
2. Meteorological conditions;
3. Water column reflection quality;
4. Relationship between reflectance and DN (digital number) based on threshold index.

These factors should be taken into account when selecting satellite or aerial images.

2.1.1 Resolution of satellite or aerial images

Various remote sensing surveying technologies, particularly high-resolution satellites, have been in operation in the last few decades: multispectral satellite missions, LiDAR, and more recently, unmanned aerial vehicles (UAVs, drones). The main goal of these technologies is to observe and measure Earth physical parameter (man-made objects, vegetation, atmospheric parameters…) and ultimately mapping them. All of these technologies are being used across various platforms today as shown on the left side of Figure 1 (Yamazaki & Liu, 2016).

The spatial and temporal resolutions of remote sensing technologies also have a wide range, as shown on the right side of Figure 1 which shows the observation range, as a cube defined by three sensor parameters (without sensor spectral aspect): (1) the spatial resolution, expressed in GSD (Ground Sampling Distance), (2) data acquisition frequency or revisit time, and (3) object range, the average distance between the sensor and the object space observed (Toth & Jóźków, 2016).

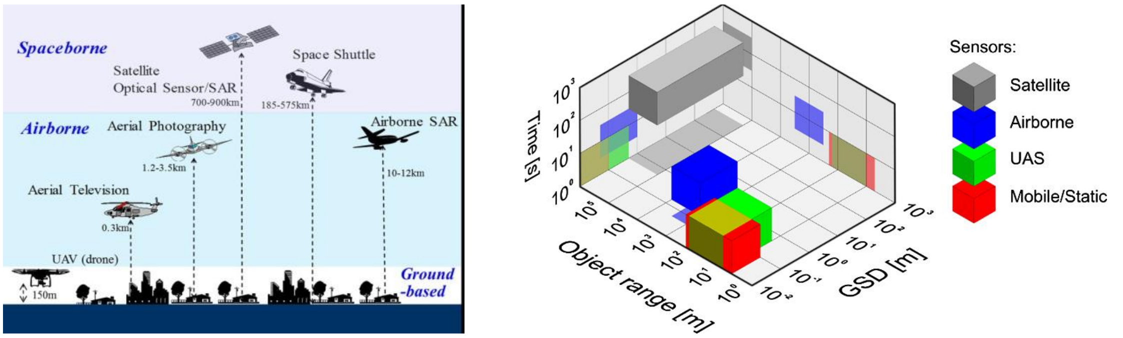

Figure 1. Various platforms and sensors used for remote sensing (left; according Yamazaki & Liu, 2016); Remote sensing observation cube (right; according Toth & Jóźków, 2016).

One of the most important limitations of this technology is sensor-dependent spatial resolution (Table 1). The remote sensing surveying technologies for observations and recordings of Earth parameters mainly have been used digital aerial cameras, which main characteristics are higher radiometric and spatial resolution than usual digital cameras.

For better results, the SDB method should be used on commercial satellite data in which the current image resolution reaches up from 0.5 to 0.3 m (WorldView 3&4; Table 1; Figure 2). SDB is cost effective and rapid survey method. This is independent technology, supporting uncertainty estimation. SDB cost generally depends on costs of satellite images, which are between 0 (free of charge) and 60 €/km^2, depending on image quality.

Table 1. Spatial resolution and the cost of individual satellite scenes used for SDB (according ARGANS, 2016) with personal data

Satellite	Spatial resolution pancromatic-multispectral (m)	Cost/km^2 (€)
Ikonos	0.82-3.20	2.64
Quickbird	0.65-2.40	22
Pleiades	0.5-2	5
TerraSar-X	1-3	2.64
WorldView 2	0.46-2	14-60
WorldView 3 & 4	0.31-1.24	14-60
RapidEye	5	0.95
Sentinel 2	10	Free
Landsat 8	30	Free

The spatial resolution achieved with this technology varies depending on the used satellite images. Today, SDB uses free Landsat 8 images with 30 m spatial resolution, through to Worldview at 1.25 m. The vertical accuracy achieved is approximately 10 - 15% of the depth and significantly reduced in areas with depths above 20-30 m. Figure 2 present SDB technology performed by different spatial resolution satellite images WorldView3 (above) and Landsat 8 (below) on Majuro Atoll of Marshall Islands presented at USGS EROS Workshop 2017 (Kim, 2017).

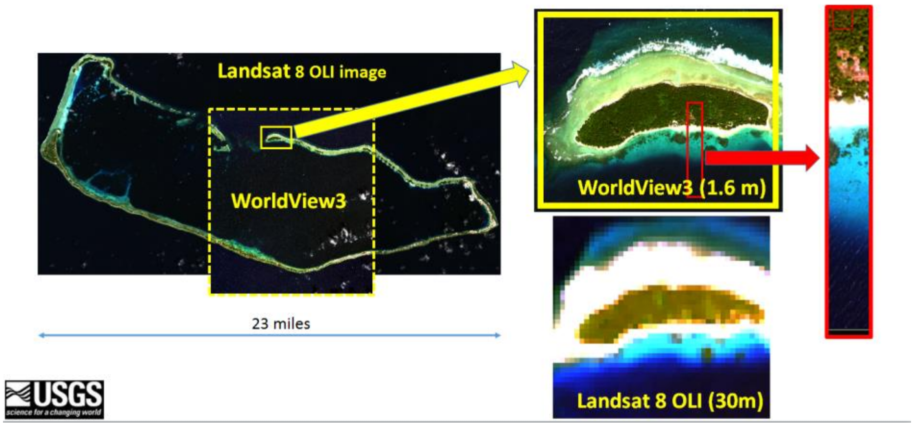

Figure 2. Majuro Atoll, Marshall Islands images obtained with different satellite resolutions (Kim, 2017).

2.1.2 Meteorological conditions

Electromagnetic energy passes through the atmosphere twice, first it is downwelling radiation from the Sun and second time is upwelling radiation from the Earth to the sensor (Figure 3). Different physical processes take place along this path, they are called meteorological conditions at the time of image recording and which very often depend on the height of the sun and the state of the atmosphere or the amount of specific particles in the atmosphere. Meteorological conditions at the time of shooting affect the quality of a satellite images and consequently are critical to the SDB method solving. Most affected processes are:

- Absorption (performed by different atmospheric particles: CO_2, H_2O, O_2, O_3) which reduces the energy intensity and blur the image, and
- Scattering (Rayleigh, Mie and nonselective scattering) that occurs on different sizes particles in an atmosphere which redirect EM energy.

Ideal meteorological conditions are around noon on a sunny, dry day with no clouds and no pollution therefore, when selecting remote sensing images for SDB method, approximately similar conditions should be chosen.

Influences of meteorological conditions at the time of shooting effects are being removed by atmospheric modeling method which corrects atmospheric disturbances with specific atmospheric data knowledge (temperature, pressure, moisture, aerosol content, etc.). The atmospheric modeling method use dark object subtraction, which assumes the existence of zero or small surface reflectance, for correct for atmosphere disturbances on image or atmospheric correction. The method works so that minimum digital number (DN) value in the histogram from an entire scene is subtracted from all pixels. There are also few radiative transfer models (LOWTRAN7 atmospheric absorption extinction model (https://pypi.org/project/lowtran/), MODTRAN - MODerate resolution atmospheric TRANsmission (http://modtran.spectral.com/), etc.) to correct images. Atmospheric correction removes the scattering and absorption effects from the atmosphere.

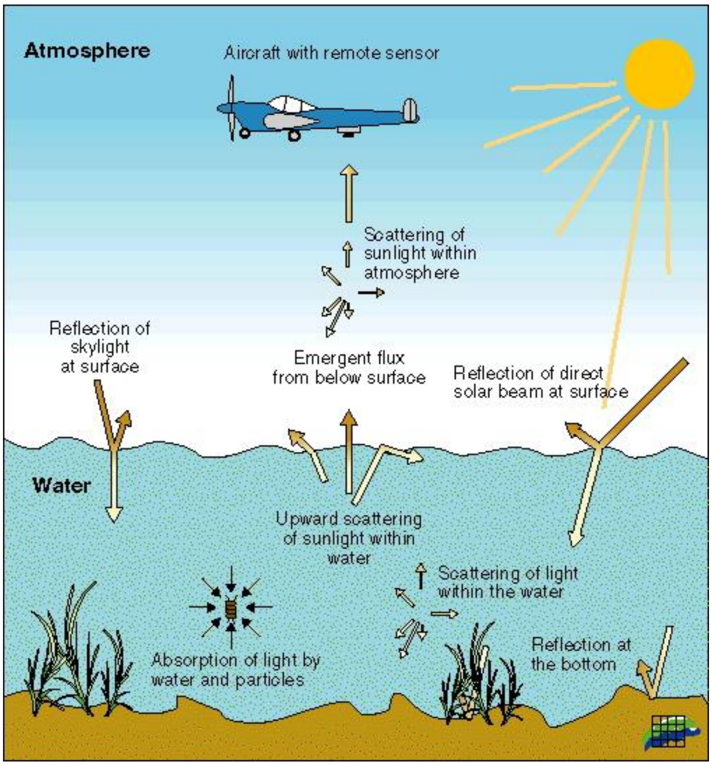

Figure 3. Atmospheric and water column effects on remote sensing data (according https://www.dmu.dk/rescoman/project/Backgrounds/challenges.htm).

2.1.3 Water column reflection quality

SDB method to depth determination use analytical modeling of light penetration through the water column in visible and infrared bands (Figure 3). Electromagnetic radiation is absorbed and it scatters while spreading through water and residue energy has been backscattered and recorded in satellite (Stumpf et al., 2003). The method efficacy depends on the water optical properties in the coastal area, such as absorption coefficients of suspended and dissolved substances, attenuation, scattering and backscatter and bottom reflections (Vinayaraj, 2017). The combinations of analytical and empirical models provides an algorithm that is most commonly used to determine depths (Lyzenga et al., 2006; Vinayaraj et al., 2016), which depends significantly of optical water properties especially water spectral properties.

Water color (clarity), which can be determined by visual methods (Figure 4) or in a satellite imagery is an indicator of water column transparency. SDB method is strongly depending on water clarity and found to be range of 1 - 1.2 Secchi disc depth (Duplančić Leder et al., 2019). Before starting to use this method someone would find an ideal image, which depends on seasonal dynamics, water turbidity, bottom topography and other water column parameters.

Figure 4. Variable colors of water (according https://forelulescale.com/).

In general reflection quality of electromagnetic radiation depends on water column transparency, the topography and sedimentological characteristics of the sea bottom (Figure 5).

SDB method use is not recommended in coastal waters with weak bottom reflection and high turbidity.

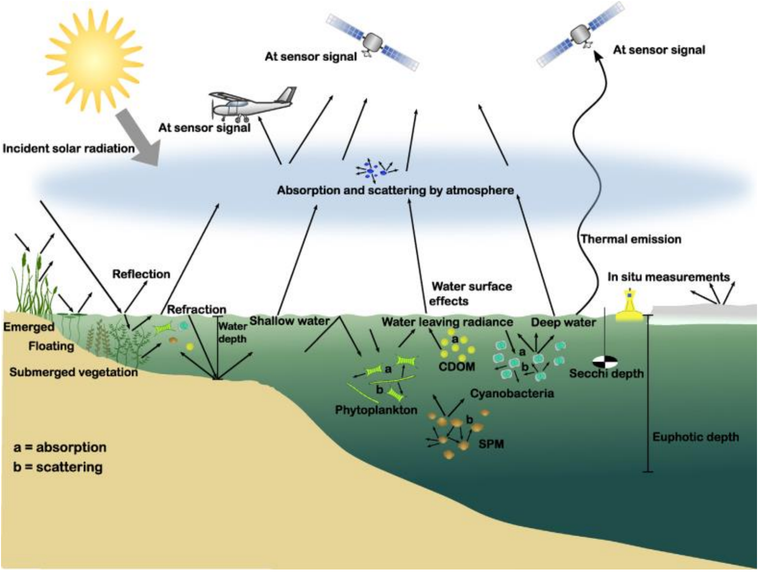

Figure 5. Interaction between radiation, remote sensing indicators of lake ecology and sensors (according Dörnhöfer & Oppelt, 2016).

2.1.4 Relationship between reflectance and DN based on threshold index

SDB algorithm in determining depth used threshold index determination and there are no universal threshold values or formulae for classifying water bodies based on indices, especially in complex water bodies. Threshold index depends on the optical properties and other water components such as phytoplankton, suspended matter, biological season changes, water pollution etc. Threshold values are also different in different wavelength bands.

Threshold index depends on physical (depth, clarity, etc.), chemical (saline, fresh, etc.), biological (algal infested etc.), thermal (temperature etc.), geological and human impact factors (Ji et al., 2009; Zeng et al., 2016; Patra et al., 2011).

3. SENTINEL-2 OBSERVATION MISSION

Sentinel-2 is European Space Agency (ESA) Earth observation mission as part of the Copernicus Program. Sentinel-2A was launched on 23 June 2015 and Sentinel-2B was launched on 7 March 2017 from French Guiana. Mission performs terrestrial observations to support services such as forest monitoring, land cover changes detection, and natural disaster management. All Sentinel mission data can be downloaded through Copernicus Open Access Hub and USGS EarthExplorer.

Mission consists of two identical satellites, Sentinel-2A and Sentinel-2B. Satellites orbit is Sun synchronous at 786 km (488 mi) altitude and 14.3 revolutions per day. The orbit inclination is 98.62° and the Mean Local Solar Time (MLST) at the descending node is 10:30 (am). The Sentinel-2 swath width is 290 km.

Temporal resolution of this mission is 10 days with one satellite, and 5 days with 2 satellites. Sentinel-2 is multi-spectral mission with 13 bands in the visible, near infrared, and short wave infrared part of the spectrum and spatial resolution of 10 m, 20 m and 60 m (Figure 6) and 12-bit radiometric resolution (https://sentinel.esa.int/web/sentinel/missions/sentinel-2).

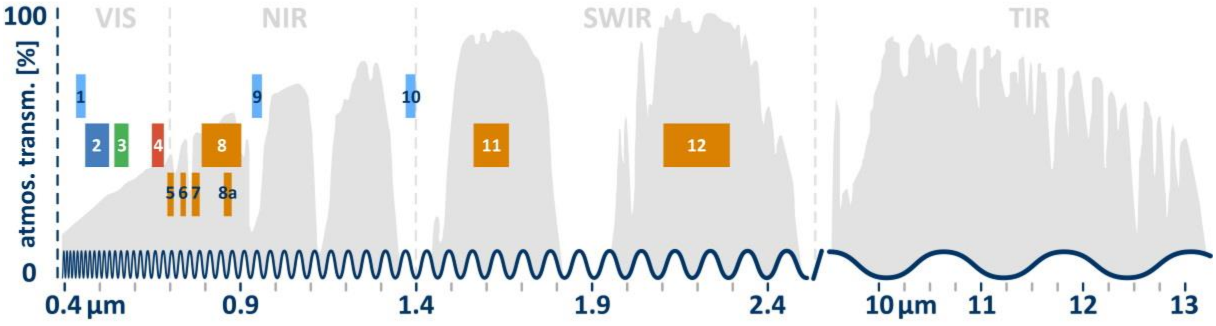

Figure 6. Sentinel 2 bands (according https://blogs.fu-berlin.de/reseda/sentinel-2/).

4. STUDY AREA

The Murterski Kanal channel (Figure 7) is situated in the middle of the Adriatic Sea at 43°48′30″N 15°37′00″E. The channel leads between the mainland coast and the island of

Murter. The narrows at Tisno (Murterski Tjesnac) are spanned by a swing bridge (Figure 7) which connects the island with the mainland (HHI, 2004).

NW part of the Murterski Kanal (up to the bridge) is much shallower than the SE part. Only in the middle part of the channel depths are between 8 and 11 m along and the coast is shallow. SE part of the Murterski Kanal is full of shoals and islets that are mostly well visible, but nearby area is very shallow. In the SE part of the Murterski Kanal depths are generally deeper than 20 m.

Figure 7. Murterski Kanal channel.
http://zasticenapodrucja.com/UserFiles/Image/gallery/586x313/murterski-kanal-m-jpg.jpg

5. RESULTS

In this analysis, from several satellite scenes from different seasons (January, September, April and March), the scene that gives the best results is selected. It is Sentinel 2 scene, recorded on 03 January 2020; pass 11h 16 min 12 sec (Figure 8). Metrological and weather conditions at the shooting time were: air temperature 10.4 °C; air pressure: 1027.0 hPa; dew point: -5.4 °C; relative humidity 34.4%; wind direction and speed: 100°, 1m/s and zenith solar angle (68.1605209470205) (https://earthexplorer.usgs.gov/).

Figure 8. Sentinel 2 scene on 03 January 2020 (according https://earthexplorer.usgs.gov/).

Figure 9 illustrate the estimated water depths of the wider area of Murterski Kanal channel computed by the satellite bathymetry model developed by Stumpf et al. (2003) from Sentinel 2 satellite images. In Figure 9 the depths are shown in the color range from 0 m (red) to 50 m (dark blue). By comparing the bathymetric map (depths and depth contours in the background) with ENC HR400512, it can be concluded that the depth gradients and coastline are actually very well surveyed by using SDB method, while individual shoals are not revealed because of the low spatial resolution of SDB method.

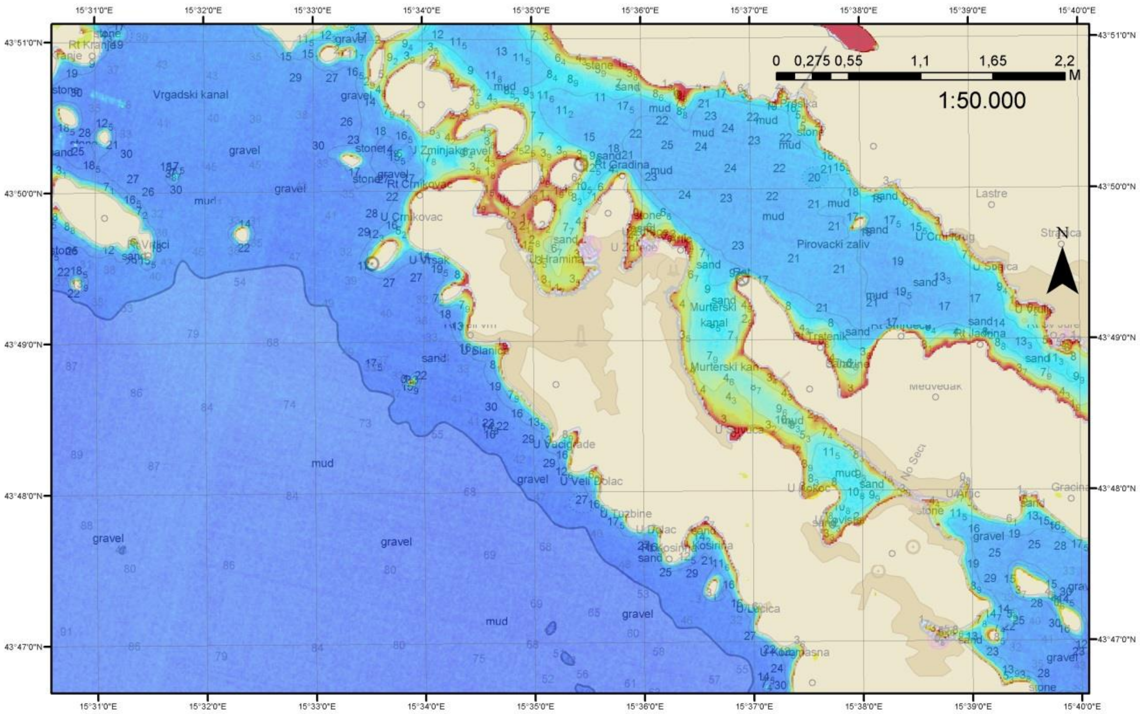

Figure 9. Satellite-derived water depths in the Murterski Kanal channel obtained from Sentinel 2 satellite images on 03 January 2020.

6. CONCLUSION

Traditional hydrographic surveys performed using large and expensive research vessels are not sufficient to provide high-quality sea depth data, especially in shallow coastal areas, all for the purpose of ensuring safe navigation. Therefore hydrographers need to find new methods of bathymetric survey. One of these methods is relatively new method called “Satellite Derived Bathymetry” (SDB), which uses high-resolution multispectral satellite imagery or other remote multispectral imagery for depth determination. SDB method is one of the most efficient and the least expensive method for bathymetry determination in shallow coastal areas. In this paper SENTINEL 2 satellites free of charge data were used to estimate the sea depths in the wider area of Murterski Kanal channel in the middle Adriatic Sea, because scientific oceanographic research indicated this area as oceanic optical water type II where euphotic zone reaches below 45 m. Because SDB method is founded on analytical modelling of light propagation from sensor through the atmosphere and the water column and back, several satellite scenes were analyzed in different seasons, to find the scene that gives the best result. The analysis of the results came to a conclusion that the depth gradients and coastline of the area of Murterski Kanal channel are actually very well surveyed by using SDB method, while individual shoals are not revealed because of the low spatial resolution of

SDB method. Generally it can be concluded that SDB method is suitable for bathymetric survey of shallow coastal area of Murterski Kanal channel, where usually clear water was observed, and that accuracy of this method does not meet current IHO Standards for Hydrographic Surveys for safe navigation. Consequently, the SDB method is suitable for determination of bathymetric data in areas without bathymetric data or in areas with old bathymetric data, for the purpose of planning the survey.

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BIOGRAPHICAL NOTES

Tea Duplančić Leder, born in Split in 1960, graduated at the Faculty of Geodesy the University of Zagreb. She completed her internship in 1986 at Elektrodalmacija Split, and then worked at the high school for a half year. She worked at the Hydrographic Institute from 1988 to 2007 in various positions. In 2002, she completed a specialized course at the International Maritime Academy (IMA) in Trieste for the production and maintenance of Electronic Navigation Charts, and in 2005 she attended specialist training at C-map Italy for quality control and validation of ENC data. She received her PhD in 2006 from the Faculty of

Geodesy, University of Zagreb, entitled “New Approach to the Making of Electronic Navigation Charts in Croatia”.
Since 2007, she has been employed at the Faculty of Civil Engineering and Architecture in Split, and in 2010, she was elected Vice-Dean for the study of Geodesy and Geoinformatics at the same Faculty. She performed the function until 2016.

Nenad Leder, born in Komiža (Vis island, Croatia) in 1958, graduated in 1981 at the Faculty of Science of the University of Zagreb, Department of Physics. His professional career as oceanographer and hydrographer spans some 35 years at the Hydrographic Institute of the Republic of Croatia. Between 2004 and 2014 he took up the post of Assistant Director and between 2014 and 2017 he was the Director. As National Hydrographer he was Croatian government’s representative at the International Hydrographic Organization (IHO) in Monaco.
In October 2004 he earned his doctor’s degree with the dissertation entitled "Barotropic and Baroclinic Waves in Wider Area of Lastovo Channel". In the period between 2005 and 2009 he performed the duties of project manager in CRONO HIP Project (Croatian-Norwegian Hydrographic Information Project), through which the Hydrographic Institute of the Republic of Croatia significantly modernized its ”production line“ from the hydrographic survey by modern multibeam echosounder, and implementation of sophisticated database of hydrographic, nautical and oceanographic data, to the production of electronic navigational charts (ENC) and paper navigational charts from the same database.
From 2017 to the present he is an assistant professor at the Faculty of Maritime Studies of the University of Split.

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