INTERPOLATION METHODS FOR SEA SURFACE HEIGHT MAPPING FROM ALTIMETRY SATELLITES IN INDONESIAN SEAS

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Abstract. Altimetry satellite data, has a very low spatial resolution for using in determine fishing ground area. With very low spatial resolution is required interpolation method that can mapped Sea Surface Height (SSH) with a good result. SSH data from Global Near Real Time from AVISO, mapped in geographic projection and interpolated with Inverse Distance Weighting (IDW) and Ordinary Krigging method. This interpolation method are expected to know which the good method for mapped SSH data in resulting better information. The results of statistical calculation shows that RMSE value and standar deviations from kriging method is smaller than IDW method.

Keywords: *Spatial interpolation, Kriging, Inverse distance weighting, Sea surface height, Altimetry*

1 INTRODUCTION

Indonesia is one of the countries that have very extensive marine waters, where 62% of the total area is ocean. By having a very extensive ocean, Indonesia has a very rich fishery commodities. Many research has been done on the determination of fishing ground areas, one of them by using a parameter Sea Surface Height (SSH) as has been done by Kanno (2006) and Wei (2009). In addition, sea surface height as a important parameter to study the ocean and atmosphere dynamic phenomenas, such as El Nino, La Nina, Indian ocean Dipole, etc. (Picaut *et al.*, 2002; Lee and Le Traon, 2006).

Sea Surface Height (SSH) is the height of the ocean's surface. On a daily basis, SSH is most obviously affected by the tidal forces of the moon and the sun acting on the Earth (Lee and Cazenave, 2001; Lindsley, 2013). Variations in SSH can be measured by satellite altimetry e.g Topex/Poseidon, Jason-1, Jason-2 (OSTM), Cryosat etc. Sea surface heights are calculated at defined 'reference points' along the track (e.g. incremental values of latitude) by interpolation between the original 1-second altimeter measurements. The orbit of an altimeter satellite is repeated at regular intervals (e.g. 9.9156 ~ 10 days, in the case of TOPEX/Poseidon and Jason-1 and -2). Altimeter data can be obtained freely from several agencies, such as AVISO (www.aviso.oceanobs.com), NASA PO.DAAC (podaac.jpl.nasa.gov), RADS (rads.tudelft.nl/rads), University of Colorado Sea Level Research Group (sealevel.colorado.edu) and CSIRO (www. cmar.csiro.au/sealevel). Altimeter data products are devoted to scientific applications and non-commercial use, and it was distributed in gridded product, provided in near-real time and in delayed time (AVISO, 2014). One spatial resolution is available: 0.25° x 0.25° on a Cartesian grid. Spatially, this resolution of SSH gridded data is considered insufficient to describe the sea surface height in internal seas (e.g. Indonesian Archipelagic waters).

Spatial analysis can be applied to gridded data in order to obtain more detail the spatial information of SSH (Myers, 1991; Li and Heap, 2014). Spatial analysis is the process of manipulating spatial information to extract new information and meaning from the original data (Mitas and Mitasova, 1999). Usually spatial analysis is carried out with a Geographic Information System (GIS). A GIS usually provides spatial analysis tools for calculating feature statistics and carrying out geoprocessing activities as data interpolation.

Interpolation is a method of constructing new data points within the range of a discrete set of known data points. The spatial interpolation methods, including geostatistics, have been developed for and applied to various disciplines (Li and Heap, 2008). There are many methods of interpolating randomly spaced point data. Some of these method are global while others are local. Global methods utilize all the known values to evaluate an unknown value, while in local methods only a specified number of nearest neighbours are used to evaluate an unknown value.

A very basic problem in spatial analysis is interpolating a spatialy continuous variable from point samples. Three commonly used interpolation methods to model spatially distribution from point data are Inverse Distance Weighting (IDW), spline and ordinary kriging. Different methods will results different output. In this research, the writer used Ordinary Krigging method and Inverse Distance Weighted (IDW) (Dug and Nusret, 2012; Setianto and Triandini, 2013; Shahbeik *et al.*, 2013; Mueller *et al.*, 2004). Inverse Distance Weighted method can be grouped in a deterministic estimate which is based on the calculation of mathematical interpolation. Kringing method can be classified into stochastic estimation where the statistical calculation performed to generate interpolation, Pramono (2008).

In determining the potential fishing ground, besides SSH parameters, can also use of Sea Surface Temperature and Choloril-a from remote sensing satellite data such as NOAA AVHRR and Terra/ Aqua MODIS. Spatial resolution of NOAA AVHRR and Terra/Aqua MODIS is 1 km. By combining the data SSH, SST and Chl-a in determining the potential fishing zones will generate information that has more value. By applying the best fit interpolation method, attempted to produce a spatial resolution of the data in more detail so that SSH can be used or integrated with remote sensing data (Sandwell, 1987; Fieguth *et al.*, 1998; Wilkin *et al.*, 2002; Kuragano And Kamachi, 2003).

The objective of this study is to determine optimum interpolation method for changing the size of the spatial resolution of satellite altimetry data is to be used or integrated in remote sensing data in the determination of potential fishing ground.

2 MATERIALS AND METHODS

2.1 Location and Data

Data used in this study is global near real time Sea Surface Height from AVISO with spatial resolution 0.25 degree. There are four data that is 23th August 22nd, 23th, 24th, 25th 2013.

These maps show a daily sample of the along-track near-real-time (NRT) sea surface height (SSH) measurements from Jason-2 satellite altimeter mission. The seasonal cycle and trend have not been removed. Each map is generated from a 10-day window of SSHA measurements. The NRT SSHA measurements from these missions are typically available within 5 to 7 hours of real time. These measurements can be used for meteorological applications (i.e. weather), marine operations (i.e. fishing, boating, offshore operations), and other applications where knowledge of current ocean conditions are relevant.

2.2 Methods

The IDW is simple and intuitive deterministic interpolation method based on principle that sample values closer to the prediction location have more influence on prediction value than sample values farther apart (NCGIA, 1997). Using higher power assigns more weight to closer points resulting in less smoother surface. On the other hand, lower power assigns low weight to closer points resulting in smoother surface. (Anderson, 2008). The equation used is as follows:

$$F(x,y) = \sum_{i=0}^{n} w_i f_i \quad (2\text{-}1)$$

where n is the number of scatter points in the set, f_i are the prescribed function values at the scatter points (e.g. the data set values), and w_i are the weight functions assigned to each scatter point. IDW is referred to as deterministic interpolation methods because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. A second family of interpolation methods consists of geostatistical methods, such as kriging, which are based on statistical models that include autocorrelation—that is, the statistical relationships among the measured points. Because of this, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions.

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process, it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. Krigging interpolation method are described in a large body of literature with reviews by Ripley (1981), Lam (1983), Webster (1984), Burrough (1986), McBratney and Webster (1986), Oliver and Webster (1990), Kleijnen and van Beers (2005), Hengla *et al.*, (2007).

Unlike IDW, kriging is method based on spatial autocorrelation. It uses semivariogram. Kriging was developed in the 1960s by the French mathematician Georges Matheron. The motivating application was to estimate gold deposited in a rock from a few random core samples. Kriging has since found its way into the earth sciences and other disciplines. An estimate of the weighted average given by the ordinary Kriging predictor at an unsampled site $Z(s_0)$ is defined by:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \quad (2\text{-}2)$$

The first step in ordinary kriging is to construct a variogram from the scatter point set to be interpolated. A variogram consists of two parts: an experimental variogram and a model variogram. Suppose that the value to be interpolated is referred to as *f*. The experimental variogram is found by calculating the variance of each point in the set with respect to each of the other points and plotting the variances versus distance (*h*) between the points. Several formulas can be used to compute the variance, but it is typically computed as one half the difference in *f* squared (Aquavco, 2013).

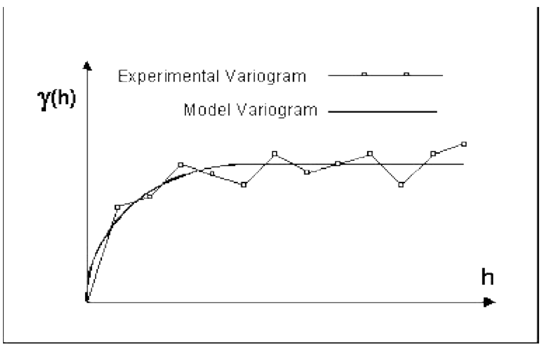


Figure 2-1: Experimental and Model Variogram Used in Kriging

Once the experimental variogram is computed, the next step is to define a model variogram. A model variogram is a simple mathematical function that models the trend in the experimental variogram. As can be seen in the above figure, the shape of the variogram indicates that at small separation distances, the variance in f is small. In other words, points that are close together have similar f values. After a certain level of separation, the variance in the f values becomes somewhat random and the model variogram flattens out to a value corresponding to the average variance. Once the model variogram is constructed, it is used to compute the weights used in kriging. The basic equation used in ordinary kriging is essentially the same as the equation used for inverse distance weighted interpolation (equation 1) except that rather than using weights based on an arbitrary function of distance, the weights used in kriging are based on the model variogram (Aquavco, 2013). The following steps are performed of this research shown in Figure 2.

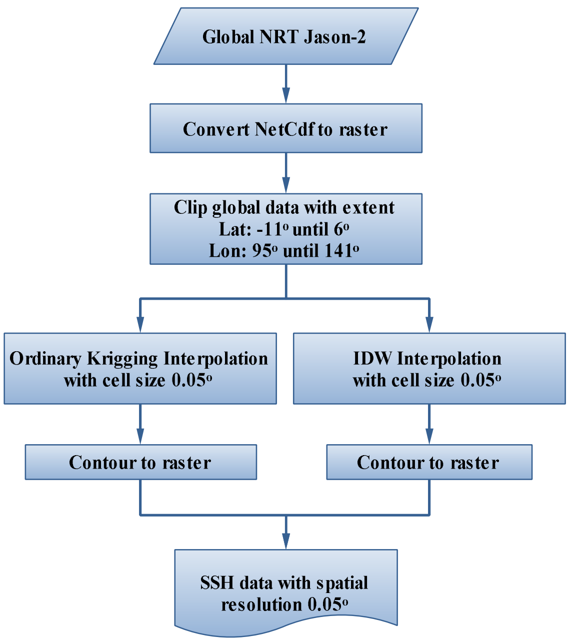


Figure 2-2: Flowcart of the process

Stages of processing based on the flow diagram in Figure 2-2, were designed and developed using the Python programming language. Global data NRT Jason-2 has the netCDF data format and to visualize the image of SSH should be done netCDF data format conversion into standard raster data formats such as GeoTIFF, IMAGE, DAT, etc. In this study using GeoTIFF data format. Reprojection and data format conversion process is a combination stages of processing, in which the image coordinate data that has a variable name Longitude and Latitude in the netCDF file is projected on the terms of corresponding the number of rows and columns. The results of the projected SSH data, do image croping or subset based Indoneian Seas, that is -11º until 6º Latitude and 95º until 141º Longitude. The final stage of the process is the interpolation processing with improved spatial resolution becomes 0.05 degrees (5 km).

3 RESULTS AND DISCUSSION

3.1 Interpolation Methods Application

Interpolation results, if compared in raster form will show differences data value spread in several areas. In figure 3-1 shows data from 22nd August 2013 before interpolation processing with spatial size 0.25 degrees. In figure 3-2 (from kriging interpolation) and figure 3-3 (from IDW interpolation) show raster data after interpolation process. The difference of figure 3-1 (before) with figure 3-2 and 3-3 (after), in the red box, showed that kriging method results arc darker and wider spread than IDW method result.

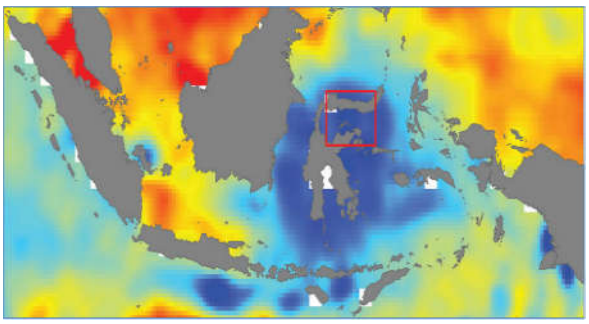


Figure 3-1: Grid data from august 22nd 2013 before interpolation

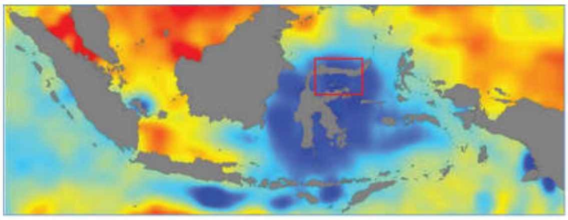


Figure 3-2: Grid data from august 22nd 2013 after kriging interpolation

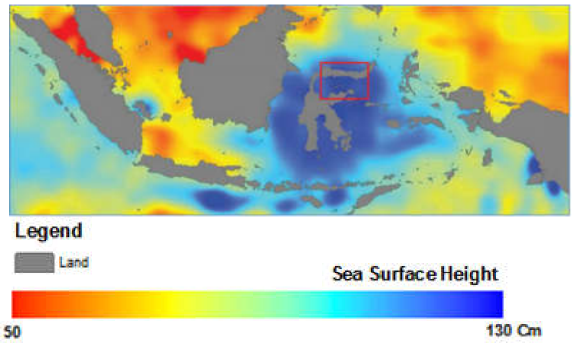


Figure 3-3: Grid data from august 22nd 2013 after IDW interpolation

3.2 Interpolatioin Method Analysis for Indonesia Seas

Result from this research is data processing from 22nd August 2013 until 25th August 2013 output contour data from IDW and kriging interpolation processing. Results from interpolation processing, contour data, converted to raster data format with spatial size 0.05 degree to be used in the next step that is determining fishing ground area.

Kriging method gives output result more variety value compared with IDW method gives. 22nd August 2013 data (figure 3-4), in several areas show difference value of interpolation result, for example in figure that showed in the red box. In kriging method, range value wider than IDW. It affected to last data after converted to raster form.

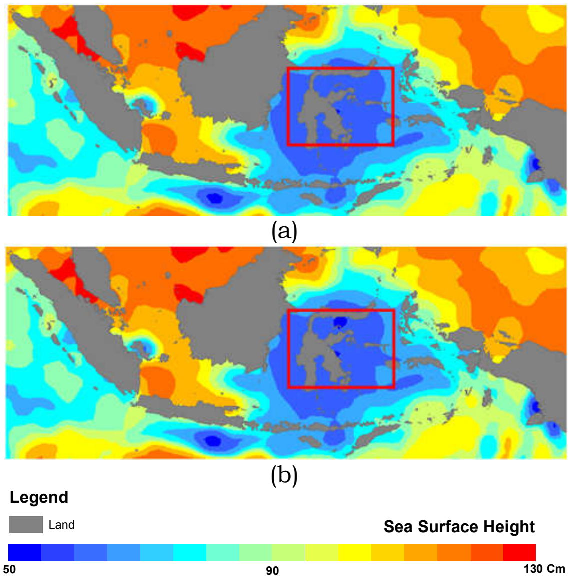
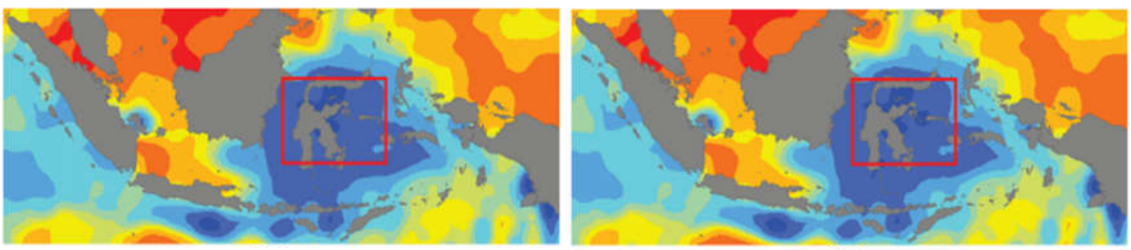


Figure 3-4: Interpolation results from date 22 August 2013, (a) IDW (b) Ordinary Krigging

From a data of interpolation processing result, can defined several differences that given. In figure 3-5, 3-6, 3-7 are result contour from next data interpolation, which is the difference between kriging method and TDW method processing result will showed in the box.

Besides of the globally visual and data spread differences, Figure 3-8 is data subset that shows edge roughness in range data value with others. Figure that showed in the red box, kriging interpolation result show smoother than IDW interpolation result. It means that value spread (arrow direction) in a value range of kriging method is smoother, and IDW method has more variety value.



(a) (b)

Figure 3-5: Interpolation results from August 23th 2013, a. IDW; b. Ordinary Krigging

From each interpolation processing, table 3-1 (IDW method) and 3-2 (Kriging method) are statistic value of processing result that has done. Mean value and RMSE are results from interpolation processing, and deviation standard is from interpolation processing raster data. Kriging method results RMSE for each data under 0.5, meanwhile IDW method upper 0.5. In table 3-1, average of mean value and RMSE is -0.01588 and 0.668775. From RMSE value average showed that IDW method has not too big value even smaller than 1.

Meanwhile Table 3-2 (kriging interpolation) mean average value and RMSE is 0.000502 and 0.298275. As mentioned before, also from average result the kriging method gives RMSE value smaller than IDW, even almost 0.

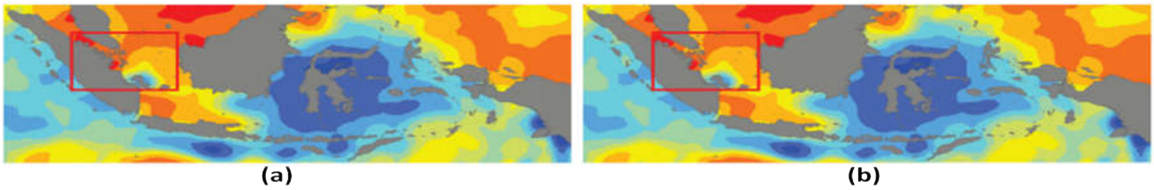


Figure 3-6: Interpolation results from August 24th 2013, a. IDW; b. Ordinary Krigging

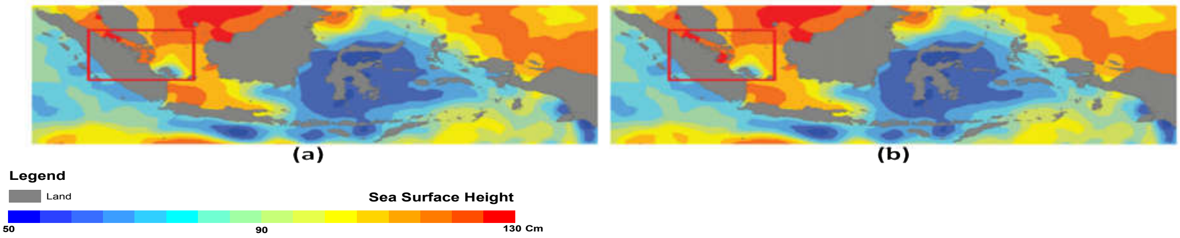


Figure 3-7: Interpolation results from August 25th 2013, a. IDW; b. Ordinary Krigging

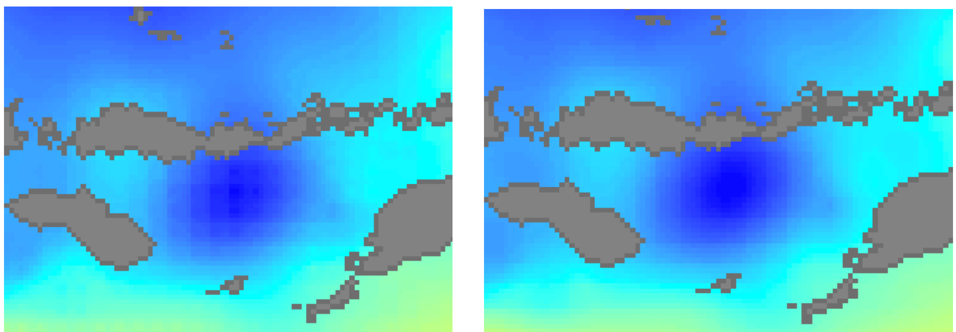


Figure 3-8: Interpolation roughness from IDW (left) and Ordinary Krigging (right)

Table 3-1: Statistic results from Inverse Distance Weight (IDW)

Date of data	Samples	Mean	RMSE	Std. deviation on raster
22 Aug 2013	11492	-0.01491	0.667	12.39
23 Aug 2013	11492	-0.0156	0.6684	12.60
24 Aug 2013	11492	-0.01652	0.6743	12.77
25 Aug 2013	11492	-0.0165	0.6654	12.75

Table 3-2: Statistic results from Ordinary Kriging

Date of data	Samples	Mean	RMSE	Std. deviation on raster
22 Aug 2013	11492	0.0004824	0.2959	12.21
23 Aug 2013	11492	0.0005042	0.2956	12.41
24 Aug 2013	11492	0.0005292	0.3021	12.57
25 Aug 2013	11492	0.0004904	0.2995	12.56

4 CONCLUSION

The conclusions can be drawn from this research is the optimum interpolation method that can be used to change the cell size spatial resolution of the SSH data is Ordinary kriging. RMSE value and standar deviations kriging method is smaller than IDW method, this is the basis for the process interpolation SSH data to generate new data with increased spatial size and have more value. By using Ordinary kriging, features adjacent or complementary value will look more smooth than using IDW so that SSH can be displayed with a value that is more detailed and varied.

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REFERENCES

Aquaveo, (2013), Ordinary Krigging. URL: http://www.emsi.com/gmshelp/Interpolation/Interpolation_Schemes/Kriging/Ordinary_Kriging.htm (accessed on September 20th 2013).

Aquaveo, 2013, Inverse Distance Weighted Interpolation. URL: http://www.emsi.com/ gmshelp/ Interpolation/ Interpolation_ Schemes/Inverse_Distance_Weighted/Inverse_Distance_Weighted_Interpolation.htm (accessed on 20th September 2013).

AVISO, (2014), Sea Surface Height Product: Product Access, Available Global Product. Accessed on 2nd Januari 2014. URL: http://www.aviso.altimetry.fr/en/data/ products/sea-surface-height-products/global/ msla-uv.html.

Burrough PA, (1986), Principles of Geographical Information Systems for Land Resources Assessment. Oxford: Clarendon Press.

Fan W., Wu Y., Cui X., (2009), The Study On Fishing Ground Of Neon Flying Squid, Ommastrephes Bartrami, And Ocean Environment Based On Remote Sensing Data In The Northwest Pacific Ocean. Chinese Journal of Oceanology and Limnology 27:408-414.

Fieguth P., Menemenlis D., Ho T., Willsky A., Wunsch C., (1998), Mapping Mediterranean Altimeter Data with a Multiresolution Optimal Interpolation Algorithm. Journal of Atmospheric and Oceanictechnology 15: 535-546.

Hengla T., Heuvelinkb GBM, Rossiter DG, (2007), About Regression Kriging: From Equations To Case Studies. Computers And Geosciences. Elsevier 33: 1301–1315.

Kanno S., Furushima Y., Nuarsa IW., Swardika IK, Ono A., (2006), Estimation of Tuna Fishing Ground In Low Latitude Region Using Sea Surface Height Gradient Derived From Satellite Altimetry: Application to Northeastern Indian Ocean. International Journal of Remote Sensing and Earth Sciences (IJReSES) 3:85-93.

Kleijnen PC, Van Beers CM, (2005), Robustness Of Kriging When Interpolating In Random Simulation With Heterogeneous Variances: Some Experiments. European Journal of Operational Research 165: 826–834.

Knotters M., Brus DJ, Oude Voshaar JH, (1995), A Comparison Of Kriging, Co-Kriging And Kriging Combined With Regression For Spatial Interpolation Of Horizon Depth With Censored Observations. Geoderma 67:227-246.

Kuragano T., Kamachi M., (2003), Altimeter's Capability of Reconstructing Realistic Eddy Fields Using Space-Time Optimum Interpolation. Journal of Oceanography 59:765-781.

Lam NS, (1983), Spatial Interpolation Methods: A Review. American Cartographer. 10(2):129-150.

Le ND, Zidek JV, (1992), Interpolation with Uncertain Spatial Covariances: A Bayesian Alternative to Kriging. Journal Of Multivariate Analysis 43: 351-374.

Lee LF, Cazenave A., (2001), Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications. International Geophysic Series Vol.69. Academic Press. ISBN: 0-12-269545-3. San Diego, California, USA.

Lee LF, Le Traon PY, (2006), Satellite Altimetry And Ocean Dynamics. C. R. Geoscience. Elsevier. 338:1063–1076. doi: 10.1016/j. crte. 2006. 05.015.

Li J, Heap AD, (2008), A Review of Spatial Interpolation Methods for Environmental Scientists. Geoscience Australia Record 2008/23. Canberra, Australia. ISBN 978 1 921498 28 2.

Li J., Heap AD, (2014), Spatial Interpolation Methods Applied In The Environmental Sciences: A Review. Environmental Modelling and Software 53:173-189.

Lindsley RD, (2013), Fitting Tidal Constituents to Altimeter Data. URL:http://digitalcommons. usu.edu/cgi/viewcontent.cgi?article=1070 &context=spacegrant (accessed on September 20th 2013).

McBratney AB, Webster R., (1986), Choosing Functions for Semivariograms of Soil Properties and Fitting Them to Sampling Estimates. Journal of Soil Science. 37: 617- 639.

Mitas L., Mitasova H., (1999), Spatial Interpolation. In: P.Longley, M.F. Goodchild, D.J. Maguire, D.W.Rhind (Eds.), Geographical Information Systems: Principles, Techniques, Management and Applications, Wiley.

Mueller TG, Pusuluri NB, Mathias KK, Cornelius PL, Barnhisel RI, Shearer SA, (2004), Map Quality for Ordinary Kriging and Inverse Distance Weighted Interpolation. Soil Science Society of America Journal 68:2042–2047.

Myers DE, (1991), Interpolation And Estimation With Spatially Located Data. Chemometrics and Intelligent Luboratoty Systems 11: 209-228.

NCGIA, (2007), Interpolation: Inverse Distance Weighting.URL:http://www.ncgia.ucsb.edu/ pubs/ spherekit/inverse.html (accessed on June 23th 2008).

Nusreta D., Đugb D., (2012), Applying The Inverse Distance Weighting And Kriging Methods Of The Spatial Interpolation On The Mapping The Annual Precipitation In Bosnia And Herzegovina. International Congress on Environmental Modelling and Software.

Oliver MA, Webster R., (1990), Kriging: A Method Of Interpolation For Geographical Information Systems. International Journal Of Geographical Information Systems. 4(3):313-332.

Picaut J., Hackert E., Busalacchi AJ, Murtugudde R., Lagerloef GS, (2002), Mechanisms of the 1997–1998 El Niño–La Niña, As Inferred From Space-Based Observations. Journal Geophysic Resource. 107.doi:10.1029/2001 JC 000850.

Pramono GH, (2008), Akurasi Metode IDW dan Kriging untuk Interpolasi Sebaran Sedimen Tersuspensi di Maros Sulawesi Selatan. Forum Geografi 22: 145-158.

Ripley B., (1981), Spatial Statistics. New York: Wiley.

Sandwell DT, (1987), Biharmonic Spline Interpolation of GEOS-3 And Seasat Altimetri Data. Geophysical Research Letters 14(2): 139-142.

Setianto A., Triandini T., (2013), Comparison of Kriging And Inverse Distance Weighted (IDW) Interpolation Methods in Lineament Extraction And Analysis. Journal SE Asian Applied Geology 5(1): 21–29.

Shahbeik S., Afzal P., Moarefvand P., Qumarsy M., (2013), Comparison Between Ordinary Kriging (OK) And Inverse Distance Weighted (IDW) Based On Estimation Error. Case Study: Dardevey Iron Ore Deposit, NE Iran. Arab Journal Geoscience 7(9):3693–3704.DOI10.1007/s1251701309 78-2.

Webster R., (1984), Elucidation and Characterization Of Spatial Variation In Soil Using Regionalized Variable Theory. In Geostatisticsfor Natural Resources Characterization, Part II. 903-913.

Wilkin JL, Bowen MM, Emery WJ, (2002), Mapping Mesoscale Currents By Optimal Interpolation Of Satellite Radiometer And Altimeter Data. Ocean Dynamics 52(3):95-103 DOI 10.1007/s10236-001-0011-2.