Journal of Marine Technology and Environment
DOI:10.53464/JMTE.01.2024.09
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

EVALUATION OF DIFFERENT INTERPOLATION METHODS VIA ArcGIS, APPLIED TO SATELLITE DATA OF SEA SURFACE TEMPERATURE SST, CASE OF THE ALBORAN SEA

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Abstract: In various fields such as Oceanography, interpolation methods are pivotal in generating continuous surface data from discrete point data. This research endeavors to conduct a comprehensive comparison and evaluation of deterministic interpolation techniques, including Radial Basis Function (RBF), Inverse Distance Weighting (IDW), and geostatistical methods like Kriging Universal (KU) and Kriging Ordinary (KO), in the context of mapping sea surface temperature (SST) within the Alboran Sea.

Among these methods, the KO interpolation method emerges as particularly promising, boasting a Root Mean Square Error (RMSE) of 0.035 and an impressive coefficient of determination (R^2) approaching unity (0.999). Furthermore, the cross-validation results reveal that the KO method not only provides the most accurate estimates but exhibits minimal bias, as evidenced by a mean error close to zero. These findings not only contribute to the field of SST mapping but also have broader implications for the interpolation of other climate parameters.
Key words: Sea surface temperature (SST), IDW, Kriging Ordinary (KO), Kriging Universal (KU), Radial Basis Function (RBF), Alboran Sea.

1. INTRODUCTION

Sea surface temperature (SST) is a physical and oceanographic parameter that has been studied and observed for a long time. Knowledge of this parameter is fundamental for oceanographers, meteorologists, and climatologists, as it is one of the results of the exchange of heat between the ocean and the atmosphere. The need for mapping in the daily lives of decision-makers has led to the emergence of Geographic Information Systems (GIS). The objective of GIS is to produce geographical data, process the geo-located information to visualise maps, and make decisions.

Spatial modelling techniques have developed considerably in recent years, thanks to the evolution of computer science. On one side, geostatistical processing software has been enhanced with simplified tools for geographic representation and, more recently, with import/export functions to communicate with GIS software, on the other side, GIS software has integrated spatial modelling tools through specialised extensions. Remote sensing has been used as an advantageous tool to improve knowledge of oceanographic aspects.

Spatial interpolation plays an important role in oceanographic data to create spatially continuous surface data. Interpolation methods are many and vary greatly in complexity and effectiveness [1]. Among the techniques that seem to be most frequently used in practice are the barycentric inverse distance methods (IDW) and classical kriging techniques such as ordinary kriging [2]. In this respect, we take as an example the interpolation of SST data in the Alboran Sea. The aim is to apply the four known and most commonly used methods, namely inverse distance weighting (IDW), kriging ordinary (KO), kriging universal (KU), and radial basis function (RBF).

The four methods have been exploited and compared to show the best spatial interpolation performances to present the SST data of the Alboran Sea, and to obtain these models, we used as GIS software the famous ArcGIS software. Commonly used methods, namely Inverse Distance Weighting (IDW), Kriging Ordinary (KO), Kriging Universal (KU), and Radial Basis Function (RBF). The four methods have been exploited and compared to show the best spatial interpolation performances in order to present the SST

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2. AREA OF APPLICATION

With a mean depth of 445 m and maximum depth of 1500 m, Alboran Sea , which fills the westernmost part of the Algerian-Provençal Basin (Sea-Mediterranean), is a very special maritime space. It is the entrance and exit of the Mediterranean Sea and the point of contact between the two continents, Africa and Europe (Figure 1).[3] The Strait of Gibraltar bounds this area to the west, the Iberian Peninsula to the North, and the Maghreb to the South. The sea is also an ecoregion designated by the World Wide Fund for Nature (WWF). It takes its name from the islet of Alboran, located halfway between the cities of Almeria and Melilla. Many commercial and passenger ports are located on both sides of this sea.

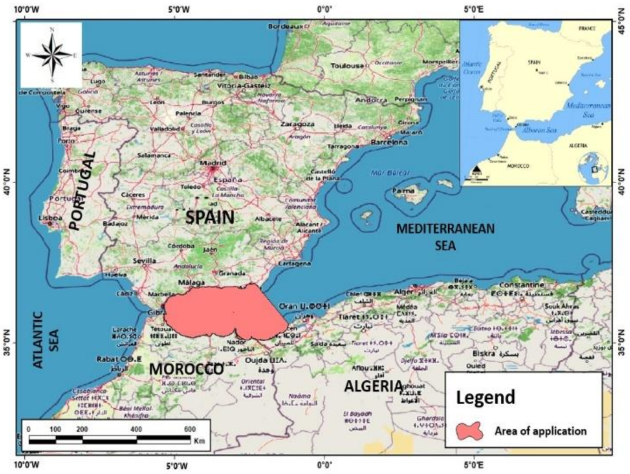

Figure 1 The geographical location of the study area

It is a highly dynamic area of the basin with marked mesoscale variability [3]. This region is characterised by two large anticyclonic gyres [4]; [5].

3. METHODOLOGY

3.1 Overview of interpolation methods

Interpolation is a mathematical process of predicting the values of unknown locations based on surrounding measured values [6]. Interpolation requires two basic assumptions about the surface: that the surface is continuous and smooth, and that the neighbouring data points have a strong correlation with the unknown area [7].

There are different interpolation techniques for creating surfaces, including IDW, spline, TIN, natural neighbour, and kriging, all of which can create different DTMs of surfaces even when constructed from the same data sources [8].

3.2 Inverse Distance Weighted (IDW)

As is obvious from the name of the interpolation technique, the weighting factor is inversely proportional to the distance [9].

Among the so-called deterministic interpolation methods is the inverse distance weighting method, which is often referred to in the literature by the acronym IDW (Inverse Distance Weighted). It is based on the principle that, for a given variable, the relative influence of an observation point decreases with the distance separating it from the point in space whose value is to be estimated [10]. The measurements of the surrounding observation points are averaged, with greater weight given to the closest points. The predicted value for a point in space is:

$$Z = \left[\sum_{i=1}^{N} \frac{Zi}{d_i^k}\right] \Big/ \left[\sum_{i=1}^{N} \frac{1}{d_i^k}\right] \tag{1}$$

While:

Z : is the estimated variable.
Zi : is the known value at measurement point i.
N : is the number of sites used for the interpolation.
d : is the distance between the unknown value point and the measurement point i.
k : is the power to which the distance is raised.

3.3 Radial Basis Function (RBF)

The RBF interpolation is made more flexible than polynomial interpolation by using a voltage parameter that controls the behaviour of the interpolation function and the smoothing parameter [1]. It is an exact deterministic interpolation method that includes different basis functions depending on the distance between the interpolated point and the sample points. A radial basis function is a function of the form:

$$S(x) = p(x) + \sum_{i=1}^{n} \lambda_i \phi(\| x - x_i \|) \tag{2}$$

With:

S: is the radius basis function.
P : is a low-degree polynomial, usually linear.
λ_i: coefficient of RBF.
x_i: The center point of the RBF.
ϕ: is a real-valued function also called the basis function.

3.4 Kriging

Kriging is a stochastic spatial interpolation method that takes into account the spatial dependence structure of the data The mining engineer D.G. Krige [11] first proposed this method [12]. There are several kriging methods, among which we used in this study: kriging universal (KU) and kriging ordinary (KO).

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The kriging method uses the semi-variogram or variogram to assign weights to observation points during the spatial interpolation process. The semi-variogram ɣ (h) is expressed by the following formula:

$$\gamma(h) = \frac{\sum_{i=1}^{N(h)}[Z(x_i + h) - Z(x_i)]^2}{2N(h)} \quad (3)$$

With :

- Z is the variable to be interpolated.
- N(h) is the number of pairs of points xi where the value of this Z is known, separated by a distance h.

3.4.1 Kriging Ordinary (KO)

Kriging Ordinary (KO) is one of the three main types of kriging that has been adopted to improve on Kriging Simple (KS) and requires that the expectation of the random function Z (x) be known. It uses the fitted semi-variogram, a diagram relating the semi-variance to the distance between the samples points used in kriging. The KO estimator is given by the following equation [13]:

$$Z^*(x_0) = \sum_{i=1}^{n} \lambda_i \, Z(x_i) \quad (1)$$

Where : $z^*(x_0)$ is the estimated value at x_0, $z(x_i)$ is the measurement value at xi and λ_i is the weight assigned to the residual of $z(x_i)$ [13].

3.4.2 Kriging Universal (KU)

Like KU, kriging universal (UK) is also a main type of kriging. Hence the idea of universal kriging (trend kriging), where the local neighbourhood trend is modelled as a smoothly varying function [14]; [15].

3.5 Application data

In this study, we used a NetCDF file (Network Common Data Form); a file format that allows storing multidimensional scientific data in a compressible format in the form of arrays of numbers of daily SST data (Figure. 2), recorded between November 10 and November 26, 2020, in the Alboran Sea. These data were obtained via https://marine.copernicus.eu/access-data. The data processing was carried out by ArcGIS software in its version 10.4 with the "geostatistical analysis" extension.

ArcGIS was used to apply the four methods of interpolation of the SST data and to produce the different maps as well as the cross-validation.

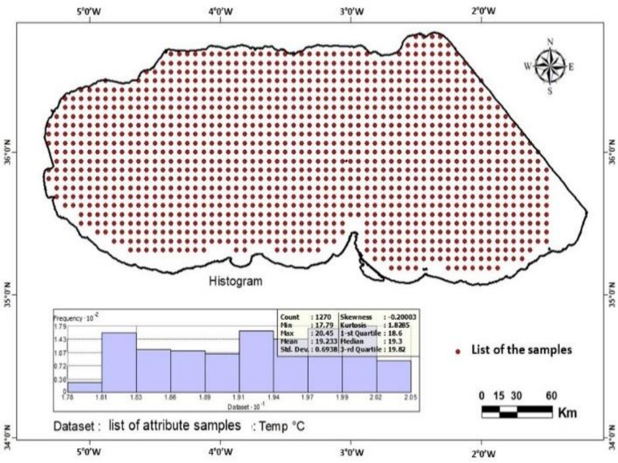

Figure 2 SST sample location map and frequency histogram.

3.6 Evaluation tests and cross-validation

In this step, we rely on the following statistical parameters to evaluate the quality of the interpolation methods:

✓ The Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z_{mne} - z_t)^2} \quad (2)$$

With: Z_{mne} is the predicted value at point i, Z_t is the observed value, and n is the number of validated points.

✓The coefficient of determination of the model R^2, whose value is between 0 and 1. The R^2 is interpreted as the proportion of the variability of the dependent variable explained by the model.

To confirm the results, the cross-validation technique was used, which compares the measured values with the interpolated values using only the information available in the sample data set.

3. RESULTS & DISCUSSION

The results of the statistical parameters obtained by the four interpolation methods are summarised in Table 1.

The RMSE values vary relatively widely, between 0.035 and 0.063 °C. The KO interpolation methods generally produce the lowest RMSE, while the IDW produces the highest. Intermediate MSE values are marked for both K.U and RBF interpolation methods (Table .1). The coefficient of determination of the model R^2 is a coefficient with a value between 0 and 1. For our study, all the interpolation methods have R^2 values very close to 1 (Table .1) but the value closest to 1 is that of the K.O method (R^2 = 0.999). However, based on the

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results of these parameters, the KO interpolation method is the best interpolation method for SST.

Table 1. Statistical description of the KO, KU, RBF, and IDW methods.

Interpolation method	Min	Max	Mean	RMSE	R^2
Kriging Ordinary	17.81	20.44	19.23	0.035	0.999
Kriging Universal	17.85	20.41	19.23	0.050	0.998
RBF	17.80	20.48	19.23	0.050	0.997
IDW	17.88	20.38	19.24	0.063	0.996

To confirm this result, we used the cross-validation technique (Fig.3).

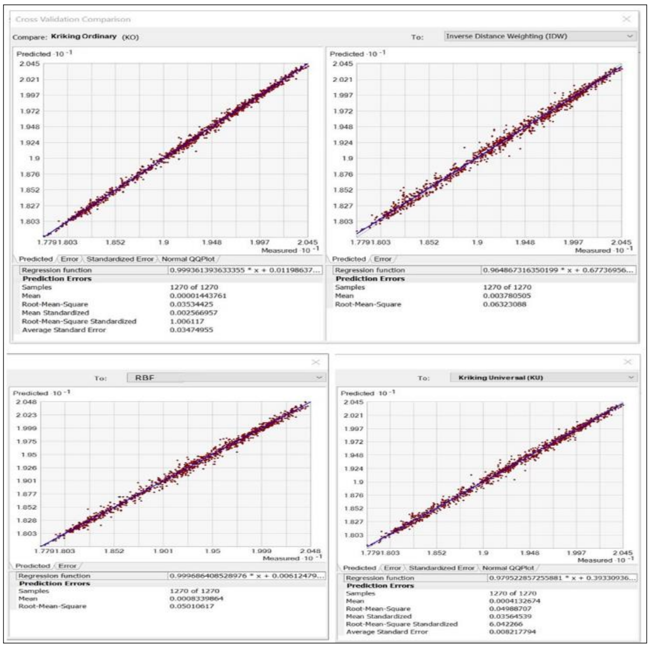

Figure 3 The comparison of the four interpolation methods KO, IDW, RBF, and KU by cross- validation.

The comparison of the two Kriging methods KO and KU, Figure 3 shows that the interpolation by the KU method presents us with a high value of the mean error (0.0004 °C) compared to the one obtained by the KO (0.00001 °C). As for the RMSE values, KO method has a lower value (0.035 °C) than the one obtained by KU (0.05 °C).

This reflects that the KO method is better than KU for interpolating SST. The slope of the linear regression is also a parameter to distinguish between the two methods. In fact, the KO method has a higher slope value (0.999) than the of KU method (0.979), thus corroborating the performance of the KO method compared to the KU method.

The comparison between the KO method and the RBF method is shown in (Figure .3). Again, the KO method shows a low value of the mean error (0.00001 °C) compared to that obtained by the RBF method (0.00083 °C). As for the RMSE, the value obtained by RBF (0.05 °C) is higher than that given by KO (0.035 °C). These results show that the KO method is more reliable and accurate than the RBF method and the slope of the linear regression for both methods shows that they are almost similar.

As for, the comparison of the KO method and the IDW method (Figure .3), it shows that the interpolation by the KO method has a low value of the mean error (0.00001 °C) compared to that given by the IDW (0.0037 °C). As for the RMSE value, the IDW method has a value almost twice as high (0.06 °C) as that obtained by the KO (0.035). This suggests that the KO method is more accurate than the IDW method. The slope of regression line of the KO method (0.999) is higher than that of IDW method (0.964).

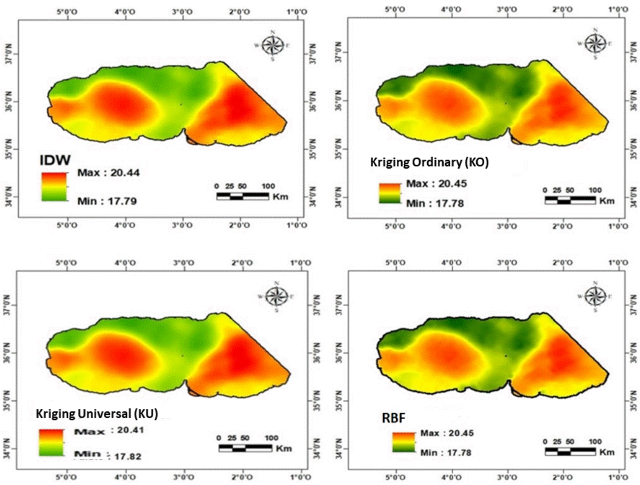

Figure 4 The SST maps obtained by the four interpolation methods IDW, KO, KU, and RBF.

The spatial distribution of the SST data obtained by the four interpolation methods showed that an area with low temperatures 17.78 to almost 19.25 °C, located in the centre of the application area, is interspersed between two areas with temperatures ranging from 19 to 20.45 °C Figure 4.

When discussing the four interpolation methods, it can be seen that the dispersion keeps more or less the same spatial distribution with all four methods. However, when looking at the average spatialization errors obtained, it can be seen that the three methods KU, RBF and IDW lead to larger overestimates than the KO method. Based on these results, it can be said that the KO interpolation is the most adequate method to predict SST than the KU, RBF and IDW methods.

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5. CONCLUSION

In conclusion, this research has undertaken a comprehensive evaluation of various interpolation methods applied to sea surface temperature (SST) data within the Alboran Sea. Through rigorous analysis, we have established that interpolation techniques, including the Radial Basis Function (RBF), Inverse Distance Weighting (IDW), and geostatistical methods such as Kriging Universal (KU) and Kriging Ordinary (KO), all hold promise for generating continuous surface data from discrete point data in oceanographic studies.

The findings of this study have unveiled noteworthy insights. While all methods exhibited similar performance metrics in terms of Root Mean Square Error (RMSE) and Pearson correlation, the Kriging Ordinary (KO) method emerged as the frontrunner. With an impressively low RMSE of 0.035 and a near-unity coefficient of determination (R^2), the KO method demonstrated its exceptional capability for SST interpolation. The Kriging Universal (KU) method, with an RMSE of 0.05 and an R^2 of approximately 0.998, followed closely in terms of accuracy. The Radial Basis Function (RBF) method and Inverse Distance Weighting (IDW) method exhibited intermediate to good performance, offering valuable alternatives.

These findings not only enhance the field of SST mapping but also offer valuable insights for a broader spectrum of climate-related studies, contributing to the advancement of scientific knowledge and practical applications in Oceanography and Meteorology.

6. REFERENCES

[1] Drapeau L., « Statistiques et Interpolations dans les SIG », *Towards the use of Geographic Information Systems as a Decision Support Tool for the Management of Mediterranean Fisheries. COPEMED, http://www. faocopemed. org/old copemed/vldocs/0000028/publi10. pd f*, (2000).

[2] Baillargeon S., « Le krigeage: revue de la théorie et application à l'interpolation spatiale de données de précipitations, mémoire présenté pour l'obtention du grade de Maître ès Sciences (M. Sc.) », *Université de Laval, Faculté des Sciences et de Génie, Québec, disponible en ligne à http://www. theses. ulaval. ca/2005/22636/22636. pdf*, (2005).

[3] Rogé M., « Etudes de cartographie altimétrique pour l'observation de la dynamique méso-échelle dans le contexte SWOT : application à la mer Méditerranée occidentale », phdthesis, Université Paul Sabatier - Toulouse III, 2018.

[4] Tintore J. et al., « A Study of an Intense Density Front in the Eastern Alboran Sea: The Almeria–Oran Front », *Journal of Physical Oceanography*, vol. 18, n° 10, (oct. 1988), p. 1384-1397. https://doi.org/10.1175/1520-0485(1988)018<1384:ASOAID>2.0.CO;2

[5] Arnone R. A. et al., « The origin and characteristics of the Algerian Current », *Journal of Geophysical Research: Oceans*, vol. 95, n° C2, (1990), p. 1587-1598. https://doi.org/10.1029/JC095iC02p01587

[6] Burrough P. A. et McDonnell R. A., « Principles of Geographical Information Systems Oxford: Oxford University Press », (1998).

[7] Liu X. et al., « LiDAR-derived high quality ground control information and DEM for image orthorectification », *GeoInformatica*, vol. 11, (2007), p. 37-53.

[8] Maune D. F. et al., « Introduction: Digital Elevation Models, Digital Elevation Model Technologies and Applications: The DEM Users Manual ». American Society for Photogrammetry and Remote Sensing, Maryland, 2007.

[9] Ashraf M. et al., « Application of geostatistics to evaluate partial weather station networks », *Agricultural and forest meteorology*, vol. 84, n° 3-4, (1997), p. 255-271.

[10] Bois B., « Cartographie agroclimatique à méso-échelle: méthodologie et application à la variabilité spatiale du climat en Gironde viticole. Conséquences pour le développement de la vigne et la maturation du raisin », PhD Thesis, Université Sciences et Technologies-Bordeaux I, 2007.

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ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

[11] Krige D. G., « A statistical analysis of some of the borehole values in the Orange Free State goldfield », *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 53, n° 3, (1952), p. 47-64.

[12] Ben Salah F., « Modélisation de la propagation des incertitudes des mesures sur l'aube d'une turbine hydraulique par Krigeage et simulations stochastiques », PhD Thesis, École de technologie supérieure, 2014.

[13] Sun Y. et al., « Comparison of interpolation methods for depth to groundwater and its temporal and spatial variations in the Minqin oasis of northwest China », *Environmental Modelling & Software*, vol. 24, n° 10, (2009), p. 1163-1170.

[14] Armstrong M., « The Theory of Kriging », in *Basic Linear Geostatistics*, Armstrong M. éd. Berlin, Heidelberg: Springer, 1998, p. 83-102. https://doi.org/10.1007/978-3-642-58727-6_7

[15] Matheron G., *Le krigeage universel*, vol. 1. École nationale supérieure des mines de Paris Paris, 1969.