

COMPARISON OF INTERPOLATION METHODS FOR SEA SURFACE TEMPERATURE DATA

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Abstrak

Metode Interpolasi pada umumnya digunakan untuk menghasilkan data permukaan dan mengisi data. Metode interpolasi yang banyak digunakan dalam pengolahan Suhu Permukaan Laut (SPL) adalah *Inverse Distance Weighted (IDW)*, *Kriging*, *Natural Neighbor Interpolation (NNI)*, dan *Spline*. Pada penelitian ini, empat metode interpolasi yang umum digunakan pada pengolahan SPL ditinjau dan dibandingkan untuk menemukan metode interpolasi yang baik untuk pengolahan SPL. Data yang digunakan adalah data *Argo Float* yang berupa titik SPL, dan data citra Aqua *MODIS (Moderate Resolution Imaging Spectroradiometer)* sebagai data pedoman atau pembanding. Metode penilaian yang digunakan adalah tampilan hasil dari interpolasi citra, perbandingan nilai maksimum dan minimum, perbandingan rerata, perbandingan *RMSE (Root Mean Square)* dan perbandingan *Standard Deviation Difference*. Hasil dari perbandingan tersebut menunjukkan bahwa metode interpolasi *IDW* merupakan metode yang cocok untuk melakukan interpolasi data SPL yang dihasilkan oleh *Argo float*.

Kata Kunci: Interpolasi, Suhu Permukaan Laut, *Inverse Distance Weighted*, *Kriging*, *Natural Neighbor Interpolation*, *Spline*

Abstract

Interpolation methods have been used in many applications to produce continuous surface data based on point data. The common interpolation methods for Sea Surface Temperature (SST) data are *Inverse Distance Weighted (IDW)*, *Kriging*, *Natural Neighbor Interpolation (NNI)*, and *Spline*. In this study, those four interpolation methods will be reviewed and compared to find the satisfactorily method. The *Argo float* data was chosen as SST point data and Aqua *MODIS image* as validation data. Each method will be reviewed and compared to Aqua *MODIS data* to find the best performance. The assessment for testing the best interpolation model are smooth performance, Maximum and Minimum comparison, mean comparison, Root Mean Square Error (RMSE) and Standard Deviation Difference. The result shows that *IDW* interpolation is the best way to make spatial interpolation for SST.

Keywords: Interpolation, Sea Surface Temperature, *Inverse Distance Weighted*, *Kriging*, *Natural Neighbor Interpolation*, *Spline*

INTRODUCTION

Sea Surface Temperature (SST) data provides a basis for many oceanographic and meteorological application. Most SST data is derived from infrared sensor in satellite observation [1]. In situ information about SST is provided by *Argo-float* data as point data. *Argo* observations in Indian Ocean are creating new insights from many different objects on ocean process, for example *Argo* is enabling a new understanding of upper ocean and temporal variability of High Salinity Water Mass (ASHSW). *Argo* also have been

used to examine buoyancy flux variation and their interaction. The combination of *Argo* and satellite observation used to find intense cooling of the sea surface at intraseasonal time scales in the southern tropical Indian Ocean during austral summer [2-4]. Spatial interpolation plays a significant role in oceanographic data to create spatially continuous surfaces data. Based on in situ data, logger, and *Argo* point data in separates sites, the values of an attribute at unsampled location needed to be estimated to generate

the spatially continuous data [5]. In this case, spatial interpolation methods provide a tool for estimating the variable value at unsampled site using data from in situ measurement. Spatial interpolation data are increasingly required for managing resources and conservation using Geographic Information System (GIS) and modelling techniques. Spatial interpolation data also used to generate continuous bathymetry map in river basin or ocean basin [6]. In this study, four common interpolation methods are reviewed and compared to show the best spatial interpolation performance to present SST data from Argos then compared to satellite imagery. The four common interpolation methods are Inverse Distance Weighted (IDW), Kriging, Natural Neighbor (NNI), and Spline. Monthly composite SST data of Aqua MODIS and monthly Argo sea surface temperature data from December 2015 – November 2016 were used in this study.

DATA AND METHOD

Monthly Argo sea surface temperature data in Indian Ocean southern part of Java, Bali, and Nusa Tenggara Island from December 2015 to November 2016 are collected and then interpolated by using four different interpolation methods to generate the unsampled sites. The interpolation process also downscales the Argo data from 1⁰ resolution into 4 km resolution similar with satellite image resolution. The first interpolation method is IDW, this method estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence or weight it has in the averaging process [7]. The IDW equation is shown below:

$$v_i = \frac{\sum_{j=1}^n \frac{1}{d_{ij}^p} v_j}{\sum_{j=1}^n \frac{1}{d_{ij}^p}}$$

Where:

V_i : Unknown Value

n :The Number of point taken to obtained the unknown value
 V_j :Known Value
 d_{ij} :Distance between unknown and known value
 p :power

Geostatistics in its original usage, referred to statistics of “earth” such as in geography and geology. Now geostatistics is widely used in many fields and comprises a branch of

spatial statistics. Originally in spatial statistic, geostatistics was synonymous with “kriging”, which is a statistical version interpolation [8]. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. More so than other interpolation methods, a thorough investigation of the spatial behavior of the phenomenon represented by the z-values should be done before you select the best estimation method for generating the output surface. Kriging states the statistical surface as a regionalized variable, with a certain degree of continuity [9]. The Kriging estimate is a linear combination of the weighted sample values, expected error equal zero and whose variance is a minimum [7]. This kriging is expressed in simple mathematical formula as in below:

$$Z(u) - m(u) = \sum_{\alpha=1}^{n(u)} \lambda_{\alpha} [Z(u_{\alpha}) - m(u_{\alpha})]$$

Where:

u, u_{α} :location vectors for estimation point and one of the neighboring data points, indexed by α

$n(u)$: number of data points in local neighborhood used for estimation of $Z(u)$

$m(u), m(u_{\alpha})$: expected values (means) of $Z(u)$ and $Z(u_{\alpha})$

$\lambda_{\alpha}(u)$: kriging weight assigned to datum $Z(u_{\alpha})$ for estimation location u ; same datum will receive different weight for different estimation location

Natural Neighbor Interpolation (NNI) finds the closest subset of input samples to a query

point and applies weights to them based on proportionate areas to interpolate a value [10]. It is also known as Sibson or "area-stealing" interpolation NNI takes the best of Thiessen polygons and triangulation and objectively chooses the number of neighbours from which to interpolate based on the geometry. The weights for each station are selected based on the proportional area rather than distance. NNI produces an interpolated surface that has a continuous slope at all points, except at the original input points. It is an exact interpolator in that it reproduces the observations at the station locations [11]. The basic equation of NNI is shown below:

$$G(x, y) = \sum_{i=1}^n w_i f(x_i, y_i)$$

Where:

- G(x,y) : Natural Neighbor Interpolation
- w_i : weight between nearest data
- f(X_i, y_i) : The known data

The spline tool uses an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points [9]. Spline is a deterministic method which seek to obtain the smoothest interpolated field consistent with the data [12]. Spline algorithm is shown below:

$$S(x, y) = T(x, y) + \sum_{j=1}^n \lambda_j R(r_j)$$

Where:

- n : Number of points

- λ_j : Coefficients found
- r_j : the distance from the point (x,y)

In performance test, 10 variances of comparative methods will be applied to compare the performance of spatial interpolation methods. Each variance of test will challenge the spatial methods like: 1) which spatial interpolation perform similar to image satellite, 2) what is the maximum and minimum of digital number for data interpolation, compared to satellite imagery, 3) which spatial interpolation methods show image smoothly. The comparison variable is shown in table 1 below.

RESULT

Monthly Argo sea surface temperature data were downloaded from Marine Atlas on regular grid 60 x 60 nautical miles square resolution in NetCDF format. Next step is processing spatial resolution of the Argo raster data similar with satellite image in 4 X 4 Km², the original data of Marine Atlas show in figure 1 below.

Inverse Distance Weight Interpolation Method

The IDW gave a consistent data shown in figure 2. in range between 0.5⁰C – 1⁰C below satellite data but IDW have poor performance in several months like in July – December. This is because the data are unevenly distributed or sparse, and also IDW result is not exactly accurate because the weight assigned to points will be influenced by neighboring points when the Argo data are more clustered, and for the result of IDW interpolation shown in figure 3.

Table 1. Comparison Variable

Variable	IDW	Kriging	NNI	Spline	Image Satellite
Smooth Performance	√	√	√	√	√
Minimum and Maximum data	√	√	√	√	√
Mean of digital number data	√	√	√	√	√
Correlation test (r test)	√	√	√	√	√
Standard deviation difference (St Dev Difference)	√	√	√	√	√
Root Mean Square Error (RMSE)	√	√	√	√	√

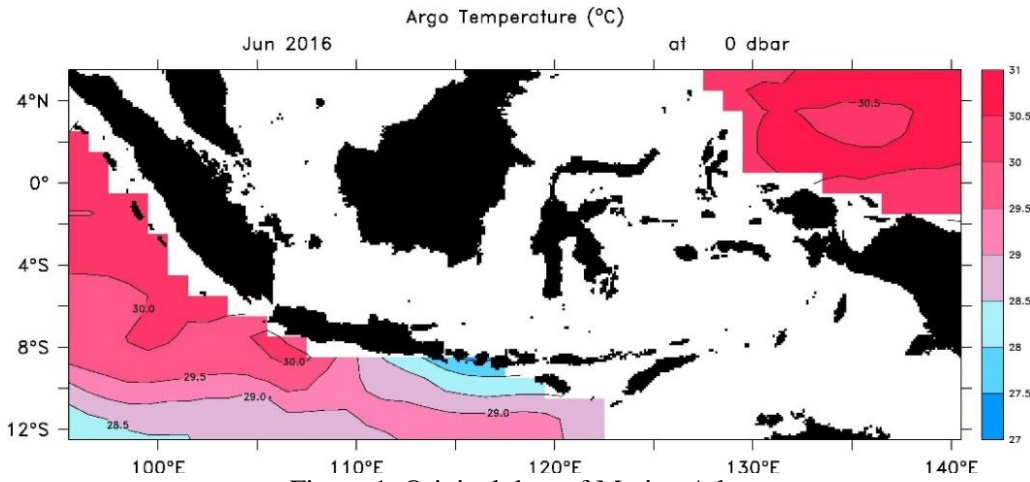


Figure 1. Original data of Marine Atlas

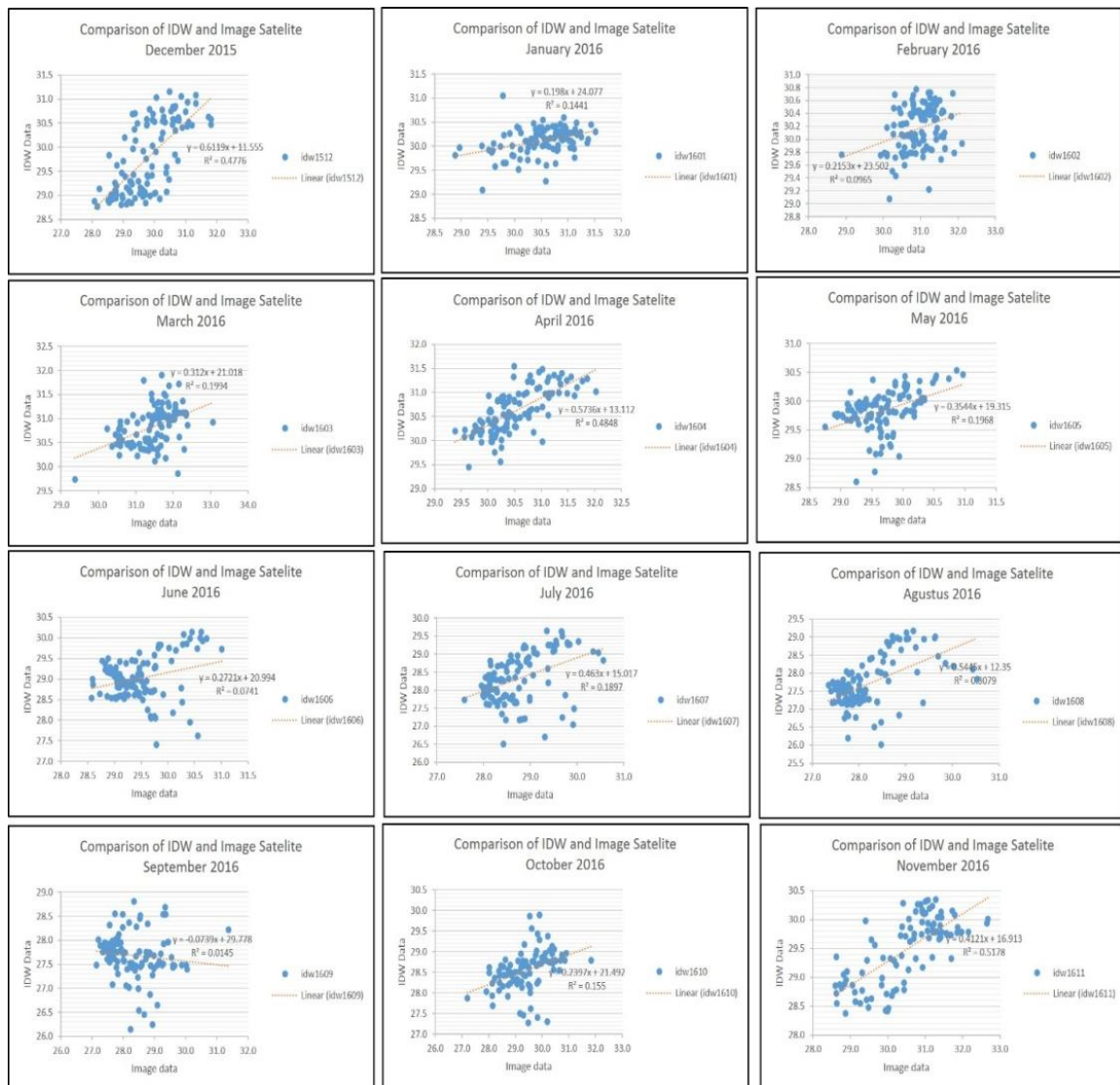


Figure 2. IDW scatter plot

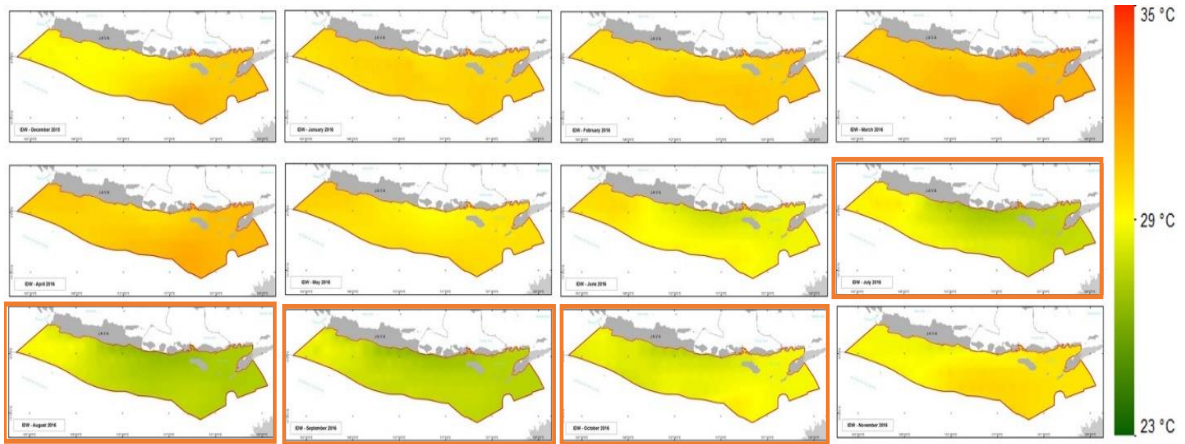


Figure 3. IDW results, orange boxes show poor visual performance

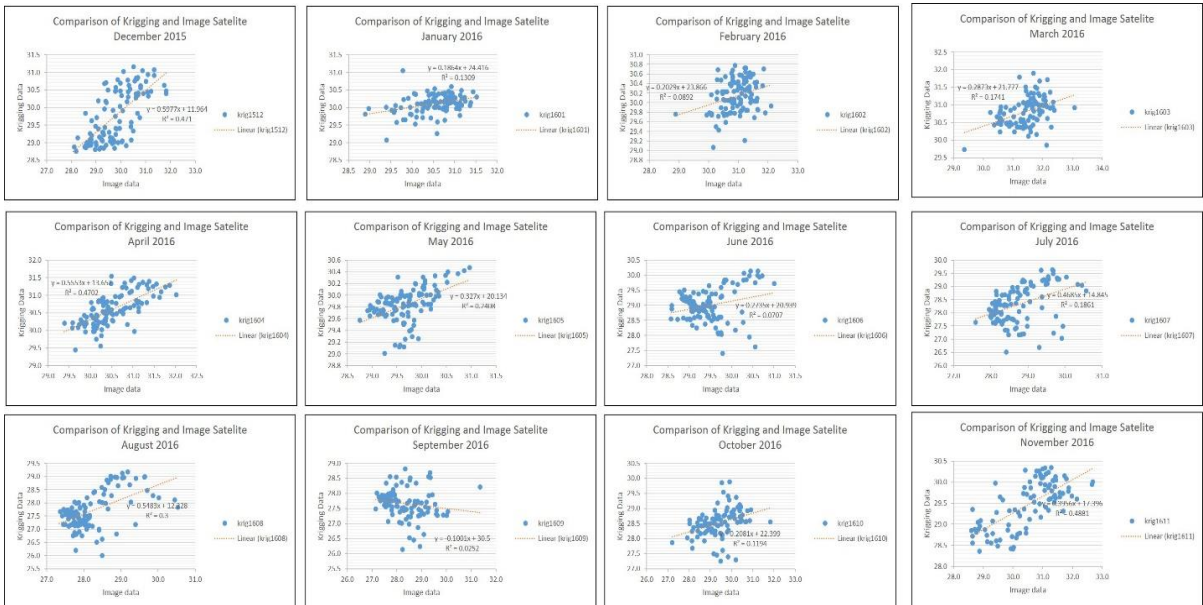


Figure 4. Kriging scatter plot

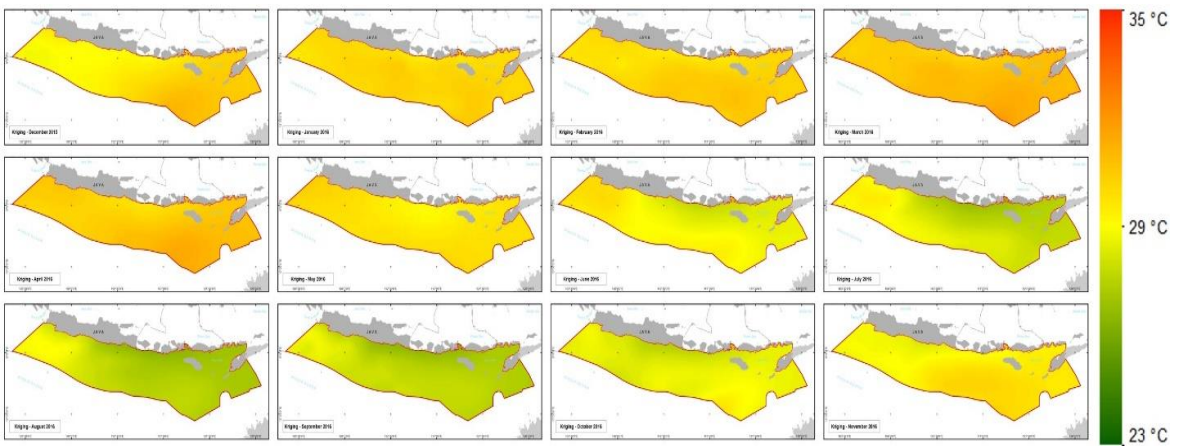


Figure 5. Kriging results

Kriging

The SST surface estimated by Kriging interpolation provides smoother pattern and good performance compared with IDW interpolation. The correlation is also higher, because kriging examines specific sample points to obtain value for spatial autocorrelation that is only used for estimating around particular point, rather than assigning a universal distance power value [13].

Natural Neighbor Interpolation (NNI)

The NNI interpolation generally works in clustered scatter points, this interpolation used identical basic equation in IDW interpolation used, but NNI can efficiently handle large input point data set. In comparison with IDW and Kriging, the NNI shows smoother performance and more consistent data show in figure 6 and figure 7 for result.

Spline

The spline interpolation shows a smooth performance except in August – October, but spline good interpolated SST is beyond the original data range show in figure 8, which means the SST were smoothed and hence underestimate show in figure 9.

Comparison Assessment

In this paper, six comparison assessment methods are applied. The first method is smooth performance (SP) by using 5 score which are 1=very bad, 2=bad, 3=intermediate, 4=good, 5=very good. This performance test is used to see the surfaces roughness for each interpolation. The second assessment is the minimum and maximum value of interpolation result compared to image satellite. It aims to see how close the interpolation data compared with the real data. The third assessment test is the mean value, similar with the maximum and minimum value, the assessment is aimed to examine how close the interpolation method compares with image form satellite. The fourth assessment is using Root Mean Square Error (RMSE) test to see how much the differences between SST resulted from interpolation methods and satellite imagery. The fifth method is Pearson Correlation test to see the correlation between interpolation and satellite image value, then the sixth is Standard Deviation Difference (STDev) to assess the closest standard deviation of interpolation method to satellite image. The assessment result is shown in table 2 below:

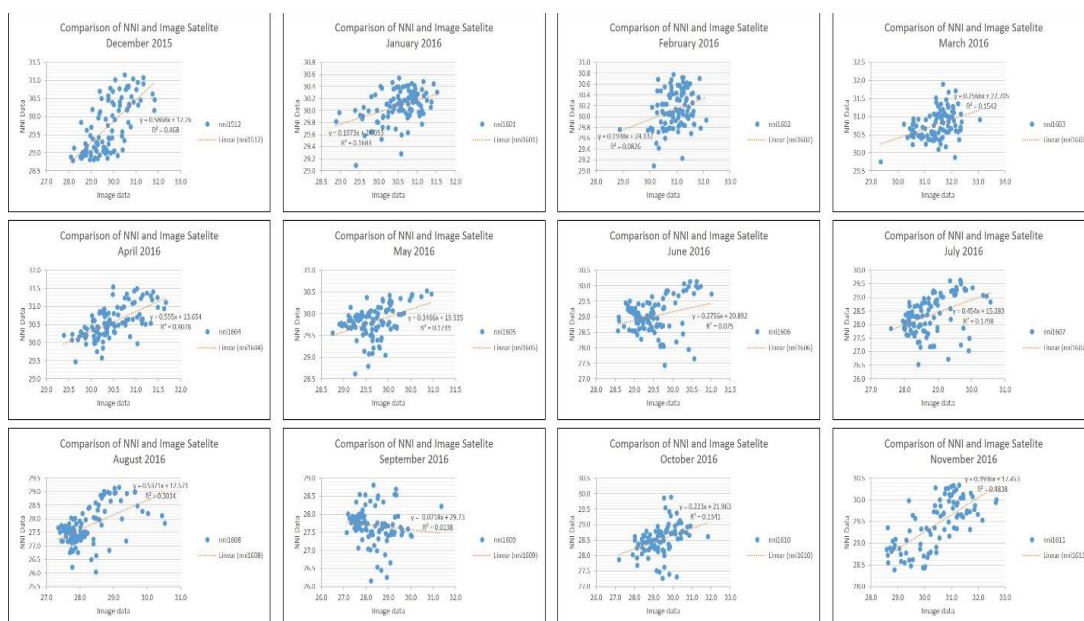


Figure 6. NNI Scatter plot

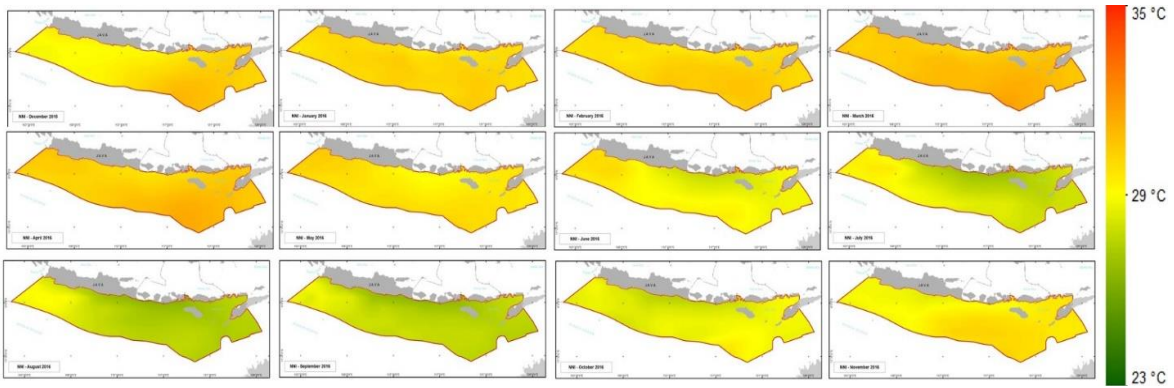


Figure 7. NNI result

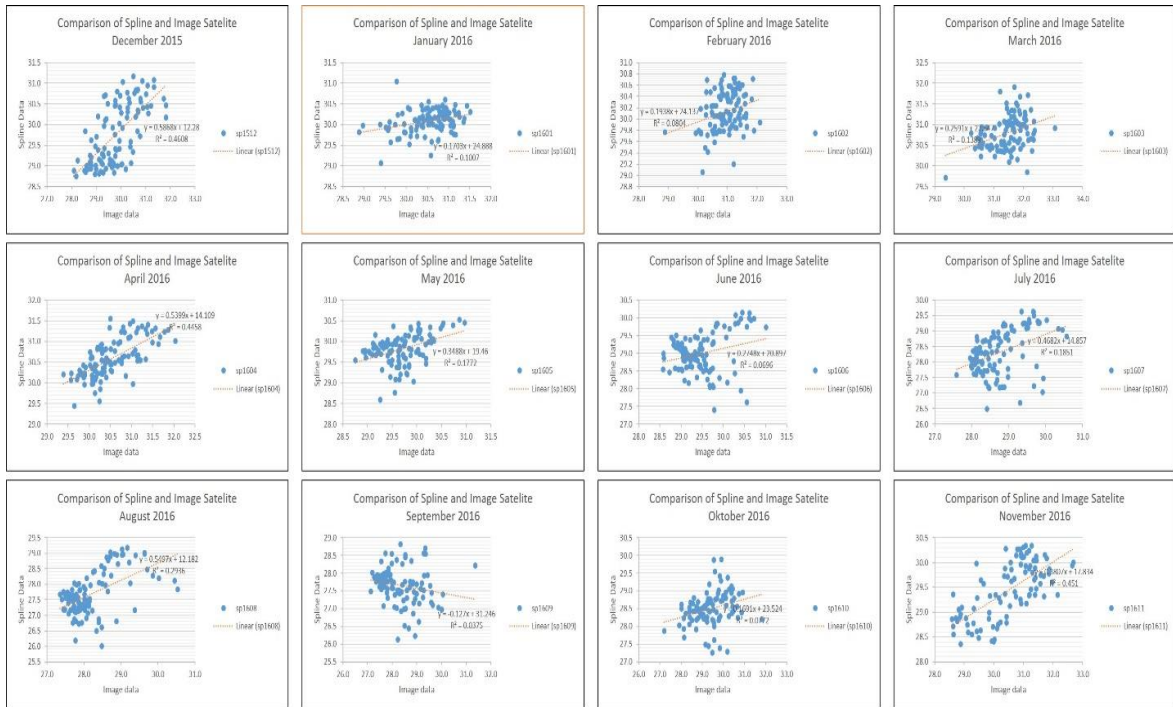


Figure 8. Spline scatter plot

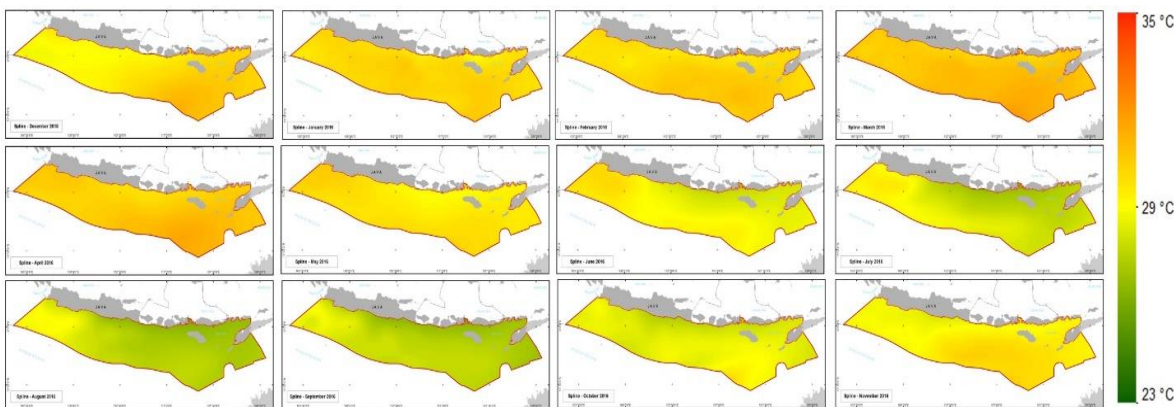


Figure 9. Spline result

Table 2. Assessment Test (December 2015 – May 2016)

Interpolation Methods	Assessment Method						
	SP	Min	Max	Mean	RMSE	Pearson	STDev
December 2015							
IDW	5	28.99	31.16	30.04	0.62	0.60	-0.05
Kriging	5	29.00	31.16	30.01	0.62	0.58	-0.07
NNI	5	29.00	31.15	30.00	0.63	0.57	-0.08
Spline	5	28.99	31.16	30.00	0.63	0.57	-0.08
Aqua MODIS		28.54	31.82	30.01			
January 2016							
IDW	5	29.60	30.55	30.22	0.64	0.13	-0.25
Kriging	5	29.59	30.54	30.20	0.66	0.11	-0.24
NNI	4	29.60	30.54	30.18	0.68	0.09	-0.23
Spline	5	29.58	30.55	30.17	0.70	0.06	-0.20
Aqua MODIS		29.60	31.52	30.70			
February 2016							
IDW	5	29.43	30.78	30.32	0.80	0.34	-0.11
Kriging	3	29.42	30.78	30.29	0.83	0.31	-0.11
NNI	5	29.42	30.78	30.27	0.85	0.28	-0.11
Spline	3	29.42	30.78	30.27	0.85	0.28	-0.10
Aqua MODIS		30.09	31.86	30.99			
March 2016							
IDW	5	30.11	31.68	30.95	0.87	0.26	-0.17
Kriging	4	30.11	31.67	30.92	0.91	0.21	-0.17
NNI	4	30.10	31.67	30.89	0.94	0.15	-0.16
Spline	4	30.10	31.67	30.89	0.95	0.14	-0.15
Aqua MODIS		30.24	33.07	31.66			
April 2016							
IDW	5	29.76	31.54	30.70	0.44	0.58	-0.02
Kriging	4	29.75	31.54	30.67	0.44	0.55	-0.03
NNI	4	29.75	31.54	30.65	0.45	0.52	-0.03
Spline	4	29.75	31.55	30.65	0.45	0.52	-0.03
Aqua MODIS		29.57	31.49	30.54			
May 2016							
IDW	5	29.04	30.19	29.70	0.40	0.08	-0.03
Kriging	5	29.12	30.10	29.72	0.38	0.10	-0.07
NNI	5	29.04	30.19	29.68	0.40	0.06	-0.03
Spline	3	29.03	30.20	29.67	0.41	0.04	-0.02
Aqua MODIS		28.96	30.35	29.63			

In table 2, IDW interpolation method perform very good in whole six months, because December 2015 – May 2016 the Indian Ocean southern part of Java, Bali and Nusa Tenggara Island in normal condition without upwelling occur thus the SST value

form Argo distribute smoothly, upwelling normally occur in early June to mid-October [14].

Table 3 in first assessment smooth performance shows that in several months the performance of all interpolation model show

bad performance, marked as orange bold in table. The bad performance happened mostly in upwelling event in southern part of Java, Bali, Nusa Tenggara Island. Because of this event, the range of data become wider and it influences the interpolation data. The second assessment compares the maximum and minimum data between interpolation model and image satellite. The purpose of this assessment is to evaluate the difference of data value. In table 2 and table 3, it is shown that the value resulted from interpolation methods has slightly different with value from satellite imagery, around $0.5^{\circ}\text{C} - 1^{\circ}\text{C}$. It means all interpolation methods show good performance in data value and the interpolation method can give similar information to image data. The mean value also shows close correlation with maximum difference of mean value between result of interpolation methods and satellite imagery is 1.15°C . The fourth assessment, the RMSE shows good correlation between all interpolation methods with image data as shown in figure 10 below:

Figure 10 shows that all interpolation methods show the similar trend, which means from all method have good correlation with the image even some method have same RMSE value. The smaller the value, more correlated the interpolation value. The next assessment is Pearson correlation, this assessment aims to examine how close the correlation between interpolation value with

image value. The comparison graph shown in figure 11 below.

Figure 11 shows the r (correlation value) of each interpolation methods. In this assessment, the confident level is in 95% (r table = 0.254), shown with red dash line and 99% (r table = 0.330), shown with yellow dash line for 61 samples in study area. From figure 11 it is shown that IDW have high correlation with image satellite compared with other methods. It means that IDW have consistent value although in smooth performance IDW perform bad performance in several months. The minus sign (-) in table 2 shows that the correlation of image value is lower than interpolation model.

The last comparison method is Standard Deviation Differences that aims to show the deviation between interpolation methods and image value. Figure 12 shows the Standard Deviation Differences of all interpolation methods compared to satellite imagery. Lowest standard deviation difference is occurred between April to August. This can be possible because of the low cloud cover in these months. Table 2 shows that IDW and Spline has the most frequent lowest standard deviation difference to satellite imagery while Kriging shows the least frequent lowest standard deviation difference. Even in several months that have high cloud cover (September to March), IDW and Spline are able to perform the lower standard deviation difference value compared to Kriging and NNI method.

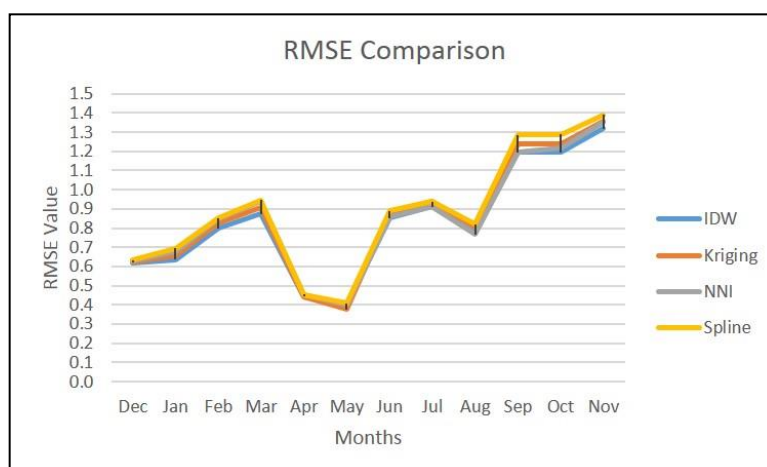


Figure 10. RMSE comparison all interpolation methods

Table 3. Assessment Test (June - November 2016)

Interpolation Methods	Assessment Method						
	SP	Min	Max	Mean	RMSE	Pearson	STDev
June 2016							
IDW	4	27.95	30.08	28.81	0.85	-0.30	-0.01
Kriging	4	27.94	30.07	28.78	0.88	-0.30	0.01
NNI	4	27.95	30.07	28.81	0.86	-0.28	-0.01
Spline	4	27.94	30.08	28.78	0.89	-0.29	0.02
Aqua MODIS		28.58	30.42	29.35			
July 2016							
IDW	2	27.04	29.64	28.02	0.91	-0.04	0.01
Kriging	2	27.03	29.62	27.99	0.94	-0.04	0.03
NNI	2	27.03	29.62	28.02	0.91	-0.05	0.01
Spline	3	27.03	29.64	28.00	0.94	-0.04	0.03
Aqua MODIS		27.60	29.94	28.55			
August 2016							
IDW	2	26.51	29.03	27.39	0.77	0.16	0.00
Kriging	2	26.50	29.01	27.37	0.80	0.13	0.01
NNI	2	26.50	29.01	27.40	0.77	0.16	0.00
Spline	2	26.49	29.03	27.36	0.82	0.12	0.03
Aqua MODIS		27.44	29.37	27.96			
September 2016							
IDW	2	26.46	28.45	27.55	1.20	-0.29	-0.34
Kriging	2	26.45	28.44	27.52	1.24	-0.37	-0.33
NNI	3	26.45	28.43	27.54	1.20	-0.26	-0.34
Spline	2	26.43	28.45	27.49	1.28	-0.43	-0.30
Aqua MODIS		27.38	30.01	28.39			
October 2016							
IDW	2	27.40	29.56	28.58	1.20	0.37	-0.24
Kriging	3	27.39	29.55	28.55	1.24	0.30	-0.25
NNI	2	27.40	29.54	28.57	1.22	0.33	-0.24
Spline	2	27.38	29.55	28.52	1.29	0.20	-0.24
Aqua MODIS		28.39	31.84	29.59			
November 2016							
IDW	2	28.37	30.31	29.62	1.32	0.64	-0.43
Kriging	4	28.36	30.31	29.59	1.36	0.61	-0.44
NNI	3	28.38	30.31	29.60	1.35	0.61	-0.44
Spline	3	28.36	30.31	29.57	1.39	0.57	-0.43
Aqua MODIS		28.60	32.69	30.71			

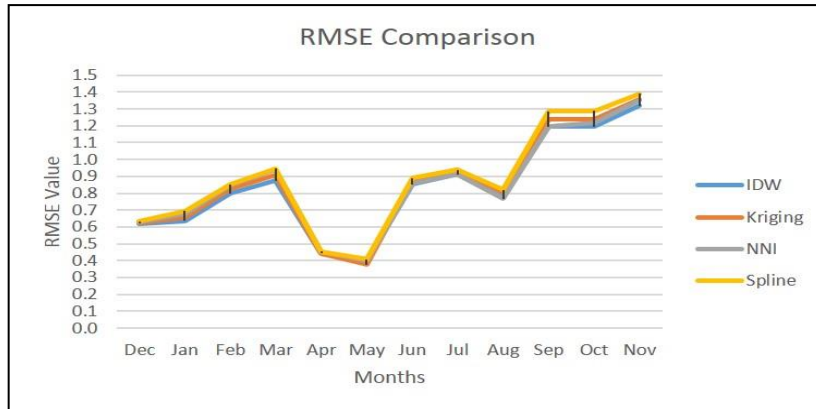


Figure 10. RMSE comparison all interpolation methods

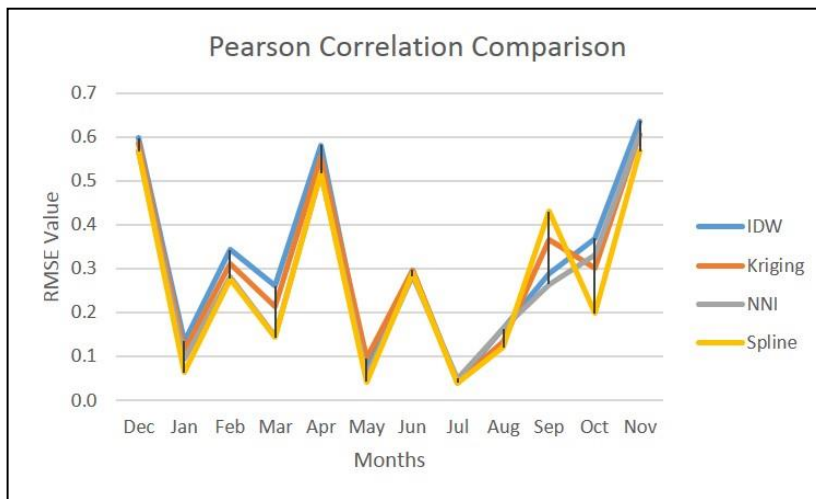


Figure 11. All r correlation graph

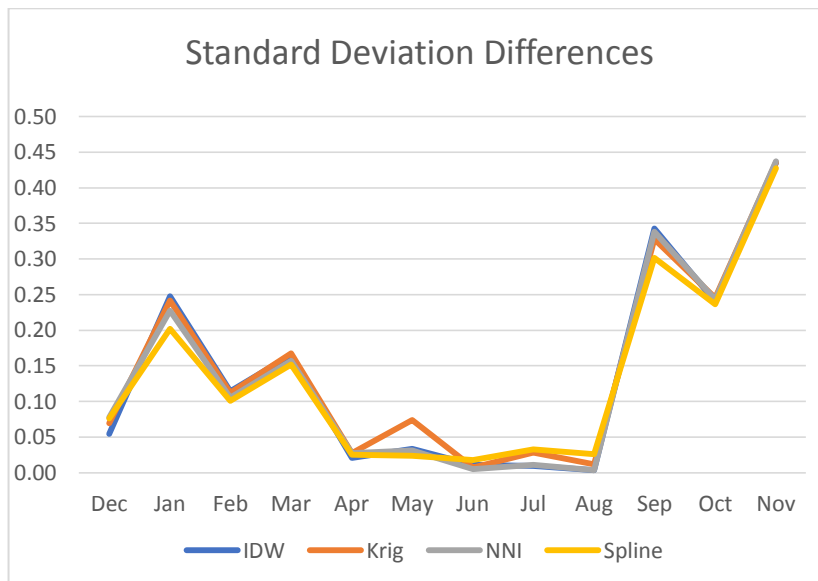


Figure 12. Graph of standard deviation differences from all interpolation methods

CONCLUSION

From all performance assessment to all interpolation method in this study, shows that all interpolation can be used in oceanographic data to make continuously surface data, but there is not single interpolation method can produce continuous SST maps all the time, particularly with dataset that has not been designed with one particular interpolation method. Overall, all of methods give similar values in RMSE, Pearson Correlation and standard deviation differences. IDW performed very good in smooth performance assessment in December 2015 – May 2016, Spline and Kriging performed intermediate to good during that period, but during upwelling period all method performed bad.

In all assessment IDW was the best choice, which is possibly due to the relatively low skewness inherent in all assessment, and for NNI is in second choice because this method use similar basic equation to the one used in IDW interpolation. For large data variation between cold SST and warm SST, suggest a high heterogeneity in the surface to be estimated or in primary variable. Therefore, when the data variation is high, sample density must be increased to capture the spatial variation of the primary variable. In this study show the best method to perform the spatial interpolation is IDW, because IDW give the consistent value, and strong correlation with the image.

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