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# Sverdruv Munk Bretschneider Modification (SMB) for Significant Wave Height Prediction in Java Sea

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author ASA designed the SMB, ANN and NLARX, wrote the manuscript. Authors SA and WLD wrote the first draft of manuscript, managed literature searches, analysis of raw data. All authors read and approved the final manuscript.*

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## ABSTRACT

Sverdruv Munk Bretschneider (SMB) methods is a semi-empirical method that has been used for the prediction of the significant wave height – Hs in global watersheds. Indonesian waters are surrounded by thousands of islands and wind movement has different nature with the waters of free movement. Java sea is flanked by the waters of Java and Borneo island. Sea breeze movement in Indonesia as a result of changes in atmospheric pressure in Asia and Australia. SMB methods require modification in the waters of Indonesia, so as to be used as a predictor in accordance with the high degree of accuracy. In this paper, a propose methods of designing the predictor with a modified SMB. The method compared by numerical methods of Nonlinear Autoregressive Exogeneous (NLARX) and expertise method of Artificial Neural Network (ANN). Case studies conducted in the Java sea along Surabaya – Banjarmasin cruises. This line is a busiest sea transportation in Indonesia. The data obtained from Badan Meteorologi, Klimatologi dan Geofisika (BMKG), the agency of meteorology, climatology and geophysics in Indonesia. The data are the wind speed and significant wave height. The length of data in interval 6 years, since 2006 until 2011. Predictor results shows a Root Mean Square Error - RMSE of modified SMB is 0.05, while NLARX method and ANN respectively are 0.24 and 0.16.

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*Keywords: SMB modified; ANN; NLARX; the significant wave height; wind speed; RMSE.*

## 1. INTRODUCTION

The significant wave height predictor design use of artificial neural networks (ANN), has been success to predict the weather variables [1]. This method has been shown to serve as predictor for a variety of process variables. The amount of data will affect the level of accuracy of prediction results. In the real-time conditions, a ANN is able to produce high prediction accuracy is good for Arabia waters [2].

Marine transportation has contributed economically to international trade, national, and inter-island. Java Sea is one of the paths that have a high density. On the other hand, the potential for shipping accidents is high in Indonesia [3]. The wave height is the average 1/3 of the highest wave is used as the reference shipping. Several studies have been conducted to obtain a high degree predictor of accuracy. The method has been proposed is fuzzy logic [4].

The uniqueness of Indonesian waters is surrounded by more than 17,000 islands, between two oceans and two continents. The predictor of Indonesia waters require a special method [5].

Fuzzy logic method that has been designed to produce a sea wave height predictor in accuracy around 72% - 92% in sea line of Surabaya - Banjarmasin. Better accuracy on predictors of ocean currents, i.e., 97-99% in the same location [4]. Predictor system was proposed to determine the feasibility of a cruise along the path. The prediction results show the accuracy feasibility of shipping in range of 74-89% for the entire gross tonnage of ship [6].

Several empirical methods frequently used by previous researchers, that are PM (Pierson Moskowitz), Wilson, JONSWAP, Donelan, SPM, CEM and SMB have been developed for the prediction of sea wave height in some waters in the world. Donelan method shows better capability than the SMB and JONSWAP method [7].

In this paper proposes a method a SMB - Sverdrup Munk Bretschneider modified, to produce high accuracy. This method is compared to NLARX – Nonlinear Autoregressive Exogeneous method and ANN. NLARX is one of the numerical methods that can be used for nonlinear systems. The capability of NLARX to complete the successful identification of nonlinear system. NLARX can map between of the data input (u) and output (y) [2].

The modeling of NLARX is a successful method to solve nonlinear identification. NLARX widely used in a variety of purposes, that is: analysis, control systems, prediction [5]. NLARX structure is expressed in equation (1). This structure shows the relationship between output and input variables at time t = 1, 2, .., by a delay factors which appears at the output and input. This delay is expressed in the parameters $n_a$, $n_b$. The factor due to the delay inputs is expressed in the form of parameter $n_k$.

The purpose of this study was obtained from the predictors of SMB, ANN and NLARX. To focus on these objectives, several issues limit determined in advance, there are wind speed and wave height of the data used are taken from the Meteorology – Climatology and Geophysics Agency – BMKG. Data in range of 2006 to 2011. Predictors is apply to shipping of Surabaya – Banjarmasin. The sea line represented in six location: are (1) 6.874824° S, 112.747800° E, (2) 4,648136° S, 113,908806° E and (3) 3.540425° S, 114.484300° E, and three other locations are between them.

## 2. METHODS

### 2.1 Maritime Weather

Maritime weather data is used for input and output of predictor system. Data of BMKG Perak II Surabaya measured hourly for 5 years in 2006 to 2011, in a number of 42000. The data represented in three location water is shows Fig. 1, i.e: (1) 112.747800 E, 6.874824 S, (2) 113.908806 E, 4.648136 S and (3) 114.484300 E, 3.540425 S. Furthermore, a point between three location above, it is located in Surabaya waters 112.747800 E, 6.874824 S will be referred to as point A, a point located in the Java Sea 113.908806 E, 4.648136 S will be referred to as point B, and point located in Banjarmasin waters 114.484300 E, 3.540425 S will be referred to as point C. The distance of A to B as far as 279 miles, the distance point A to point 1 of 100 miles, the distance point A to point 2 of 200 miles.


**Fig. 1. The location of maritime weather predictors**

## 2.2 Design Sverdruv Munk Bretschneider – SMB as a Predictor

One of the methods of wave forecasting is a method introduced by Sverdrup and Munk (1947) and followed by Bretschneider (1958). The method is known as the method of SMB (Sverdrup Munk Bretschneider). Sverdrup and Munk (1947) proposed a semi-empirical formula to predict the significant wave height. They explain the mechanism of energy transfer from wind to waves using normal and tangential wind stress. SMB models is shown in Equation (1).

$$(gH_{s\ SMB}/V_w^2) = 0.0283\ [0.0125\ (gF/\ V_w^2)^{0.42}] \quad (1)$$

With:

$V_w$ = wind speed (m/s)
F = fetch (m)
G = acceleration due to gravity (9.8 m/s$^2$)
$H_{s\ SMB}$ = significant wave height of SMB models (m)

The significant wave heights prediction results with this methods in a large error, so that the modification was performed according to the method of SMB. The modification is done by adding the error of ANN result in one hour before, it is shown in the equation 2.

$$Hs\ (t + 1) = Hs_{SMB}\ (t) + e\ (t\text{-}1) \quad (2)$$

Where,

$H_s$ (t+1) = significant wave height in one hour later (m)
$H_{s\ SMB}$ (t) = significant wave height result of SMB method in the present (m)
e(t-1) = the error of ANN result in one hour ago
t = time (hour)

## 2.3 Design Artificial Neural Network as a Predictor

Neural Network is a popular algorithm in AI – Artificial Intelligence and has been widely applied in the fields of transport, control, prediction, financial, etc. Fig. 2 shows a block diagram of wave height predictor. The first step in ANN algorithm is a scaling of input and output data of wind speed and wave height. Preprocessing the data or scaling of data needed to speed up the convergence during a training on the identification and validation of NN that carry of data into the range 0 to 1. The equation of (3) is scaling of input ANN variables.

$$X_2 = \frac{X_1 - \min(X)}{\max(X) - \min(X)} \quad (3)$$

With:

$X_2$ = the data that has been scaled
$X_1$ = the real data
Min (X) = minimum data
Max (X) = maximum data

Having obtained the scaling input and output, it will be used for training and validation by comparison to amount of 80% and 20% data. The architecture of ANN using Multi Layers Perceptron (MLP) which consists of input layer in Fig. 2 (the present of wind speed (Vw (t)), the present of significant wave height (Hs (t)), and one hour before of the significant wave height (Hs (t-1))). The hidden layer and output layer is significant wave height in one hour ahead (Hs (t + 1)). After designing the architecture of the network we conducted descaling, using equation 4.

$$X_1 = X_2(\max(X) - \min(X)) + \min(X) \quad (4)$$

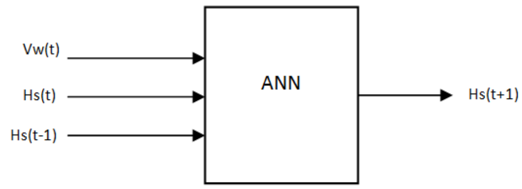



**Fig. 1. Block diagram of ANN designed predictors**

### 2.4 NLARX

Nonlinear Autoregressive Exogenous modeling (NLARX) is a successful method to solve nonlinear identification. Structure of NLARX is shows in equation 5.

$$y(t) = f[y(t-1), \ldots, y(t-n_a), u(t-n_k), \ldots, u(t-n_k-n_b+1] + e(t) \quad (5)$$

With,

$y(t)$ = output of predictor
$u(t)$ = input of predictor
$e(t)$ = error
$t$ = time (hour)

## 3. RESULTS AND DISCUSSION

The wind speed at A, B and C points and 3-points data result of interpolation (point 1, 2, and 3) is shown in Fig. 3 [2]. Blue is the wind speed data at point A, dark green indicates wind speed at point B, the red indicates the wind speed at point C. A light green indicates wind speed at point 1, the yellow indicates wind speed at point 2, and magenta shows the wind speed at point 3 of the wind speed data contained in Fig. 4. It is known most of large wind speed by the yellow line (point 2), followed by point B (dark green line). It is proved that the wind speed at sea is greater than the wind speed was on the edge of the sea. The wave height in the middle of the sea is higher than the height of the edge of the ocean waves. The greater the wind speed, the greater the wave height that occurs. This is evidenced in Fig. 4, where the wind speed is highest at point 2 at 30.38 knots and wave heights are also present in the highest.

### 3.1 Modelling Results

The maximum wind speed before the scaled is 16.81 knots on February 7, 2009 and cause to evidence of significant wave height is 0.69 meters. From Figs. 3 and 4, it can be seen the greater the wind speed, the wave height will also increase. Large wind speeds occur at other times, that is on December 29, 2007 of 14.9 knots, February 9, 2008 by 13.9 knots, February 6, 2011 of 12.7 knots, and January 14, 2010 of 15.2 knots. The statistics of wind speed is shown in Table 1.

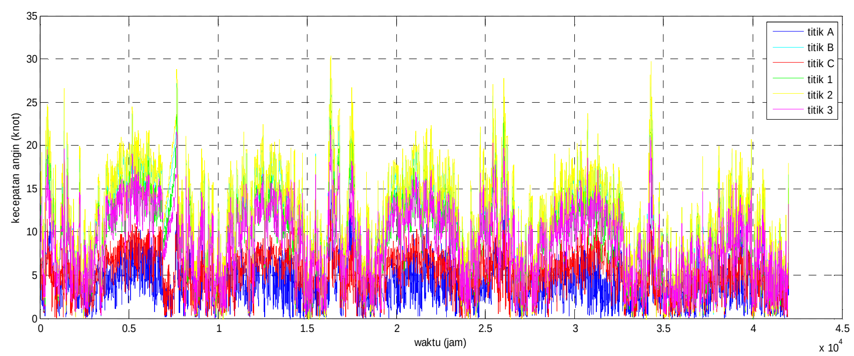



**Fig. 2. The mean of wind speed in 6 locations in sea line of Surabaya – Banjarmasin**

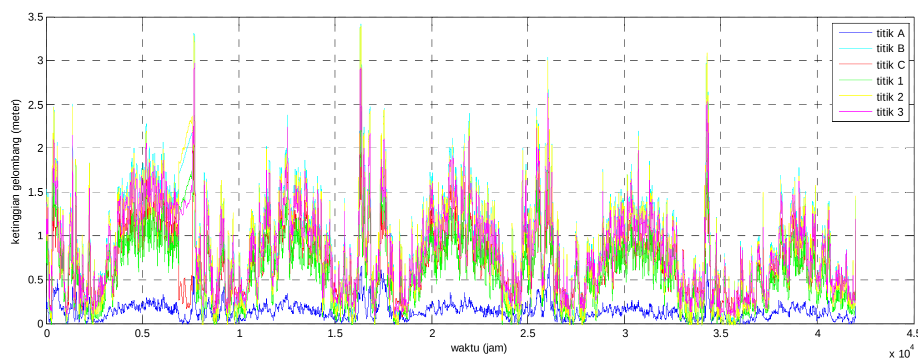



**Fig. 3. The mean of wave height in 6 locations in sea line of Surabaya – Banjarmasin**

**Table 1. The statistic of wind speed in 3 locations of sea line Surabaya-Banjarmasin**

| $V_w$ | Point of A | | | Point of B | | | Point of C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Ave | Min | Max | Ave | Min | Max | Ave |
| 2006 | 0.07 | 11.06 | 3.90 | 0.23 | 25.04 | 12.40 | 0.03 | 11.49 | 5.36 |
| 2007 | 0.03 | 14.89 | 3.80 | 0.04 | 27.92 | 10.81 | 0.12 | 13.36 | 4.93 |
| 2008 | 0.02 | 13.86 | 4.04 | 0.22 | 24.38 | 11.64 | 0.05 | 10.36 | 5.10 |
| 2009 | 0.08 | 16.81 | 3.72 | 0.19 | 25.77 | 11.14 | 0.04 | 11.21 | 4.97 |
| 2010 | 0.03 | 15.49 | 3.48 | 0.10 | 27.29 | 7.89 | 0.07 | 10.86 | 3.53 |
| 2011 | 0.43 | 14.35 | 6.18 | 0.22 | 25.94 | 10.56 | 0.04 | 12.28 | 4.25 |
| Average | | | 4.19 | | | 10.74 | | | 4.69 |

The wind speed at point B (in middle of Java Sea) has a minimum speed of 0.04 knots and a maximum of 27.92 knots on 27 December. The Beaufort number in this condition accordance of 7. The wave height is appropriate about 4 - 5.5 meters. The recommendations for sailing in this condition is prohibited sailing for ships with tonnage up to 10000 GT. Along observation period occurs 46 times the wind blows at 7 of Beaufort scale.

Validation ANN aims to decide a gain with the highest fitness value. Data validation is used as much as 8400 data. The ANN validation at point A of 96.01% fitness, the fitness at point B of 96.85%, point C of 97.53%. While validation of SMB fitness higher yield compared with ANN at points B and C.

## 3.2 Result of Predictors

Based on ANN weights of the validation results, it can be predicted wave heights using these weights. The first weights (W1) of 4x7, which is a 4 is composed of 3 layer of inputs and 1 is bias. The input layers are the present of wind speed (Vw (t), the present of significant wave height (Hs (t)), and the significant wave height in hour before (Hs (t-1))). Size of 7 is the number of hidden layers. The size of second weights (W2) of 8x1, where 8 is 7 of hidden layer and 1 is bias. 1 is the output layer is significant wave height in one hour later (Hs (t + 1)).

Validation on NLARX, with $n_a$ at 5, $n_b$ by 2, and nk is 1, the fitness obtained at point A is 94.99%, at point B is 97.67%, and at point C is 97.73%. The fitness values are shown in Table 2. The amount of data used to validate the prediction is 1446, i.e. the data from 21 November 2010 until April 2, 2011.

Fig. 6 shows the results of predictions in 1 hour later of the height of the wave using ANN predictor, NLARX, and SMB. The amount of data test is 1446 data, in the intervals of September 17, 2010 to October 28, 2010. In the picture the young blue line is the actual data from BMKG, the blue line shows the predicted results of NLARX, the red line shows the prediction of ANN, and the green line shows the prediction of the SMB.

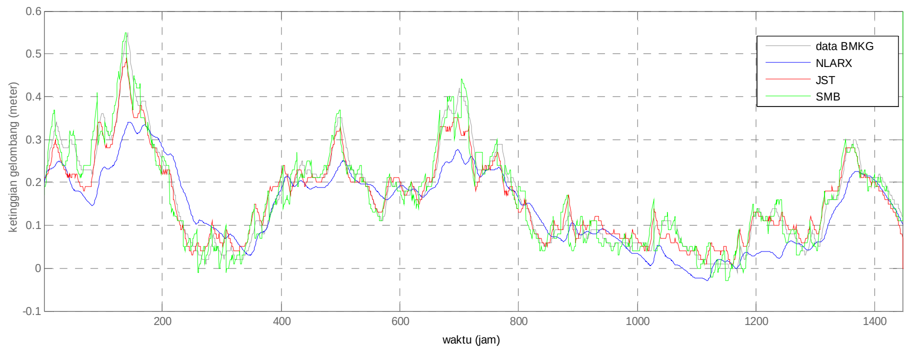
RMSE value is an indicator of the accuracy of predictor. RMSE values shown in Table 3. The RMSE of SMB to whole point location of Java Sea waters, showed lower than other of two methods. The average of SMB RMSE's is 0.05.

**Table 2. The fitness of validation using ANN and SMB in three locations**

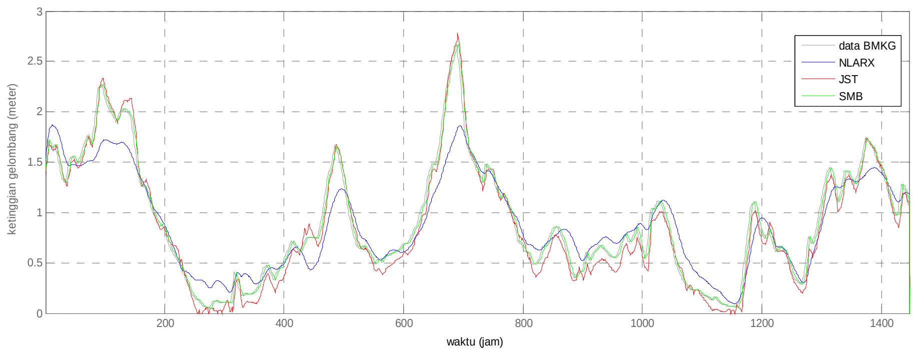
| Validation | Point of A | Point of B | Point of C |
|---|---|---|---|
| ANN | 96.01% | 96.85% | 97.53% |
| SMB | 94.99% | 97.67% | 97.73% |

**Table 3. The RMSE of the significant wave height result of predictors**

| Points | ANN | NLARX | SMB |
|---|---|---|---|
| A | 0.03 | 0.04 | 0.02 |
| B | 0.41 | 0.23 | 0.06 |
| C | 0.15 | 0.10 | 0.03 |
| 1 | 0.12 | 0.26 | 0.03 |
| 2 | 0.38 | 0.13 | 0.09 |
| 3 | 0.32 | 0.2 | 0.07 |
| **Average** | 0.24 | 0.16 | 0.05 |




**(a)**

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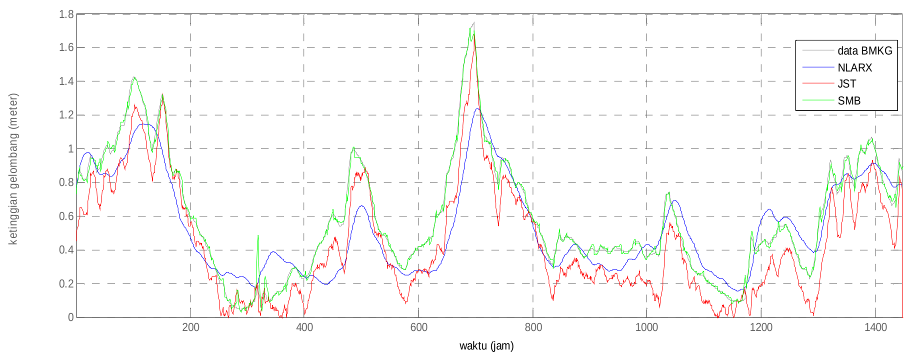
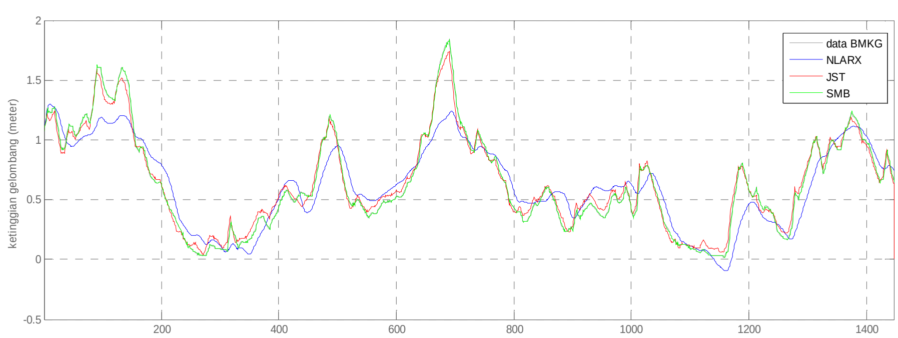



**(c)**

**Fig. 5. The actual and result of wave height predictors in 1 hour later in A, B, and C using SMB, ANN, NLARX**

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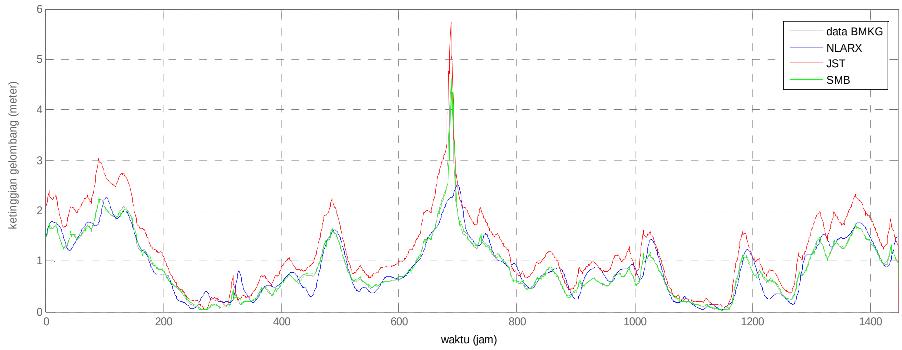


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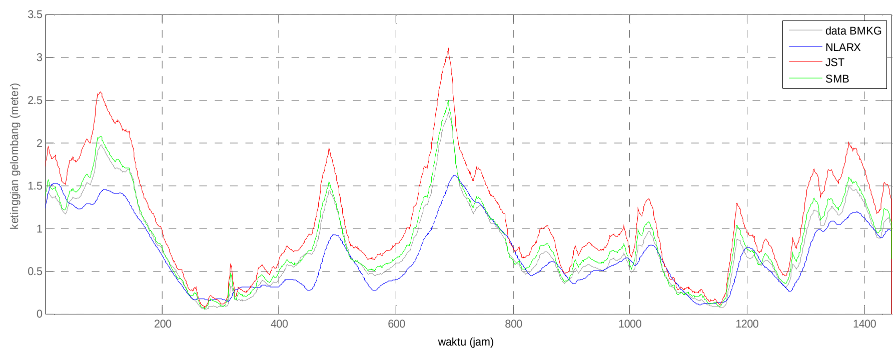


**(c)**

**Fig. 6. The actual and the result of wave height predictor in 1 hour later in points 1, 2, and 3 using SMB, ANN, NLARX**

## 4. CONCLUSION

From the analysis and discussion that has been done, it can be concluded:

- The height of the waves on 113.908806 E, 4.648136 S (point B) is higher than the 112.747800 E, 6.874824 S (point A) and 114.484300 E, 3.540425 S (point C).
- From the predicted results at point A, point B and point C, as well as on the 3-point interpolation, SMB predictor can result smaller RMSE than ANN and NLARX with - average 0.05.
- Prediction using ANN method produces RMSE with average of 0.24, NLARX 0.16, and SMB 0.05.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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