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VARIABILITY AND VALIDATION OF SEA SURFACE TEMPERATURE ESTIMATED BY PATHFINDER ALGORITHM OF NOAA-AVHRR SATELLITE IN THE NORTH PAPUA WATERS

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Abstract. Variability and validation of sea surface temperatures (SST) in north Papua waters were conducted using SST estimated by Pathfinder algorithm of NOAA AVHRR satellite and SST measurements from TAO buoy in 2001-2009. Satellite data (SST Pathfinder) were daily, weekly, and monthly composite with 4x4 km^2 resolution and downloaded from http://poet.jpl.nasa.gov. *In situ* data (SST measurement from buoy TAO) were measured at a depth of 1.5 m and recorded every hour (http://www.pmel.noaa.gov/tao_deliv). The *in situ* data then converted into daily, weekly, and monthly average data. In general, the SST values of both satellite and *in situ* SST in the north Papua waters ranged between 27.10 - 31.90 °C. During the east season (June-September), SST values (27.90-31.90 °C) were generally higher than the SST values (27.10-30.13 °C) during the west season (December-February). In general, the SST values both day-time and night-time from *in situ* and the satellite measurements showed no significant differences except in waters close to the shore. The results also showed that the coefficient of determination values (R^2) between the satellite and the *in situ* SST measurements were relatively low (65%) and up to 5% of RMSE. The relatively low correlation between *in situ* dan satellite SST measurements may be due to high cloud coverage (90-96%) in the north Papua waters so that SST satellite data become less representative of the *in situ* data. These results also indicated that the Pathfinder algorithm can not be used as a valid estimate of SST NOAA AVHRR satellite for the north Papua waters.

Keywords: SST Pathfinder, NOAA AVHRR, Validation, TAO buoy, North Papua Waters

1. Introduction

1.1. Background

The north Papua waters were known to have a dynamic oceanographic characters where water masses coming from the southern hemisphere through the South Equatorial Current (SEC) and from the northern hemisphere of the Pacific Ocean via the North Equatorial current (NEC) and the North Equatorial Counter Current (NECC) (Wyrtki, 1961; Kashino *et al*., 2011). In this region always appears a Halmahera Eddy that its variability is closely correlated with the balance of heat and fresh water in the surface layer of the western Pacific equatorial region (Kashino *et al*., 2011). During the period of June-August, a strong current coming from the northern Irian circled in the southern tip of Halmahera and later returned to the Pacific ocean together with Equator Sakal current (Nontji, 2005).

In this region, the trade winds occur throughout the year that dragged the warm water mass from the tropical waters of the Pacific to the west and accumulate in the tropical waters of northern Papua. Therefore, this region is known for its warm water pool (warm pool) with temperature >29 °C and low salinity (<32) (Wyrtki, 1961). However, information regarding the variability of sea surface temperature in this region is still poorly known.

Currently, the measurement of sea surface temperatures (SST) has been made easier by the presence of remote sensing technology that can detect a synoptic SST and can be used to study the physical processes of ocean surface. Sea surface temperatures can be estimated directly by satellite sensors within the spectrum of thermal infrared such as the National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer (NOAA - AVHRR) satellite. To estimate SST, many algorithms have been developed such as IR SST (Infra Red Sea Surface Temperature) (Evans and Podestà, 1998), MCSST (Multy Channel Sea Surface Temperature), NLSST (Non-Linear Sea Surface Temperature) (Walton *et al*., 1998; Kumar *et al*., 2003), and PFSST (Pathfinder Sea Surface Temperature) (Quirin *et al*., 2008). The development and validation of SST algorithms were generally conducted in the mid and high latitude regions.

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For tropical waters, the development and validation of SST algorithms are still rarely conducted since the human resources and facilities are very limited. High cloud coverage and high frequency of rainfall in the tropical region make the SST algorithms developed in mid and high latitudes become less suitable applied to Indonesian waters (Nababan, 2009). A relatively high range of SST in sub-tropical and high latitude waters makes that current SST algorithms are less accurate to be applied in Indonesian waters which have a relatively low SST range. Therefore, prior to a development or application of an algorithm for SST estimation for the Indonesian waters, it is necessary to first validate the existing SST algorithm. One SST estimation algorithm of NOAA AVHRR satellite with high accuracy is Pathfinder algorithm (Kumar *et al*., 2000, 2003; Quirin *et al*., 2008). Therefore, in this study, the validation of SST values of NOAA AVHRR satellite estimated by Pathfinder algorithm was performed using teh SST data from the buoy TAO measurements which is located in the north Papua waters.

The objectives of this study were to determine the pattern and variability of SST in the north Papua waters and to validate SST values of NOAA AVHRR satellite estimated by Pathfinder algorithm.

2. Method

2.1. Location and Data

The location of this study was the north Papua waters using SST data estimated by Pathfinder algorithm of NOAA AVHRR satellite and *in situ* SST measurements of TAO buoy located at 137 °E and 2-8 °N (Figure 1). Both SST data from satellites and the TAO buoy measurements were taken from three stations i.e., Station 1 (located at 137 °E and 8 °N), Station 2 (located at 137 °E and 5 °N), and Station 3 (located at 137 °E and 2 °N (Figure 1).

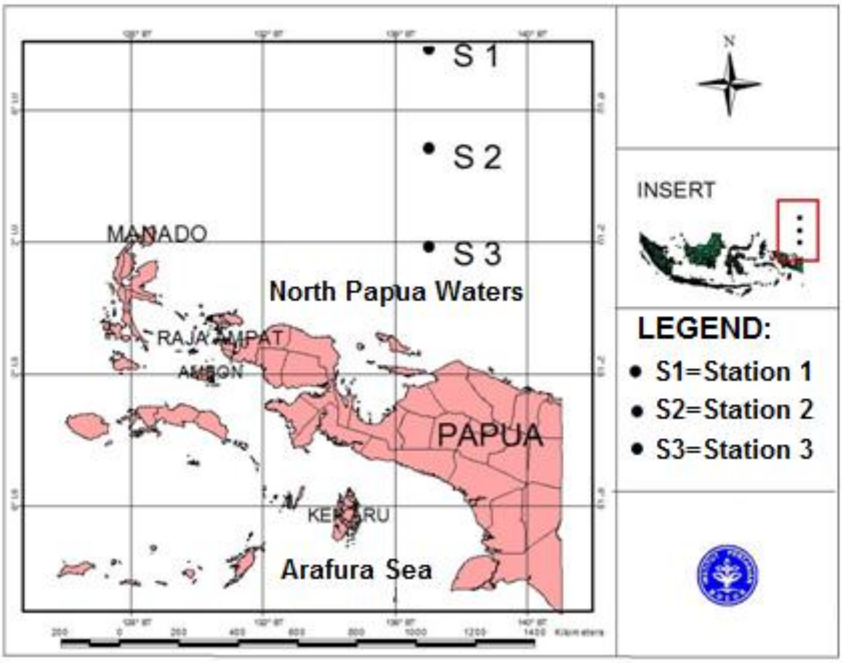


Figure 1. Study location in the north Papua waters where S1, S2, and S3 were stations of TAO buoy and SST satellite were extracted.

In situ SST data from TAO buoys were taken from a depth of 1.5 m per hour in 9 years (2001-2009). This data were obtained from NOAA website (http://www.pmel.noaa.gov/tao/data_deliv/110w.html) along the information of latitude, longitude, time of data collection, and water depth. Temperature data bias was 0.1 °C (Murakami, 1999).

Satellite SST data estimated by Pathfinder algorithm (PFSST) (Evans and Podestà, 1998) were in the form of composite data (daily, weekly, and monthly) in 4x4 km^2 resolution for 9 years (2001-2009) and were obtained from the NASA website (http://poet.jpl.nasa.gov). The satellite data included information on latitude, longitude, land, coastline, and sea surface temperature estimated value.

2.2. Data Analyses

Both satellite and in situ SST data were separated between day time (06.00-17:59 local time) and night time (18.00-05:59 local time). Before the separation was carried out, the in situ SST (recorded in GMT) first converted into eastern Indonesian time (local time). The difference between the GMT and eastern Indonesia time (Papua) was +9 hours. From hourly SST data then it were averaged into daily, weekly, dan monhtly SST data.

The level 7 of satellite SST estimated by Pathfinder algorithm data were used in this study because the data was considered to have the best quality with no cloud cover. Pathfinder SST data processing was performed by the University of Miami that divided into four steps i.e., ingestion to calibrate radiation and georeference, pathfinder SST calculation, spatial binning, and temporal binning. The software used to process the pathfinder data was developed by the University of Miami (Kilpatrick *et al*., 2001).

Validation of SST satellite with TAO buoy measurements was carried out by calculating the coefficient of determination between the two variables (R^2) and calculating the RMSE (Root Mean Square Error) values by the following formula (Harinaldi, 2002):

$$RMSE = \frac{\sqrt{(error_1)^2 + (error_2)^2 + ... + (error_n)^2}}{n} \times 100\%$$

where: error = *in situ* SST – SST satellite, n=total data.

To determine whether the mean value of *in situ* SST was significantly different than the mean value of SST satellite, we performed a one way anova of mean t-test.

3. Result And Discussion

3.1. Seasonal Variability of Sea Surface Temperature

Based on the TAO buoy measurements, monthly mean SST in the north Papua waters of the year 2001 - 2009 ranged between 27.73 °C (February) - 30.49 °C (August) (Figure 2, 3 and 4). The highest SST from TAO buoy measurements was found in the station farthest offshore (30.49 °C, August) and the lowest was found at the station closest to the coast (27.73 °C, February).

Based on the NOAA AVHRR Pathfinder estimates, monthly mean SST in the north Papua waters of the year 2001-2009 ranged from 27.10 °C (February) - 31.90 °C (June). Similar with the TAO buoy measurements pattern, the highest SST Pathfinder estimation was found offshore (31.90 °C, June) and the lowest SST was found closest to coast (27.10 °C, February).

Based on the one way analysis of variance of mean SST values, SST from TAO buoy measurements were generally higher and significantly different from that the SST Pathfinder estimation (α=0.01). This was because the SST from TAO buoy measurements were taken at a depth of 1.50 m while the SST Pathfinder estimation was detected at a depth of a few millimeters on the surface (skin temperature). Therefore, cooling skin effect by air-sea interaction within a thin layer of surface water can lower the temperature of the water (McClain 1985; Sukresno, 2008).

Daily SST data characteristics based on satellite estimated data and TAO buoy measurements were also analyzed. Results showed that there were no significant different (α=0.05) both *in situ* and satellite mean SST values during day time vs. night time except in the location near to the coast. The significant different (α=0.01) of SST mean values during day time vs. night time was only observed in the location near to the coast due to the influence of the interaction of land and sea. There were also no significant different between SST satellite estimated values extracted from 1x1 pixels and 3x3 pixels.

In general, the SST variability during east season (June-September; 27.90-31.90 °C) both from the Pathfinder estimation and TAO buoy measurements were relatively higher than during west season (December-February; 27.10-30.13 °C). The increase of SST during the east season generally occurred due to the season-east Monsoon winds moving from Australia to Asia through Indonesia region contained little water vapor, resulting in relatively smaller cloud cover or rainfall and the relatively higher of radiation (heating) in Indonesia than that during the east season. The decrease SST in the north Papua waters during the west season may be due to the relatively high cloud cover and rainfall in Indonesia. This was caused by the wind blowing from the continent of Asia towards Australia through South China Sea and the Pacific Ocean containing high water vapor and moisture, resulting a lot of clouds and rainfall in Indonesia. Relatively high cloud cover or rainfall during the west season reduced solar radiation penetration on the sea surface and resulted in a relatively lower of the SST.

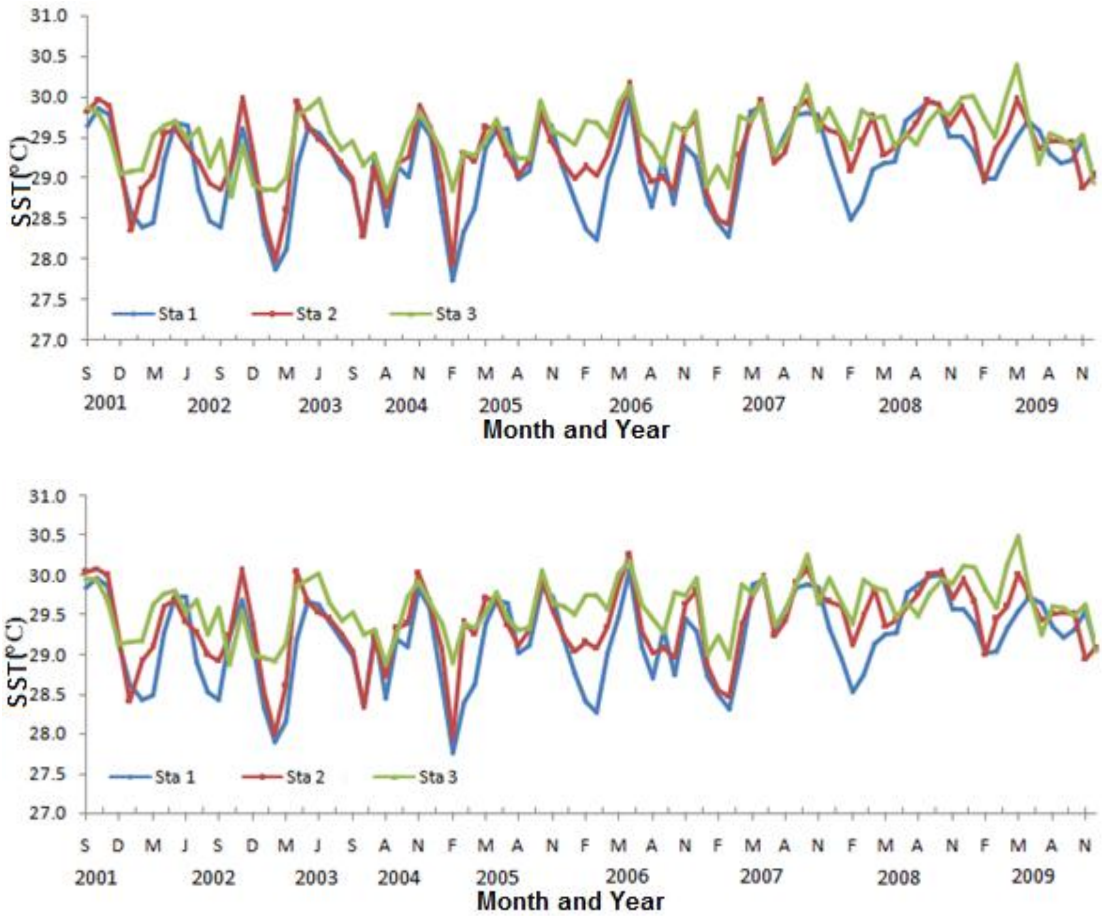
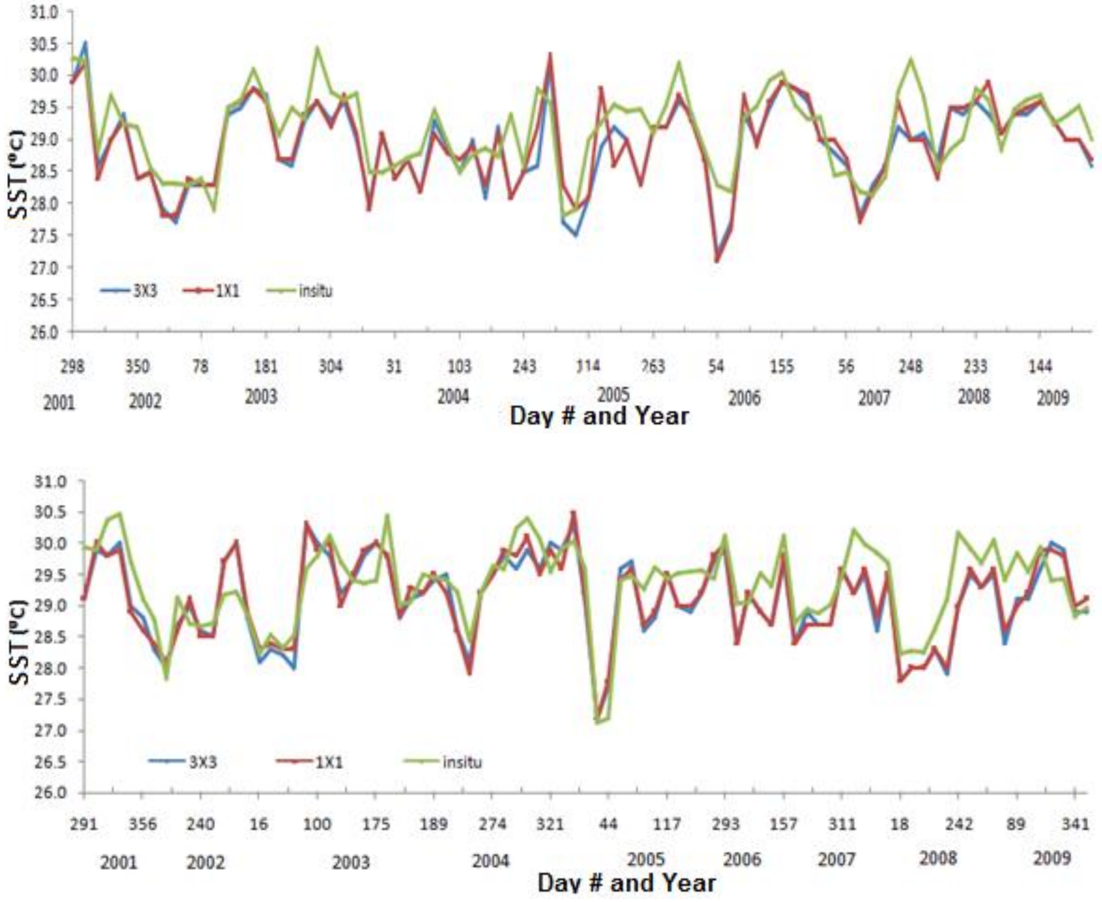


Figure 2. SST mean values from TAO buoy measurements. Day time (Top) and night time (bottom).



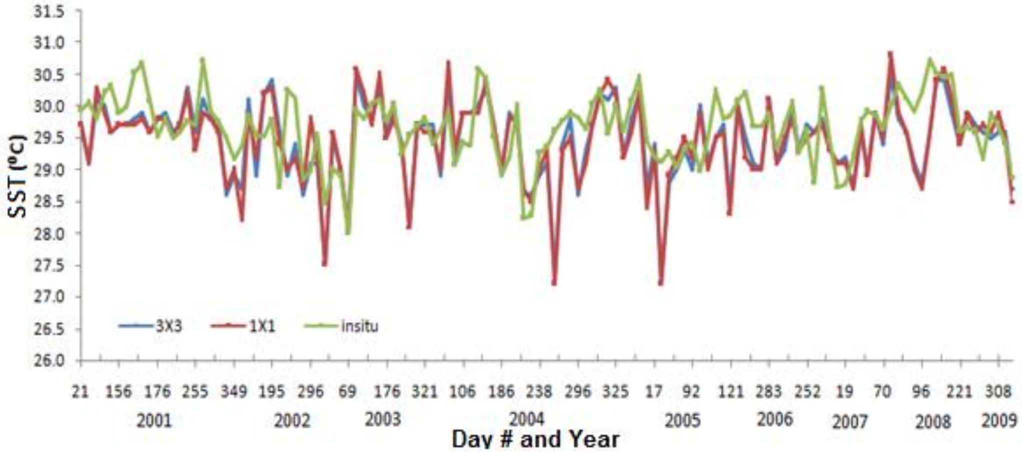


Figure 3. Daily SST mean values from TAO buoy measurements and satellite estimates during night time, station 1 (top), station 2 (middle), and station 3 (bottom).

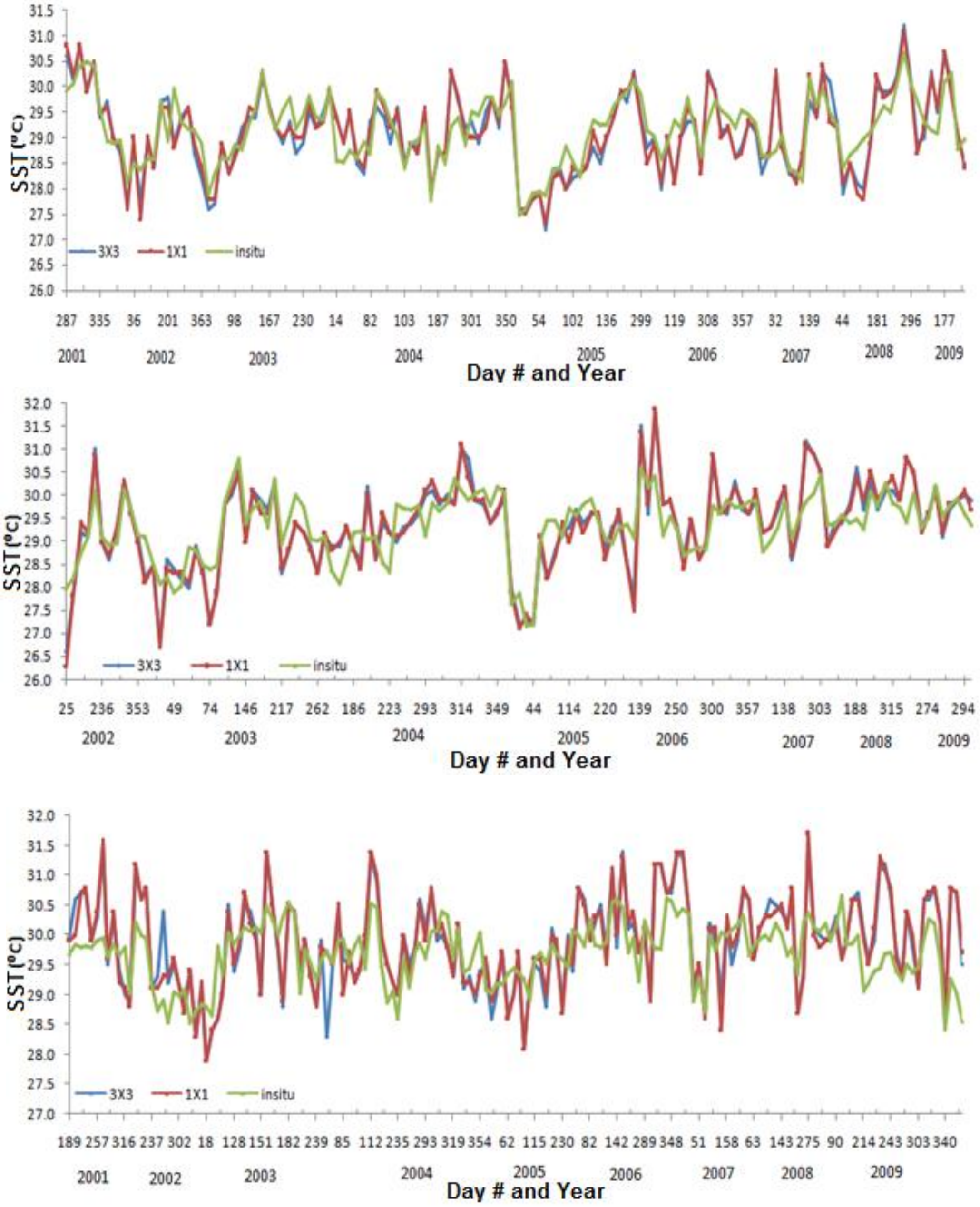


Figure 4. Daily SST mean values from TAO buoy measurements and satellite estimates during day time, station 1 (top), station 2 (middle), and station 3 (bottom).

3.2. Validation of SST Pathfinder Estimate

In the SST satellite data analyses, it is often encountered some extreme (non-valid) data and the data is commonly identified with the value of 255 or 999 or -999, as well as the extreme low or extreme high of SST values or outside the normal range of SST values. Therefore, It is necessary for quality control efforts. A quality control data is an effort to remove a series data of invalid or extreme values, so that the data used for further analyses will be valid data. The quality control analyses results showed that the non-valid SST satellite data dominated the valid SST satellite data (90.84-96.47%; Table 1). The results also showed that non-valid data in daily SST were higher than that in weekly SST data. Non-valid data on weekly SST were less because weekly data was the result of 7 days average composite. High non-valid SST satellite data indicated that this region was covered by cloud up to 96% of the time. For validation, non-valid data were eliminated from the analyses.

Table 1. Percentage of non-valid data of SST Pathfinder estimate in the north Papua waters.

Time	Pixel Size	Station 1		Station 2		Station 3	
		daily	weekly	daily	weekly	daily	weekly
Day Time	1X1	95.28	48.15	94.86	71.06	94.71	69.44
	3X3	91.24	53.70	91.27	54.63	90.84	53.47
Night Time	1X1	96.44	78.47	96.47	78.47	96.08	76.39
	3X3	92.67	60.19	92.82	64.35	93.03	64.81

From Table 1, It was also shown that non-valid data from 3x3 pixel size were in general smaller than that from 1x1 pixel size. This was because the SST data from 1x1 pixel size only contained a single SST data, while 3x3 pixels size contained maximum of 9 SST data.

The relationship between the *in situ* and satellite SST both day and night time were indicated by relatively low coefficient of determination (R^2=0.60-0.71) with positive linear trends. This results indicated that about 30-40% of other factors influenced the relationship between *in situ* and satellite SST data. The RMSE analyses also showed signifcant results of 3.33-5.69% (Table 2) indicating a relatively high variability between *in situ* and satellite SST data. The relatively low R^2 and relatively high RMSE values indicated that Pathfinder algorithm was not a suitable algorithm to estimate SST from NOAA AVHRR satellite in the north Papua waters. The relatively high bias of SST Pathfinder estimate from *in situ* SST was probably affected by the relatively high cloud coverage above the north Papua waters so that the satellite data were not representaive to that *in situ* data. Therefore, a development of an algorithm for SST estimation from satellite NOAA AVHRR data is needed to be conducted by time matching individual satellite and *in situ* SST data.

Table 2. The RMSE values of daily and weekly in situ and satellite SST data.

Data		Daily RMSE values		Weekly RMSE values	
		1X1 pixel	3X3 pixels	1X1 pixel	3X3 pixels
Station 1	Day time	3.61	5.69	5.23	4.68
	Night time	4.45	4.32	4.96	4.88
Station 2	Day time	3.85	3.68	4.55	4.58
	Nigth time	4.49	4.55	4.42	5.16
Station 3	Day time	3.49	3.54	3.88	3.81
	Night time	3.37	3.33	3.73	3.79

4. Conclusion

The SST monthly mean values of the north Papua waters in 2001-2009 ranged of 27.10-31.90 °C. During the east season (June-September), *in situ* SST (average of 29.39 °C) and satellite SST (average of 29.57 °C) were generally higher than that during west season (December-February) i.e., *in situ* SST (average of 29.08 °C) and satellite SST (average of 28.95 °C). The results showed that the SST values of both *in situ* and satellite between night-time and day-time were not significantly different except the station located near to the coast.

The mean values of SST extracted from 1x1 pixel size and 3x3 pixels size were generally not significantly different. However, the north Papua waters indicated a very high cloud covered (91-96%).

The validation results showed that the coefficient of determination (R^2) between the satellite and the *in situ* SST measurements were relatively low (65%) and up to 5% of RMSE. The relatively low correlation between *in situ* and satellite SST measurements may be due to high cloud cover (91-96%) in the north Papua waters so that SST satellite data become less representative of the *in situ* data. These results also indicated that the Pathfinder algorithm can not be used as a valid estimate of SST NOAA AVHRR satellite for the north Papua waters.

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