DEVELOPMENT OF AN ALGORITHM TO PREDICT COASTAL BUOY TEMPERATURE FROM ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR)

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ABSTRACT

Elizabeth City State University currently operates a TeraScan Grounding station capable of receiving and processing imagery data collected by satellites managed by the National Oceanic and Atmospheric Administration (NOAA). The imagery received in the Infrared spectrum both measures sea surface temperatures and cloud cover for the eastern coast of North Carolina. Once the data sets were collected, they were statistically analyzed using the analysis of variance methodology and regression. Strong correlations were observed during the AVHRR-Buoy comparison for two of the three areas under the study. The NOAA-16 AVHRR SST emerged as the most consistent with the insitu data from the ORIN7 Buoy. This was due to its high coefficient of determination.

Keywords— Remote sensing, Ocean temperature, Thermal Sensor, Temperature Sensor.

1. INTRODUCTION

Temperature is an important environmental feature as its variation influences many other environmental activities such as evaporation. Sea surface temperature (SST) is probably the most complex physical oceanic and marine meteorology parameter. Observing, understanding and ultimately predicting its variability is of major importance because SST anomalies are related to several aspects of the global climate. The SST fields are used as boundary conditions for atmospheric and oceanic models, as well as for the verification of model outputs. High-resolution SST maps can depict oceanic surface currents and eddies. Near-real- time (NRT) processing of SST estimation is therefore sought for fishery and weather forecasting applications [1]. The major advantage of satellite remote sensing of SST is its wide coverage of data acquisition in near-real-time. Satellite instruments that observe in the infrared part of the spectrum in principle measure skin SST. One such instrument is the Advanced Very-High Resolution Radiometer (AVHRR) [2] used on satellites operated by the National Oceanic and Atmospheric Administration (NOAA). In practice, AVHRR measurements have been tuned to bulk SST measurements made by buoys [3]. Observations of SST made by ships and buoys are generally made a few centimeters to a few meters below the surface and below both the cool skin and warm layer [4]. These SSTs are called bulk SSTs. The SST directly at the surface is called skin SST and can be significantly different from the bulk SST especially under weak winds and high amounts of incoming sunlight [5, 6]. Several groups have developed methods to adjust bulk SSTs to skin SSTs [6, 7].

This study focuses mainly on sea surface temperature measurements that are collected by NOAA satellites (15,16,18,19) and three NOAA buoys (DKN7, ORIN7, HCGN7) located off the North Carolina coast. The research aimed at developing an algorithm using the Satellite Sea Surface Temperatures (SST) and the buoy temperatures to model the variation between the measurements from both platforms. Prior to the creation of the model, the variance between the sensors was statistically tested to determine if the differences were significant within a 95% level of confidence. The regression model was considered acceptable if a coefficient of determination of at least 50% was found.

2. METHODOLOGY

The data used for the research considered sea surface temperature measurements from two platforms; satellite data and insitu buoy data.

2.1 Satellite Data

The satellite data was obtained using the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Satellites; NOAA-15, NOAA-16, NOAA-18 and NOAA-19. These datasets or measurements were obtained from the Center of Excellence in Remote Sensing Education and Research (CERSER) site (http://cerser.ecsu.edu/terascan). The satellite images obtained, covered the period from 22nd April, 2011 to 14th June, 2011. Within this period 101 images were selected for processing and finally compared to the insitu data. The images were also selected based on the amount of cloud cover present above the regions of interest within the image. It was thus ensured that the images selected were free of cloud cover for the area of interest. SST data with the region of interest was then extracted using ENVI 4.7 image processing software.

2.2 Buoy Data

Three buoys were used in the verification of the SST obtained from the satellite images. These were all located off the coast of North Carolina. The buoys were operated by The Center for Operational Oceanographic Products and Services (CO-OPS) of the National Ocean Service (NOS). The buoys are displayed in Figure 1 below.

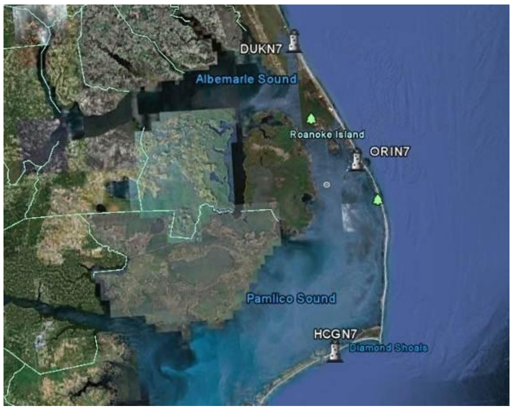

Figure 1: Map showing buoys

1. Station DUKN7 – Duck Pier NC - 36.183N 75.747W
2. Station ORIN7 – Oregon Inlet Marina NC – 35.795N 75.548W
3. Station HCGN7 – Hatteras, NC - 35.208N 75.703W

The SST readings for the above mentioned buoys were retrieved from the National Data Buoy Center (http://ndbc.noaa.gov/). These readings were also taken from 22nd April 2011 to 14th June 2011, at approximately the same time as the satellite readings. Temperature records were done using the Coordinated Universal Time (UTC) to ensure that both readings were done within the same time zone. After both datasets were collected, they were then subjected to statistical analysis.

The main tools used in the data analysis procedures included Microsoft Office Excel 2010 Spreadsheet software and Minitab 15. The first procedure involved an analysis of variance (ANOVA), which was carried out in Minitab 15. This stage applied the balanced ANOVA method. The satellite SST was used as the predictors while the buoy SST as the response. This was ran in all the various regions of interest where the SST's had been gathered. The confidence interval for the test was set at 95% based on the t-distribution. The formulated hypothesis would then be accepted or rejected based on the results from this test. The P-value from the test resulted in 0.001, which meant there was a statistically significant difference in the temperatures. With statistical proof that the variance was significant the next procedure involved conducting regression analysis on both datasets. This was done on an individual site basis in Microsoft Office Excel Spreadsheet software. Both SST datasets were then displayed as scatter plots, and a trendline was applied to the created chart. A regression analysis was run and the R^2 value calculated. This represented the coefficient of determination. Based on the results of the regression a model equation would be created if the compared datasets showed at least 50% correlation. With both regression and ANOVA implemented, the following results were achieved:

3. RESULTS

The time series plot of the two datasets showed the HCGN Buoy generally recorded higher SST as compared to the NOAA satellite AVHRR sensor as seen in Figure 2.

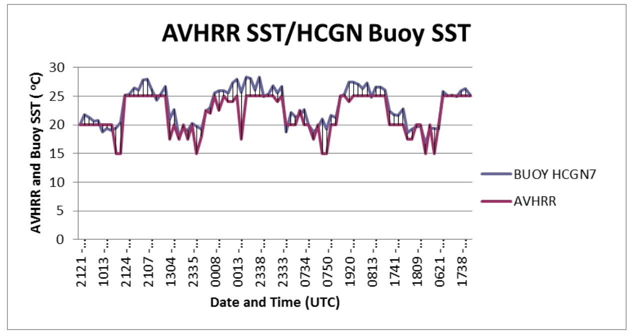

Figure 2: Time series plot of AVHRR SST and HCGN7 Buoy SST

The AVHRR/Buoy comparison revealed a mean temperature difference of +1.44 thus inferring that the buoy recorded an average temperature that was 1.44 degrees Celsius higher than that recorded by the AVHRR sensor. Further analysis was carried out on the two groups of data by means of a linear regression analysis. This showed a correlation between the Buoy and the AVHRR sensor SST with an R2 value of 0.75. Given that the regression showed correlation of more than 50% a model could be created for the difference in SST using the equation Y=0.8939x+1.0254 from Figure 3.

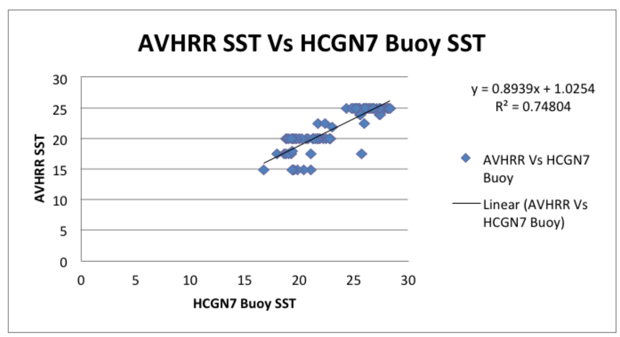

Figure 3: Linear regression analysis of AVHRR SST Vs. HCGN7 Buoy SST

The next comparison between the DUKN7 Buoy and its corresponding AVHRR SST measurements showed great variations in the measured SST of the two datasets as seen in Figure 4.

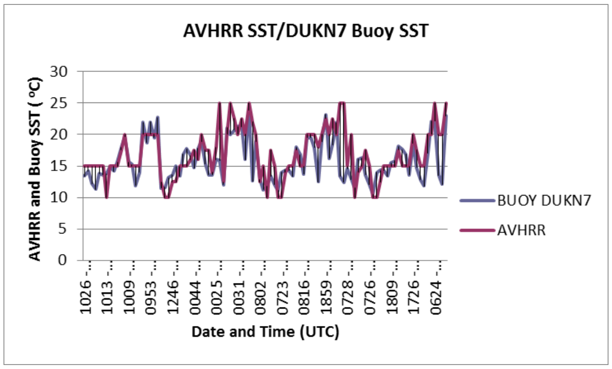

Figure 4: Time series plot of AVHRR SST and DUKN7 Buoy SST

A mean temperature difference of -1.11 degrees Celsius was observed between the Buoy and the AVHRR SST. This was the highest mean temperature difference recorded for all SST comparisons under this project. This implied that the AVHRR predicted temperatures were warmer than the Buoy SST by 1.11 degrees Celsius.

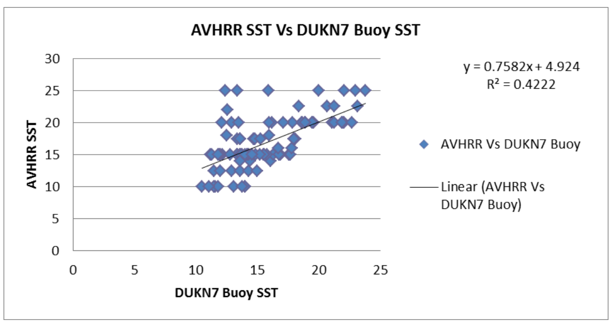

Figure 5: Linear regression analysis of AVHRR SST Vs. DUKN7 Buoy SST

Linear regression carried out on the same datasets (Figure 5) also revealed what was speculated when an R2 value of 0.42 was obtained. Since the correlation observed was less than the benchmark fifty percent (50%) stated by our objectives, the model (Y=0.7582x+4.924) for the AVHRR SST – DUKN7 Buoy relationship would not be a suitable or accurate correction formula.

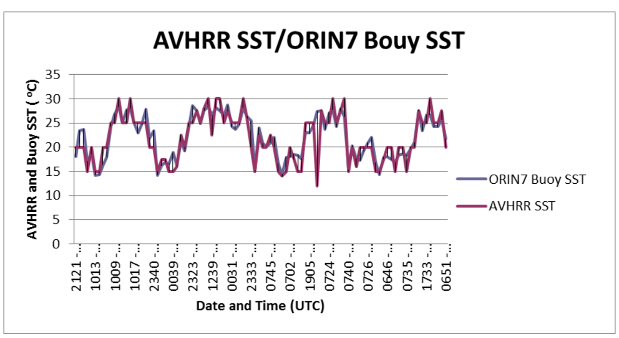

Figure 6: Time series plot of AVHRR SST and ORIN7 Buoy SST

From the time series plot displayed in FIGURE 6 the AVHRR SST was observed to be slightly lower than the SST measurements made by the ORIN7Buoy. A mean difference of +0.27 degrees Celsius was observed inferring that the ORIN7 Buoy SST measurements were slightly higher than the AVHRR SST on the average. This also implied that this data set had the least variance since it recorded the least mean SST difference among all the comparisons.

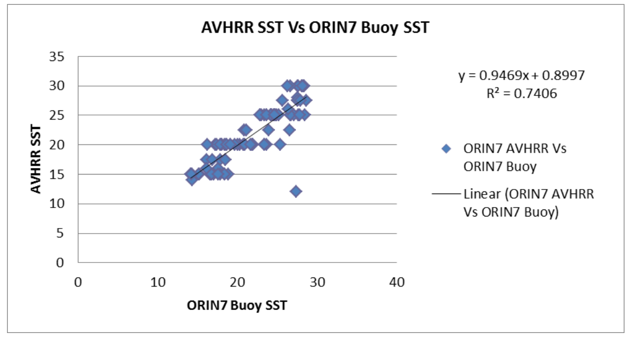

Figure 7: Linear regression analysis of AVHRR SST Vs. ORIN7 Buoy SST

The linear regression carried out for the AVHRR –ORIN7 Buoy SST in figure 7, recorded an R2 value of 0.74 implying a good correlation between the two measurements. With a correlation of 74%, the model, Y=0.9469x+0.8997 could be used in modeling AVHRR SST measurements with more accuracy with respect to the ORIN7 Buoy.

Because the AVHRR SST measurements came from different sensors (NOAA-15, NOAA-16, NOAA-18 and NOAA-19), it was necessary to compare SST measurements between each sensor. The goal was to determine if one sensor was more accurate than the other as shown in Figure 8.

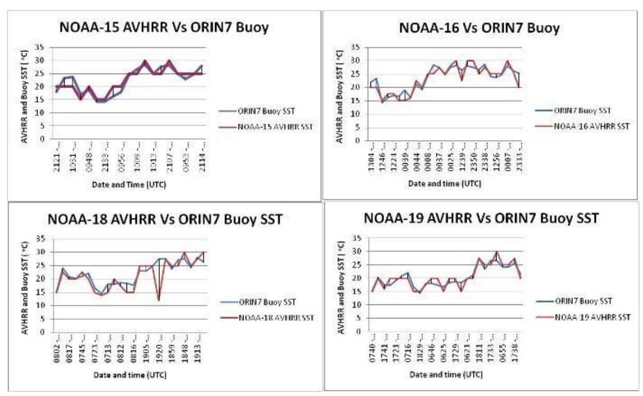

Figure 8: Time series plot of all NOAA AVHRR SST Vs ORIN7 Buoy SST

On the average, the NOAA-18 AVHRR sensor recorded the highest variance when compared to the Buoy SST. The mean temperature difference observed for this comparison was 0.770833 degrees Celsius. The lowest mean temperature difference was measured by the NOAA-15 AVHRR sensor recording an average temperature difference of -0.02105 degrees Celsius between buoy and the sensor. This implied that on the average NOAA-15 AVHRR SST were slightly higher than the temperatures recorded off the ORIN7 Buoy. The NOAA-16 and NOAA-19 sensors recorded mean temperature differences of 0.414815 and -0.11923 respectively.

With respect to the linear regression analysis carried out on all NOAA AVHRR SST sensors, correlations were drawn between the satellite sensors and the ORIN7 Buoy. The highest correlation was observed between the NOAA-16 AVHRR sensors and the Buoy SST measurements. The calculated coefficient of determination for this comparison was the highest for this comparison at 0.858. The NOAA-19 and NOAA-15 AVHRR sensors also recorded high correlations with the buoy with calculated R2 values of 0.840 and 0.801 respectively. In this light the most appropriate AVHRR sensor to use in SST comparisons or estimations based on the ORIN7 Buoy would be the NOAA-16 AVHRR. A model for the correction of the AVHRR SST can then be employed by making use of the equation Y=1.002x-0.289.

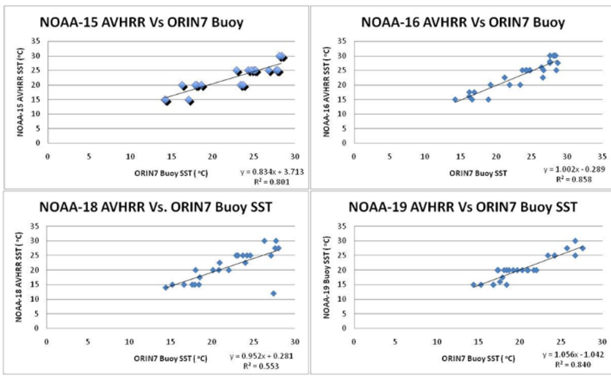

Figure 9: Linear regression analysis of all NOAA AVHRR SST Vs ORIN7 Buoy SST

Results from this project infer that while comparable by most standards, AVHRR SST measurements still needed improvements. This was due to the fact the AVHRR measurements are skin temperatures whiles the buoy measurements recorded bulk temperatures and as such the derived linear equations would only be useful in converting skin to bulk temperatures and vice versa. Since the study was also carried out within a short period (approximately 2 months) SST relationships between platforms cannot be applied at different times of the year due to changes in climatic conditions across seasons. Because there was a tendency for atmospheric variables to undervalue the observed SST, a comparison needs to be made between AVHRR SST and additional atmospheric variables such as wind speed, air temperature, and humidity [8]. This can be done to investigate if any of these variables will affect the performance of the AVHRR sensor. In a study described by Malrig in 2009, it was revealed that a relationship existed between humidity and the performance of AVHRR SST temperatures.

4. CONCLUSION

It was observed that there was a statistical difference between the buoy and satellite measurements at a 95% level of confidence for all the sites. Based on the results of the project it could be deduced that the NOAA AVHRR SST measurements were comparable to the SST of the HCGN and ORIN7 buoy with the ORIN7 buoy comparison being the most consistent with an R^2 value of 0.74 and mean temperature difference of +0.27^{o}C. A further comparison of the all the NOAA AVHRR sensors saw the NOAA-16 AVHRR emerging as the most consistent with the ORIN7 buoy data by having the highest correlation of 0.855 when compared with the buoy SST measurements over the same period.

5. ACKNOWLEDGEMENT

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