Estimating the Distribution of CO_2 Parameters in Surface Water of the Indian Ocean from Temperature and Salinity

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Abstract— ***The distribution of CO_2 parameters in the ocean is important for understanding the fate of anthropogenic carbon emission and its effects on global climate change. Among the four essential parameters, pH, alkalinity (TA), pCO_2, and total inorganic carbon (Tco_2), any two of them are sufficient to fully define the aquatic CO_2 system. Traditionally, each CO_2 parameters has to be determined using either field sampling or in situ sensors which are inefficient. As a result, temporal and spatial variations of CO_2 system are poorly understood. Recently, linear correlations between CO_2 parameters and temperature, salinity, and concentrations of dissolved organic carbon (DOC) and particulate organic carbon (POC) of various surface waters have been developed (Lohrenz and Cai 2006, Berryman et al. 2007, Small and Reid 2007, Yuan 2009). Since sea surface temperature (SST) can be determined from satellite sensors, concentrations of DOC and POC can be estimated from satellite data, and the satellite sensor for sea surface salinity will be launched soon, these correlations will enable estimation of global distribution of CO_2 parameters from satellite data. We tested these linear equations by predicting CO_2 parameters from sea surface temperature and salinity along cruise transects in the Indian Ocean. We compared our prediction with field measurements of CO_2 parameters and evaluate the potential of these linear equations for estimating CO_2 parameters. The final research paper presents our final results, which show which formula could possibly be future ways of estimating the distribution of CO2.***

Index Terms—carbon dioxide, temperature, salinity, partial-pressure carbon dioxide, alkalinity, linear regression

I. Introduction

Oceans are reservoirs for carbon dioxide. Accurate estimation of carbon dioxide in the ocean is essential for the study of global carbon cycling and climate change. It is very difficult to measure carbon dioxide (CO_2) in the field, so the four essential parameters of CO_2 are used. The four parameters are pH, alkalinity (TA), partial pressure carbon dioxide (pCO_2), and total inorganic carbon, any two of them are sufficient to fully define aquatic CO_2. Partial pressure of carbon dioxide, pCO_2, is a measurement of carbon dioxide, CO_2, and one of the most powerful greenhouse gases that affects the climate [*Berryman et. al 2007]*. Satellite remote sensing is an alternative for measuring pCO2, but the remote sensing algorithm for CO2 has not been reported [*Small and Reid 2007, Yuan 2009]*. In efforts to better measure carbon dioxide in the ocean, we tested liner equations against sea surface temperature and salinity in the Indian Ocean. Then, we compared predictions to measured pCO2 and evaluated the applicability and accuracy of the linear equations. The accuracy of the equations used to measure pCO2 will better assist in determining the levels of carbon dioxide in oceans.

II. Methods

In attempt to study the distribution of pCO_2 using remote sensing data, Lohrenz and Cai developed a remote sensing algorithm to calculate pCO_2. Their algorithm contained parameters SST (sea surface temperature), Cha *a*, climatological salinity and chromphortic dissolved organic matter (CDOM) [*Berryman et. Al 2007* Although their formula was not reported in their studies, we applied similar equations to our study. With the insight gained from previous studies, we tested the accuracy of the empirical formula derived by Yuan.

Field measurements from cruise transects of the Indian Ocean were obtained from the CDIAC website during June 29 2002-July 25 2002. Cruise plots created from the Indian cruise were IO3, 1O8, IO9, I10.

Because of the extent amount of raw data collected during the cruise, it was best to divide measurements into three sectors. The first set consisted of data collected from I03. The second data set included measurements from 108 and the first half of I09 (IO9a). Last, measurements from the second half of I09 and I10 were combined. This division yielded three sets of results.

The data was sorted using analysis software, Microsoft Excel. Data that contained a pressure greater than 15 dbar was

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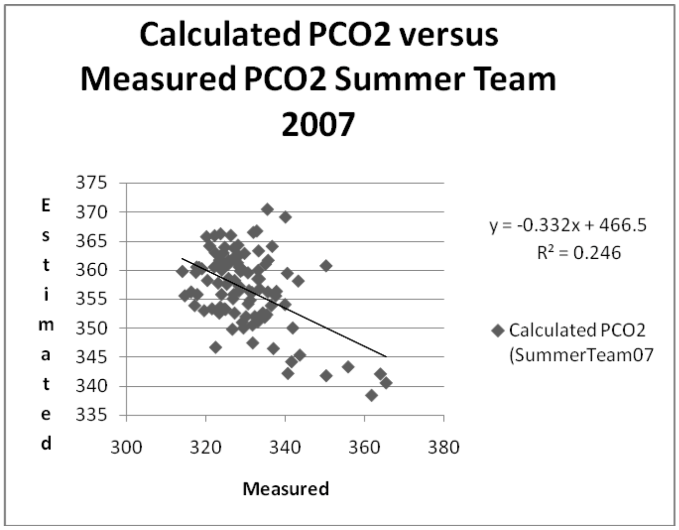
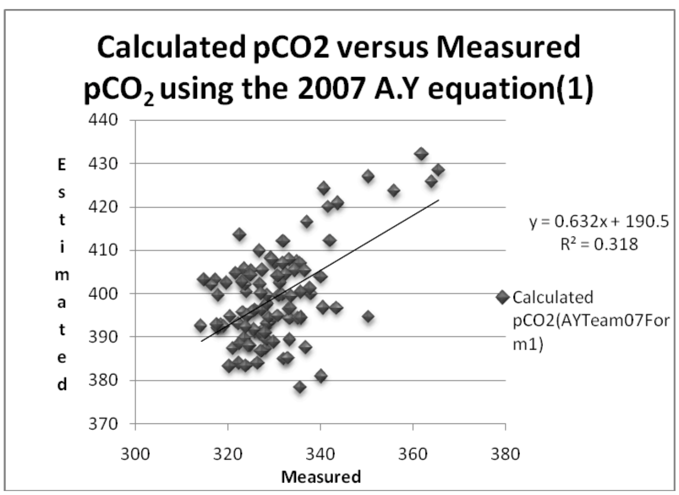
excluded; measurements with salinity of -.999 were also excluded from calculations. These data measurements were removed to provide better accuracy. A linear relationship between field measurements and estimated formulas were applied to data. The comparison resulted in a linear regression plot allowing us visualize and compare calculated pCO2 versus estimated pCO2.

III. RESULTS

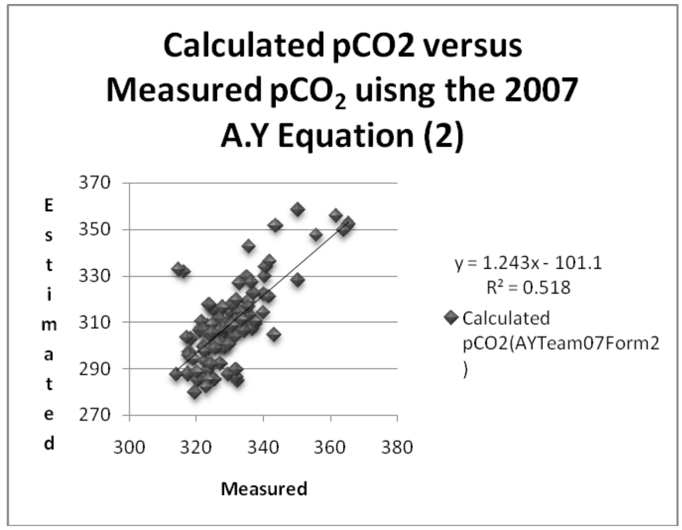
IO3:



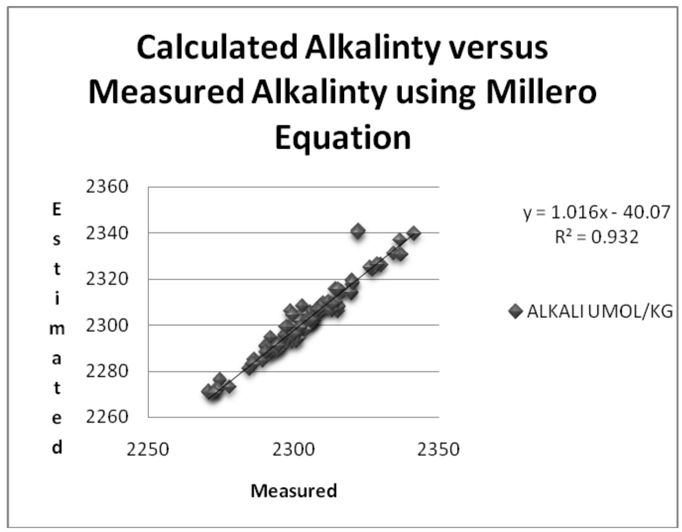
Graph 1: Displays the correlation between estimated pCO_2 and measured pCO_2 of the 2007 Summer Team



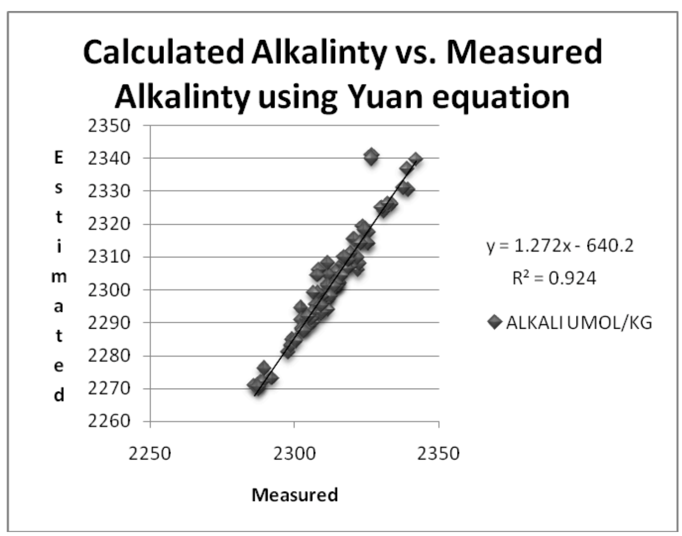
Graph 2: Displays the correlation between estimated pCO_2 and measured $pCO_2$of the 2007 Academic Team



Graph 3: Displays the correlation between estimated pCO_2 and measured pCO_2 of the 2007 Academic Team



Graph 4: Displays the correlation between estimated alkalinity and measured alkalinity using Millero equation



Graph 5: Displays the correlation between estimated alkalinity and measured alkalinity using the Yuan alkalinity equation

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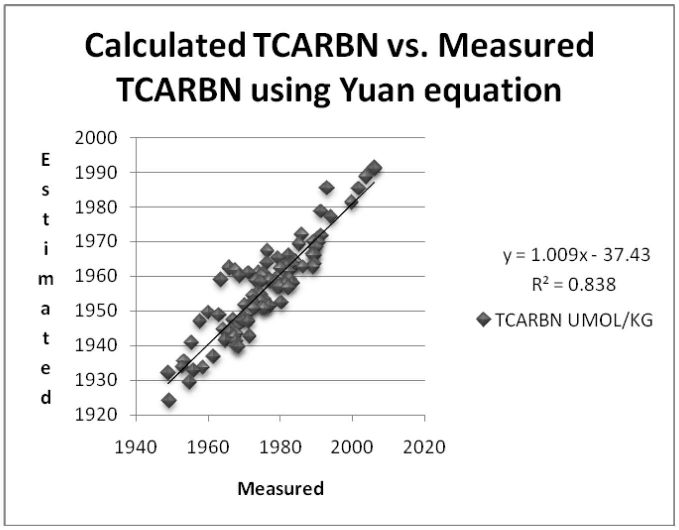
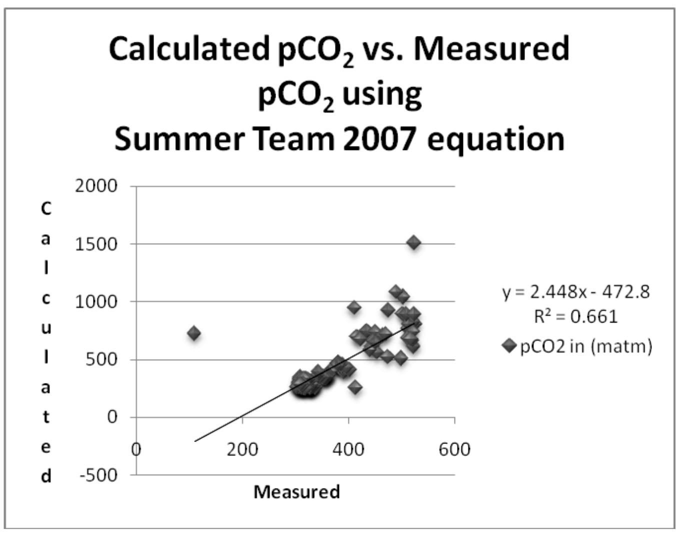
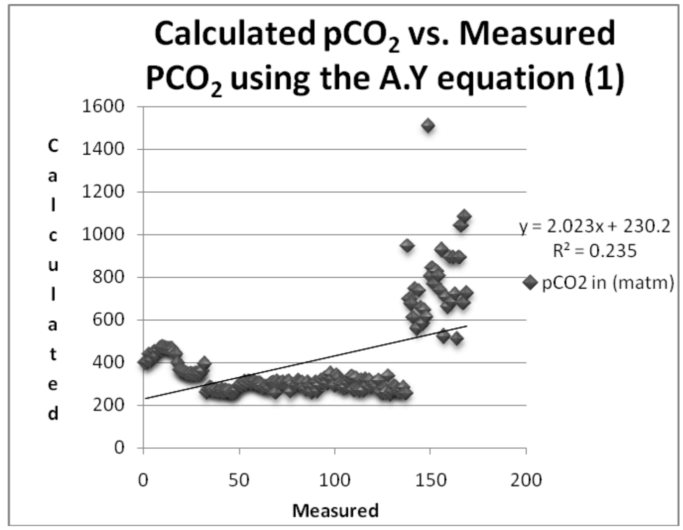


Graph 6: Displays the correlation between estimated TCO_2 and measured TCO_2 using the Yuan TCO_2 equation

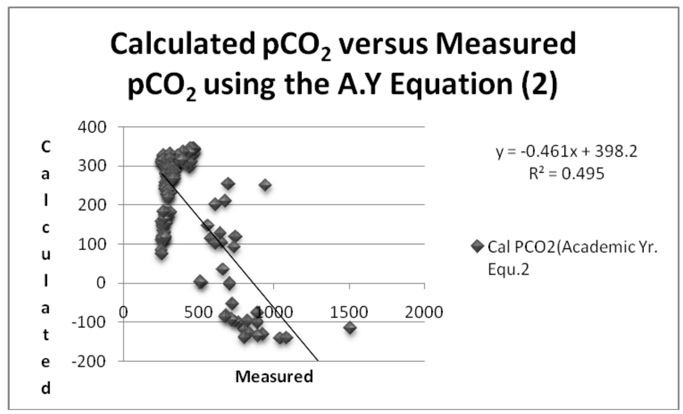
IO8 and IO9a:



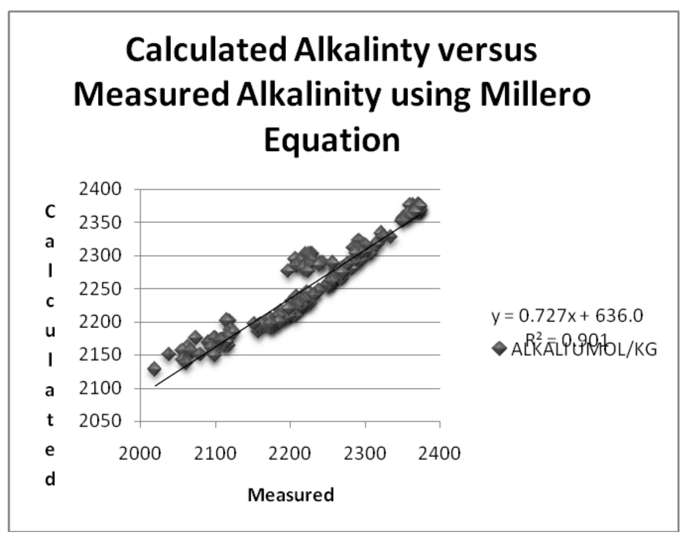
Graph 7: Displays the correlation between estimated pCO_2 and measured pCO_2 of 2007 Summer Team



Graph 8: Dispalys the correlation between estimated pCO_2 versus measured pCO_2 of the 2007 Academic Team



Graph 9: Displays the second correlation between calculated pCO_2 and measured pCO_2 of the 2007



Graph 10: Displays the correlation between estimated alkalinity and measured alkalinity using Millero equation

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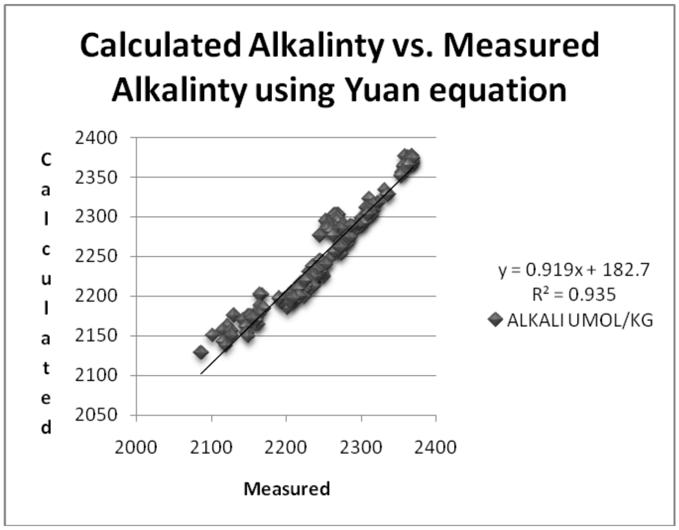
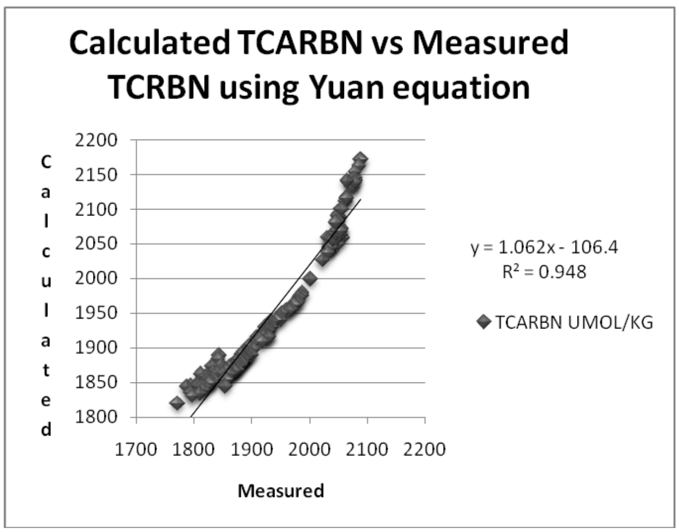
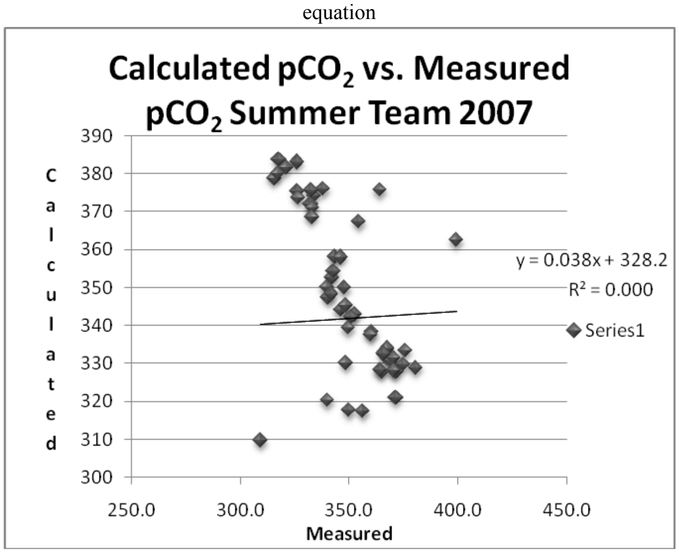


Graph 11: Displays the correlation between estimated alkalinity and measured alkalinity using the Yuan alkalinity equation

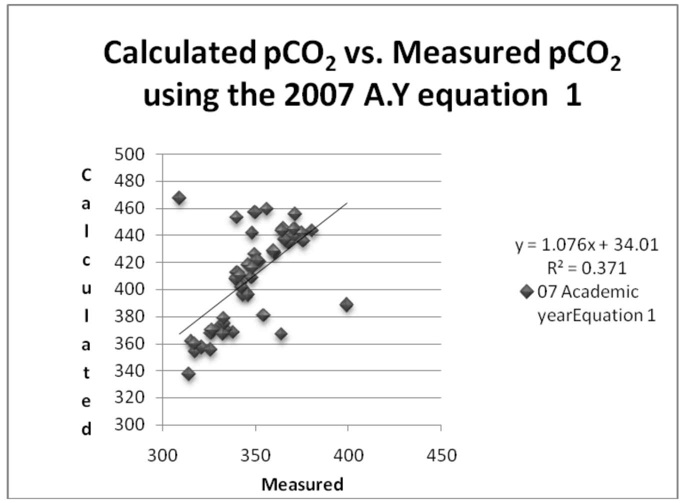
IO9a and I110



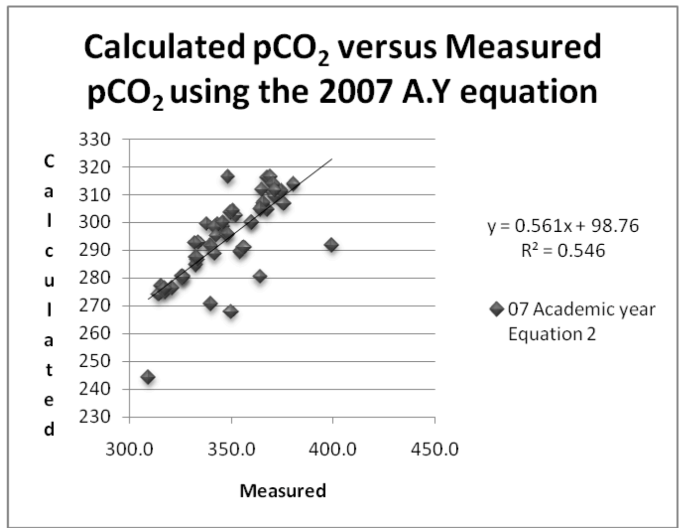
Graph 12: Graph 6. Displays the correlation between estimated TCO_2 and measured TCO_2 using the Yuan TCO_2 equation



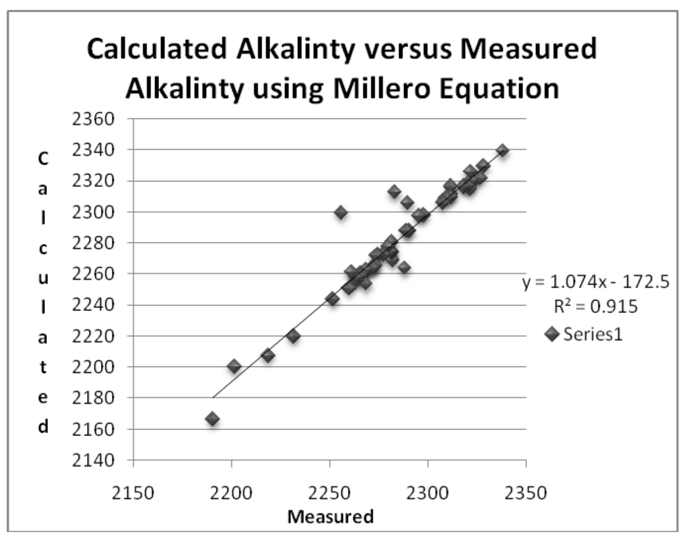
Graph 13: Displays the correlation between estimated pCO_2 and measured pCO_2 of the 2007 Summer Team



Graph 14:



Graph 15:



Graph 16:

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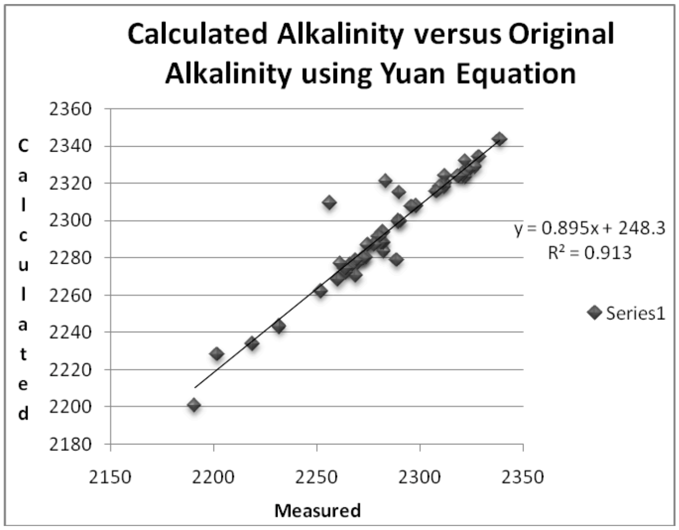
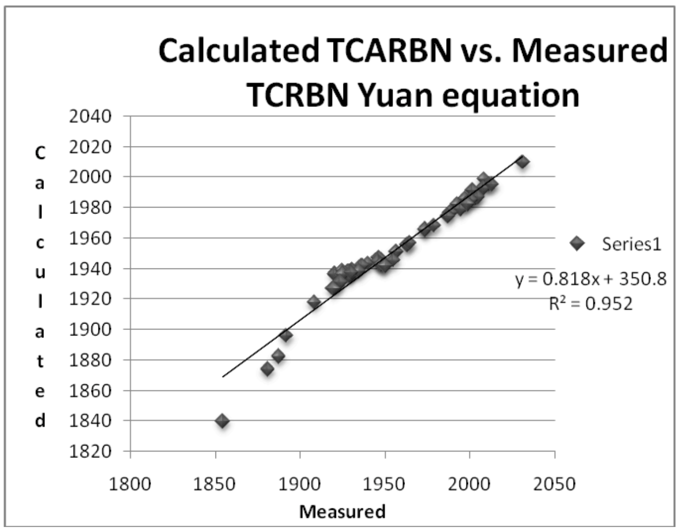


Graph 17:



Graph 18: Displays the correlation between estimated TCO_2 and measured TCO_2 using the Yuan TCO_2 equation

IV. Discussion

IO3:
After truncating all of data that was defined and the calculations were done, the data showed that Yuan's and Millero's formulas were the most accurate. Yuan's formula for estimating alkalinity was very close to the measured data of the Indian Ocean cruise plots. A graph to show the correlation was created in Figure (4). The R-Square for this correlation is 0.924. This was an exceptional number because the closer the r-square value is to one, the better the correlation. Yuan's second formula tested total carbon (TCARBN). The r-square for this formula was 0.838. This simply means that this formula was not as good as the first but not too bad. This correlation was shown in Figure (5). It has a seventeen percent variation. Millero used a simple linear regression to test the total alkalinity also. The r-square for his correlation was 0.932. This means that this formula has little variation. The correlation that represented this formula was shown in Figure (4). These formulas show that if the temperature and salinity are given then one can calculate the alkalinity. This is more empirical than theoretical. Theoretically if one has the DIC, alkalinity, or pH, he or she can calculate the pCO_2. This theory is tested in the academic year 2007 Undergraduate Research Experience (URE) team and also the summer 2007 Undergraduate Research Experience team. The URE 2007 summer team used a multiple linear regression to estimate the pCO_2. The r-square for this team's data was 0.246. This shows that this formula works very poorly with this data. This regression is shown in Figure (1). The academic year team's formula also tested pCO_2. The first formula's r-square was 0.318 and the second formula's r-square was 0.518. This was shown in Figures (2) and (3).

IO8, IO9a:
The most accurate equation for this data set was the Yuan equation. The equation showed the best slope and y- intercept relationship. Yuan's equation for Alkalinity resulted in the following: $R^2$of 0.935, the slope was 0.919, and the y-intercept was -182.7 (Figure 11). The results for Yuan's equation for Carbon Dioxide came out to be: R^2 of .948, slope of 1.062, and y-intercept of -106.4. The R^2 for the Yuan equation was as closer to one than any of the other equations (Figure 12). Millero's equation gave us great feed back with the results from his equation. The R^2 for Millero's equation turned out to be 0.901, the slope was 0.727, and the y-intercept was 636 (Figure 10). His results were similar in some ways to the results from Yuan. The equations from the Academic Year 2007 weren't as effective as Millero's and Yuan's equations. . The R^2 for the Academic Year 2007 was .235, the slope was 2.023, and the y-intercept was .235. There was also a second formula that the Academic Team 2007 formulated, the R^2 was .495, the slope was -0.461, and the y-intercept was 398.2. Their equation was also as ineffective as the Academics Team's equations. The R^2 equaled .661, the slope was 2.448, and the y-intercept was -472.8.

IO9b, I10 (Figures 12-18)
The results from the first equation by the Academic year 2007 displayed an R^2 value of 0.371, a slope of 1.076 and a y-intercept value of 34.01, Figure 14, this chart measured pCO_2. The second equation obtained from the Academic year 2007 also measured pCO_2. Final calculations from this equation were; R^2 amounted to 0.546, slope; 0.561, and the y-intercept came to be 98.76 (Figure 15).
Millero's equation configured an R^2 value of 0.915, a slope of 1.074, and -175.5 was the final y-intercept value (Figure 16). The first Yuan equation measured alkalinity. The R^2 calculated from this plot was 0.913, with a slope of 0.895 and a y-intercept value of 248.3 (Figure 16). Yuan's second linear equation measured TCO_2. The value of R^2 of this graph is 0.952; with a slope value of 0.818 and y intercept value of 350.8 (Figure 17).
For the equations to be considered perfect, the r-square value would equal one, the slope would equal one and the y-intercept would equal zero. After testing all equations, ability to predict pCO_2 from temperature and salinity and observing all results, the most accurate formula would be Millero's. The Academic Year 2007 (2) presented the worst results. The

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cause of their bad results could be due to the fact that their formulas were theoretical while the Yuan equations and Miller equations were both empirical. These differences in the equations may have caused the linear regressions of the academic and summer team to be inapplicable to this study. This also shows that the formulas created by the academic and summer teams cannot be applied to other bodies of water.

IV. Conclusion

There is a need to develop innovative methods that accurately assess regional carbon dioxide levels based on satellite remote sensing data. Although the academic and summer formulas fail to accurately estimate pCO_2 in the Indian Ocean, the potential of the Yuan equation ability to predict pCO2 levels in the Indian Ocean appears to be high. Future studies can be done to see if equations apply to other oceans.

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