Comparisons of Physical Properties of Ocean Subsections of Similar Latitudes to In Situ Data

Henry Sue

March 2017

Abstract

Comparisons between the thermophysical properties of seawater at two different locations in the Southern Hemisphere, but similar latitudes may give insight to heat and salinity distributions within the ocean. Remote sensing provides data and parameters to allow us to compare the conditions of seawater at our designated areas. Using data collected from the MODIS instrument aboard the satellite Aqua, plots of Sea Surface Temperature (hereafter referred to as "SST") are generated. In addition, data collected from the Aquarius Satellite allows for the generation of a plot of Sea Surface Salinity (hereafter referred to as "SSS"). By comparing salinity and temperature of both points, correlation or lack thereof can be distinguished. Since seawater's salinity capacity is affected by temperature, we should expect to see that the salinity correlates with temperature. Only recently has SSS been able to be measured remotely, by measuring microwave backscattering. The resulting data from this investigation may provide insight into whether remotely sensed data is accurate enough to be used in lieu of in situ data. Remotely sensed salinity data and in situ salinity data from the World Ocean Database will be compared, offering a better understanding of how accurate remotely sensed salinity data is. A primary concern is whether a more accurate method for remotely documenting sea surface salinity is needed.

1 Introduction

Salinity and temperature are important physical characteristics of seawater. When modeling the ocean, salinity and temperature determine the density, which also determines ocean circulation. Thermohaline variability affects nutrient availability and habitability. Typically, more habitable areas exhibit larger biodiversity. The goal of this project is to investigate the accuracy of Salinity measurements and the subsequent density in the areas off the coast of South Africa, and New Zealand. Using MIT's thermophysical seawater properties toolbox [Sharqawy et al., 2010] , we can compare expected values of density to observed values by remote sensing.

In order to compare the effects of SST and SSS on seawater density, we must choose different areas of interest that can represent the variability of relevant parameters. Our base region of interest is the Tasman Sea off the Coast of Southwest New Zealand. This region is selected as a point of interest because of its low seasonal variability. [Oliver et al., 2014] Its temperature is regulated by the alternating balance of sub-antarctic currents and the South Equatorial Trade Current. Our second region of interest is the False Bay, off the coast of Cape Town, South Africa. The False Bay is selected, due to its abnormally warm surface temperature [Atkins, 1970] . This can partially be explained by the interaction of the warm Agulhas current and the cool Benguela current. Another interesting aspect is the biodiversity of the False Bay [Griffiths et al., 2010]. Expected values of Sea Surface Temperature for both areas should correlate with monthly temperature variations. In the Southern Hemisphere, the warmest months occur between November through March, whereas the colder months occur between April and October. However, Sea Surface Salinity is affected differently by seasonal capacity changes, which can alter seawater density values. SSS is largely dependent on the balance of local precipitation and evaporation. Because seasonal changes of precipitation and evaporation have high variability, we should expect to see it affect seawater density much more.

Combining both parameters allows us to plot the change in Seawater Density over our timespan (2014). Sea surface Salinity is measured remotely by the backscattering of microwave radiation. Microwave remote sensing has inherently lower spatial resolution, so we may expect it to have a larger impact on our calculations. Its larger variability may also call into question its accuracy in comparison to other parameters.

The goal of this study is to first compare temperature and salinity data at both regions of interest to check for expected correlation, and next, to compare salinity data from both satellite datasets and in situ datasets provided by the World Ocean Database. By doing this, we can compare data to check if the satellite data is accurate.

2 Methods

The first area that will be investigated is the approximately 250 km x 250 km square centered at the false bay off the coast of Cape Town, South Africa. This region is interesting because it is 6°C warmer than surrounding bays of South Africa. [Figure 1]

The second area that will be investigated is the approximately 275 km x 275 km square centered around the Southwestern coast of New Zealand. This region is interesting because the Western Coast's Chlorophyll concentrations should indicate colder waters, yet the sea surface temperature is normal. [Figure 2]

To begin our calculations, we must first identify and parse temperature and salinity data. Two areas of interest are selected. Each area contains approximately 30% land which provides coastal information. By including small portions of land within the area of study, we can measure the temperature and salinity gradient off the coast. The first area of study is defined by the 250 km x 250 km area centered around the False Bay, off the coast of Cape Town, South Africa. The second area of study is defined by the 275 km x 275 km area centered off the Southwest corner of New Zealand in the Tasman Sea. These specific areas are selected to contrast an area of normal temperature and low salinity variation with an area of warmer temperature and moderate salinity variation, which are represented by the Tasman Sea region and the False Bay region, respectively.

Sea Surface Temperature data is measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua Satellite. The spatial resolution of MODIS for the Temperature parameter is 9 km, although the data set also provides up to 4 km resolution. Sea Surface Temperature is calculated by comparing radiance to blackbody temperature. Monthly averages of Sea Surface Temperature in both areas of interest are plotted for the year of 2014 to show seasonal variation and correlation between both areas. Additionally, monthly averages for sea surface temperature are plotted for the entire study time range (Aug 2011 – May 2015) [Figure 3], which indicates strong correlation over the entire time range. Data was extracted from the netCDF files using matlab, and The Sea Surface Temperature Data was accessed and downloaded via the Oceancolor interface provided by NASA [NASA Goddard Space Flight Center, 2014].

Sea Surface Salinity data is measured by the Aquarius device aboard the Argentine SAC-D spacecraft. Aquarius is an instrument that uses the L-Band to measure microwave backscattering of the ocean surface to calculate Sea Surface Salinity. The spatial resolution for the Aquarius instrument is 100 km, which is gridded to each degree. Monthly averages of Sea Surface Salinity in both areas of interest are plotted for the year of 2014 [Figure 5]. Additionally, monthly averages for sea surface salinity are plotted for the entire study time range, (Aug 2011 – May 2015) [Figure 6]. This time range is chosen because it offers the entire range of measurements where the Aquarius instrument was active before its failure in 2015. The Sea surface Salinity Data was accessed and downloaded via the Oceancolor interface provided by NASA.

In-Situ Sea Surface Salinity data is collected by sensors onboard stationary buoys scattered around the ocean. Data values are tabulated from the salinity value on the first day of each month between August 2011 to May 2015 [Figure 7]. Missing values were interpolated by looking for the nearest available value. The largest discrepancy between the date of a missing data entry was 4 days between the first day of the month and the date of the nearest available value. The data was provided by the World Ocean Database and was downloaded through their online data library. Data submitted after the update to the 2013 database is considered preliminary and has not been subject to the same quality control compared to 2013 and prior. [Boyer et al., 2013]

3 Results

3.1 Sea Surface Temperature

Sea Surface Temperature is measured by MODIS Aqua. The data used is the monthly composite of daytime Sea Surface Temperature with a resolution of 9 km. The data spans the 12 month range of 2014. [Figure 3] This plot is a monthly average for the span of one year to indicate seasonal variation and correlation between the different areas. In the False Bay, temperatures had an average value of 20.2. degrees Celsius. The maximum observed temperature was 21.1 degrees Celsius in the month of December. The minimum temperature was 19.3 degrees Celsius in the month of June. In the Tasman Sea, temperatures had an average value of 13.6 degrees Celsius. The maximum observed temperature was 15.7 degrees Celsius in the month of March. The minimum observed temperature was 11.7 degrees Celsius in the month of September. Both plots follow a similar trend, starting high in January, falling to a minimum during the summer and rising towards the Winter.

Sea Surface Temperature was plotted in the 46 month range from August 2011 to May 2015, which follows the time span of the Aquarius satellite's lifetime. [Figure 4] In the False Bay, the temperatures had an average value of 21.8 degrees Celsius. The maximum temperature was 23.8 degrees in the month of September 2012. The minimum temperature was 19.3 degrees Celsius in the month of June, 2014. In the Tasman Sea, the temperatures had an average of 13.9 degrees Celsius. The maximum temperature was 16.8 degrees Celsius in the month of November 2014. The minimum temperature was 11.2 degrees Celsius in the month of February 2015. Both plots follow a similar trend, with high temperatures during the Winter seasons and low temperatures in the Summer.

3.2 Sea Surface Salinity

Sea Surface Salinity is measured by Aquarius. The data used is the monthly composite of Sea Surface Salinity with a resolution of 1 deg. The data spans the 12 month range of 2014. [Figure 5] The plot consists of monthly averages over the span of a year to indicate that there is little to no correlation between the two areas. In the False Bay, the average Salinity over the time span of 2014 is 35.5 g/kg. The maximum value is 35.6 g/kg in the month of March. The minimum value is 35.1 g/kg in the month of April. In the Tasman Sea, the average Salinity over the time span of 2014 is 35.4 g/kg. The maximum value is 35.7 g/kg in the month of November. The minimum value is 35.0 g/kg in the month of May.

Sea Surface Salinity was plotted in the 46 month range from August 2011 to May 2015 [Figure 6], which follows the time span of the Aquarius satellite's lifetime. In the False Bay, the salinity had an average value of 35.6 g/kg. The maximum salinity was 36.9 g/kg in the month of December 2013. The minimum salinity was 33.5 g/kg in the month of November 2012. In the Tasman Sea, the salinity had an average of 35.4 g/kg. The maximum salinity was 34.1 g/kg in the month of May 2013. The minimum salinity was 34.1 g/kg in the month of December 2011. The two areas do not have any notable correlation. Both plots center near 35.5 g/kg with few outliers.

The In Situ Sea Surface Salinity data was plotted in the 46 month range from August 2011 to May 2015, which follows the time span of the Aquarius satellite's lifetime. The data was gathered from anchored buoys. [Figure 7] In the False Bay, the salinity had an average value of 35.7 g/kg. The maximum salinity was 36.3 g/kg in the month of February 2013. The minimum salinity was 35.0 g/kg in the month of August 2012. In the Tasman Sea, the salinity had an average of 35.5 g/kg. The maximum salinity was 36.0 g/kg in the month of January 2015. The minimum salinity was 35.0 g/kg in the month of May 2015. The two areas do not have any notable correlation. The False Bay Area is be more variable than the Tasman Sea area.

4 Discussion

4.1 Correlation of Temperature and Salinity

Sea Surface Temperature was plotted over the span of 2014 [Figure 3], which shows correlation of data seasonally. The False Bay seems to stay an approximate constant temperature of 7 degrees Celsius warmer than the Tasman Sea for each month. Between the months of January and August, both areas show a downward trend of temperature, and both areas show an upward trend between September and December. Sea Surface Temperature was also plotted over the span of the Aquarius satellite's lifetime, from Aug '11 to May '15. [Figure 4]. As expected, both areas show seasonal trends of high temperatures during the months of December and January as well as low temperatures during the months of August and September. There is strong correlation between the peaks and troughs of each area's temperature.

Sea Surface Salinity was plotted over the span of 2014 [Figure 5]. There seems to be no immediate correlation between salinity values seasonally, nor does there seem to be any relation between salinity values monthly. The observed Salinity in the False Bay seems to stay slightly constant, around 35.5 g / kg, whereas the observed Salinity in the Tasman Sea seems to fluctuate wildly. Sea Surface Salinity was then plotted over the span of Aug '11 to May '15, which represents the span of the Aquarius Satellite's lifetime [Figure 6]. At first glance, the data seems to have points where both areas have similar trends of salinity (Aug '12 - Dec '12), however with further observation, it seems as though there are points where both areas are wildly dissimilar (Aug '11, Jun '13 - Aug '13). There is no concrete correlation between observed values of Salinity as well as a large amount of variation, so seasonal and monthly salinity correlation can be ruled out.

Seawater's Salinity Capacity relies on temperature, as well as evaporation and precipitation. This relation is the reason we should expect to see correlation between temperature and salinity data. However, since there seems to be no average seasonal variation for salinity, we see little to no correlation between remotely sensed Sea Surface Temperature and Sea Surface Salinity.

4.2 Correlation of Remotely Gathered and In Situ Salinity Measurements

Remotely Sensed Sea Surface Salinity was gathered earlier for the time span of Aug '11 to May '15 [Figure 6]. Salinity data was also gathered from the World Ocean Database, using measurements from Anchored Buoys. The in-situ data is plotted over the same time span, from Aug '11 to May '15 [Figure 7]. The in-situ data appears to have no seasonal correlation, as well as being extremely variable. In both areas, it seems as though there are no months where peaks and troughs align. Furthermore, although both areas seem to have values centered around 35.5 g / kg salinity, the False Bay has readings of above 36 g / kg salinity in 2011, and falls to 35.5 g / kg salinity. However, the Tasman sea starts around 35.5 g / kg salinity, and falls even lower, to 35 g / kg salinity.

Both Remotely Sensed Sea Surface Salinity and In-Situ Salinity are plotted on the same axis [Figure 8]. In the False Bay (Blue and Green lines, In-situ and Remote, respectively), although there are points where data agrees (Sep '12 - Jan '12, Dec '14 - Feb '14), there are also points where the data disagrees (Oct '11, Aug '12, Oct '13, Feb '14). In the Tasman Sea (Red and Purple lines, In-Situ and Remote, respectively), there are both points that agree (Apr '12, Sep '12, Jun '14) and points that disagree (Dec '11, Oct '14). Data from both areas and both sources reveal no direct correlation beyond the fact that all salinity values are centered around 35.5 g / kg. Without further research into the algorithms that extract salinity values from backscattering data, and validation for in-situ sources, there is no conclusive conclusion to be made from this data. Furthermore, the in-situ data is slightly more imprecise than satellite data, which could possibly be because of boundary conditions for the data parsing algorithm, or the nature of the non-curated data from the anchored buoys.

4.3 Limitations of Analysis

The studies detailed do not accurately reflect the relation of Seawater Salinity and Seawater Temperature. As written in [Nayar et al., 2016] and [Safarov et al., 2009], the physical properties of seawater are closely related. In addition, the remote Sea Surface Salinity measurements should be quite accurate, as shown in [Nardelli et al., 2016] and [Klemas, 2011]. However, because the data set used for in-situ data has not yet been curated, and brought to world ocean database standards [Boyer et al., 2013], there exists an intrinsic amount of unconfirmed data and uncertainty. Finally, because of the limited timespan of the Aquarius instrument, we cannot compare data over a longer span of time, which would lead to a more conclusive study, as well as provide more accurate data, as the World Ocean Database can validate and update its data to its standards.

5 Conclusions

By analyzing data recorded from both satellite and in-situ sources, we concluded that there seems to be no correlation between salinity measurements and temperature measurements in both the False Bay and the Tasman Sea. Furthermore, there seems no conclusive correlation between satellite gathered and in situ salinity data. Although the degree of precision is better than field data, without a more detailed study of the satellite algorithm and its calibration, as well as the validation of in-situ data, the accuracy of salinity data cannot be understood. Future studies on this topic may include calibrating and comparing in-situ salinity measurements that are extremely accurate with satellite data of the same area. Another interesting direction that can follow is the analysis of the satellite algorithm to further develop accurate remote salinity measurements.

6 Figures

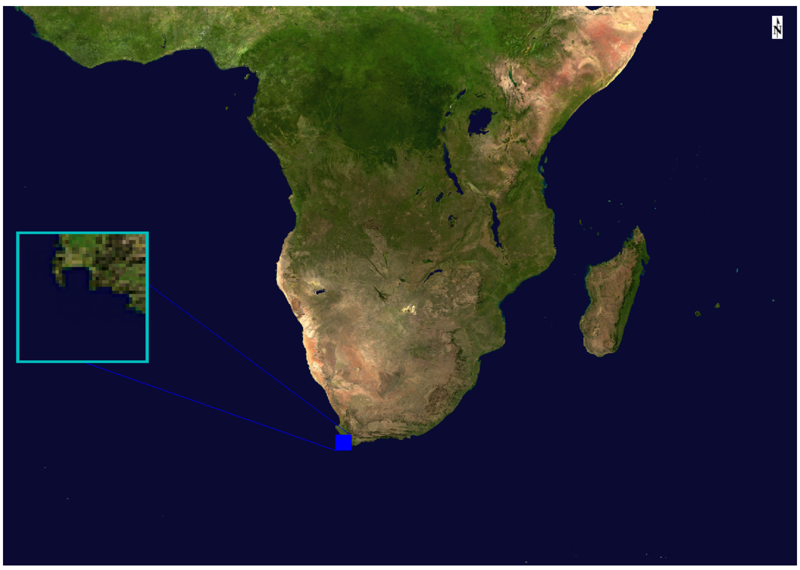

Figure 1: 250 x 250 km square region centered around the False Bay off the coast of Cape Town, South Africa. The turquoise box is a enlarged view to show geographic features. The background image is the Blue Marble image.

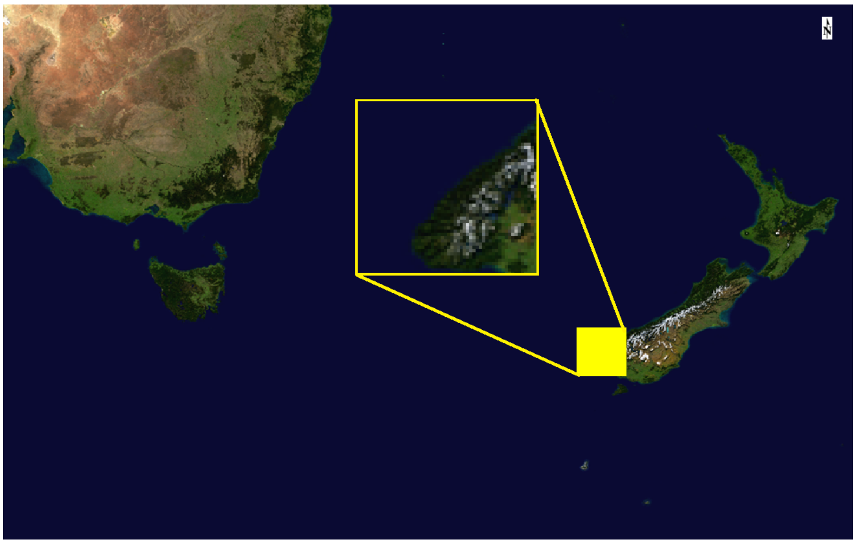

Figure 2: 275 x 275 km square region centered around the Tasman Sea off the Southwest coast of New Zealand. The yellow box is a enlarged view to show geographic features. The background image is the Blue Marble image. Although land area is included in the image, data is collected only from the Sea Surface. Land data is masked out.

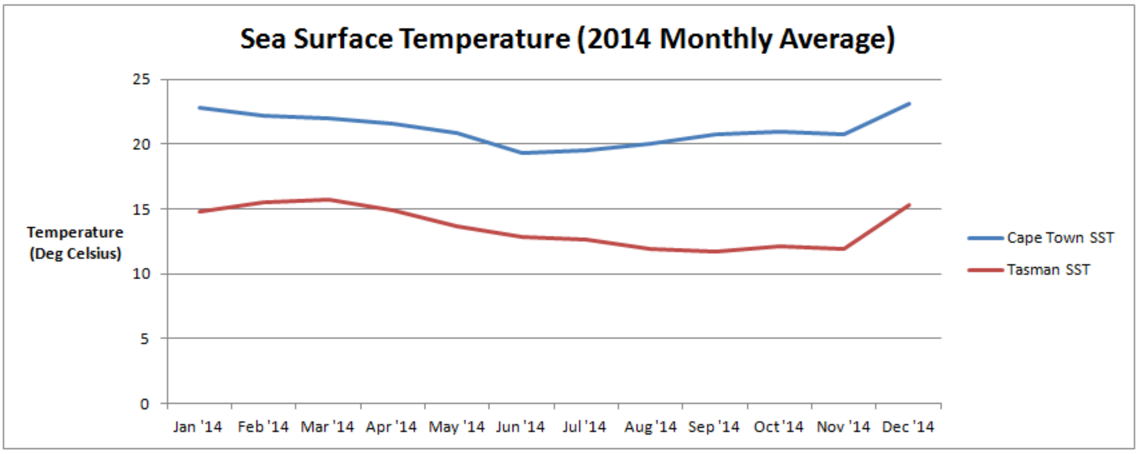

Figure 3: Comparisons between Surface Temperatures of False Bay (Blue) and Tasman Sea (Red). There is strong correlation between the two areas, as well as seasonal variations over the span of a year. The time span plotted is between Jan '14 and Dec '14. The data is parsed from MODIS Aqua Daytime measurements.

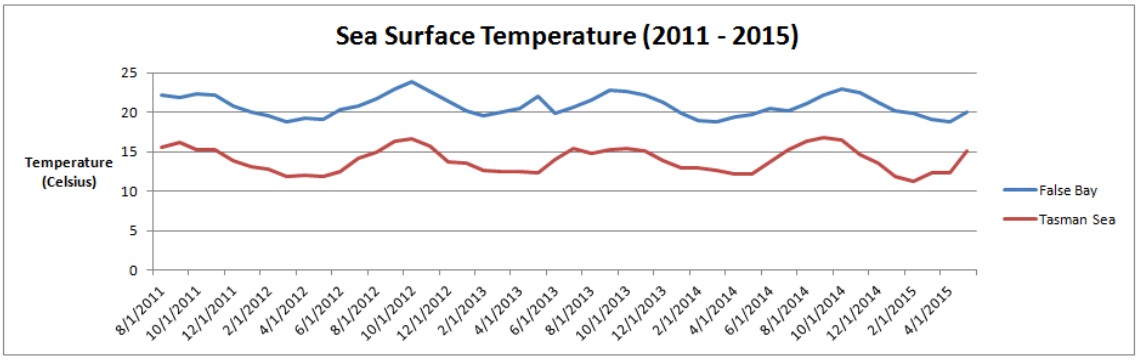

Figure 4: Comparisons between Surface Temperatures of False Bay (Blue) and Tasman Sea (Orange). There is strong correlation between the two areas, as well as seasonal variations over the span of a year. The time span plotted is between Aug'11 and May '15. This time span is chosen because it represents the entire timespan of data collected by the Aquarius satellite. The data is parsed from MODIS Aqua Daytime measurements.

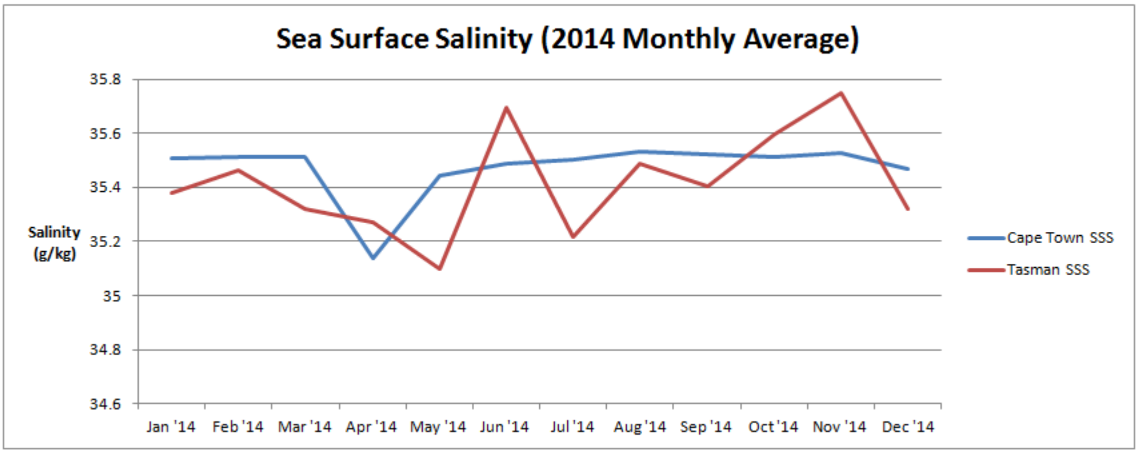

Figure 5: Comparisons between Surface Salinity of False Bay (Blue) and Tasman Sea (Red). There is little to no correlation between the two areas over the short timespan. The time span plotted is between Jan '14 and Dec '14. The data is parsed from the Aquarius satellite, using the smoothed algorithm.

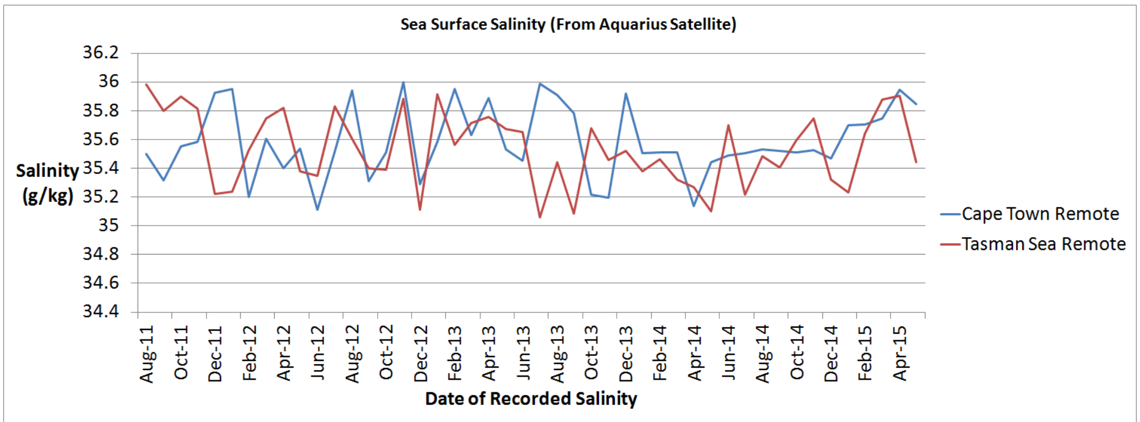

Figure 6: Comparisons between Surface Salinity of False Bay (Blue) and Tasman Sea (Red). The time span plotted is between August '11 and May '15. The data is parsed from the Aquarius satellite, using the smoothed algorithm.

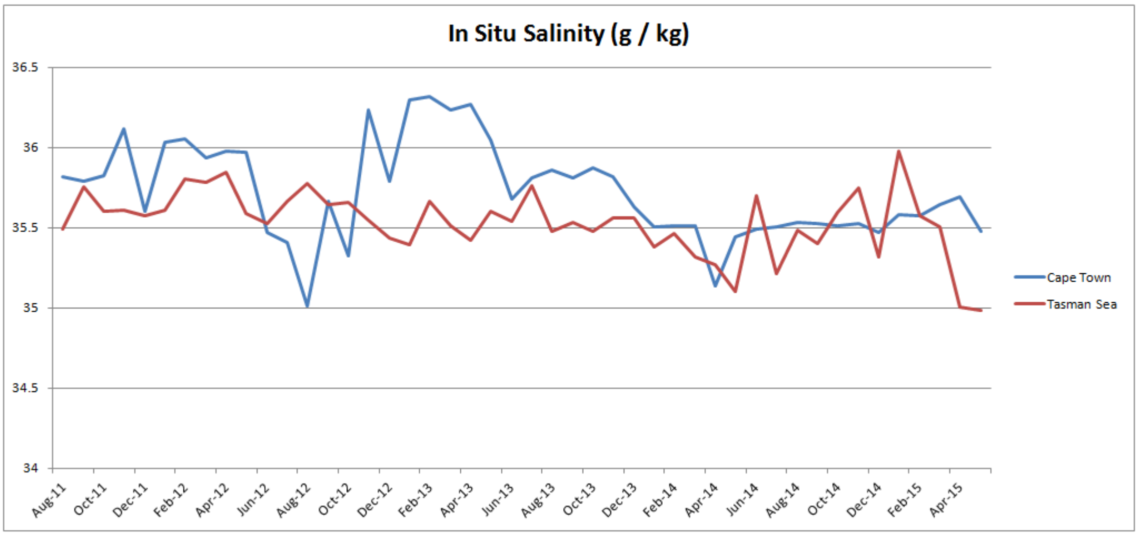

Figure 7: Comparisons between Surface Salinity of False Bay (Blue) and Tasman Sea (Red). The data was gathered by measuring salinity in the ocean. Data is collected from stationary buoys. Data set provided by the World Ocean Database.

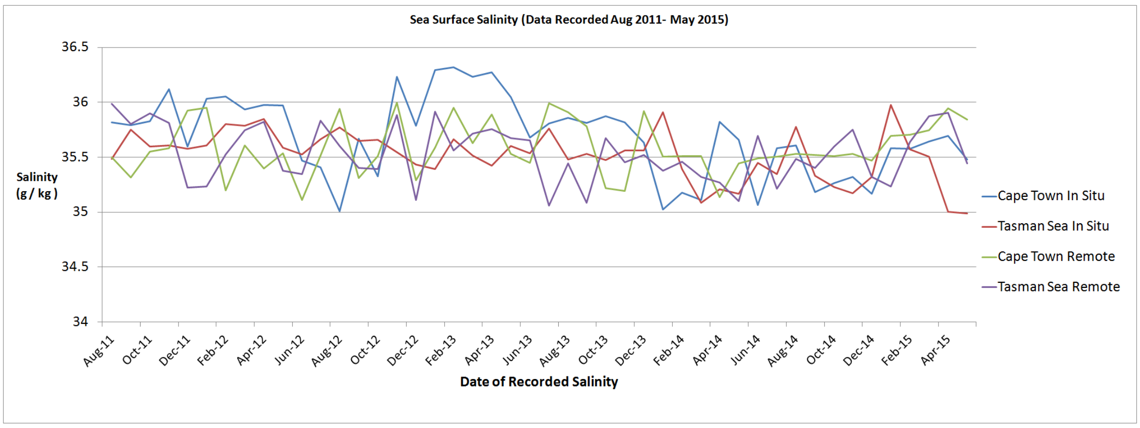

Figure 8: Comparisons between In Situ Surface Salinity Data of False Bay (Blue) and Tasman Sea (Red) and Remotely Sensed Sea Surface Salinity Data of False Bay (Green) and Tasman Sea (Purple). The in situ data was gathered by measuring salinity in the ocean. In Situ Data is collected from stationary buoys. In Situ Data set provided by the World Ocean Database. The Remotely Sensed Data is from the Aquarius satellite, using the smoothed algorithm.

References

[Atkins, 1970] Atkins, G. R. (1970). Winds and current patterns in false bay. *Transactions of the Royal Socciety of South Africa*, 39(2):139–148.

[Boyer et al., 2013] Boyer, T. P., Antonov, J. I., Baranova, O. K., Garcia, H. E., Johnson, D. R., Mishonov, A. V., O'Brien, T. D., Seidov, D., Smolyar, I., Zweng, M. M., Paver, C. R., Locarnini, R. A., Reagan, J. R., Coleman, C., and Grodsky, A. (2013). World ocean database 2013.

[Griffiths et al., 2010] Griffiths, C. L., Robinson, T. B., Lange, L., and Mead, A. (2010). Marine biodiversity in south africa: An evaluation of current states of knowledge. *PLoS One*, 5(8):e12008. 10-PONE-RW-16785R1[PII].

[Klemas, 2011] Klemas, V. (2011). Remote sensing of sea surface salinity: An overview with case studies. *Journal of Coastal Research*, 27(5):830–838.

[Millero et al., 1980] Millero, F. J., Chen, C.-T., Bradshaw, A., and Schleicher, K. (1980). A new high pressure equation of state for seawater. *Deep Sea Research A*, 27:255–264.

[Nardelli et al., 2016] Nardelli, B. B., Droghei, R., and Santoleri, R. (2016). Multi-dimensional interpolation of SMOS sea surface salinity with surface temperature and in situ salinity data. *Remote Sensing of Environment*, 180:392–402.

[NASA Goddard Space Flight Center, 2014] NASA Goddard Space Flight Center, O. E. L. (2014). Seawifs ocean color data.

[Nayar et al., 2016] Nayar, K. G., Sharqawy, M. H., Banchik, L. D., and Lienhard V, J. H. (2016). Thermophysical properties of seawater: A review and new correlations that include pressure dependence. *Desalination*, 387(1):1–24.

[Oliver et al., 2014] Oliver, E. C. J., Wotherspoon, S. J., Chamberlain, M. A., and Holbrook, N. J. (2014). Projected tasman sea extremes in sea surface temperature through the twenty-first century. *Journal of Climate*, 27(5):1980–1998.

[Safarov et al., 2009] Safarov, J., Millero, F., Feistel, R., Heintz, A., and Hassel, E. (2009). Thermodynamic properties of standard seawater: extensions to high temperatures and pressures. *Ocean Science*, 5(3):235–246.

[Sharqawy et al., 2010] Sharqawy, M. H., Lienhard V, J. H., and Zubair, S. M. (2010). Thermophysical properties of seawater: A review of existing correlations and data. *Desalination and Water Treatment*, 16(1-3):354–380.