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Attributing Accelerated Increases in Salinity in the Mediterranean Coastal Zone to Climate Change and Seawater Desalination Brine and the Resultant Unsustainability of Modern Desalination Technology

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HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

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By

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Introduction

The mitigation of anthropogenic climate change is becoming more and more necessary and essential in all aspects of our everyday lives. Rapidly growing and expanding human populations across the globe mean that the smallest of actions coalesce into large scale impacts on our environment. Changes in policy drive changes in individual's daily routine.

As populations increase and climates change, geographic areas that once had abundant water resources are facing shortages. Climate change is bringing droughts to areas that have never faced such an issue due to decreased precipitation and increased evapotranspiration (Marcos-Garcia et al., 2017). Readily available freshwater sources are not keeping up to support populations as they grow (Figure 1). As this water crisis develops and intensifies, alternate sources of clean drinking water are being developed and perfected. Among the front runners of alternate sources of clean drinking water is desalination technology.

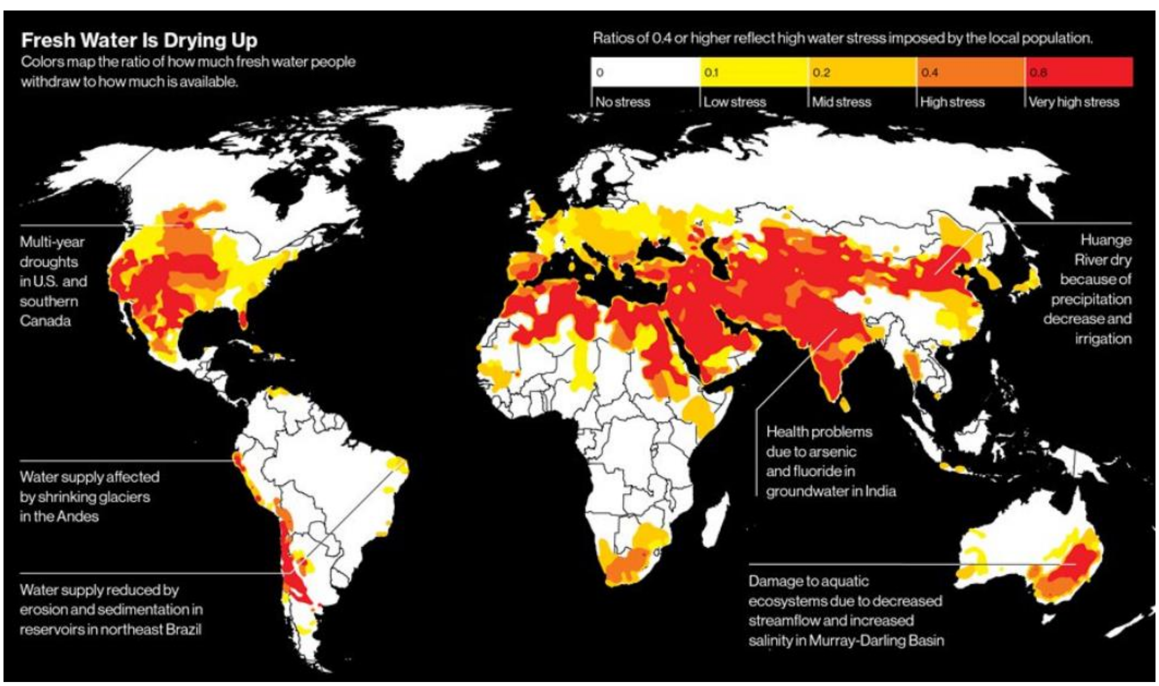

Figure 1 - Worldwide Water Shortages (Talbot 2015)

Desalination is the process of taking water from our oceans and seas that is otherwise undrinkable, removing the salt and producing drinking water. The most prevalent modern day desalination technology utilizes reverse osmosis (RO). 80% of all desalination plants worldwide use RO desalination (Greenlee et al., 2009).

The process of RO desalination uses a semi permeable membrane to reverse the process of natural osmosis. Osmosis is defined as “movement of a solvent (such as water) through a semipermeable membrane (as of a living cell) into a solution of higher solute concentration that tends to equalize the concentrations of solute on the two sides of the membrane” (Merriam-Webster 2018). If the natural process of osmosis were to take place between two bodies of water separated by a semi permeable membrane, the freshwater would flow toward the seawater to eventually dilute it enough for the two to be equal. Since the opposite result is desired in RO desalination, static pressure is applied to the seawater side to force the H_20 molecules in the opposite direction and create more freshwater.

Along with the benefits of desalination, comes the impact on the environment around us. One of the most harmful effects of desalination technology is the discharge of waste water of extremely high salt content, known as brine (Ahmed and Anwar 2012). After processing seawater, desalination plants accumulate an excess of highly saline brine that is returned back to the body of water from which it was pulled. Typically, the brine returned to the sea or ocean has double the salinity of the source water (Cooley et al., 2013). In the case of an enclosed body of water, the total salinity will rise while the technology of the reverse osmosis desalination equipment remains the same, allowing for less and less freshwater to be pulled from the higher salinity source water. Membranes then need to be exchanged more frequently. The energy costs rise as does the wear and tear on the plant, and eventually the costs rise to the point where it is no longer a viable alternate source of potable water for the surrounding communities.

Desalination brine has been shown to have detrimental impacts on benthic communities in close proximity to the discharge points (Palomar and Losada 2011). This brine not only increases salinity, but also raises the temperature of the water in close proximity to discharge. Another threat introduced by desalination brine is hypoxia as the high salinity brine carries inversely less dissolved oxygen (Ahmed and Anwar 2012).

All of these environmental impacts of brine occur and are well known on the microscale level. The gap in understanding comes when identifying long term changes to the environment on a macroscale level.

Macroscale impacts of desalination brine have been observed in large bodies of water but are not as well understood and known as microscale impacts. A prime example of a macroscale impact is in the Persian Gulf where the enclosed sea is approaching 'peak salt.' Peak Salt is the point where desalination technology is economically infeasible due to the high salinity of the water (Leahy & Purvis 2016). This is due to the large amount of desalination plants in a relatively small area that continually pump out fresh water and return highly saline brine. The refresh rate through circulation and rainfall in this area is slow enough that the desalination brine is increasing the overall salinity of the Persian Gulf.

The combination of bathymetry and climate coupled with a high concentration of desalination plants in the Persian Gulf may be unique to this planet and likely is the only place on Earth that is experiencing 'peak salt.' However, it is certainly not the only body of water on the planet that is and will be surrounded by desalination plants that are pumping large amounts of highly saline brine back into the natural environment. Impacts from brine on benthic populations and the salinity of their surrounding environs has already been proven, but looking at the macroscale impact on large bodies of water still presents the opportunity for further research. There is no question the brine does increase salinity of its surrounding water on a microscale, but the extent to which this impacts the entire bodies of water that are not fully enclosed still remains to be seen.

One such example is provided by the unique bathymetry of the Mediterranean basin and the growing number of desalination plants in the area. The Sea already has a negative water balance, where the amount of evaporation is greater than the replacement of freshwater through precipitation and runoff (Talley and Swift 2011). The bowl-shaped, closed basin naturally accumulates dense and cold water that is only allowed to exit and enter the Atlantic when spilling over the Gibraltar sill. During the summer, as evaporation exceeds precipitation, sea surface salinity increases and this saline water sinks in the winter to join the existing high salinity deep waters (Millero 2016).

This water balance is expected to tip further to the negative side due to climate change. Hochman (2017) predicts that the relatively cold and rainy winter months in the Eastern Mediterranean could be shortened from four months to two months and be replaced by a longer hot and dry summer climate by 2100. This change will allow a longer period each year where higher temperature means more evaporation occurs and precipitation is less likely. Weather patterns from 1860-2005 have also shown the decadal variability and annual-mean conditions in the area to already be warmer and drier (Hochman et al., 2018).

Coastal Zones are the frontline of the ongoing battle between human development and our natural environment. The border between nature and civilization is becoming more and more blurred. Due to population expansions, human developments growing along coastlines, and water shortages worldwide, desalination is becoming more of an essential technology for survival. While the output of freshwater to nearby populations is essential, the detrimental environmental impacts of the brine portion of output are not sustainable with the current technology and need to be mitigated (Heck et al., 2017).

Statement of Purpose

Anthropogenic climate change influences our oceans on a global scale and has brought about increased salinity levels in large areas of our oceans such as the North Atlantic (Dunbar 2009). Concentrations of large scale desalination plants around small bodies of water add to this pattern and have shown even larger increases in salinity due to desalination brine discharge (Purnama et al., 2005). Salinity profile data over time should show similar increases in salinity in the Mediterranean Sea due to climate change and localized data should show increased salinity due to brine discharge. This study aims to pinpoint the extent of this increase in salinity from desalination brine and to determine if these changes are detectable on a large scale over a long period of time in an increasing pattern throughout the basin.

This pattern should then display that the increase of salinity in the basin is accelerating due to brine discharge and tipping the already natural salinity cycle of the Mediterranean Sea. Based on the acceleration of this change and future planned desalination plants, it can be determined if the salinity increase is at a sustainable level. Desalination brine by itself is very unlikely to have much impact on such a large body of water as the Mediterranean Sea, however, detecting a slight change from brine discharge and then combining this change with already increasing salinities due to anthropogenic climate change could give us a glimpse into a future with larger scale desalination processes and the vital need to utilize sustainable technology as opposed to the environmentally detrimental present day technology. If even a slight change in overall salinity is detected, this data could be used to interpolate future salinity levels with increased desalination plant development in the future.

Increased salinity levels in areas of close proximity to brine discharge are easily detectable with the right equipment and would directly correlate desalination technology with unsustainable increases in salinity. The challenge remains to detect changes on a larger scale.

All types of modern technology should strive to be net-zero emission and net-zero impact on the environment. Desalination technology is no exception. The results of this study can be used to prove that modern desalination technology is unsustainable and harmful to the environment. Rather than eliminating the process, the only viable solution is to improve and upgrade the technology to have no negative impact on the environment.

Methods

The challenge of this study was to isolate changes in salinity over time and associate them with large scale industrial brine discharge from desalination plants. The Mediterranean Sea is surrounded by desalination plants ranging in size and technology utilized. This study concentrated on plants that produce at least 10,000 m^3/day of fresh water and utilize reverse osmosis desalination technology.

The largest plant in the Mediterranean is the Sorek Desalination Plant in Tel Aviv, Israel producing 624,000 m^3/day of fresh water per day and in operation since October 2013. The Tajura plant in Libya has been in operation since March 1984 and is the largest reverse osmosis plant in the country. It produces 10,000 m^3/day of fresh water daily (Aboabboud & Elmasallati, 2007). Spanish Alicante II produces 100,000 m^3/day of fresh water per day and has been operational in Valencia since December 2008 (Andres 2017). Based on the location of these plants, a geographic area of the Mediterranean Sea was selected in close proximity to where the plant's brine is discharged.

The Argo float array blankets the Mediterranean (Figure 22) and over time provides nearly full coverage of its surface and depths up to 2000m. This array of over

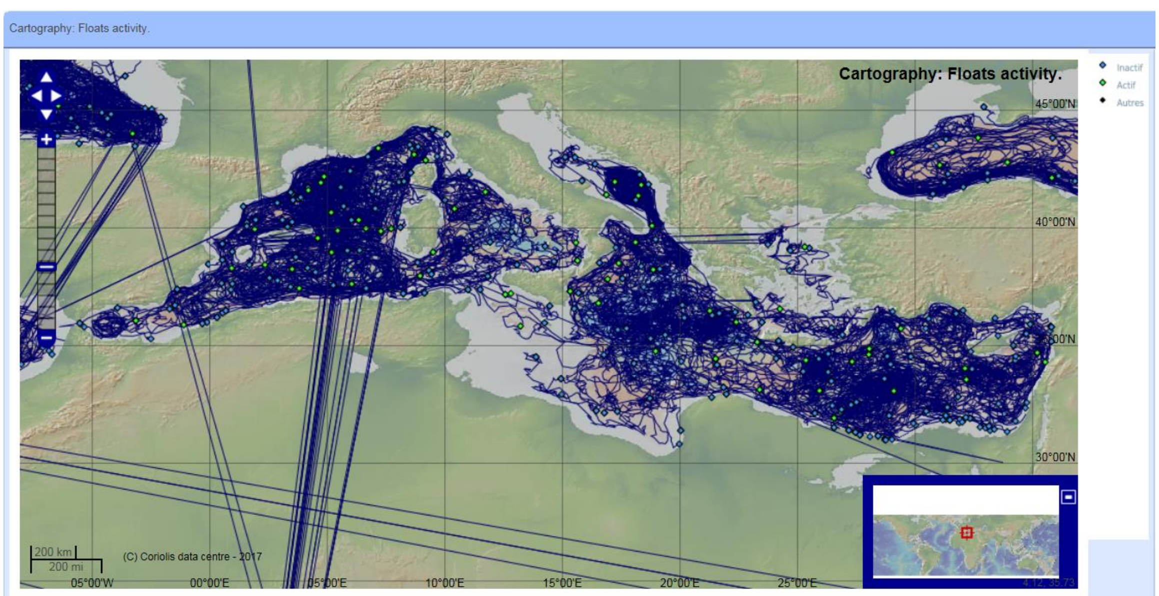

Figure 2 - A Snapshot of Active Argo platforms (Argo 2018)

3,800 free-drifting profiling floats covers the entire surface of our planet and is an immense source of data for studies such as this. Salinity data pulled from Argo floats is provided at an accuracy of +/- 0.01 psu unless otherwise indicated in the data (Argo 2018). Data can be flagged for accuracy on a measure of 1-4 once adjustments have been made. Any data that is a 3 or 4 quality control flag should not be used for scientific purposes. The floats are also not static and vulnerable to drift from currents and weather and therefore can cover a large geographical area over time. These two factors will need to be weighed in the results as comparing one profile to another profile will be using data from two different locations, even if in close geographic proximity.

To isolate the direct impact of desalination brine discharge, the immediate areas surrounding these plants was selected to analyze data. While of course thorough mixing and distribution of the brine occurs, it was hoped the close proximity of the discharge would at least show minor patterns of change. As brine is essentially double the salinity of the surrounding waters, it is denser and sinks to the bottom and slowly spreads out over the ocean floor.

Table 1 - Summary of Desalination Plants Selected for Research

Country	Plant Name	Location	Production Capability	Began Operation
Israel	Sorek	Tel Aviv	624,000 m^3/day	October 2013
Libya	Tajura	Tajura	10,000 m^3/day	March 1984
Spain	Alicante II	Valencia	100,000 m^3/day	December 2008

As the Mediterranean has a mild climate, it only consists of two seasons, winter and summer. Data was separated by season and year to maintain seasonal fluctuations for a true chronological comparison.

An area equal to 1.5 degrees latitude by 1 degree longitude (or 1.5 degrees longitude by 1 degree latitude) of the coast of Israel (Figure 33) and Spain (Figure 44) was selected. An equal area was selected to ensure conformity in the distance from the point of discharge, which is centered on each area selected. However, it was found when collecting data off the coast of Libya (Figure 55) that with this relatively small area selected, no stations had passed through the area. After further analysis it was found that due to the shallow depths and the nature of the currents off the coast of Libya, stations were further out. This area was thus expanded to include a total of 1.5 degrees latitude by 2.5 degrees longitude, essentially multiplying the searchable area by 2.5.

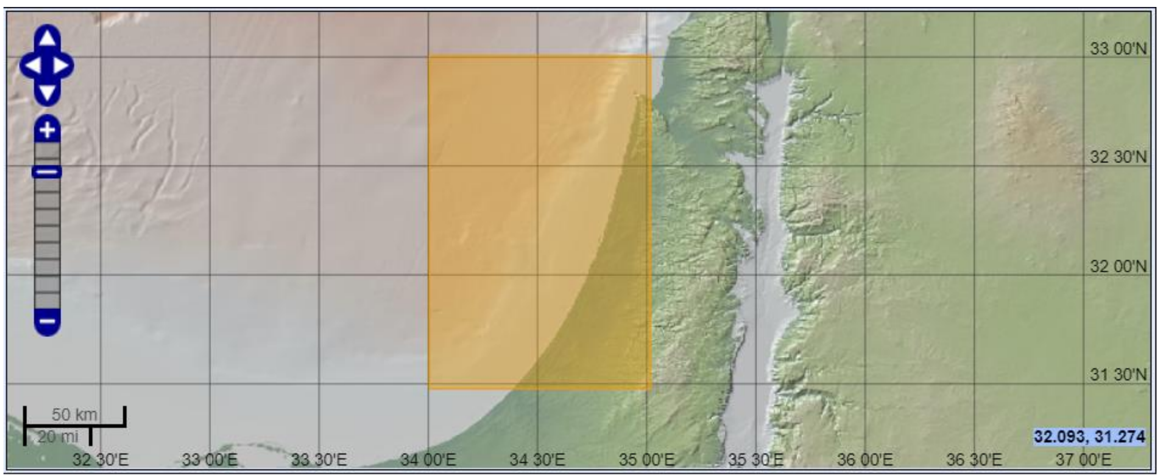

Figure 3 - Argo Array Selection off the Coast of Israel

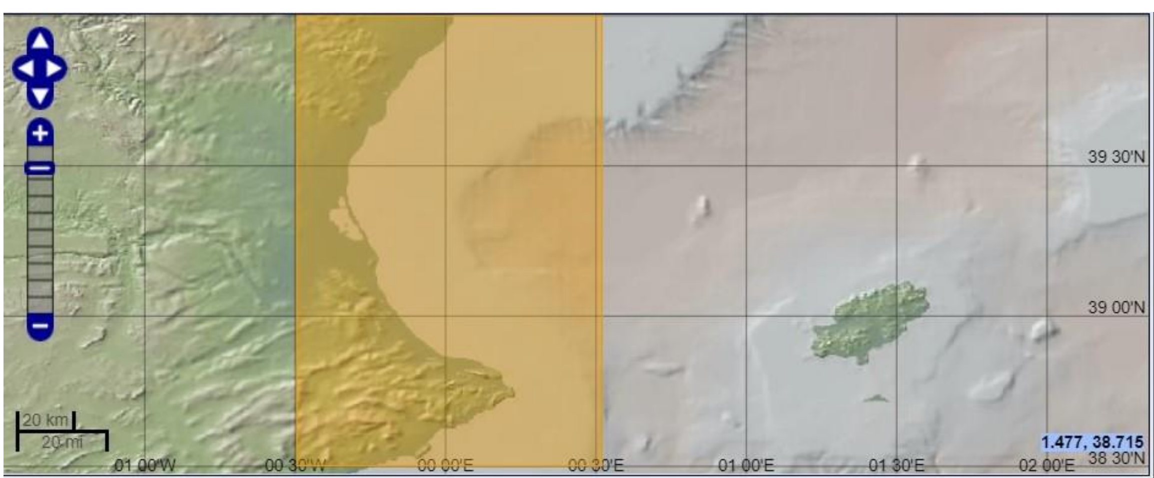

Figure 4 -Argo Array Selection off the Coast of Spain

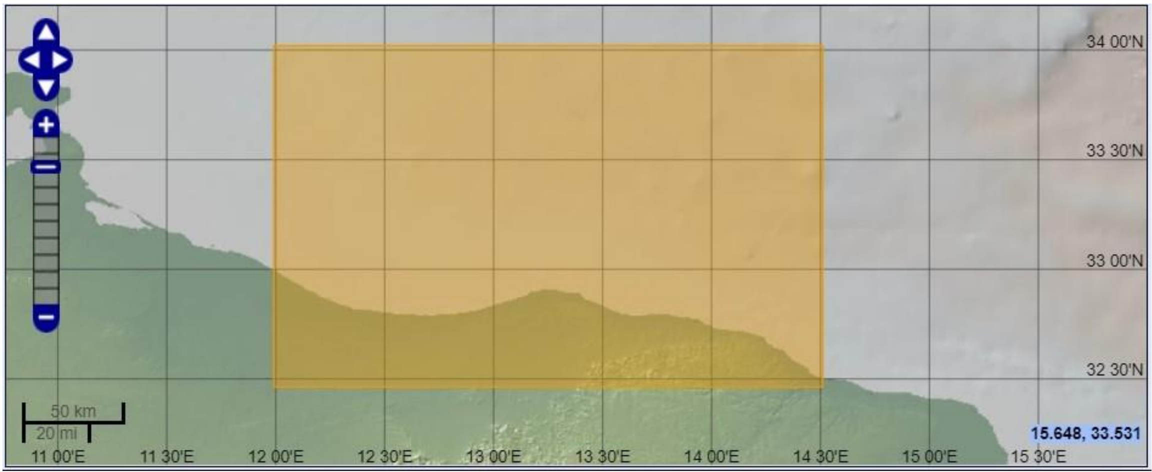

Figure 5 - Argo Array Selection off the Coast of Libya

The Argo data selection tool provides a valuable resource and affords the flexibility needed in this project to isolate floats that were in a specific area during a specific time. Figure 66 shows the data selection criteria used to pull data off the coast of Israel.

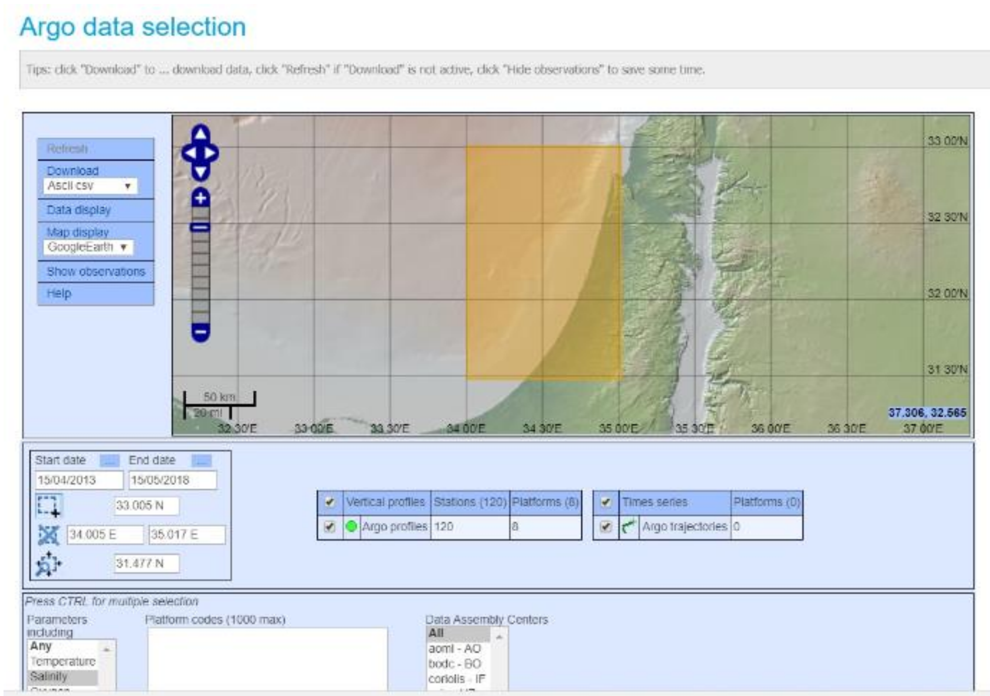

Figure 6 - Argo data selection Coastal Israel

120 stations (profiles) from 8 different platforms throughout the area provided a significant amount of data in this area.

All data pulled from the platforms was analyzed in excel. The data was separated by station then by the time of year. Because of the dual seasonality of the Mediterranean, seasons were categorized by winter (October through March) or summer (April through September) for each year. To then further narrow down the target data, a range of depths were isolated for each region. With this narrowed set of data, means, standard deviation, and errors were calculated (Appendix B, Table 3).

Review

This study presented many challenges. The Mediterranean is an immense body of water that is affected by many variables. Isolating the impacts of desalination brine on such a massive and complex system requires an all-encompassing data set and consideration of all variables. Variables to consider in the data collected include time, location, and depth. The data is dependent on each of these variable and each one needs to remain consistent. The relatively small amount of brine being expelled from these desalination plants into such a large sea also presents a unique challenge to detect on a macroscopic scale.

Other conditions that present a challenge in isolating this unique impact include thermohaline mixing due to currents and weather. The desalination brine is quickly dispersed in the sea and moves away from the source quickly. Over a longer time period, such as a century, patterns of changes in salinity may emerge that could be linked to desalination as the root cause.

Using the Argo float array also presented its own limitations in gathering data. These floats collect profiles from the surface all the way to depths of 2000 m. As the deepest enclosed sea on Earth, the Mediterranean Sea has an average depth of 1500 m. Its deepest point is 5,267 meters, meaning many areas of the Mediterranean go unsurveyed by the Argo array (CEMEX 2018). Unfortunately for this project, those missed areas are ultimately the most essential as the bottom is where the highly dense, saline brine gathers over time.

Another limitation of the Argo float array presented itself when researching the salinity profiles off the coast of Libya. The coastal waters are relatively shallow and the search criteria set for selecting platforms returned zero results. The search grid was then expanded by 2.5 times the grid of the other areas analyzed (Figure 55). This resulted in a limited dataset from only two platforms; one in the winter of 2013 and the other in the winter of 2015 (Figure 10).

With these new search parameters, two seasons of data were able to be collected off the Libyan coastline, in close proximity to the Tajura Desalination Plant brine discharge location. Pulling the data from these stations over a time period of 10 years (April 2008-April 2018), showed a clear shift in salinity (Figure 1010) from the Winter of 2013 to the Winter of 2015, especially at depths of greater than 150 decibars (or approximately 150 meters). However, this data set is too small to conclusively tie this resultant increased salinity to desalination brine.

The data set provided off the coast of Israel, near Tel Aviv produced the most results. Setting up the search parameters on the Argo array site provides a list of floats that have passed through the area. Data for each one can then be downloaded for each float. All of the data profiles are listed in one spreadsheet chronologically. For the purpose of this study, data needed to be limited to the geographical area selected and then by the season. Data was pulled from each spreadsheet into a new, seasonally separated spreadsheet. This allowed for multiple floats to be listed that passed through the same area during the same season and took salinity profiles.

Once the data had been rearranged by season and floats were grouped together, it was then possible to create scatter plots to show salinity (PSAL in PSU) vs depth (pressure in decibars) over time (Figure 77-Figure 111).

As there was such a large amount of data collected off the coast of Israel, the graphs were separated into three time periods to better display how they changed over time.

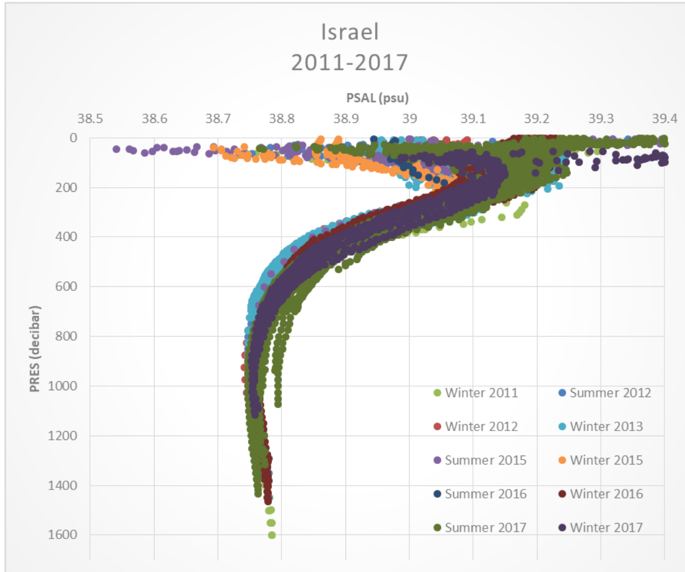

Figure 7 – Salinity / Pressure Profile off the coast of Israel (2011-2017)

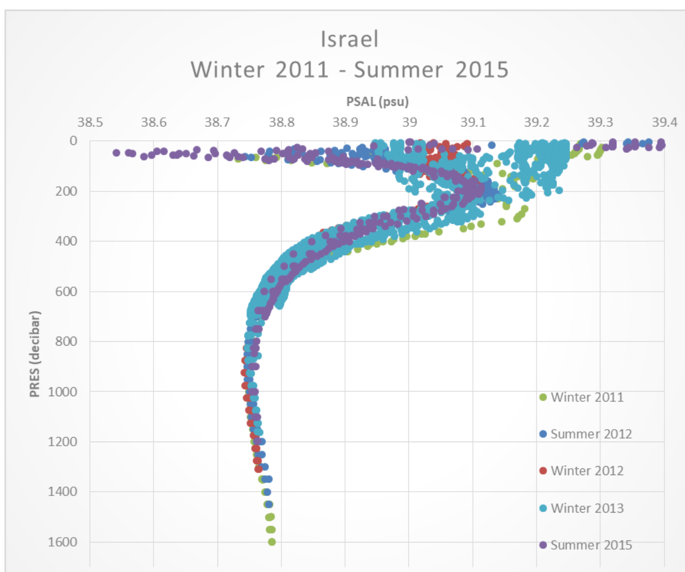

Figure 8 - Salinity / Pressure Profile off the coast of Israel (2011-2015)

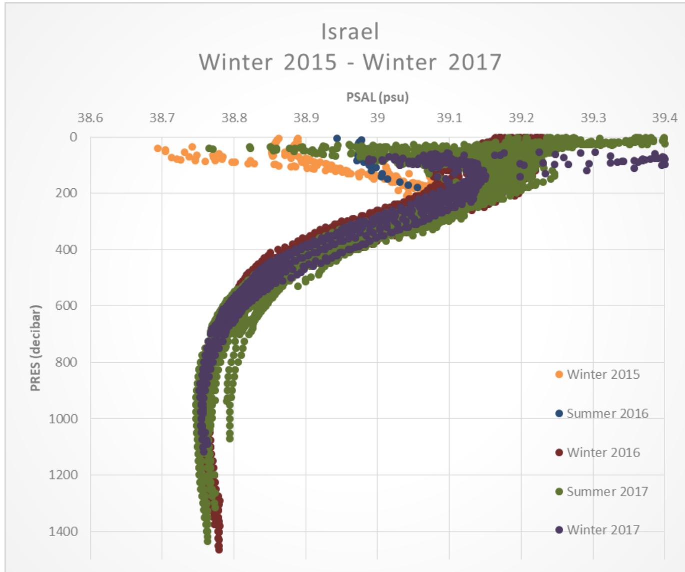

Figure 9 - Salinity / Pressure Profile off the coast of Israel (2015-2017)

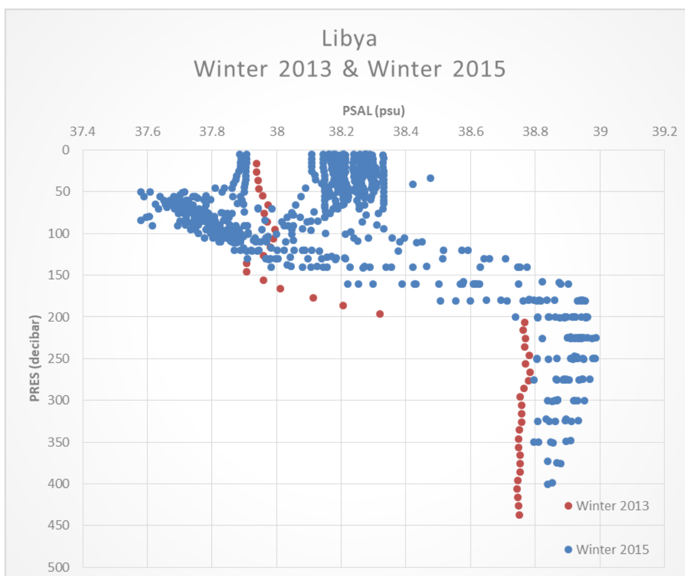

Figure 10 - Salinity / Pressure Profile off the coast of Libya (2013 & 2015)

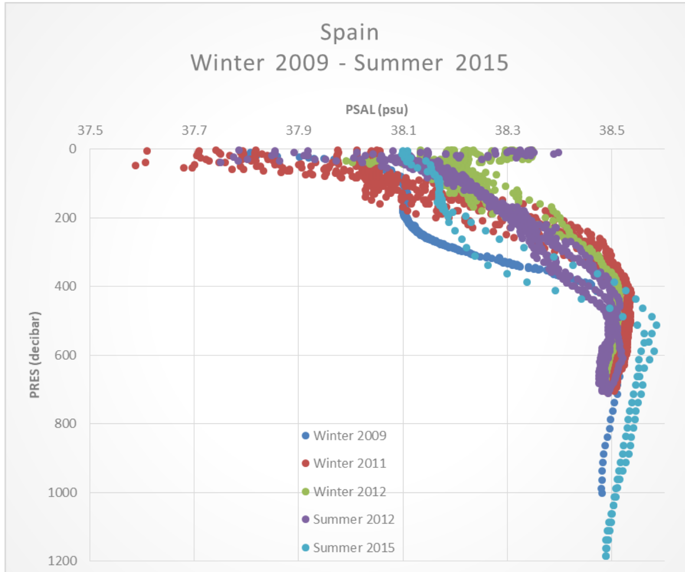

Figure 11 - Salinity / Pressure Profile off the coast of Spain (2009-2015)

Results

To better analyze the results, data was isolated at a specific depth for each set that could better demonstrate the change in salinity over time for each region. The selected depth for Israel was 950 to 1050 meters as this was the deepest set of measurements that could be pulled consistently for each season (Figure 122). For Libya, the depth selected was 300 to 400 meters as the data set was rather shallow and this was the deepest measurements available (Figure 133). The same is true for the data off the coast of Spain, it was relatively shallow, so a depth of 600 to 700 meters was selected as shown in Figure 144.

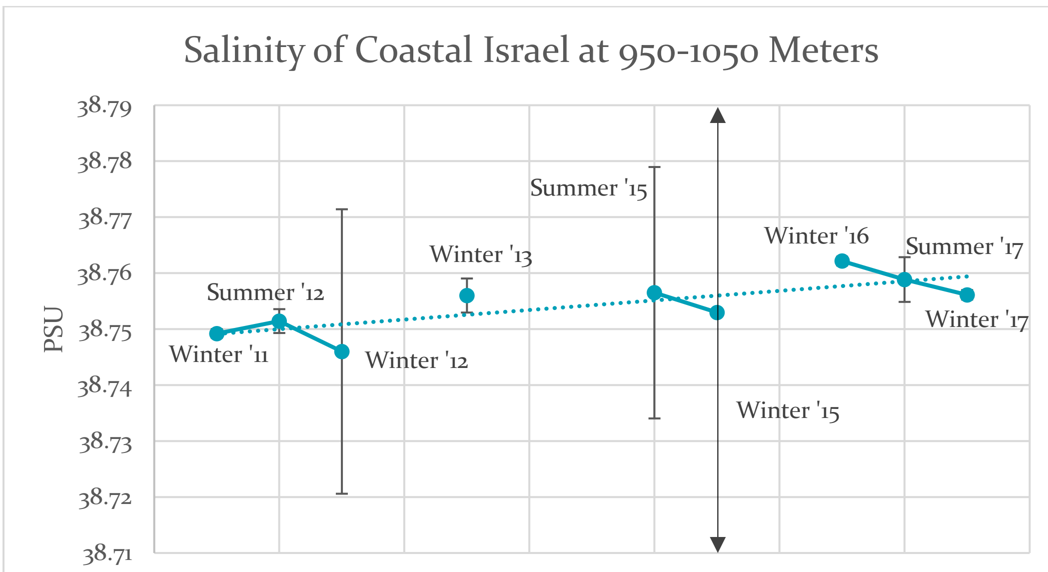

Figure 12 – ARGO salinity measurements off the coast of Israel at 950-1050 Meters depth (Confidence Intervals with arrows indicate no confidence due to only one independent data point being available)

The data set taken off the coast of Israel did come back with a clear trend that demonstrates an increase in salinity over time. Analyzing the measurements taken at a depth of 950 meters to 1050 meters shows that from the Winter of 2011 to the Winter of 2017 there was a clear increase. In general, the salinity measurements in the summer were higher than those in the winter as was expected. Overall, the salinity in this region, at this depth, increased from approximately 38.75 psu to 38.76 psu, a delta of 0.01 psu.

While this is not necessarily a significant increase, it does show a clear trend upwards of increasing salinity.

As the Sorek Desalination Plant only began operation in October 2013, it should be noted that the first three seasons of data (Figure 12) would not have been impacted by desalination brine. The trend upward for the data set cannot be specifically attributed to desalination discharge or to climate change.

Salinity measurements off the coast of Libya, as discussed earlier, were scarce. Due to the shallow measurements available, data from 300 to 400 meters depth were isolated. There is a trend upwards in this case as well, showing a salinity of approximately 38.75 PSU in the Winter of 2013 up to a salinity of approximately 38.83 PSU in the Winter of 2015. However, there was only one independent data point available for the Winter of 2013, providing a confidence interval of plus and minus infinity as indicated in Figure 13. This leaves the results of the Libya data analysis inconclusive.

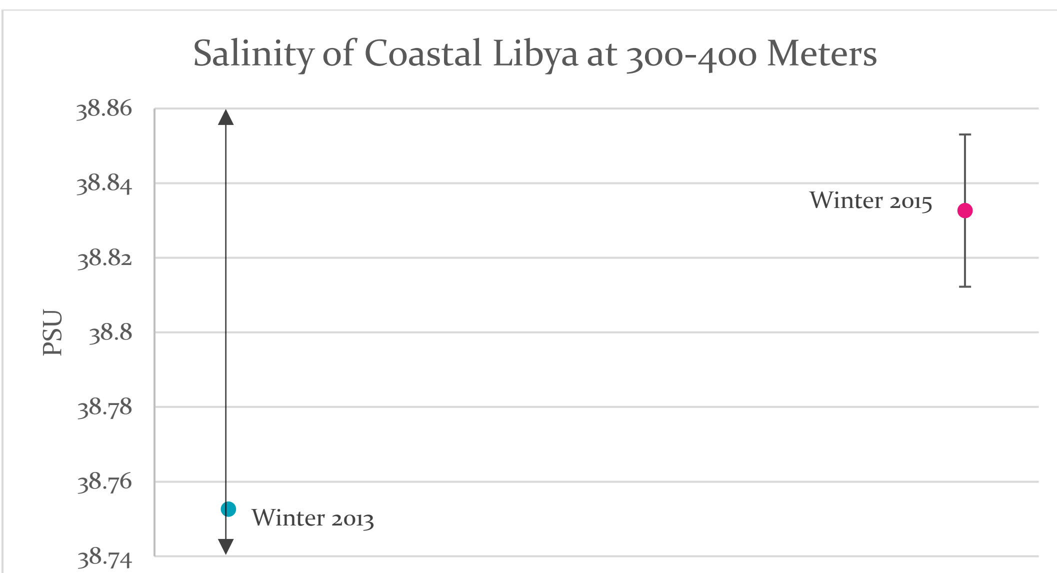

Figure 13 – ARGO salinity measurements off the coast of Libya at 300-400 Meters depth (Confidence Intervals with arrows indicate no confidence due to only one independent data point being available)

Data collected off the coast of Spain was taken at a depth of 600 to 700 meters during five seasons spread out over six years. The results of this data were a little more mixed but as demonstrated by the trendline in Figure 14, there also was a slight increase in salinity over time of the coast of Spain at this depth. During the Winter of 2009, the PSU at this depth was just under 38.52. By the Summer of 2015, salinity at this depth had increased to nearly 38.56. This increase in 0.04 PSU is more significant than the changes in the other data sets. However, the individual data points for Winter 2009 and Winter 2012 have confidence intervals of plus and minus infinity leaving no confidence in the accuracy. With these data points disregarded the trendline would be more horizontal, showing no change.

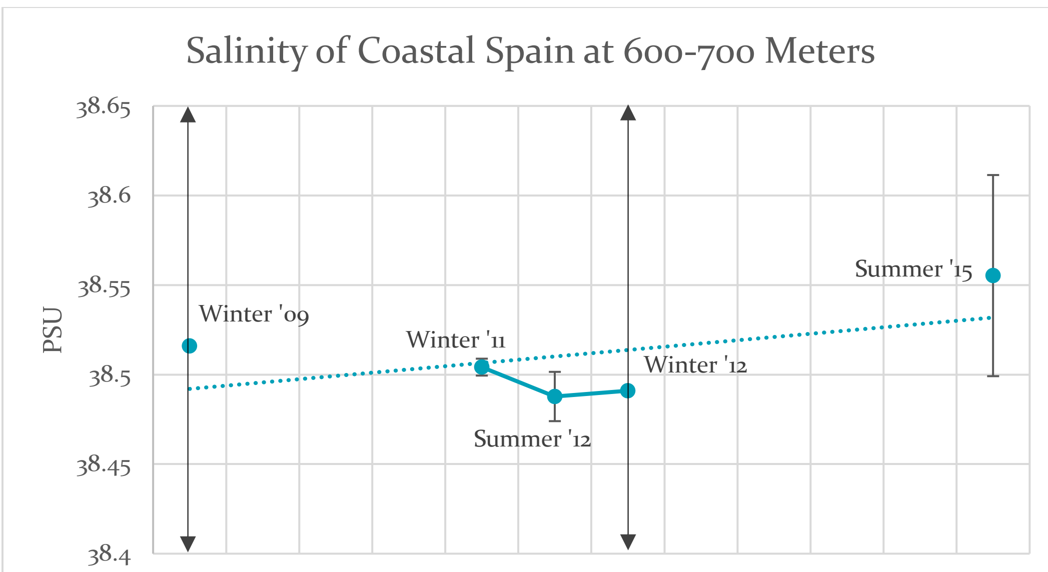

Figure 14 – ARGO salinity measurements off the coast of Spain at 600-700 Meters depth (Confidence Intervals with arrows indicate no confidence due to only one independent data point being available)

The results of the three data sets all came back with an upward trend in increasing salinity over time. This is to be expected, as the Mediterranean Sea is undergoing a general increase in temperature and salinity (Vargas-Yanez et al., 2017).

As all three areas selected are in close proximity to desalination brine discharge points, the results are hopeful in showing that the areas are increasing in salinity at relative depths. It should be also mentioned that the accuracy of the Argo float array is quoted at +/- 0.01 psu. As shown in Figure 122 - 14, the confidence intervals are very high on some data sets, and plus/minus infinity on others. The combination of these two possible errors should be taken into consideration when analyzing the results.

Inherent to such a large system of data collecting sensors, the ARGO float often sees errors, especially as the floats age. One of these such errors are accounted for by making calibration corrections to the floats for salinity measurements. Such is the case for float #1900948 which was used to collect data near the coast of Libya from October to December of 2015. The salinity measurements were adjusted to be more accurate based on the condition of the float with an average correction of .0273 psu. The standard error for this set of measurements was 0.00787 with a margin of error of 0.01627. Appendix A shows the measurements used from float #1900948 and its correlated salinity adjustments. The adjustment to salinity is much larger than both the standard error and margin of error.

The next part of this study, and the real challenge, would be to isolate desalination brine as the point source. To do this, one would need to eliminate other causes of increased salinity. These could include a shift in the halocline over time, general changes in thermohaline circulation, seasonal variations, natural trends, and other anthropogenic influences besides desalination brine discharge.

Therefore, the results of this study are inconclusive as the data could not be tied directly to desalination plant discharge in the Mediterranean contributing to the anthropogenic increase in salinity of the Sea. Further research is warranted and a more precise approach to isolating the impacts of these plants could still yield the expected results.

Analyzing the data from this study provides a miniscule snapshot of how salinity in the Mediterranean fluctuates over time. While some trends can be observed from the scatter plots and the selected depth analyses, the variables present render most of the data undecipherable. To get a better picture of the changes in salinity in the Mediterranean Sea over time, one would need a larger data set over a longer period of time. Alongside this, there would need to be more data points collected at the bottom of the sea and these would need to be compared to currents and thermohaline circulation.

One plausible method of detecting and analyzing the settling and accumulation of desalination brine at the bottom of the sea would be to utilize a different type of data collecting equipment. If an array of sensors were placed on the bottom of the sea that then were able to read salinity there and possibly some meters above, we could get a better picture of how brine is accumulating at depth. Modeling the flow of the discharge and how it is dispersed over the bottom of the sea and how it accumulates over time could be matched with the array of sensors and then traced up higher into the water column.

Summary and Conclusions

The volume of the Mediterranean Sea is estimated to be 3,750,000 km^3. It is estimated that as of 2012 the worldwide production of potable water from desalination of seawater is approximately 5 km^3/year (Dawoud 2012). The largest desalination plant on the Mediterranean, the Sorek in Israel is capable of producing 627,000 m^3 of potable water per day. At only 30% of the intake water, 70% is returned as brine or approximately 1.46 million m^3 per day. This comes out to over 0.5 km^3 of brine being put into the Mediterranean annually by just one plant. If in the future the Mediterranean increased to produce as much as the global estimates for 2012, we could see upwards of 12 km^3 of brine being dumped into the Mediterranean Sea every year.

While this fraction may seem miniscule and irrelevant, it is important to remember that the combination of all small impacts we have on our environment add up to an enormous anthropogenic shove that does change the world around us. 12 km^2 of highly saline water distributed along the seafloor every year could be devastating to benthic communities. Monitoring and keeping an eye on potential catalysts such as this is the only way to mitigate negative past and present impacts on our planet and continue in the direction of sustainability.

Brine discharge from desalination plants pose an environmental risk to our already threatened oceans and seas. The high salinity, high temperature has proven negative impacts on ecosystems, flora, and fauna. The time to address this threat is now. Other impacts of desalination brine are not fully understood and could be larger scale than we suspect.

The key example of this is "peak salt" in the Persian Gulf. The fact that desalination technology is having trouble keeping up with the salinity levels of the Persian Gulf should be a bright red flag that the environment will also struggle to keep up and cope with these rapid and large scale anthropogenic changes to our planet.

The Persian Gulf does present a unique situation to the planet. It is highly sensitive to hypersaline conditions due to the hot climate in the area and of the surrounding countries. The double edged sword is that because of this climate, these countries do not have as abundant fresh water sources as elsewhere in the world and are leaning more and more on desalination technology (Smith et al., 2007). With an average depth of 50 meters, this body of water is much more susceptible than the Mediterranean (Persian 2018). As our planet undergoes climate change we should maintain a close watch on other areas that could potentially develop into an area that is as vulnerable to hyper salinity as the Persian Gulf.

Future research could look into the specific situation in the Persian Gulf and use a similar method to detect accelerated increases in salinity due to desalination brine over the past 50 years. The difficulty with this, however, is that there are no ARGO floats in the Persian Gulf so another data collection method would have to be used. To collect historic data on the salinity in the Persian Gulf, one would have to rely on readily available data from satellite imagery or oceanographic equipment that has been on site in the past. Future data collection could be established by deploying a network of floats similar to the ARGO array, specific to the Persian Gulf and compatible with the shallow depths. This research could be used to solidify the need for more sustainable desalination technology.

Desalination technology has the potential to be fully sustainable and green with the right precautions. Brine should not be dumped untreated back into the bodies of water it was pulled from.

Most desalination plants do take into consideration the necessity to ensure their brine discharge is an adequate distance from the feed intake to avoid contaminating the intake but they are essentially missing the big picture of how their combined discharges from all plants could impact the region as a whole.

A creative brine disposal solution comes not far from the Sarek Desalination Plant in Israel, on the Red Sea. Plans are underway for a $900 million desalination plant along the Israel/Jordan border on the Red Sea. Brine discharge from this facility is to be piped 100 miles to the Dead Sea. This will not only alleviate the risk of raising the salinity of the Red Sea through desalination but will help to replenish the Dead Sea that has been losing a meter of water level annually ever since its source water was diverted in the

1960s (Jacobsen 2016). The threat remains, however, on how this brine will impact the Dead Sea.

Other factors to increase the sustainability of desalination technology include location selection, energy efficiency, and waste water treatment. Future desalination technology planning must consider plant location to minimize conflict with nature. Currently technical and economic aspects are the main drivers when selecting a location, but environmental aspects such as waste water discharge, life species, and quality and quantity of freshwater should also be weighed heavily in these decisions (Dweiri et al., 2018). The source of energy for desalination technology must itself be sustainable and environmentally friendly to keep the whole process as green as possible. These sources include wind and solar or reusing waste heat from nearby industrial plants. Various solutions exist to dilute brine back to its original salinity or extract minerals to reduce the potency.

While all of these solutions are readily available today, they are often expensive, scarcely used, and lack economic incentive. Making desalination technology more sustainable needs to be pushed forward through not only best practices but legislation, permitting, and legal enforcement (Koontz & Hatfield, 2016). With these factors in place, the economy will work out the challenges through healthy competition within the desalination industry.

While the results of this study do not present conclusive evidence that desalination brine is increasing the overall salinity in the Mediterranean basin, it has already been shown that the basin is experiencing increasing temperatures and reduced rainfall due to climate change (Jeunesse et al., 2015). Adding any amount of desalination brine can only add to this issue, even if only on a small scale. Coupling this with studies that display negative impacts on localized benthic communities, there remains a clear threat to the Mediterranean Sea. Developing sustainable technology is the only way forward to effectively protect this unique and beautiful region of our planet.

Appendix A – ARGO Data Adjustments

Table 2- Salinity Adjustment #1900948

Platform	Date (YYYY-MM-DDTHH:MI:SSZ)	Latitude (degree_north)	Longitude (degree_east)	Pressure (decibar)	Original Salinity (psu)	Adjusted Salinity (psu)	Adjustment (psu)
1900948	2015-10-15T13:26:19Z	33.01	14.361	300.1	38.932	38.906	0.0260
1900948	2015-10-15T13:26:19Z	33.01	14.361	325	38.913	38.887	0.0260
1900948	2015-10-15T13:26:19Z	33.01	14.361	349.5	38.896	38.87	0.0260
1900948	2015-10-15T13:26:19Z	33.01	14.361	375.4	38.879	38.853	0.0260
1900948	2015-10-15T13:26:19Z	33.01	14.361	399.1	38.853	38.827	0.0260
1900948	2015-10-19T13:13:08Z	33.104	14.092	322.4	38.896	38.87	0.0260
1900948	2015-10-19T13:13:08Z	33.104	14.092	350.5	38.855	38.829	0.0260
1900948	2015-10-23T13:18:09Z	33.181	14.118	324.6	38.933	38.9071	0.0259
1900948	2015-10-23T13:18:09Z	33.181	14.118	348.4	38.91	38.8841	0.0259
1900948	2015-10-23T13:18:09Z	33.181	14.118	375.2	38.867	38.8411	0.0259
1900948	2015-10-27T13:09:09Z	33.238	13.84	300.6	38.861	38.835	0.0260
1900948	2015-10-31T13:09:16Z	33.208	13.87	300.9	38.853	38.827	0.0260
1900948	2015-11-04T13:10:47Z	33.233	13.92	300.5	38.863	38.837	0.0260
1900948	2015-11-04T13:10:47Z	33.233	13.92	325.4	38.862	38.836	0.0260
1900948	2015-12-18T13:09:55Z	33.098	14.078	322	38.835	38.8059	0.0291
1900948	2015-12-22T13:14:14Z	33.068	14.128	300.4	38.838	38.8089	0.0291
1900948	2015-12-22T13:14:14Z	33.068	14.128	324.7	38.807	38.7779	0.0291
1900948	2015-12-22T13:14:14Z	33.068	14.128	349.8	38.795	38.7659	0.0291
1900948	2015-12-26T13:17:51Z	33.023	14.212	325.2	38.843	38.8139	0.0291
1900948	2015-12-26T13:17:51Z	33.023	14.212	350.1	38.809	38.7799	0.0291
1900948	2015-12-30T13:24:15Z	32.962	14.397	300.3	38.919	38.8899	0.0291
1900948	2015-12-30T13:24:15Z	32.962	14.397	324.6	38.892	38.8629	0.0291
1900948	2015-12-30T13:24:15Z	32.962	14.397	349.7	38.849	38.8199	0.0291
1900948	2015-12-30T13:24:15Z	32.962	14.397	373.2	38.838	38.8089	0.0291

Appendix B – Summary of Data

Table 3 - Standard Deviation and Error Calculations

	Depth Range (m)	Season	Mean (PSU)	Standard Deviation	Count	Standard Error	Margin of Error	+	-
Israel	950-1050	Winter '11	38.7492	0.0003	3	0.000181	0.000781	38.7500	38.7484
		Summer '12	38.7514	0.0017	5	0.000768	0.002133	38.7536	38.7493
		Winter '12	38.7460	0.0028	2	0.002000	0.025412	38.7714	38.7206
		Winter '13	38.7560	0.0012	3	0.000707	0.003043	38.7590	38.7530
		Summer '15	38.7565	0.0025	2	0.001768	0.022461	38.7790	38.7340
		Winter '15	38.7530	N/A	1	N/A	N/A	∞	∞
		Winter '16	38.7622	0.0019	26	0.000378	0.000779	38.7629	38.7614
		Summer '17	38.7589	0.0099	26	0.001939	0.003994	38.7629	38.7549
		Winter '17	38.7561	0.0008	6	0.000332	0.000854	38.7570	38.7553
Libya	300-400								
		Winter 2013	38.7526	N/A	1	N/A	N/A	∞	∞
		Winter 2015	38.8326	38.8326	10	0.009019	0.020401	38.8530	38.8122
Spain	600-700	Winter '09	38.5160	N/A	1	N/A	N/A	∞	∞
		Winter '11	38.5042	0.0070	11	0.002115	0.004712	38.5089	38.4995
		Summer '12	38.4878	0.0111	5	0.004957	0.013760	38.5015	38.4740
		Winter '12	38.4910	N/A	1	N/A	N/A	∞	∞
		Summer '15	38.5553	0.0062	2	0.004419	0.056153	38.6114	38.4991

Appendix C – Formulas and Calculations

Variables

Sample Standard Deviation = SN

Sample Size = N

Mean = x̄

Degrees of Freedom = v

Equations

1. Sample Standard Deviation Formula:

$$S_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

2. Degrees of Freedom Formula:

$$v = N - 1$$

3. Standard Error Formula:

$$Standard\ Error = \frac{S_N}{\sqrt{N}}$$

4. Margin of Error Formula:

$$Margin\ of\ Error = t * [Standard\ Error]$$

5. Confidence Interval Formula:

$$Confidence\ Interval = \bar{x} \pm [Margin\ of\ Error]$$

Description of Calculations and Formulas Used

All data pulled from the ARGO database was grouped by region, then by season. Within each season, independent data was pulled from each float cycle. Each float could have multiply cycles and represent multiple seasons if the data allowed so from here on out, grouped data will be referenced by region and season. Some seasons also had multiple floats in the area.

The first step after grouping the data was to find the mean for each season. Using this mean and the sample size, a standard deviation was calculated (Equation 1). Based on the Degrees of Freedom (Equation 2) and the T-value (t) pulled from the chart (Table 4), a Standard Error was calculated. This was in turn used to calculate the Margin of Error and the Confidence Interval.

Table 4 - Cumulative t-distribution values (Thomson & Emery, 2013)

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TABLE A4.3B Cumulative *t*-distribution (Two-tailed Tests). Similar to Table A4.3A Except that Values Give Cumulative Distribution, $F(t)$, Under the *t*-distribution Curve for Different Degrees of Freedom, ν, Regardless of Sign, Such that the Probability $P(|t_\nu| > |t_{\nu,F}|) = F(t)$. The example here is for $n = 20$. For Example, for $\nu = 9$, the Probability $P(|t_9| > |t_{9,F}| = 2.262) = F(2.262) = 0.05$ and $P(|t_9| < |t_{9,F}| = 2.262) = 1 - F(2.262) = 0.95$, Corresponding to the 95% Confidence Interval. Note that $F_{0.200}$, $F_{0.100}$, and $F_{0.010}$ Correspond to the 80, 90, and 99% Levels, Respectively

	F **Probability of a Larger Value, Sign Ignored**								
ν	**0.500**	**0.400**	**0.200**	**0.100**	**0.050**	**0.025**	**0.010**	**0.005**	**0.001**
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	0.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	0.741	0.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	0.727	0.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	0.718	0.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	0.711	0.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	0.706	0.889	1.397	1.860	2.306	2.732	3.355	3.832	5.041
9	0.703	0.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	0.700	0.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	0.697	0.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	0.695	0.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	0.694	0.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	0.692	0.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	0.691	0.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	0.690	0.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	0.689	0.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	0.688	0.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	0.688	0.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	0.687	0.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	0.686	0.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	0.686	0.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	0.685	0.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	0.685	0.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	0.684	0.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	0.684	0.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707

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