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A Comparison of MBARI II Buoy Temperature and Salinity Measurements to SODA and GDEM Climatology

Heidt, Sarah

Monterey, California: Naval Postgraduate School

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NAVAL POSTGRADUATE SCHOOL

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OC3570 – PROJECT REPORT

A Comparison of MBARI II Buoy Temperature and Salinity Measurements to SODA and GDEM Climatology

by

LT Sarah Heidt

September 19, 2008

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I. Introduction and Background

The purpose of this study is to determine whether climatology models can accurately represent the ocean environment. In military operations, such as Undersea Warfare, having the most accurate depiction of the undersea environment enables the war-fighter to tactically exploit the environment to his advantage. Taking measurements of key ocean variables such as salinity, temperature, and pressure on a global scale can prove costly and futile. Arguably, in-situ measurements provide the most accurate representation of the environment, but when and where this data is unavailable the military needs climate models to fill in the gaps.

In this study, two climate models, one that has been used by the Navy since 1984 and one not currently used by the Navy are compared using in-situ measurements of temperature and salinity from the MBARI II buoy off the coast of the Monterey Bay. Climate data, most closely representative of the buoy location, was obtained from both databases for the month of January and compared to in-situ data from the buoy for consistency. Each climate data set will be compared with the in-situ measurements of salinity and temperature from the buoy and also with each other to determine if and when one climate data set is more consistent than the other.

II. Data and Methodology

In-Situ Data

For this study, in-situ data was collected and obtained from the MBARI II buoy located at 36.70N 122.39W off the coast of the Monterey Bay, as shown in Figure (1). The MBARI II buoy is part of an Ocean Acquisition System for Interdisciplinary Science (OASIS) project, which began in 1992 by MBARI. The buoy is one of three of its kind deployed off the coast, which uses real time access and two-way telemetry to store, record, and transmit a complete package of atmospheric and oceanic data at 10 minute intervals. For this study, only the buoy's CTD and MicroCat thermistor string measurements taken at 11 vertical depths (0 to 300 meters) were used.

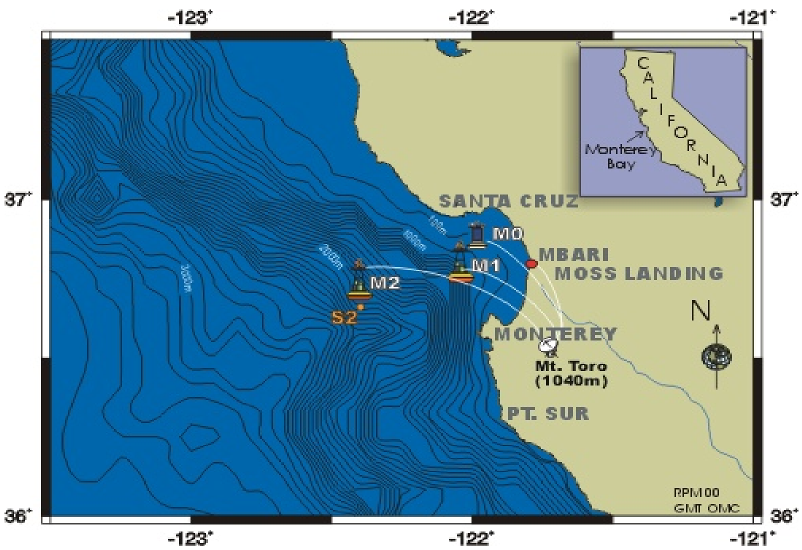

Figure 1: MBARI II buoy location.

An important element of collecting and analyzing data is ensuring the data undergoes proper quality control. Thanks to the effort and hard work of Fred Bahr (NPS Contractor) the data was carefully evaluated one data point at a time for *bad* or *misleading* data. Due to the year round collection of data at 10 minute intervals this is a time intensive process that begins with an automated quality control check for gross outliers. The next step is to review the data three depths at a time, variable by variable, time interval by time interval, flagging data that may potentially be *bad*. This is largely a judgment call based on years of experience working with the data, but Fred methodically flags *bad* data that spikes into depths above or below as seen in figures (2) and (3). Salinity data spikes (figure 2) are typically more obvious than temperature spikes (figure 3) and are likely due to instrument fouling from biological matter. Zinc anodes are mounted near the instruments to prevent/reduce fouling, but over time become less effective and can cause degraded salinity measurements. Temperature spikes are usually harder to discern and flag as *bad* data since what may be perceived as a *bad* data point spiking into another depth could be due to an internal wave and most likely an accurate measurement.

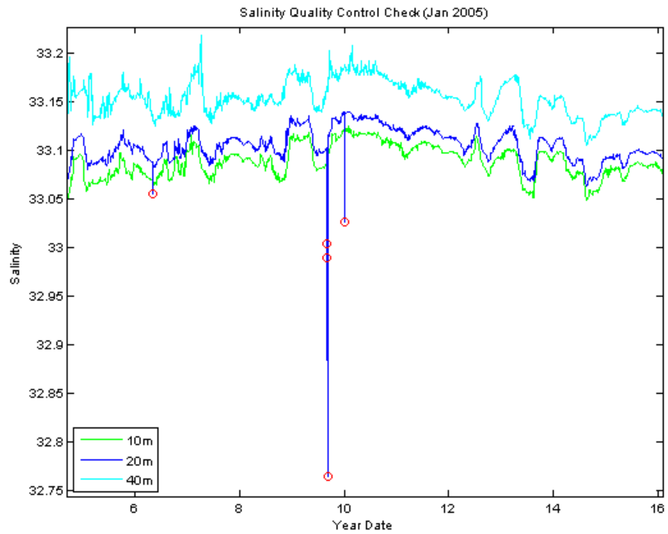

Figure 2: Salinity quality control data check. Red circles indicate flagged/bad data.

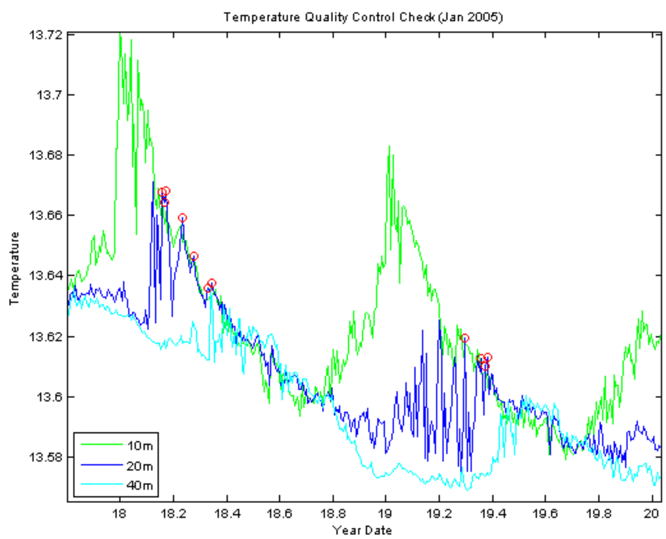

Figure 3: Temperature quality control data check. Red circles indicate flagged/bad data.

Once the quality control check was completed the data was run through MATLAB to plot monthly temperature and salinity means vs. depth for each January from 1992 to 2008. From these initial plots it was determined that the salinity data was only useable for this study from 1999 to 2008 and temperature data was only useable from 1994 to 2008 due to missing measurements and *bad* data at several of the 11 recorded depths.

Climatology Data

Currently, the U.S. Navy uses a climatology database called the 'Generalized Digital Environmental Model' (GDEM) developed by the Naval Oceanographic Office in 1975 for naval planning purposes. GDEM is largely based on long term mean (LTM) calculations, which are climatological averages of a specific variable over a 30 year (or more) time period. While this may be a good foundation for characterizing the undersea environment when in-situ measurements cannot be taken, in many cases, the LTM is misleading. This is because ocean variability, which in Undersea Warfare operations provides critical information to enable tactical exploitation of the undersea environment, is often smoothed out when using a LTM. The GDEM database is computed from in-situ temperature measurements and salinity profiles from 1920-1995 extracted from the Master Oceanographic Observational Data Set (MOODS). This data is assimilated into 3-D monthly grids of LTM temperature and salinity data sets. GDEM has a spatial coverage of 0°-360° and 60°S to 90°N, a horizontal grid resolution of .25° X .25°, and a vertical resolution of 78 levels from 0 to 6600 meters.[1]

Unlike GDEM, a climatology database called 'Simple Ocean Data Assimilation' (SODA) uses global *reanalysis* to provide monthly means of upper ocean temperature, and salinity. The SODA database was created using optimum interpolation data assimilation based on the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model (MOM).[2] A *reanalysis* uses modern analysis processes to analyze past and present states of the climate system by applying a consistent set of analysis

[1] Michael R. Carnes. Description and Evaluation of GDEM-V 3.0, Naval Oceanographic Office, 29 Apr. 2003.
[2] James A. Carton, G. Chepurin, and X. Cao. A Simple Ocean Data Assimilation Analysis of Global Upper Ocean 1950-95. Part I: Methodology, Journal of Physical Oceanography, 2000, Vol. 30.

procedures to all times in the reanalysis period. This yields a gridded data set that is temporally and spatially continuous. *Reanalysis* is a method used in a contemporary type of climatology called *smart climatology,* which utilizes modern developments in analyzing climatology (such as *reanalysis*) for military applications.[3] SODA consists of assimilated data from temperature and salinity profiles from the World Ocean Atlas-94, which includes MBT (prior to mid-1980's), XBT, CTD, and station data, as well as hydrographic, SST, and altimetry data (post 1986). SODA has a spatial coverage of 0° to 360° and 75.25°S to 89.25°N, a variable horizontal resolution of .3° X .3° to .5° X .5° depending on latitude, and a vertical resolution of 40 levels from 5 to 5374 meters.[4]

For this study GDEM grid point 477, 952 and SODA grid point 254, 476, both located at 36.75N 122.25W, were the closest grid points to the actual buoy location. Since GDEM represents an equally weighted LTM of all available temperature and salinity data per month from 1920 to 1995 at the prescribed grid point, only one profile could be generated for comparison. Unlike GDEM, the SODA database provides equally weighted monthly mean data for each year, so a profile for each month could be generated and used for comparison.

Temperature and salinity vs. depth profiles of buoy, GDEM, and SODA data were plotted using MATLAB. Since temperature data for the buoy was only valid back to1994 and GDEM and SODA data was only available up to 2004, temperature vs. depth profiles were only generated and compared for each January from 1994 to 2004. Likewise, salinity data was only valid back to 1999, so salinity vs. depth profiles were only generated and compared for each January from 1999 to 2004.

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[3] Tom Murphree and B. Ford. Smart Climatology for Antisubmarine Warfare: Initial Assessments and Recommendations, 14 Aug. 2007.
[4] Murphree.

It is important to note that GDEM, SODA, and the buoy data sets had varying array lengths coinciding with their respective vertical levels. This inhibited further statistical analysis such as average differencing and calculation of the correlation coefficient. Although linear interpolation could have been used to obtain values at equivalent levels, salinity and temperature (especially throughout the surface, thermocline, and halocline) are uniquely variable and would have been smoothed out in error using this approximation. Instead, further analysis of the data was done using *conditional climatology*. Conditional climatology uses *conditions* such as highest winds, coldest temperatures, or lowest salinities to pull out similar time frames of data and infer climate similarities. For this study, highest and lowest January temperature data from 1994 to 2004 was used to infer El Nino and La Nina conditions.

III. Results

Temperature vs. Depth Profiles

In this study, both the GDEM and the SODA data sets did a relatively good job of representing the temperature and salinity profiles for the MBARI II buoy. Looking at the temperature vs. depth profiles for each January from 1994 through 2004 in Appendix A, it can be seen that in most cases SODA did do a better job of capturing the general temperature vs. depth pattern, especially the surface variability. GDEM, on the other hand, did not capture this surface variability but did seem to do a better job of capturing the deeper temperature pattern where there is much less variability.

Further analysis, using *conditional climatology*, was done by generating a sea surface temperature (SST) time series, and selecting the three coldest and three warmest January's from 1994 to 2004 (figure 4) . The three warmest years, 1996, 1998, and 2003, and the three coldest years, 1999, 2000, and 2002 were averaged together separately for SODA and the buoy. GDEM is a LTM and could not be

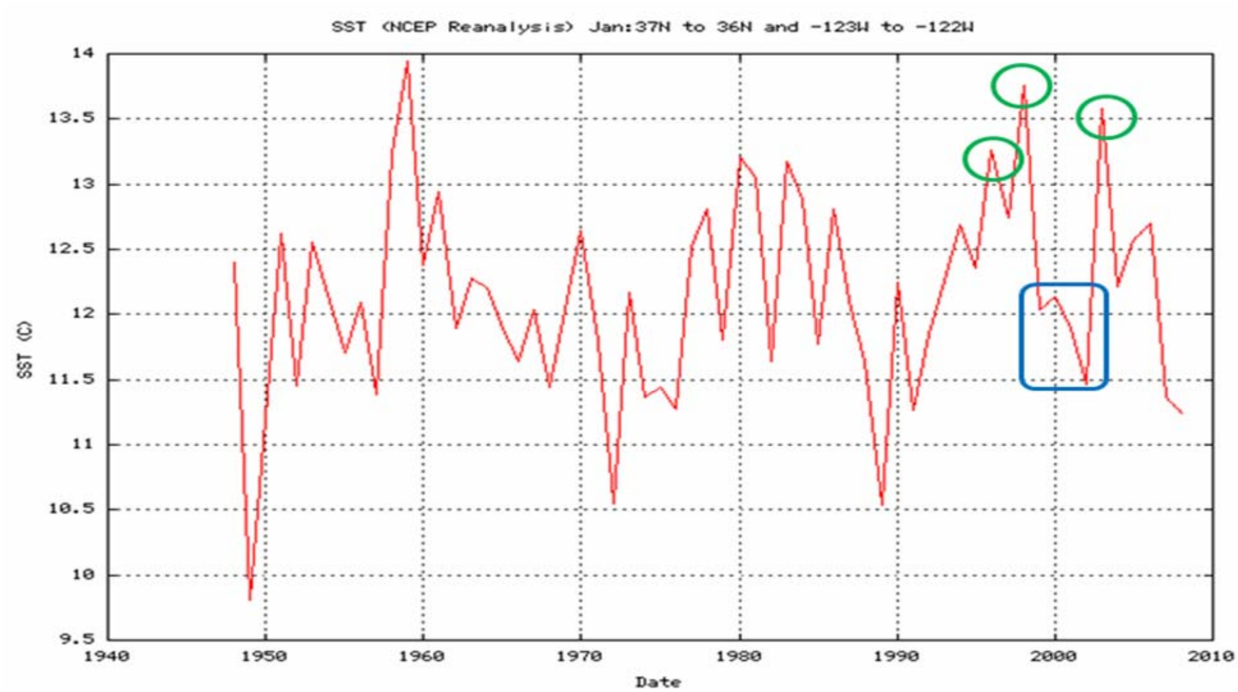


Figure 4: SST time series from 1940 to 2010. Green circles depict the warmest years chosen. The blue box encompasses the three coldest years chosen.

separated in the same manner. In figure (5), the SODA, GDEM, and buoy long term means (average of all data from 1994-2004) were plotted in addition to the means of the three warmest and three coldest years for SODA and the buoy. From this figure, it can be seen that the SODA cold, warm, and LTM temperatures are very consistent with the respective MBARI buoy means from the surface to approximately 50 to 75 meters. The GDEM LTM was inconsistent with both the SODA and MBARI buoy means near the surface. What also became apparent in this figure is that SODA and GDEM are far less consistent and generally cooler then the MBARI data below 100 meters. This could be the result of many different factors: (1) SODA and GDEM do not accurately represent deep currents, (2) there is not as much data below 150 meters to be incorporated into the models, and (3) the MBARI buoy measurements are from a specific point that may not be well represented by the SODA and GDEM gridded areas.

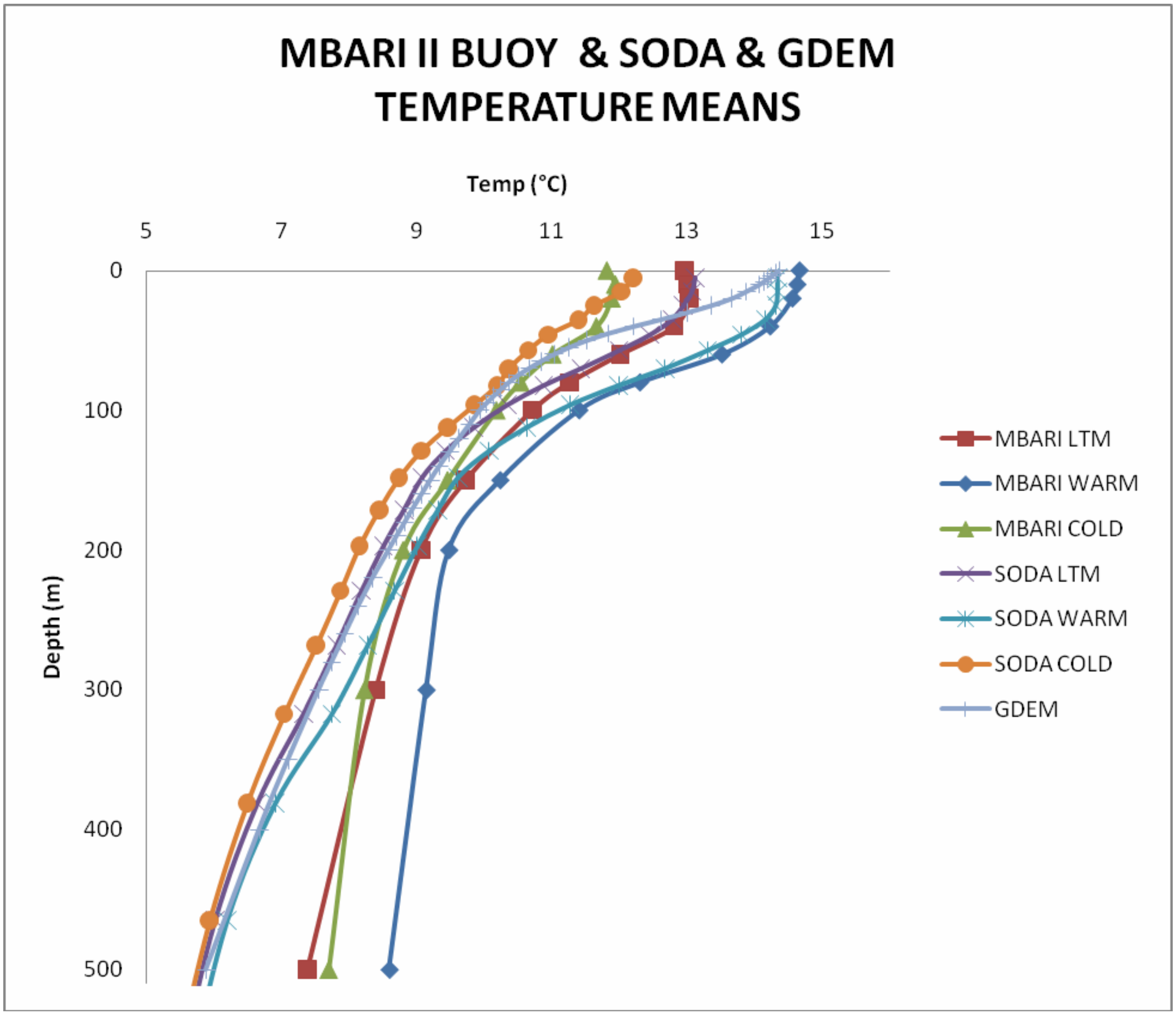


Figure 5: SODA and MBARI warm, cold, and LTMs, and GDEM LTM.

Additionally, to further convey the concept of *conditional climatology*, the three coldest and three warmest SST years were plotted using a composite plotting tool from a NOAA website.[5] By using these high and low SST conditions, figures (6) and (7) allow us to infer La Nina conditions from the coldest SST years and El Nino conditions from the warmest SST years.

[5] Earth Systems Research Laboratory <http://www.cdc.noaa.gov/cgi-bin/Composites/>

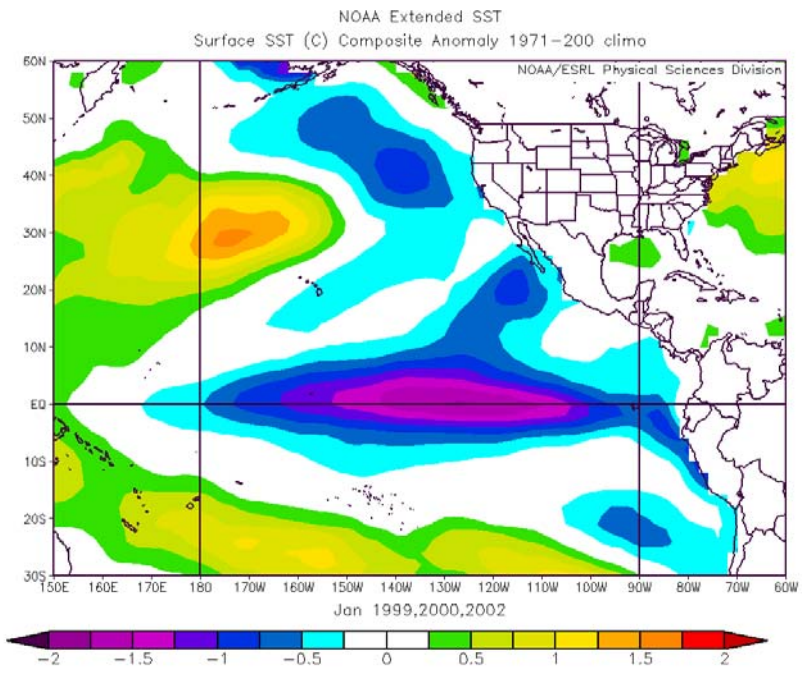


Figure 6: Composite SST anomaly of 3 coldest years indicating a La Nina event.

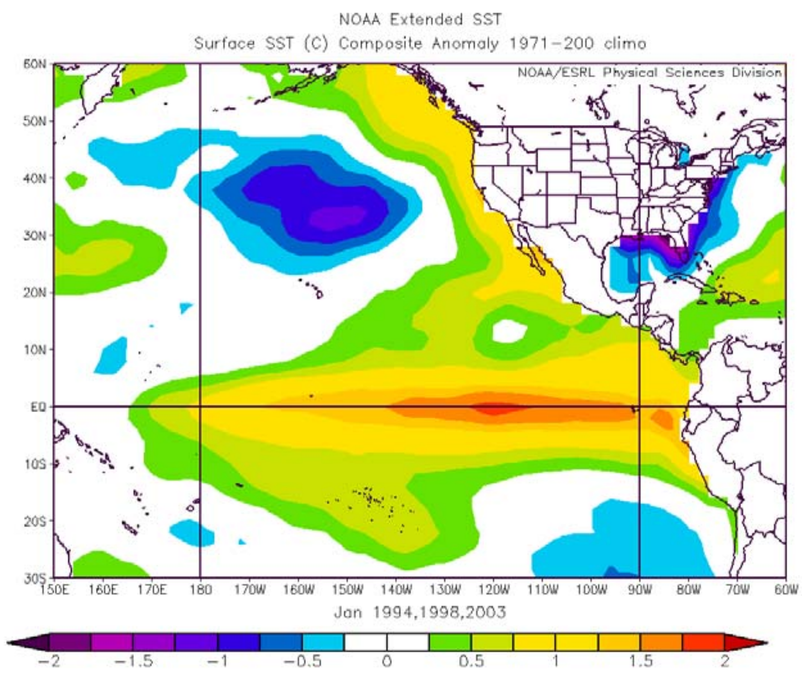


Figure 7: Composite SST anomaly of 3 warmest years indicating an El Nino event.

Salinity vs. Depth Profiles

Similar analysis was done for the salinity vs. depth profiles for each January from 1999 to 2004 shown in Appendix B. Obtaining substantial results from such a small data set is difficult. However, from this study, GDEM was more consistent then SODA in capturing the general MBARI salinity pattern during the highest salinity years of 2001 and 2002. SODA was more consistent then GDEM in capturing the general MBARI salinity pattern during the lowest salinity years of 2003 and 2004. Using conditional climatology, this can also be seen in figure (8), where lowest and highest salinity years were averaged together in the same manner that warmest and coldest SSTs were averaged together.

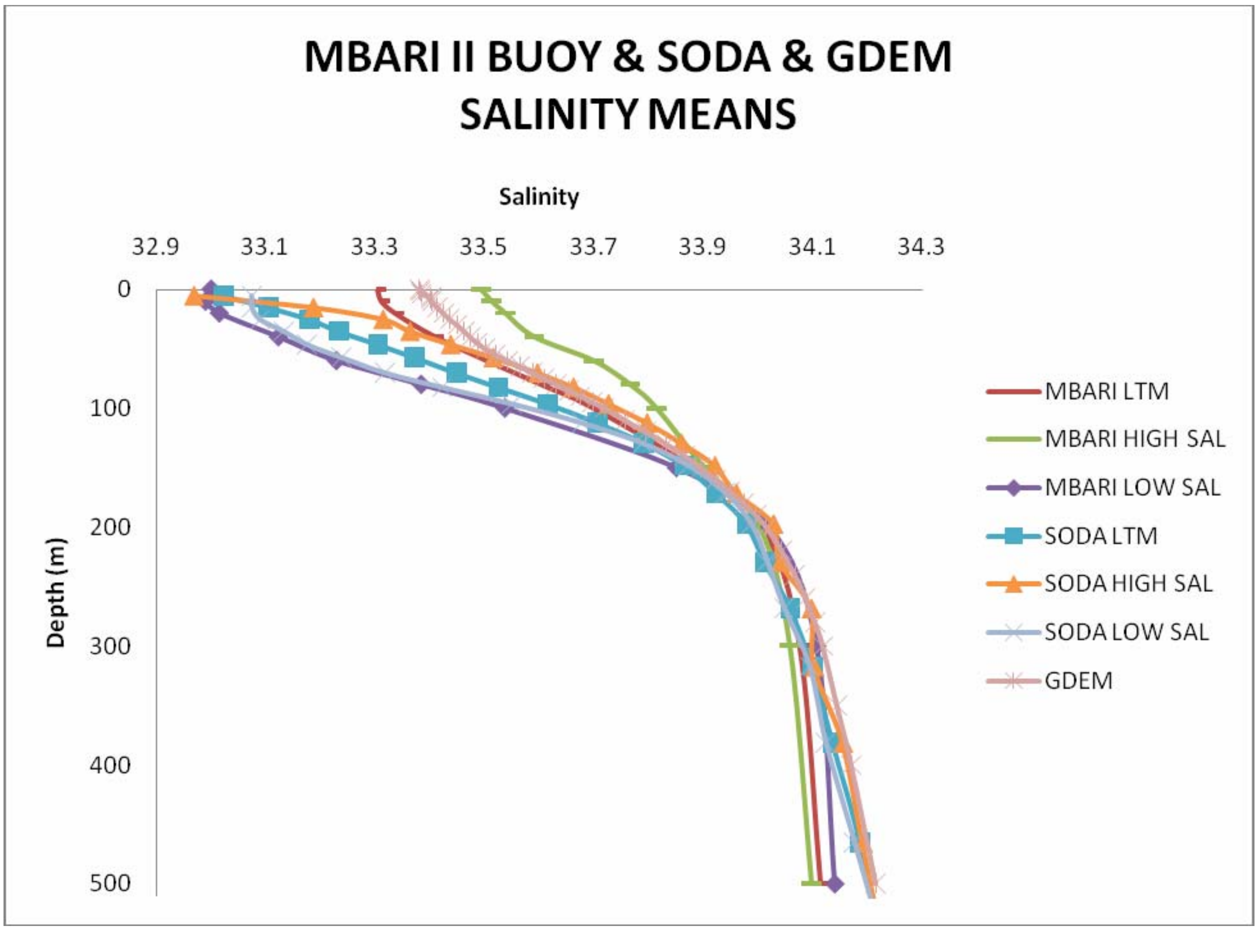


Figure 8: SODA and MBARI high salinity mean, low salinity mean, and LTMs, and GDEM LTM.

IV. Conclusions, Future Work, and Questions

Conclusions

This study showed that climatology, even LTM climatology, does a fairly decent job of capturing the general characteristics of in-situ temperature and salinity profiles. In this study the SODA climatology data set did a much better job of capturing the surface variability of temperature then GDEM. However, both climatology data sets were inconsistent with the in-situ buoy data below 100 meters. Conclusions from the salinity profiles, although interesting, are far less substantial, and leave quite a bit of room for future studies. All together, this study showed that while climatology can certainly help us to characterize the undersea environment, there are still aspects of the environment, such as surface variability and deep ocean currents that climatology still falls short at. For this reason, the best answer is to model a sensing strategy based on BOTH climatology and in-situ data.

Future Work

There is a lot more that could be done with this data set and similar data sets. From working with this data and doing this study I have four recommendations for future work that would allow for more substantial conclusions:

1) Do similar work using an in-situ data set that goes back several more years.
2) Use a climate data set that is more current (up to 2008) and has greater spatial resolution.
3) Expand this study to include a string of buoys or an area of in-situ measurements versus just one point in the ocean.
4) Expand this study to show seasonal variation by looking at months other then January.

Questions

This study showed that SODA has a large advantage over GDEM in that it has much higher temporal resolution, allowing for a more complete analysis and increased potential for climate scale forecasting. Why then, is the U.S. Navy still using LTM climatology?

REFERENCES:

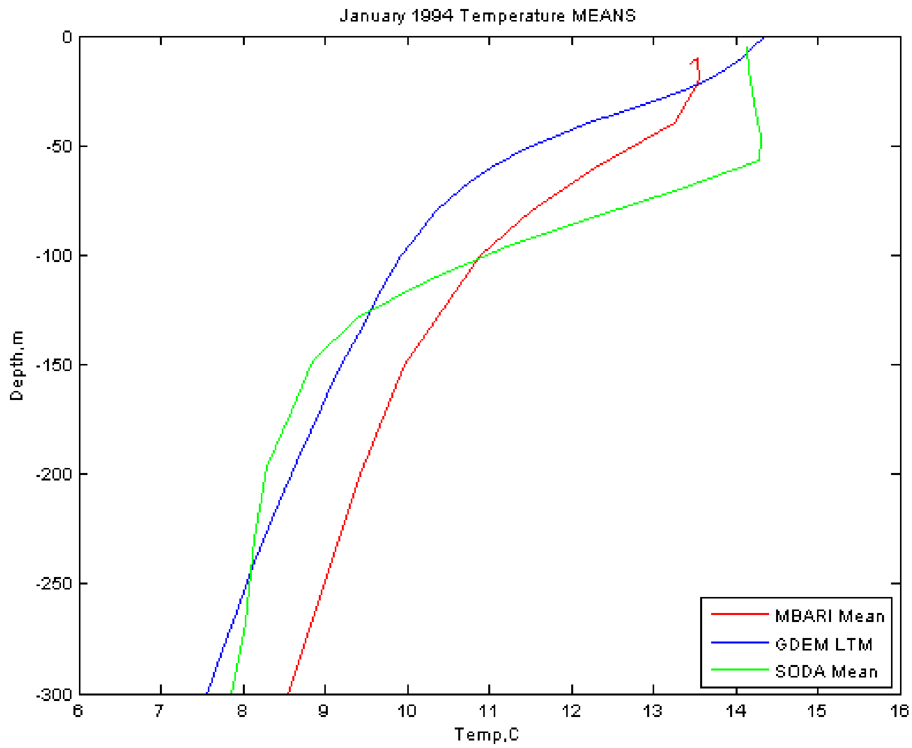
Carnes, MichaelR., *Description and Evaluation of GDEM-V 3.0*, Naval Oceanographic Office (N312), April 2003.

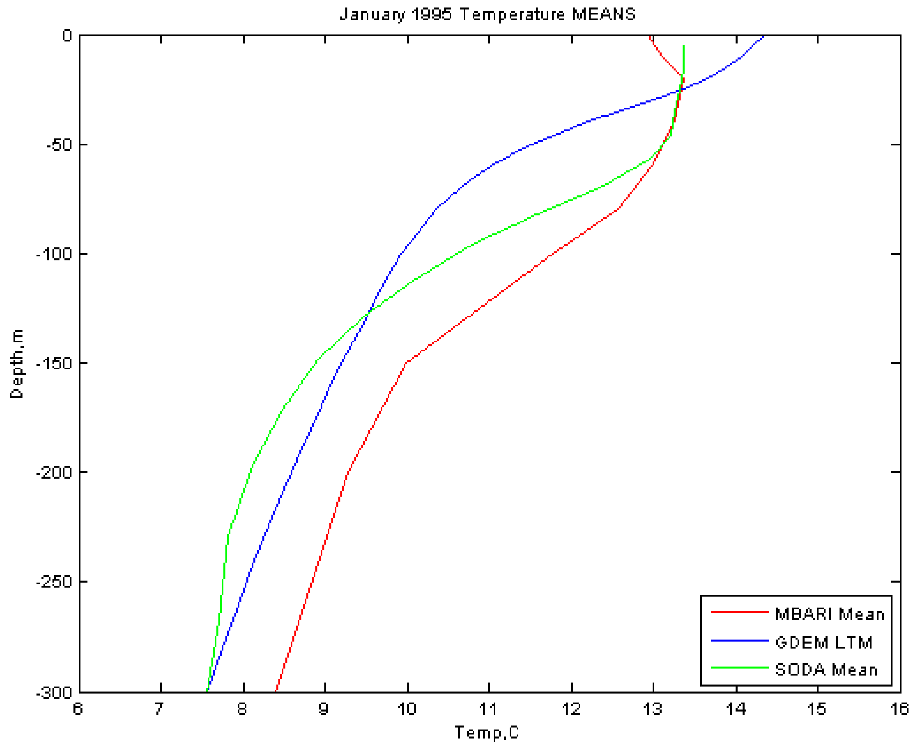
Carton, James A., Chepurin G., & Cao X. *A Simple Ocean Data Assimilation Analysis of Global Upper Ocean 1950-95. Part I: Methodology*, Journal of Physical Oceanography, 200, Vol. 30.

Earth Systems Research Laboratory Website: http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl

Murphree, T., and B. Ford, 2007. *Smart Climatology for Antisubmarine Warfare: Initial Assessments and Recommendations*. Brief to CAPT Jim Berdeguez, CNMOC, Stennis Space Center, MS 14 August 2007, slide 16.

ANNEX A: TEMPERATURE PROFILES




January 1995 Temperature MEANS
Depth,m
Temp,C
0
-50
-100
-150
-200
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-300
6
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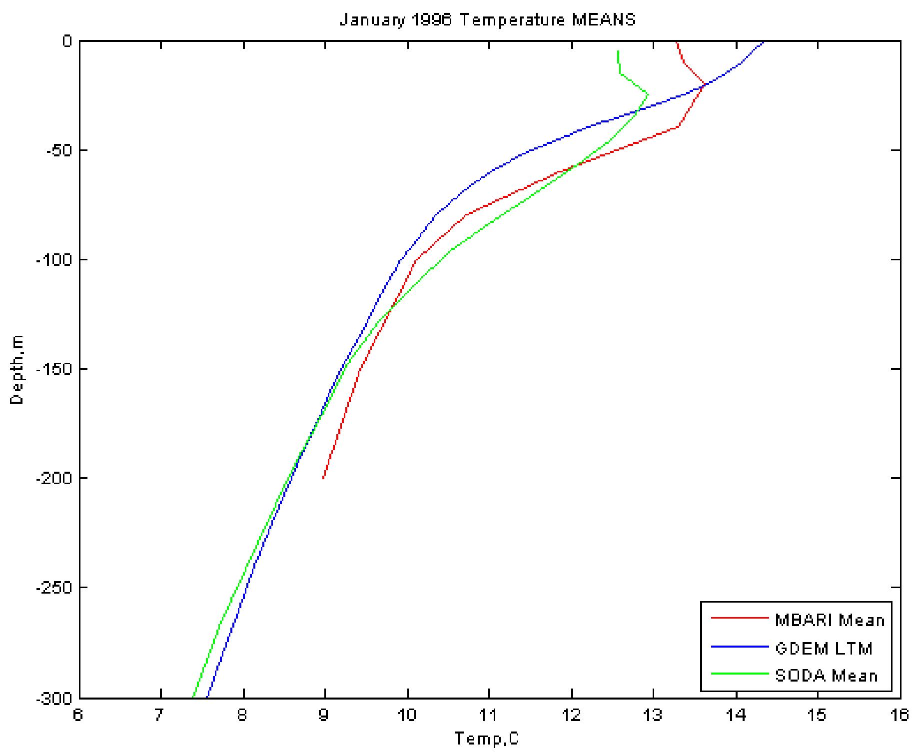
16
MBARI Mean
GDEM LTM
SODA Mean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Temp,C
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-100
-150
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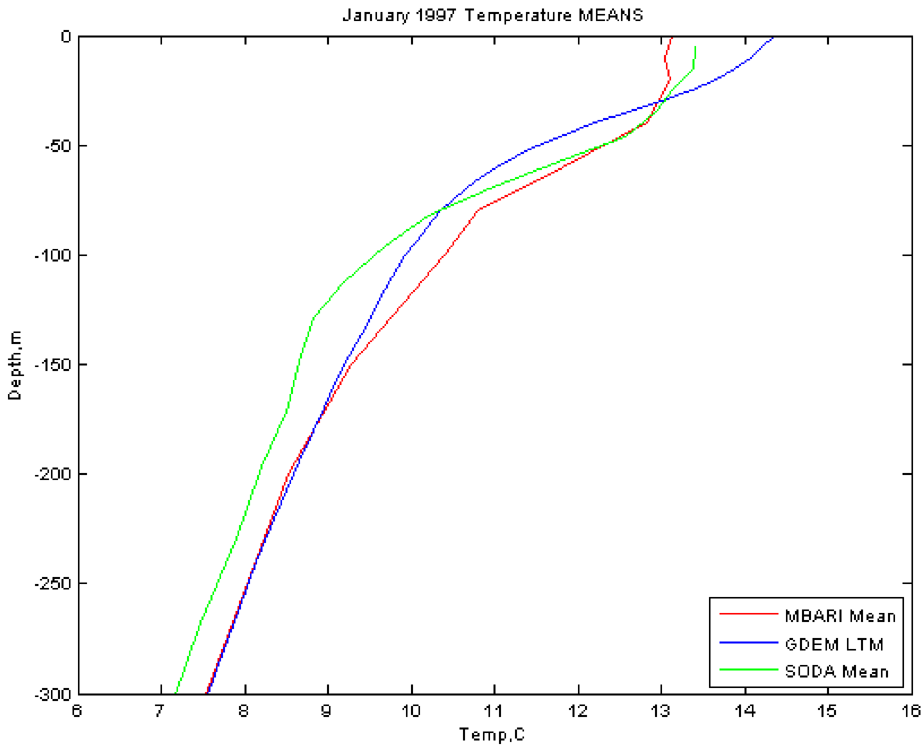
MBARI Mean
GDEM LTM
SODA Mean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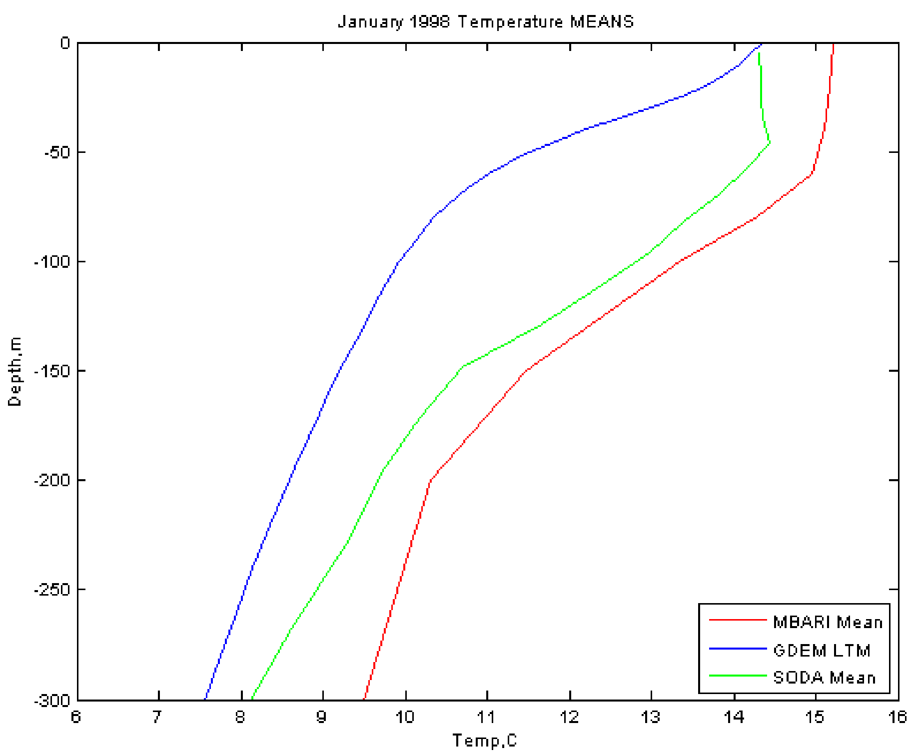
Depth,m
Temp,C
MBARI Mean
GDEM LTM
SODA Mean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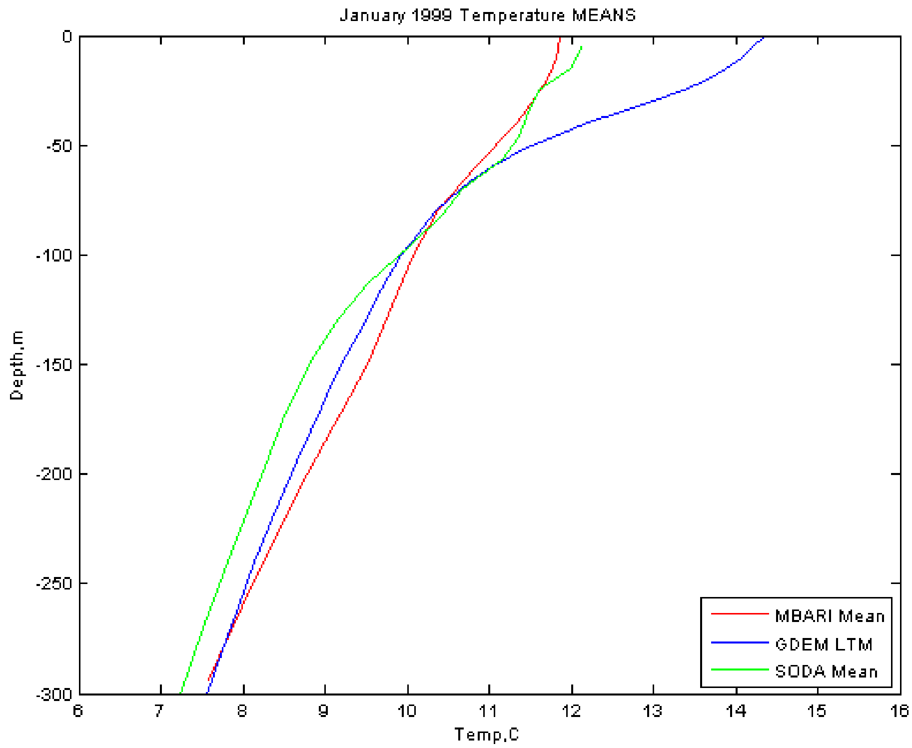
Depth,m
Temp,C
MBARI Mean
GDEM LTM
SODA Mean


January 1999 Temperature MEANS
Depth,m
Temp,C
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-50
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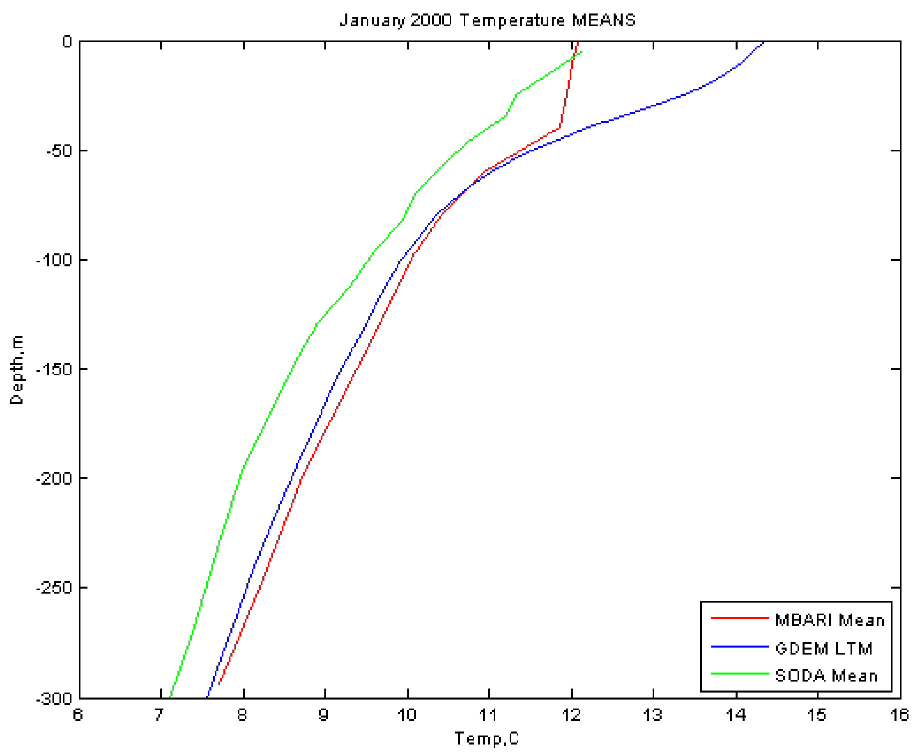
MBARI Mean
GDEM LTM
SODA Mean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Temp,C
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-150
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-300
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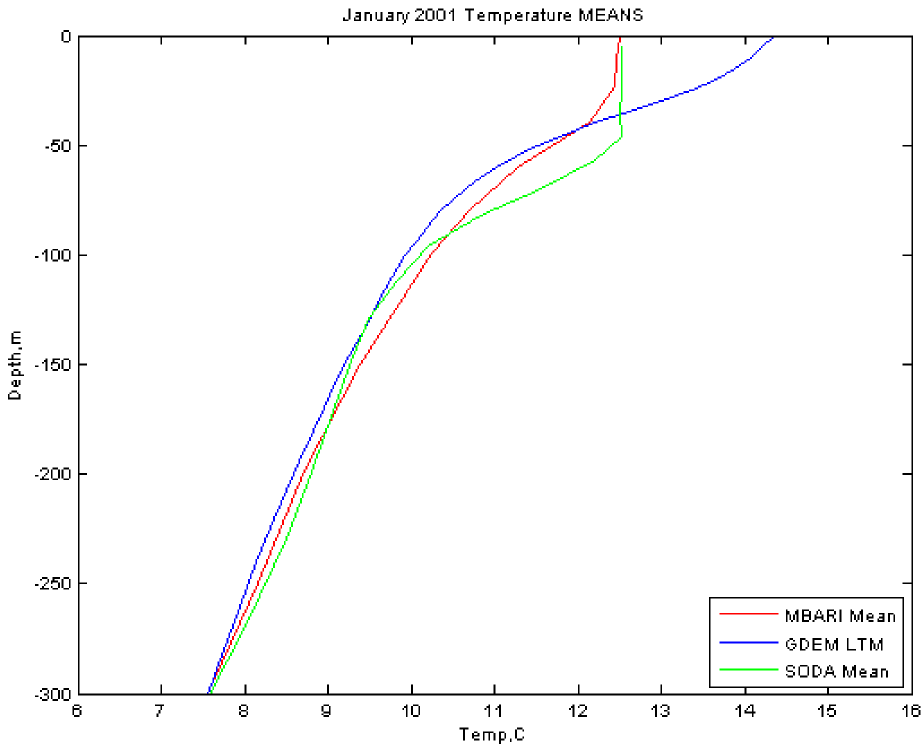
16
MBARI Mean
GDEM LTM
SODA Mean


January 2001 Temperature MEANS
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-200
-250
-300
Depth,m
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12
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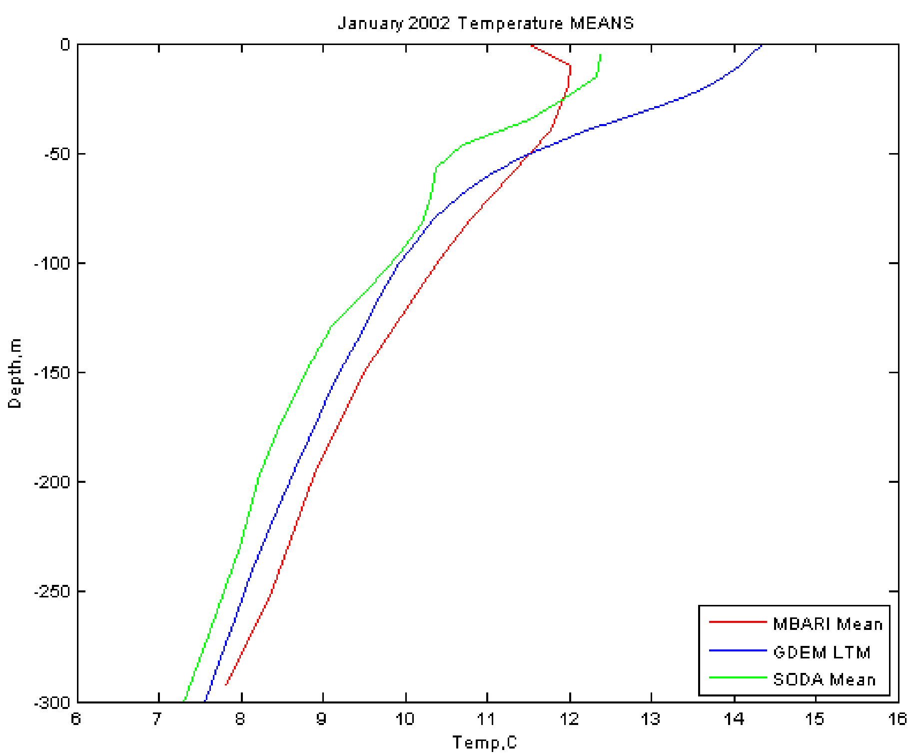
14
15
16
Temp,C
MBARI Mean
GDEM LTM
SODA Mean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-250
-300
Depth,m
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7
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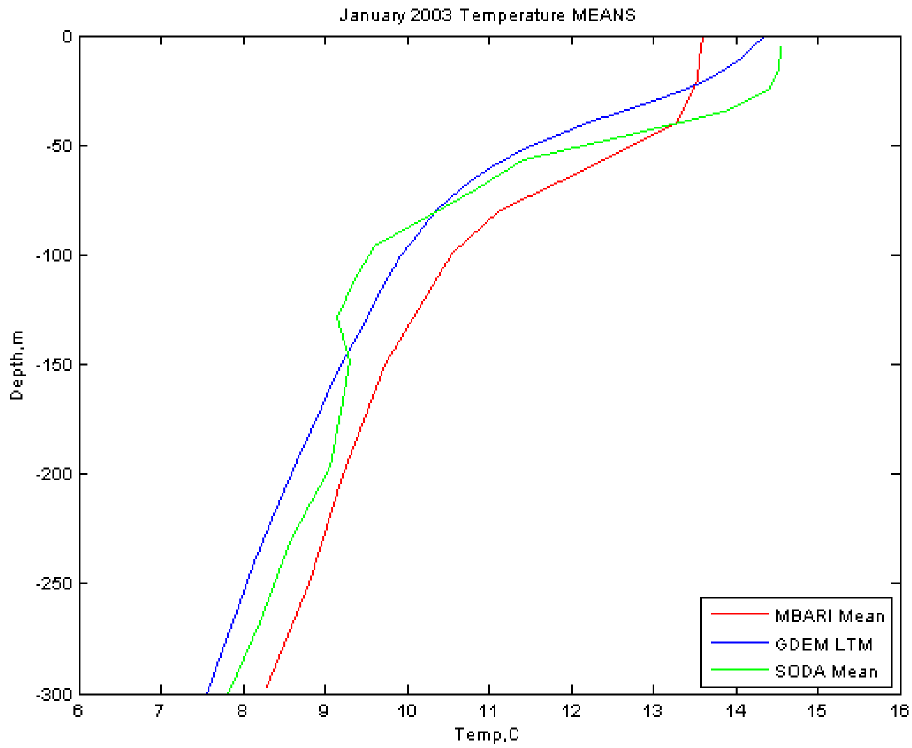
16
Temp,C
MBARI Mean
GDEM LTM
SODA Mean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Temp,C
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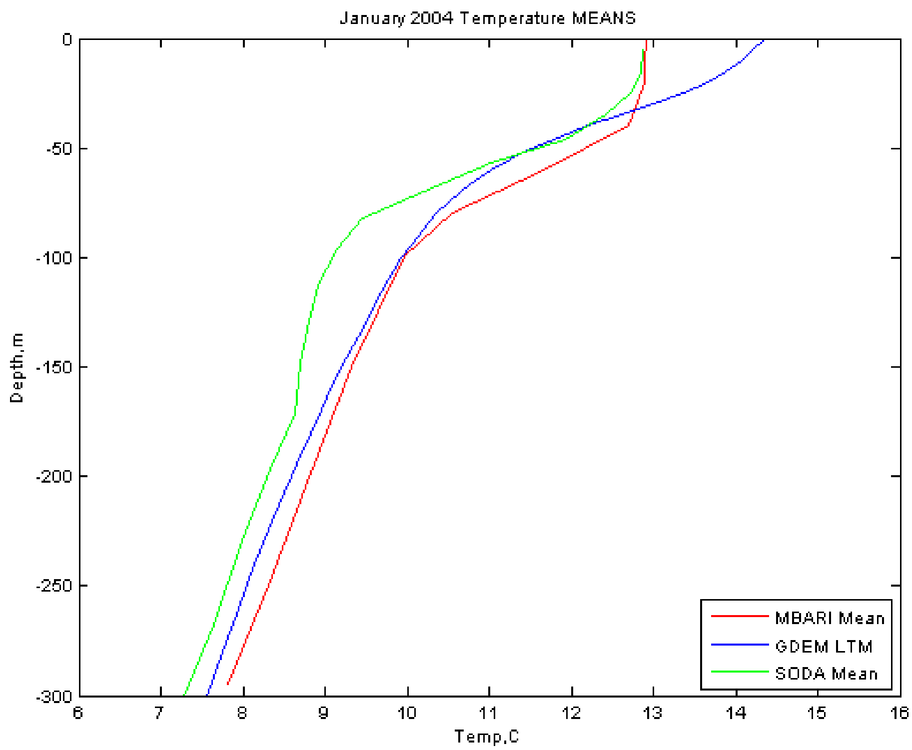
MBARI Mean
GDEM LTM
SODA Mean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Temp,C
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-100
-150
-200
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-300
6
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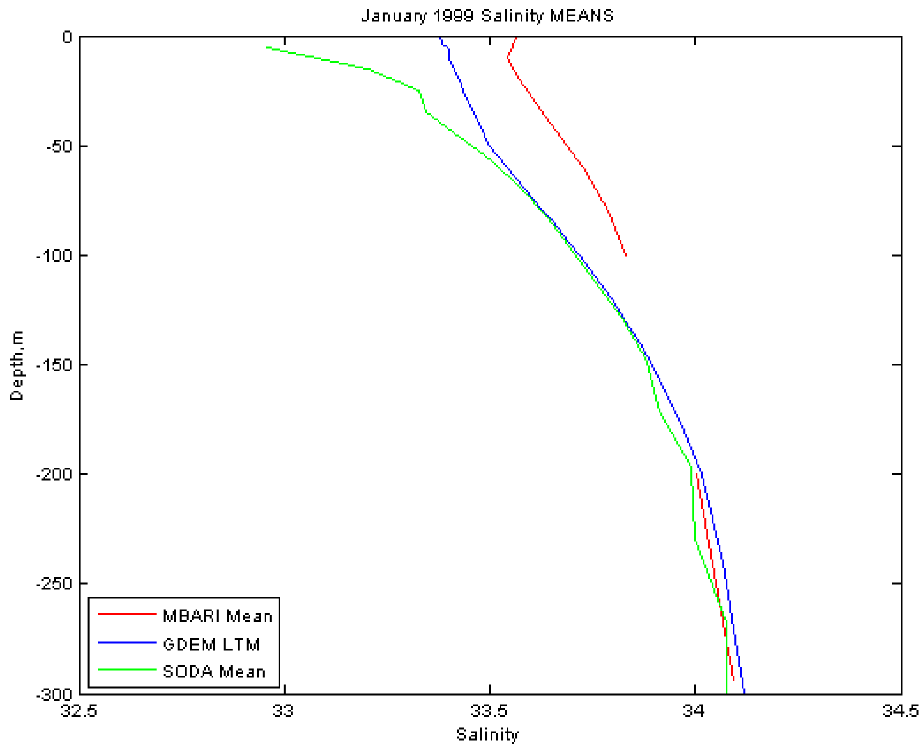
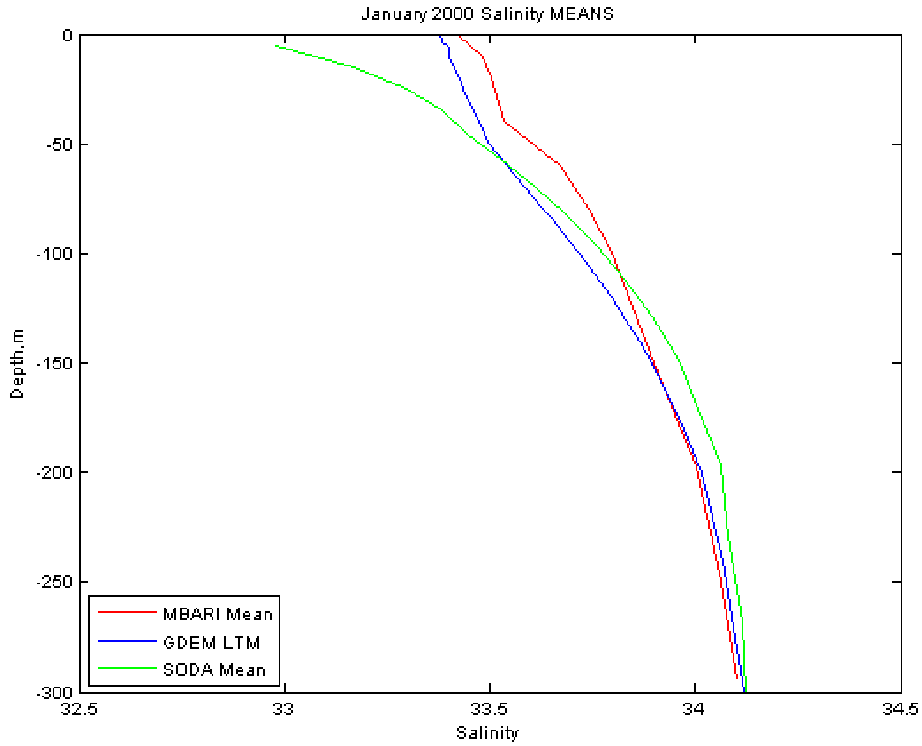
MBARI Mean
GDEM LTM
SODA Mean

ANNEX B: SALINITY PROFILES




January 2000 Salinity MEANS
Depth,m
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-300
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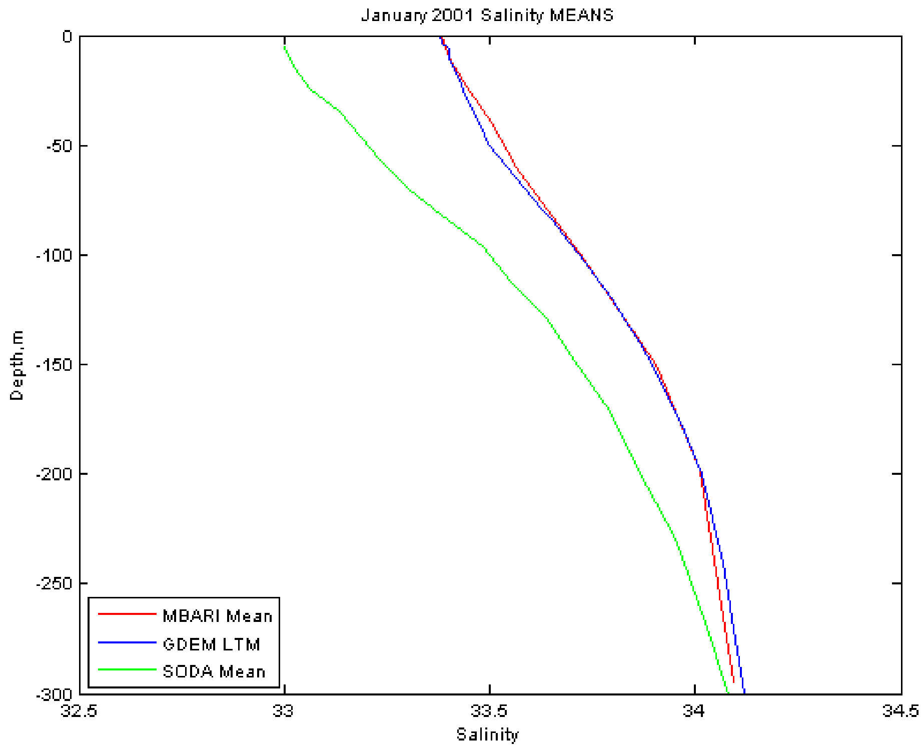
33
33.5
34
34.5
Salinity
MBARI Mean
GDEM LTM
SODA Mean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Salinity
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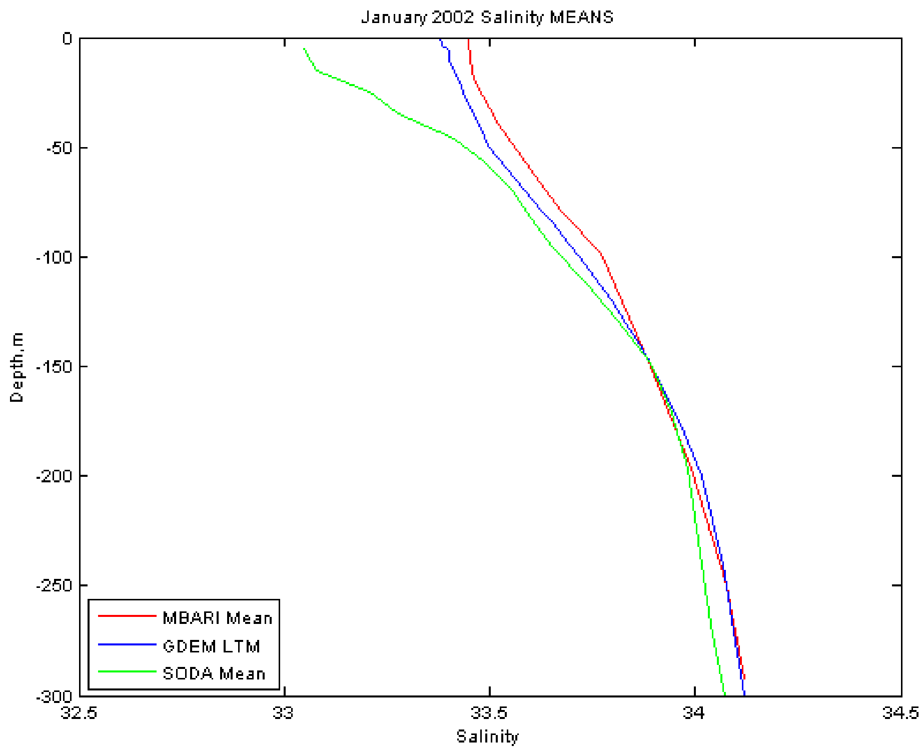
GDEM LTM
SODA Mean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Salinity
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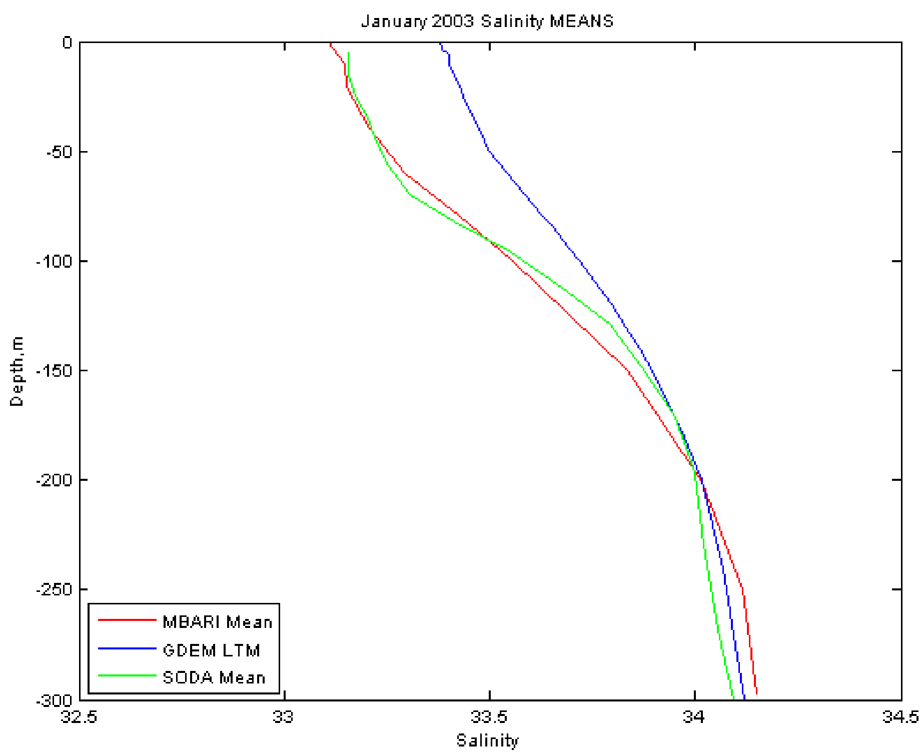
34.5
MBARI Mean
GDEM LTM
SODA Mean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Depth,m
Salinity
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-300
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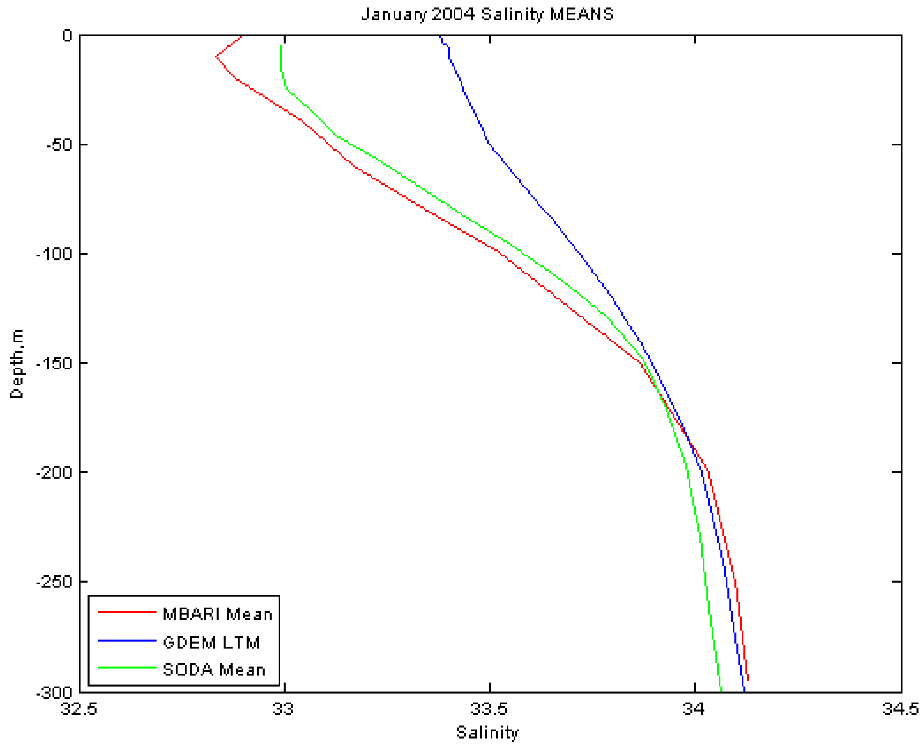
33
33.5
34
34.5
MBARI Mean
GDEM LTM
SODA Mean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-200
-250
-300
Depth,m
32.5
33
33.5
34
34.5
Salinity
MBARI Mean
GDEM LTM
SODA Mean