Two Different Descriptions of a Thermocline in the Persian Gulf

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Research Article

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Abstract

The Persian Gulf (PG) is a shallow sea connected to the rest of the world by the Strait of Hormuz. Temperature changes in the water column, which indicate the thermocline, are typically explained by the depth of the mixed layer and the thermocline. The thermocline is caused by a sudden decrease in temperature in the water column's subsurface layer, resulting in stratification in the PG from winter to summer. The parameters are approximated numerically through the Princeton Ocean Modeling (POM) method and compared to those determined by some CTD profiles collected in the PG. The most obvious method for approximating thermocline depth is to find the maximum negative slope $\frac{\partial T}{\partial z}$ in a temperature profile. The method produces applied results with sufficient depth resolution and smooth temperature changes with depth. This method is a component of the Princeton Ocean Modeling (POM) framework for numerically modeling temperature variation in the water basins used in this study. The depth of the mixed layer is approximated by the surface equality temperature (Sea Surface Temperature), regardless of the thermocline approximation. The variable isotherm behavior accurately approximates the thermocline depth. Thermocline formation occurs in the PG during the summer, and this article will conclude using two methods, observational and numerical modeling.

Introduction

Variations in temperature and salinity oceanographic observations indicate that ocean waters have a layered structure, particularly at the thermocline and halocline, representing vertical diffusions [1]. The thermocline is a layer of water in the water column where temperature changes more rapidly with depth than at the surface or deep water. The thermocline is a density gradient or pycnocline due to the density's temperature dependence, which is most pronounced at low latitudes. The thermocline is a physical gradient that affects the exchange of properties. The formation of thermoclines is a critical event in marine physics (Pedlosky 2006). The most obvious method for approximating thermocline depth is to find the maximum negative slope $\frac{\partial T}{\partial z}$ in a temperature profile. The method produces applied results with sufficient depth resolution and smooth temperature changes with depth. This method is a component of the Princeton Ocean Modeling (POM) framework for numerically modeling temperature variation in the water basins used in this study.

The maximum slope is frequently below the mixed layer in smoothed profiles, and the thermocline gradually weakens with depth. As a result, the thermocline depth is approximated because the depth of maximum slope does not reveal the thermocline layer's center (Wang and Lukas 2000). The most common and straightforward method is to use the mean isotherm depth to determine the thermocline depth (Kessler 2006). The thermocline is a boundary because it may correspond to an ecological temperature limit and gradients in nutrients or other limiting factors. The depths of the mixed layer and thermocline may be physically significant. The thermocline thickness is proportional to its shape and is dependent on both temperature and depth ranges. It should assess the thermocline's effectiveness as a physical or ecological boundary and the stratification of the water column within the thermocline layer.

This article compares two methods for clearly approximating the thermocline using 1992 CTD data and numerical modeling results for temperature and salinity in the PG. Surface heating confirmed the summer stratification's strength.

Materials And Methods

The data collected by CTD during the Mt. Mitchell cruise, including temperature and salinity variations with depth, demonstrate T and S variations with depth and serve as initial data in POM for numerical modeling in the PG. The Mt. Mitchell Cruise's measurement stations are depicted in Figure 1.

Figure 2 depicts plots of temperature profiles from measurement stations in three distinct regions (northwest of the PG, deep part of the PG, and near the Strait of Hurmoz). They all exhibit the seasonal thermocline in the PG during the summer. Almost every profile has a temperature inversion below the thermocline due to the interleaving of cold and low-salinity air from the Arvand river in the shallower region of the PG.

While it is simple to identify the bottom of the mixed layer, it does not correspond to the top of the thermocline if there is no sharp "corner" or change in slope. Thus, the thermocline's top point is shifted deeper to define the thermocline. However, there is no apparent discontinuity at the thermocline's bottom. When it depicts multiple depth intervals with a steep temperature gradient, only one thermocline is indicated to encompass the steepest temperature gradient. Strong thermocline layers form in the summer ($\Delta T = 11^{\circ}\text{C}$), while weak thermocline layers form in the winter at deep stations ($\Delta T = 9^{\circ}\text{C}$) in the Strait of Hurmoz, implying that the thermocline forms in both winter and summer, but only in the Strait of Hurmoz; this is due to water outflow.

By observing the temperature profiles at the measurement stations, the approximate thermocline position was determined. The POM is used to numerically simulate temperature and other thermocline characteristics, with the results compared to observational data. The thermocline's depth and shape are determined by latitude, season, and climatic conditions. According to temperature profiles (Figure 2), the PG "seasonal thermocline" forms during the summer, when heat flux at the surface is positive, and wind stress is low. The seasonal thermocline has been explained as a secondary thermocline that forms above the deeper thermocline, as observed numerically and experimentally in the PG temperature profiles in Figure 3.

Because different methods are used to determine thermocline parameters, thermocline formation produces similar and true data; due to the problem's equal conditions. The results obtained using various methods may vary somewhat; however, in this study, the maximum slope method, in which the thermocline's top is the bottom of the ML, demonstrated similarity to the POM. Although the standard deviation of temperature is frequently used compared to a stratification parameter, it requires temperature and salinity profiles in which the temperature at the bottom of the mixed layer $\text{Temperature} = \text{Sea Surface Temperature} - 1$.

$$\emptyset = \frac{1}{h} \int_{-h}^0 (\rho - \rho^-) g z \, dz$$

(Bidokhti and Shekarbaghani 2011)

Results

The thermocline is explored numerically as part of this research, and the results match those obtained through measurements. The correlation coefficient of temperature between modeling and measurement is 0.85, and MLD is well approximated by the temperature criteria (sea surface temperature -1 degree centigrade), emphasizing the results obtained in (Kara, Rochford and Hurlburt 2000). When ML is distinguished from the isothermal layer, this criteria is inapplicable, and MLD must be recognized based on densities. As previously stated, the maximum slope method is influenced by the interval over which the slope is attempted. Three regions' profiles provide excellent approximations of thermocline depth, although they do not match the model. Thus, the depth of the mixed layers and thermocline must be approximated using the -1°C sea surface temperature, temperature criteria.

Previous research has demonstrated results in the primary biases at high latitudes, where the temperature range is narrow, and the surface temperature may be close to deep water. The authors of (Yang and Wang 2009) concluded that in studies examining the effects of climate change on thermocline depth as an

isotherm depth and as a depth with a maximum $\left(\frac{\partial T}{\partial z} \right)$, the opposite sign exists.

It was stated that there is an enhanced thermocline during global warming; this occurs as a result of the surface layer warming faster than the lower layers. Our findings regarding thermocline structure and variability may not be accurate in all cases. Over most PG, the temperature difference between the surface and subsurface increases exponentially; in fact, the vertical temperature difference between the surface and subsurface can reach 9°C in some parts of the case study zone during the summer.

As a result, the thermocline forms throughout the water column in the PG during the summer, as well as in the Strait of Hurmoz during the winter; because the water column in the deeper stationed, i.e., at the Strait of Hurmoz, is composed of two layers, there are two distinct water masses in the Strait of Hurmoz throughout the year, with the thermocline forming in the winter and summer.

References

1. Bidokhti AA. & Shekarbaghani A. The layered structure in exchange flows between two basins (Middle and southern basins of the Caspian Sea). Int. J. Mar. Sci. Eng. 1. 13–22 (2011).
2. Kara AB., Rochford PA. & Hurlburt HE. An optimal definition for ocean mixed layer depth. J. Geophys. Res. 105:16803–16821 (2000).
3. Kessler WS. The circulation of the eastern tropical Pacific: A review, J. of Progress in Oceanography. Vol. 69. 181–217 (2006).

4. Pedlosky J. A history of thermocline theory. In: M. Jochum and R. Murtugudde. Physical oceanography: Developments since 1950. Springer. p. 139–152 (2006).
5. Wang B. and Lukas R. Annual adjustment of the thermocline in the tropical Pacific Ocean. J. Climate. 13:596–616 (2000).
6. Yang H. and Wang F. Revisiting the thermocline depth in the equatorial Pacific. J. Climate. 22:3856–3863 (2009).

Figures

Figure 1

The locations of the measurement stations in PG during the Mt. Mitchell cruise

Figure 2

Selected CTD temperature profiles in 3 regions (Figure1) summer (top) and winter (below)

Figure 3

Mean depth temperature changes in the water column of the PG, showing thermocline formation in summer – (—) measurement and (—) by POM – in the PG