

# Measuring physical characteristics and properties of Loihi seamount

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Physical properties of hydrothermal plume

### **Non-Technical Summary**

#### Physical properties of the hydrothermal plume from the Loihi seamount.

Loihi seamount is an underwater active volcano that is located 35km southeast of the Hawaii. Loihi's summit rises about 1000 meters below the sea surface and the pit is about 1200 meters below sea surface. The seamount is actively venting hydrothermal fluid into the ocean. Hydrothermal fluid is warm, less dense water being released from the vent on the seafloor and rises through the water column forming a plume. The plume will continue to rise through the water column until the density of the plume is equal to the density of the background ocean water.

The R.V. Thomas G. Thompson was at the Loihi seamount on December 30<sup>th</sup> and 31<sup>st</sup> 2010 . There, a conductivity-temperature-depth (CTD) package measured physical properties of the plume, such as temperature, pressure, salinity, and density. The CTD measurements showed there were temperature anomalies that correlated with salinity and density anomalies. These correlations in anomalies are a plume signature. The plume signatures occurred along the northern walls of Pele Pit about 25 - 40 meters above the seafloor. This lead to the calculation of the source temperature of 8.1 to 32.2 degrees Celsius, which is a sign that no major geological events occurred recently.

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### **Abstract**

From December 27<sup>th</sup> 2010 through January 4<sup>th</sup> 2011, a survey of the hydrothermal plume on Loihi seamount was conducted. One purpose of surveying Loihi was to gather data in order to study the physical properties of hydrothermal plumes from one of Loihi's pits, Pele's Pit. Pele's Pit was chosen as the site to study because it is the most hydrothermally active pit of the Loihi seamount. The Loihi seamount is an active underwater volcano that has several known venting sites. On December 30<sup>th</sup> and 31<sup>st</sup> physical properties, such as, temperature, density, pressure, and salinity were measured using the conductivity – temperature - depth (CTD) package. The CTD measurements revealed temperature and salinity anomalies on the northwest wall of Pele's Pit near known hydrothermal venting sites. These anomalies are  $\sim 0.1$  degrees Celsius and  $\sim 0.005$  PSU, which are consistent with plume anomalies. These anomalies occurred about 25-40 meters above the seafloor. A source temperature of about 8.1 – 32.2 degrees Celsius was calculated revealing that temperatures have continuously decreased since 1996.

### **Introduction**

The R/V Thomas G. Thompson surveyed and sampled the water and seafloor in the Pacific Ocean around Hawaii from December 27<sup>th</sup> 2010 to January 4<sup>th</sup> 2011. From December 30<sup>th</sup> to 31<sup>st</sup>, the Thompson was at Loihi seamount measuring physical properties of the hydrothermal plume from the seamount.

A hydrothermal plume is the result of warm less dense water, called hydrothermal fluid, being released from a vent on the seafloor and rising through the water column until it reaches a point where the density of the hydrothermal fluid is equal to the density of the ambient water

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(Speer and Rona, 1989). At this point the plume spreads horizontally. The hydrothermal plume initially rises due to buoyancy, initial momentum or both (Little et al., 1987). The hydrothermal plume initially rises quickly, but slows down as ambient fluids mix with it. Therefore, the neutrally buoyant plume is not as hot as its source. The initial difference between vent fluids and ambient fluids is diluted by a factor of  $\sim 10^3 - 10^4$  by the time the plume is neutrally buoyant (Lupton et al., 1985; McDuff, 1995). This is why a neutrally buoyant plume can sometimes be difficult to identify because the anomalies between the plume and ambient water are small.

Salinity and temperature anomalies of hydrothermal water compared to ambient water are two tracers that are used to indicate whether a hydrothermal plume was present.

Hydrothermal fluids have higher temperatures and lower salinities than ambient waters. They are both considered good tracers because they both can remain detectable even if the vent source is far away.

Another characteristic of hydrothermal plumes is they have a low transmission of light because they are more turbid. The low transmission of light and higher temperature is how a plume can be spotted using a CTD as long as the hydrothermal fluid recently left the vent source (Rona et al. 1997). Therefore, simultaneous changes in temperature, salinity and transmission of light can be noted as an indicator of hydrothermal plumes; however a change in transmission of light may not always occur.

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Loi'hi is an underwater volcano and the youngest of the Hawaiian volcanoes located 35km southeast of the Hawaii and directly over the Hawaiian Hot Spot. A Hot Spot is a volcanic region where the underlying mantle is hot compared to the mantle elsewhere (Chernicoff and Whitney 2007). Fresh lava flows, which are associated with hydrothermal activity, were discovered by dredging around the summit (Malahoff et al. 1982). This is what led to the certainty that Loihi is an active volcano and not just a seamount and renewed scientist interest in the Hot Spot (Garcia et al. 2006). A series of more than 4000 small earthquakes in July and August 1996 caused the collapse of Pele's Vents forming a depression called Pele's Pit. The physical characteristics of a plume evolves from the initial conditions of the seafloor (Speer and

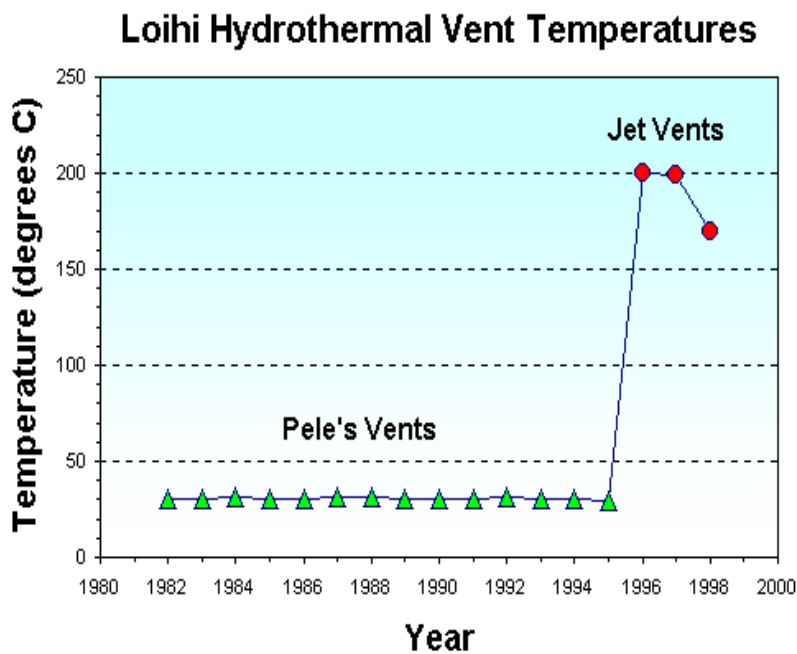


Figure 1: The Hawaii Undersea Research Laboratory took temporal samples at Pele's hydrothermal vents. After the surge of earthquakes in 1996, temperature decreases.

<http://www.soest.hawaii.edu/HURL/Q199.htm>

Rona 1989), therefore this alteration in the crustal conditions changed the hydrothermal circulation of Loi'hi (Wheat et al. 2000).

Pele's pit has been studied for chemical and physical properties for both before and after the collapse

(Wheat et al. 2000; Glazer and Rouxel. 2009; Garcia et al. 2009). Over the past 30

year in which these studies took place there are differences in values of what was collected.

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Glazer and Rouxel (2009) discovered within their own study a difference in hydrothermal fluids discharging from Pele's Pit between their 2006-2008 samples and their 1996-1997 samples. In 1997 Glazer and Rouxel (2009) measured temperatures of 200 degrees Celsius within Pele's Pit, while between 2006 and 2008 they only recorded temperatures of 21.6 to 55 degrees Celsius. The Hawaii Undersea Research Laboratory reported they believe that Pele's hydrothermal system is returning to pre-collapse conditions (Figure 1). Therefore it appears that Pele's hydrothermal vents' properties are constantly changing on a relatively short time scale.

There are 4 known venting sites along the floor and wall of Pele's pit. They are Lohiau, Ula, Ikaika "Forbidden", and Hiolo Vents (Figure 3, Wheat et al., 2000). Since there are at least four venting areas, there could have been many separate plumes. However, more than likely there would be one plume or pool of water that will fill Pele's pit that all four vents may contribute too. This scenario is more likely because Pele pit is a pit where the only predicted continuous input of new water is from the hydrothermal fluid.

The goal of this paper is to determine the current source temperature of the vents in Pele's Pit and to compare them to previous findings. Noting that if the current findings are unsuspected, it could be a sign of recent geological activity occurred. The other goal of this paper is to determine if there are many plumes or just one big one.

## **Materials and Methods**

Fieldwork of the Loi'hi seamount took place aboard the R/V T.G. Thompson between the 30<sup>th</sup> and 31<sup>st</sup> December 2011 (GMT time). Fieldwork conducted at Loi'hi seamount consisted of a series of four CTD tow-yo transects (Figure 2). The tow-yo technique was employed in order

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to locate the hydrothermal plume. The tow-yo technique consisted of raising and lowering the

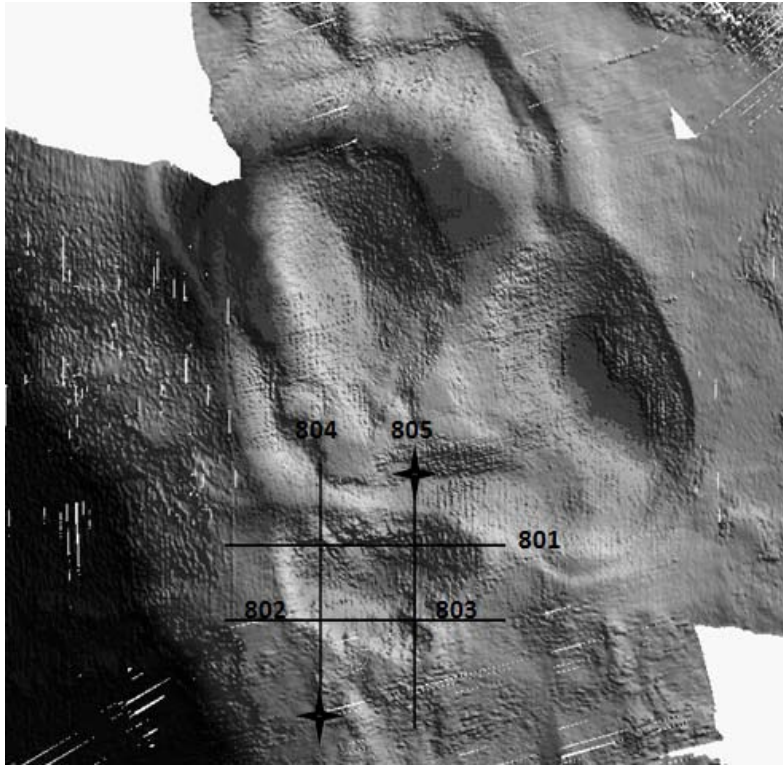


Figure 2: Map showing Loihi seamount with 4 transect lines across Pele's Pit. The star south of transect 804 and north of transect 805 are the locations where the two control CTD vertical casts were taken.

CTD package as the Thompson moved across the water at  $1 \sim 1.5$  knots. These tow-yo transects occurred between 10 – 40 meters above the seamount and followed the transect lines. The CTD measured many physical properties such as temperature, salinity, density and depth.

Analysis of the CTD data at Loi'hi was compared to other CTD cast outside of Loi'hi as controls (Figure 2). The temperature, salinity and density of the plume

were compared to ambient waters with the same depth, in order to show the anomalies at Loi'hi were true signals of a plume's presence when compared to ambient seawater characteristics. Where there were significant anomalies, such as a temperature increase of .1 degree Celsius and .005 PSU, it would be assumed to be a hydrothermal plume. At these locations, the height above the seafloor and the buoyancy frequency that was calculated (Appendix, equation 3) can give us buoyancy flux (Appendix, equation 2). Once the buoyancy flux is known the source temperature and heat flux can be derived (Appendix, equation 4 and 1).

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### Results

The general trend of the result from the CTD data is that the overall temperature is higher and salinity and density are lower inside Pele's Pit than outside Pele's Pit for the same depths (Figure 3-5). Within Pele's pit there is a spike in temperature, salinity, and density on transect 804. This spike occurs around 1120 to 1135 meters below the sea surface, which correlates to about 25-40 meters from the seafloor. Using the models given by Speer and Rona (1989) and Little et al. (1987) (Appendix) a source temperature between 8.1 to 32.2 degrees Celsius and a heat flux of .179 to 1.34 MW was calculated. In order to get this temperature a few assumptions were made. First the source area (A) and source velocity were source velocity were assumed to be  $.1 \text{ m}^2$  and  $.1 \text{ m/s}$  respectively. These are common values for low temperature vents (Scheirer et al. 2006 and Speer and Rona 1989). The other assumption that was made was to assume the change in salinity (Appendix, equation 4) had no effect on the buoyancy flux.

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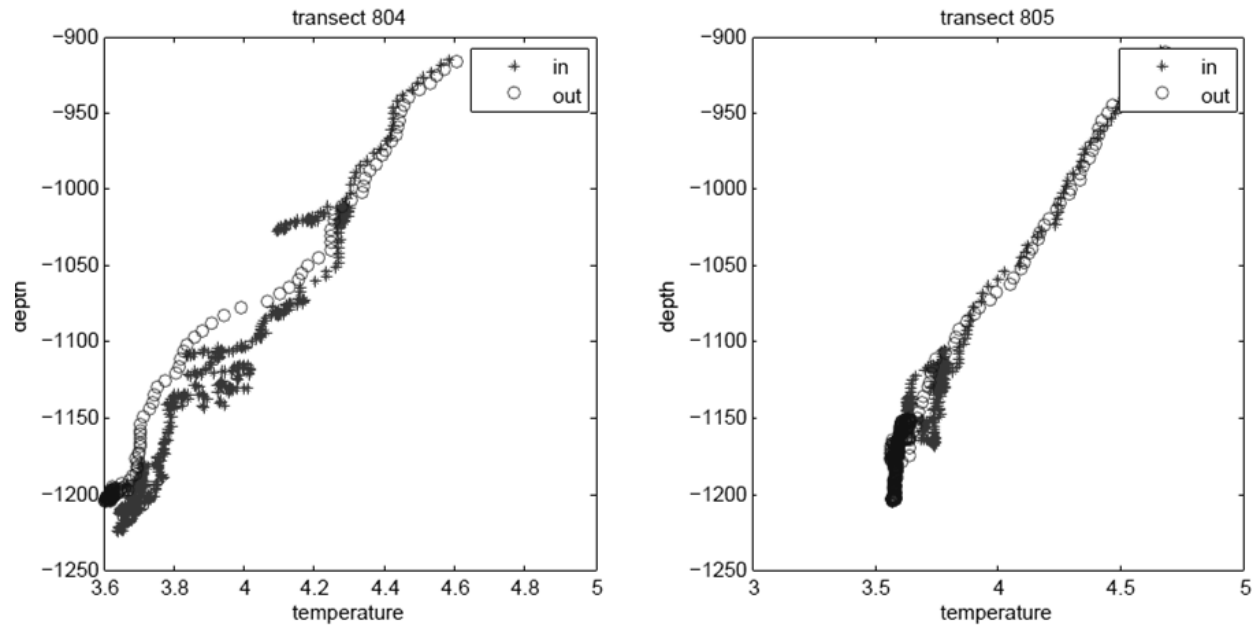
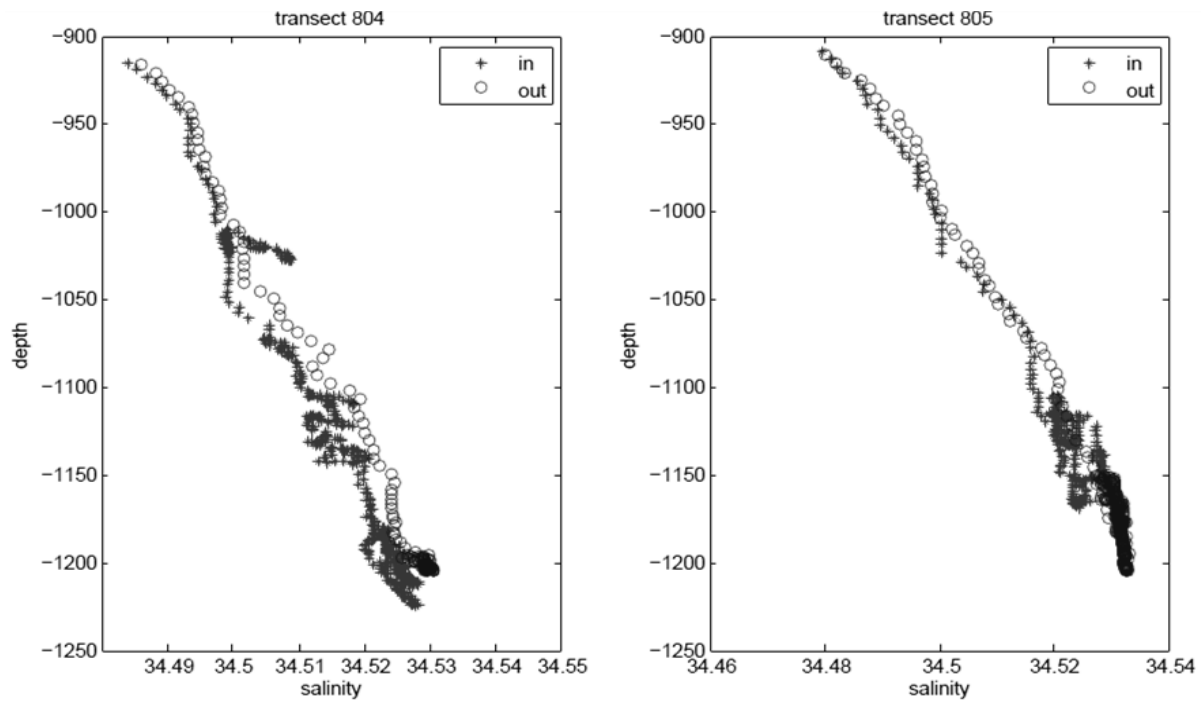


Figure 3: Transects 804 and 805 run north to south. The edge of the pit is at 1020 meters deep for transect 804 and 1050 meters for transect 805. Overall for both profiles there is a higher temperature inside the pit than outside. At 1120 meters to 1135 meters there is a significant spike in temperature.



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Figure 4: Transects 804 and 805 comparing salinity in and outside the pit. There is a significant spike at about 1120 meters to 1135 meters deep, which correlate to Figure 3's spikes.

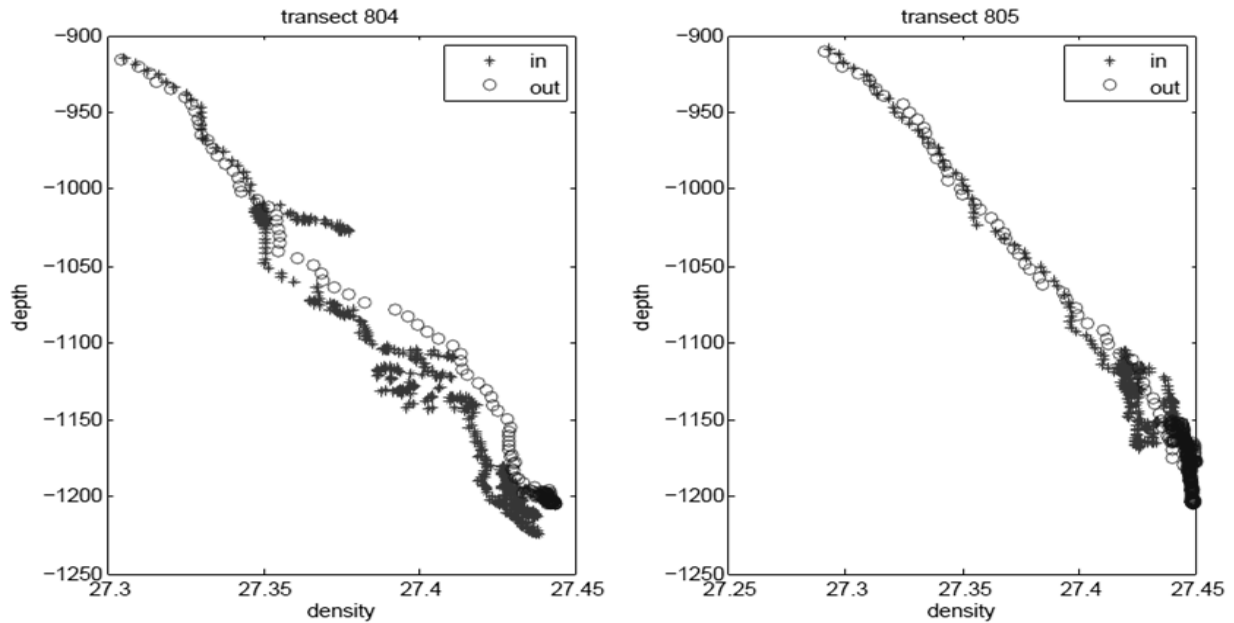


Figure 5: Density with depth for both transect 804 and transect 805. The significant spike in transect 804 correlate with the spikes in Figure 3 and 4.

## Discussion

Most studies of hydrothermal plumes are conducted at mid-ocean ridges and there are few studies of hydrothermal plumes at volcanically active seamounts, such as Loi'hi (Lupton 1996). However, at both locations the hydrothermal plumes' physical properties and structure are different compared to their surrounding ambient waters.

The water within Pele's Pit is warmer and has a smaller salinity and density inside than the ambient water outside Pele's Pit. Therefore, it appears as if the warm water pools inside of

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Pele's Pit, as predicted. This also means that there is not a lot of flushing of hydrothermal fluids inside the pit.

Even though the hydrothermal water pools within Pele's Pit there was one definitive plume signature recorded. On transect 804 there is a plume signature that occurs at 1120 to 1135 meters deep, which correlates to 25-40 meters above the seafloor. This plume signature gives us a source temperature from its vent of 8.1 to 32 degrees Celsius, which follows the trend of temperatures lowering since the 1996 earthquakes. Source temperatures in 1997 were measured at 112-200 degree Celsius (Wheat et al, 2000) and during 2006-2008 were 21.6 to 55 degrees Celsius. Since temperatures are continuously decreasing as expected, it can be assumed no major geological event occurred.

Based on the data that was collected by the CTD, there were no plume signatures above 40 meters off the seafloor. However, there was no data collected above those 40 meters. Therefore, it is entirely possible that there are other plume signatures that were not caught by this study. If there are plumes located higher than 40 meters above the ground, this would lead to a higher buoyancy flux and in turn a higher source temperature. Therefore, possibly making the claim 'no major geological event occurred recently,' false.

## **Conclusion**

This study has found that hydrothermal fluid pools in Pele's pit especially on the northern end of the pit, as predicted. As stated by the Hawaii Undersea Research Laboratory, the source temperatures are returning to pre-earthquake conditions and temperatures' ranging from 8.1 to 32.2 degrees Celsius agrees with that statement. However there was no data

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collected above 40 meters off the seafloor. Therefore, in order to make this study better, it can be proposed to collect a wider range of depths.

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## Appendix

(1) 
$$Q = \frac{\rho c_p Bo}{g\alpha}$$

(Little et al., 1987) Where Q is the heat flux added to the source, p is density of the fluid, alpha is the coefficient of thermal expansion (assumed to be  $1.48 \times 10^{-4}$  per degree Celcius), g is acceleration due to gravity, and c is specific heat capacity at constant pressure (assumed to be 4200 Joules per kg per degree Celcius).

(2) 
$$Z_{\max} = 5Bo^{1/4}N^{-3/4}$$

(Speer and Rona, 1989) Z is the max height of the hydrothermal plume. Bo and N are buoyancy flux and buoyancy frequency respectively. This equations differs from Little et al. (1987) by a factor of  $\pi^{1/4}$ .

$$N^2 = \frac{-g \alpha \bar{T}_z + \beta \bar{S}_z}{\rho}$$

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(3)

(Speer and Rona, 1989) All defined variable are the same as above. Beta is the coefficients of saline contraction (assumed to be  $7.5 * 10^{-4}$ )

(4) 
$$Bo = -g \left[ \alpha T_0 - \bar{T} + \beta S_0 - \bar{S} \right] A_0 W_0.$$

(Speer and Rona, 1989)  $A_0$  and  $W_0$  is the source radius and initial velocity respectively.  $T_0$  and  $S_0$  is the source temperature and source salinity, where  $\bar{T}$  and  $\bar{S}$  are the ambient water temperature and salinity respectively.