Eddy impact on anthropogenic chemicals in the lee of Hawai'i

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Non-technical summary

Eddies are formed in the lee of the Hawaiian Islands when the Trade Winds blow across the steep topography. The winds are blocked by the volcanoes and speed through the channels between the islands, especially the Alenuihaha channel between the Big Island and Maui, and the difference in pressure on the ocean surface creates an eddy (Bidigare et al. 2003). This study was conducted aboard the R/V Thomas G. Thompson from 27 December 2010 – 6 January 2011. This study analyzed human-made chemicals found within and surrounding an eddy in the lee of Hawai'i. These chemicals likely came from the islands, mixing into the surface waters and possibly the entire water column. Both human-made and natural land-based compounds were found in the lee of the islands. Both of these sub-groups of chemicals were likely affected by the eddy, with some compounds found only outside the eddy and some found only inside. Of the anthropogenic compounds, DCHP had the greatest total amount with 51.798 ug/L, and lilial had the least total amount with 0.014 ug/L; in general, there were a greater number of anthropogenic chemicals found outside the eddy. However, other compounds did not seem to be affected by the eddy, which might indicate that man-made compounds are more common in the ocean than previously recognized.

Abstract

This study analyzed the anthropogenic chemicals found within and surrounding an eddy in the lee of Hawai'i. This study was conducted aboard the R/V Thomas G. Thompson from 27 December 2010 – 6 January 2011. The quantifiable anthropogenic chemicals found within the eddy were cumene, lilial, ethyl vanillin, dibutyl phthalate, bisphenol a, and dicyclohexyl phthalate. The quantifiable natural or anthropogenic chemicals were benzaldehyde, limonene, benzyl acetate, thymol, eugenol, salicylic acid, vanillin, and trans-cinnamic acid. Cumene, limonene, eugenol, salicylic acid, lilial, benzaldehyde, and dibutyl phthalate were found solely or mostly outside the eddy. Thymol, vanillin, and ethyl vanillin were found solely or mostly within the eddy. Benzyl acetate, trans-cinnamic acid, bisphenol a, and dicyclohexyl phthalate were found everywhere regardless of the eddy. Of the anthropogenic compounds, DCHP had the greatest total amount with 51.798 ug/L, and lilial had the least total amount with 0.014 ug/L; in general, there were a greater number of anthropogenic chemicals found outside the eddy. There are a few possible reasons for the differences in trends between the compounds, based on the transport of the compounds. For instance, the common occurrence of bisphenol a and dicyclohexyl phthalate, both plastic derivatives, might indicate that anthropogenic compounds are more ubiquitous in the open ocean than previously recognized.

Introduction

Both warm and cold core eddies are a common occurrence in the lee of Hawai'i, formed by the north-easterly winds driving across the steep topography (Benitz-Nelson and McGillicuddy 2008). They form within the surface waters and can last from 4 weeks to 4 months depending on the pattern of the trade winds (Dickey et al. 2008). These eddies have been studied by the E-Flux program, an international research endeavor to accumulate more knowledge on eddies. The E-Flux program studied two cold-core eddies of different ages, *Noah* and *Opal* (Benitz-Nelson and McGillicuddy 2008) and found similar causes of formation and patterns of water movement.

Areas of high eddy formation can be found between 160°W and 156°W west of the Big Island of Hawai'i (Yoshida et al. 2010). Both cyclonic, cold-core, and anti-cyclonic, warm-core, eddies will likely form and stay within this area; however, cyclonic eddies travel mostly northwestward while anti-cyclonic eddies travel mostly southwestward (Calil et al. 2008). Although eddies are relatively slow moving – 0.17 knots for the quickly moving *Opal* (Kuwahara et al. 2008) – they can be difficult to track in the field. This is due to the delay of processing satellite or Acoustic Doppler Current Profiler (ADCP) data into a current vector that can be used to determine the ship's location within the eddy. Additionally, the eddy continues to move while the individual sample stations are being located. When such stations are determined based on their relative position to the eddy rather than a fixed point they become infinitely more difficult to locate.

Few studies have been done on eddies, and no previous study has been done on the transport of anthropogenic chemicals in and around eddies. The only previous studies done on both anthropogenic chemicals and eddies have focused on dissolved anthropogenic gasses specifically CFC-11, CO_2, and $\Delta^{14}C$. One such study used an ocean general circulation model to find that eddies impede the transport of such tracers into the atmosphere by decreasing the sea-air flux (Lachkar et al. 2007). Other studies on anthropogenic chemicals have focused on areas near shore with known contaminants or hazardous chemicals found in locations distant from humans (Blais 2005, Edmonds et al. 2001). None have focused on land-based anthropogenic chemicals in eddies.

Anthropogenic chemicals originate from all land surfaces inhabited by humans. In the nutrient-poor tropical oceans (Benitz-Nelson and McGillicuddy 2008), these anthropogenic chemicals may have a large impact on biological productivity; nutrient runoff from plantations may increase biological productivity and oil runoff from streets may decrease it. Although such biological surveys are not within the scope of this study, it is important to observe the transport of anthropogenic chemicals so that further studies may benefit from this spatial information.

Methods

Samples were collected at a total of 16 different stations. Two stations were near the islands and far from the eddy; they were used as controls for the samples taken within and immediately outside the eddy. The two control stations were -4 and -3. Another two stations were outside but nearby the eddy: -1 and 23. One station, 0, was on the edge of the eddy. The remaining stations were inside the eddy: 1, 2, 12, 13, 15, 16, 17, 18, 19, 20, 22, and 23. Only one of those stations, 13, was in the center of the eddy.

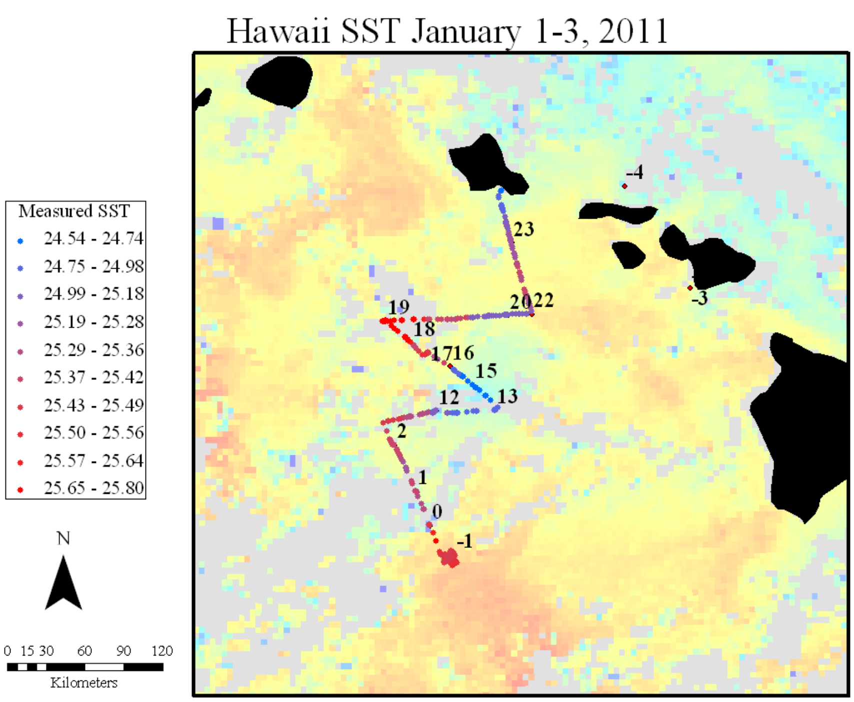

Figure 1 Sea surface temperature (SST) of the surface ocean around the islands of Hawai'i during the time of the cruise. SST collected by ship shown along cruise track. Station locations plotted along cruise track as well.

The eddy was located using various means. The Naval Research Laboratory's 1/30° Nowcast/Forecast model of ocean altimetry, current speed, and direction was one of those means. In addition to this model, ADCP data was run through a Matlab script outputting current vectors roughly 20 minutes after the original data was collected. This information, along with immediate sea surface temperature (SST) data, was used to locate the eddy and the ship's position within the eddy. The ADCP data was especially useful for determining the center of the eddy.

Table 1 In order of ship track, the station name, station number, and sample name. The labeling of the samples follows a pattern, from first letter to last: a "c" indicates a control, an "e" indicates a sample near or in the eddy; the following number is the chronological number of the sample; an "o" indicates outside the eddy, an "e" indicates on the edge of the eddy, an "i" indicates inside the eddy. Additionally, some samples have "a" versions and "b" versions. These are exactly the same samples except that one was processed in the lab and one was processed on board ship.

Station Number	Sample	Origin	Location Processed
-4	c1o	flow through	ship
-4	c2o	CTD	lab
-3	c3oa	flow through	ship
-3	c3ob	flow through	lab
-3	c4o	CTD	lab
-1	e1oa	flow through	lab
-1	e1ob	flow through	ship
0	e2ea	flow through	lab
0	e2eb	flow through	ship
0	e3ea	CTD	ship
0	e3eb	CTD	lab
1	e5ia	CTD	ship
1	e5ib	CTD	lab
2	e6i	flow through	lab
2	e7i	flow through	lab
12	e8i	flow through	lab
12	e9i	CTD	lab
13	e10i	flow through	lab
13	e11i	CTD	lab
15	e12i	flow through	lab
16	e13i	flow through	lab
17	e14i	flow through	lab
18	e15i	N/A	lab
19	e16i	CTD	lab
19	e17i	flow through	lab
20	e18i	CTD	lab
22	e20i	flow through	lab
23	e19i	flow through	lab

A total of 29 samples were collected from the 16 different stations. Each sample was collected in a 10-L collapsible plastic bottle from either the flow through seawater system on the R/V Thompson or a CTD rosette cast. The water from the flow through was collected from surface waters roughly 1-2 m below the surface, while the water from the CTD casts was collected at 5 m depth. At seven stations water was collected both from the flow through and from the CTD in order to calibrate the flow through and recognize possible contaminants from the ship itself. These stations were -4, -3, 0, 1, 2, 12, and 13.

Although 10 L of water was collected for each sample, only 8 L of water per sample was used for filtering and the subsequent processes. On board ship the samples were filtered using GF/F filters under <15 mmHg, except for three samples – e14i, e17i, and e20i – which were filtered once they returned to the lab. Also on board ship, samples c1o, c3oa, e1ob, e2eb, and e3ea, and e5ia were acidified to a pH of <3 using HPLC-grade hydrochloric acid. They were then extracted using the methods for solid phase extraction found in Keil and Neibauer (2009), using 200 mg Waters Oasis HLB cartridges. All other samples were acidified and extracted once reaching the lab at the UW campus.

The extraction phase was carried out in stages for multiple samples. Due to the large volume of water collected for each sample and to ensure that the cartridges did not dry out, not every sample was run overnight. For those samples that were not run overnight, each cartridge and its tube were placed in a plastic ziploc bag while water was still in the tube and then placed in the refrigerator overnight. The samples were also placed in the refrigerator overnight. The next morning all materials were removed from the fridge and set up once more to continue extractions. Following extractions, the samples were eluted and run on a Time of Flight Gas Chromatograph Mass Spectrometer (TOF). This is different than the methods in Keil and Neibauer (2009), which used an Agilent 6890N GC coupled to 5975 MSD fitted with a J&W DB-5MS column. The TOF could “see” all chemicals found in the samples because it allowed all of the ions from the sample into the flight chamber at the same time, but then caused them to hit the detector one at a time. This line-up of chemicals could be done because the flight time, from the flight chamber to the detector, varied with the square root of the mass-to-charge ratio of the ions; so the small ions could reach the detector before the large ions. The TOF could then find and quantify the anthropogenic chemicals available in and outside of the eddy.

The number of different anthropogenic chemicals, the amount of each, and the total amount of anthropogenic chemicals found at each station were collected and plotted using Excel. In addition, the anthropogenic chemical data received from the TOF was correlated with ADCP and SST data in order to be placed in their correct locations within or outside of the eddy. ArcGIS was used to layer the station locations on top of the ADCP current data and SST in order to analyze the chemical data in correlation with eddy movement.

Results

The eddy located was a cold-core cyclonic eddy, with a diameter of over 120 km. It was located between 19°N and 20.75°N, and 157°W and 159.5°W. Once plotted, the ADCP and SST data revealed that the eddy had a likely core radius of 60 km, and average surface currents of 0.5 m/s. During the cruise the eddy moved in a northwesterly direction (Fig 2).

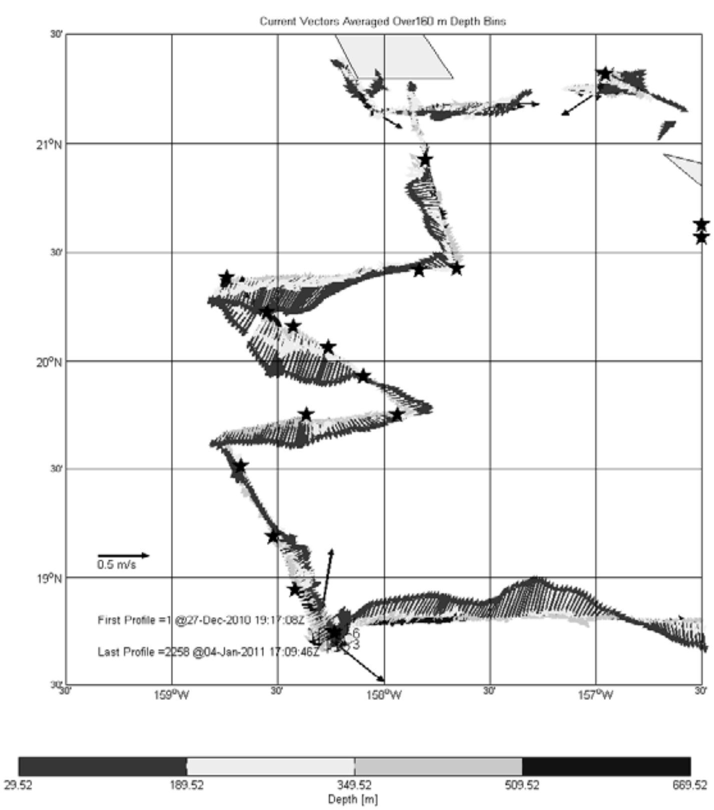

Figure 2 ADCP data collected during the cruise and plotted according to 20 m binned means. Shade of arrow corresponds to the depth averaged for each bin. Length of arrow corresponds to speed of current. Station locations are plotted as stars along the cruise track.

The water collected from the flow-through did not have a one to one correlation with the water collected from the CTD. The total number of compounds found from a single sample did not always match the total number of compounds found from a different sample from the same station, the difference between the samples being whether they were collected from the flow through or the CTD. In most instances where samples from the same station did not have the same number of compounds, the sample collected from the flow through had a lesser number of compounds than the sample from the CTD (Appendix A). The correlation between the flow through and CTD samples had an R^2 value of 0.0164.

There were a total number of 14 recognizable compounds found. These compounds were cumene, benzaldehyde, limonene, benzyl acetate, thymol, eugenol, salicylic acid, vanillin, lilial, trans-cinnamic acid, ethyl vanillin, dibutyl phthalate, bisphenol-a (BPA), and dicyclohexyl phthalate (DCHP). The greatest number of compounds found in any one sample was 8 and the fewest number of compounds was 4. DCHP and vanillin were the only compounds found in every sample, followed closely by BPA, which was lacking in only one sample. Even though benzyl acetate was not found in every sample, it had the greatest total amount of all the compounds with 320.317 ug/L total. DCHP followed as the next greatest total amount with 51.798 ug/L total.

The chemicals found that can be determined to be wholly anthropogenic were cumene, lilial, ethyl vanillin, dibutyl phthalate, BPA, and DCHP (Fig 3). The

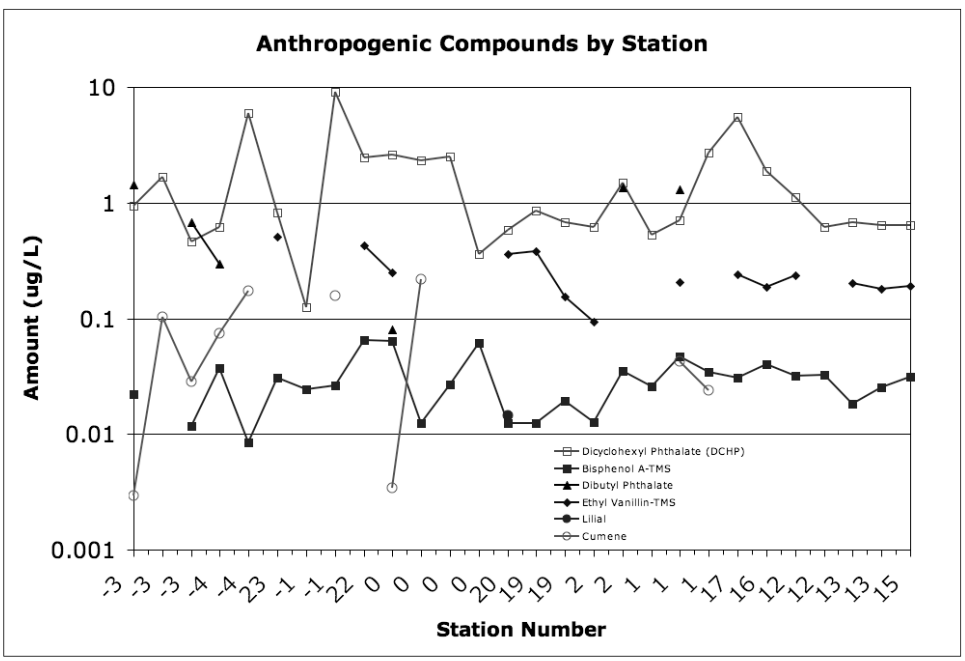

Figure 3 The amount of anthropogenic compounds ordered by station number and the distance from the center of the eddy, plotted on a log-scale y-axis.

chemicals found that may or may not be anthropogenic were benzaldehyde, limonene, benzyl acetate, thymol, eugenol, salicylic acid, vanillin, and trans-cinnamic acid. From the anthropogenic chemicals, the ones found inside the eddy were ethyl vanillin, BPA, and DCHP. Of those three, BPA and DCHP were also found outside the eddy with no clear trend. Only ethyl vanillin had a trend of being found only inside the eddy. The anthropogenic compounds found only outside the eddy were dibutyl phthalate, cumene, and lilial. Lilial was only found once, near the islands, but the two other compounds were found both near the islands and on the opposite side of the eddy.

The chemicals found that may be anthropogenic and may be natural were limonene, benzyl acetate, thymol, eugenol, salicylic acid, vanillin, trans-cinnamic acid, and benzaldehyde. Of the natural compounds, benzyl acetate did not show much of a trend, and trans-cinnamic acid seemed to disregard the eddy, although it had higher amounts closer to the islands. Salicylic acid had greater amounts found outside the eddy and limonene, eugenol, and benzaldehyde were not found in the eddy at all. Only vanillin was found in greater amounts inside the eddy.

Of the anthropogenic compounds, DCHP had the greatest total amount with 51.798 ug/L, and lilial had the least total amount with 0.014 ug/L. DCHP was ubiquitous in the samples, while lilial was only found outside the eddy. The two other compounds found purely outside the eddy were cumene with a total of 0.826 ug/L and dibuthyl phthalate with 5.153 ug/L. Cumene was comparable to the total amount of BPA, which was 0.804 ug/L; however, like DCHP, BPA was ubiquitous in the samples. The single compound found only outside the eddy was ethyl vanillin with 3.975 ug/L. In general, there were a greater number of anthropogenic chemicals found outside the eddy. The full data set can be found in Appendix A.

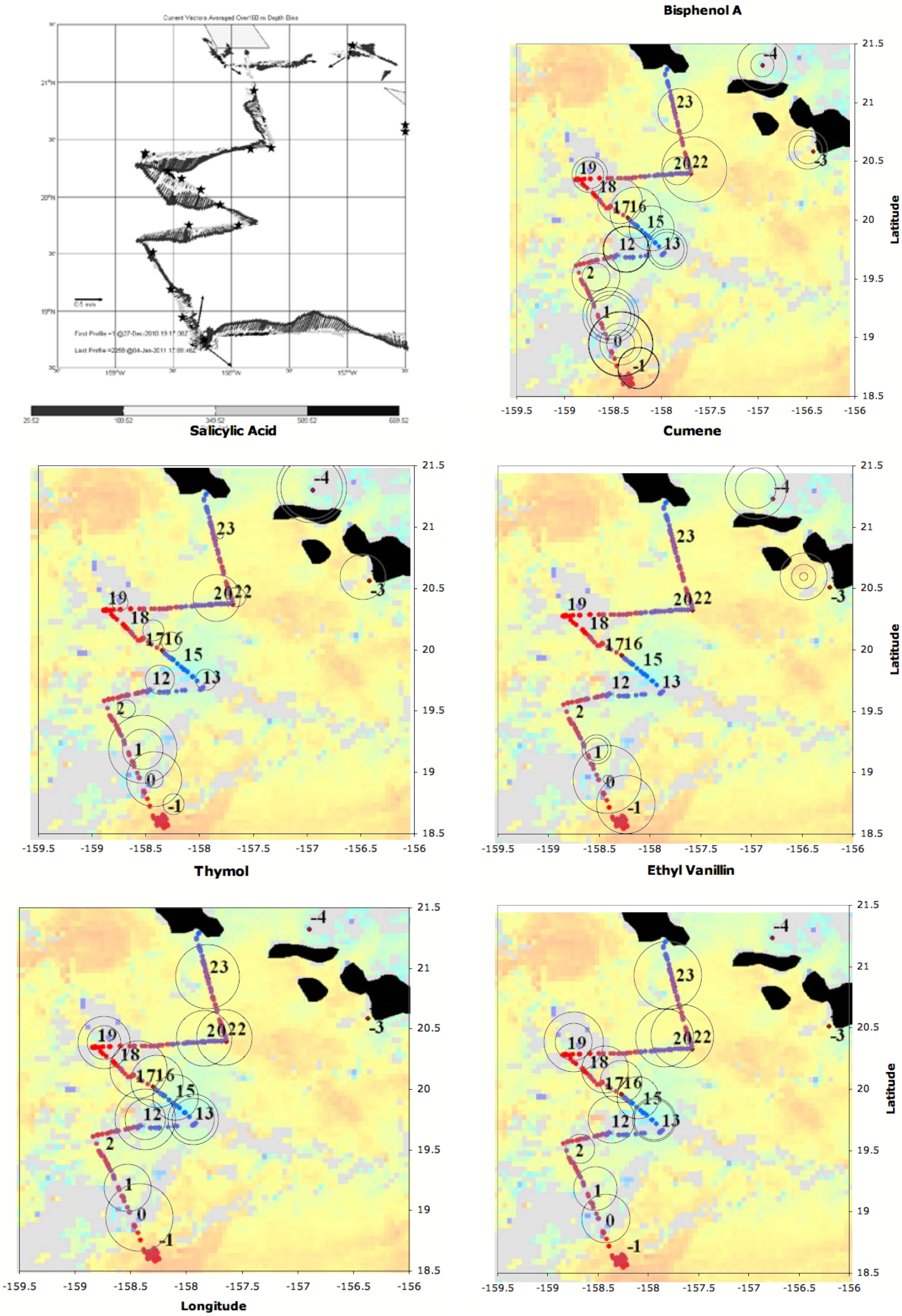

Figure 4 The top left figure is the ADCP plotted cruise track with station locations plotted along the cruise track. The remaining figures are compounds plotted according to latitude and longitude. Each circle corresponds to one sample, and some stations had multiple samples, thus some circles are centered on the same places. The size of the circle corresponds to the amount of compound measured in ug/L was found within each sample.

Discussion

Although the eddy is a stronger feature in the upper levels of the water column (Kuwahara et al. 2008) where the samples were collected, the eddy impacted different compounds in different ways, and didn't impact some compounds at all (Fig 4). This variation can be seen through all of the compounds, both the anthropogenic and the natural ones. But the natural compounds tended to be found in greater quantities outside of the eddy – out of 8 natural compounds, limonene, eugenol, salicylic acid, and benzaldehyde were found either solely or mostly outside of the eddy, benzyl acetate and trans-cinnamic acid were common everywhere, and thymol and vanillin were found mostly inside the eddy. The anthropogenic compounds had similar trends. Out of 6, cumene, lilial, and dibutyl phthalate were found solely or mostly outside of the eddy, ethyl vanillin was found only inside the eddy, and BPA and DCHP were found in equal amounts everywhere.

Since some of the compounds do follow a pattern of differentiation seemingly caused by the eddy, it is likely that the vertical shear mentioned by Kuwahara et al. (2008) was similarly strong in the eddy located for this study. This might have caused a slight boundary between the inside and the outside of the eddy, trapping some of the compounds inside the eddy while pushing others out. However, it is also possible that this eddy was old and thus weakening, as witnessed by Nencioli et al. (2008), and the shear along its edges was no longer as strong as it had been when the eddy had first formed. This could have caused some overlap in compounds found inside or outside the eddy or along its edges.

Conversely, there are four possible reasons for compounds to follow one of the three general patterns of inside the eddy, outside the eddy, and everywhere. The first reason is that the compound is natural and is a derivative of bacteria or plankton in the ocean. It is known that trans-cinnamic acid is a derivative of bacteria (Onofrejova et al. 2010), however, this is difficult to quantify for the other compounds due to little being known about such chemicals in the open ocean. The second possibility is that the compound reached the ocean through rivers or runoff, and the third is that the compound was blown into the ocean by the wind. Anthropogenic compounds would likely be burned on land in order to reach the ocean by wind but for natural compounds that is unlikely. The fourth possible reason for differences in distribution is that anthropogenic compounds could be leached from plastic waste already in the ocean. This is especially likely for the plastic derivatives such as BPA and DCHP. The eddy would then affect these four different paths of compounds reaching the open ocean differently.

For the instances of the plastic derivatives found both in and outside the eddy, it could be argued that plastic on board the ship contaminated the samples or that plastics from the analysis process contaminated the samples. If the samples were contaminated due to plastic tubing or piping on the ship, this would be seen as a consistent signature within the samples. The only case in which this could have happened is DCHP, as no other plasticizer is found in every sample. If the samples were contaminated due to dumping or burning of trash on the ship – which did occur during the cruise – there would be no consistent signature within the samples. Thus, at this point, it is impossible to find out if burning of trash on the cruise contaminated the samples. Finally, it is not possible for plastics from the analysis process to have contaminated the samples, since the plastics used during the analysis process are purposely not tested for. Although these possibilities exist, the ratios seen in Fig 3 are extremely similar to the ratios found by Fromme et al. (2002) when measuring plastics in different water sources. This might indicate that even if samples were contaminated during the cruise, they were not contaminated to the extent that the data is unusable. Rather, any contamination that occurred is insignificant.

It could then be argued that these plastic derivatives are so prevalent in our environment that they can be found even in such pristine island environments as Hawai'i. Such an argument is supported by two different sources: plastic debris found in surface and benthic locations globally within the oceans (Barnes et al. 2009), and plasticizers that leach from the paint used on ships' hulls (Merlatti et al. 2007). Although plasticizers may not be used in every type of paint, plastics debris have become ubiquitous within the world's oceans (Fig 5). The plasticizers found within this study could have originated from either of those sources.

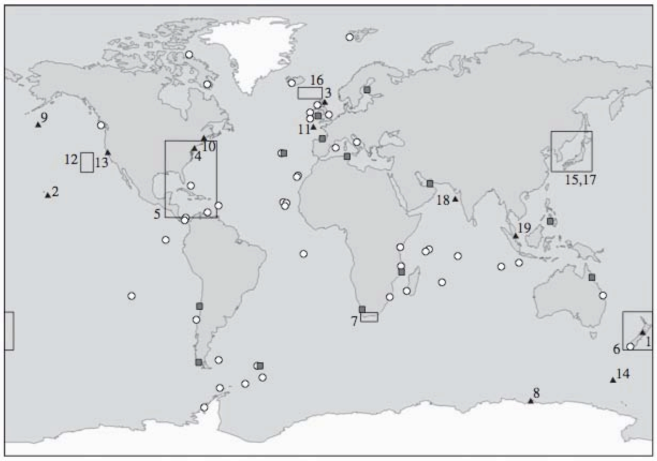

Figure 5 Each of the dots and boxes indicates an area where plastic debris were found and reported (Barnes et al. 2009).

Conclusion

Anthropogenic chemicals originate from all land-surfaces touched by humans. It is not clear if eddies near the Hawaiian Islands influence anthropogenic chemical transport to a significant degree, however it seems likely that eddies have some influence on the transport of these chemicals. Whether or not eddies influence anthropogenic compounds, it has been concluded that anthropogenic chemicals can be found in the open ocean around Hawai'i. Since this is an isolated island location there are only two possible ways for the compounds to have gotten there: one is for them to have come from the island, the other is for them to be mixed into the ocean everywhere. The latter could especially be true for the compounds that did not seem to have trends affected by the eddy. To conclude, more research is needed on compounds in the open ocean and in eddies so that humans can learn about the lifespan, locations, and effects of the compounds we create.

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Appendix A

Table 2 All data from research cruise. Sample e14i(orange) was thrown out from the dataset due to incorrect labeling. Sample e15i was thrown out due to machine error. Sample e5ib2 had an mysterious origin, but was likely a double sample taken at station 1; the results can be seen in all figures.

	c1o	c2o	c3oa	c3ob	c4o	e1oa	e1ob	e2ea	e2eb	e3ea	e3eb	e14i(orange)
Cumene	0.1731242	0.07357037	0.10367133	0.02822961	0.00294435		0.15857822			0.21710157	0.00342234	
Benzaldehyde												0.1255544
Limonene	0.13254657		0.17818748	0.07220762	0.02899872	0.03790609				0.45630901	0.03361642	
Thymol											0.022355	0.00986236
Eugenol				0.01544118	0.02431513	0.01144619			0.00620619			
Salicylic Acid	0.08355864	0.06518163	0.03667733				0.00800739	0.00623526		0.05336943		0.03027707
Vanillin	0.33483492	0.37874417	0.0163168	0.14468257	0.10568887	0.04159674	0.4927727	0.16950263	0.30941796	0.31749085	0.66272409	0.48420987
Lilial												
trans-Cinnamic Acid		0.02664015		0.01290021	0.0120991	0.00321279						0.00272783
Ethyl Vanillin											0.24964661	0.36225347
3,4 dihydroxybenzoic acid	0.08052867	0.16306449	0.0303526	0.14772217	0.16359455	0.07892605	0.12062637	0.10007955	0.11030961	0.11535123	0.09885442	
Dibutyl Phthalate		0.29847433		0.68066716	1.44448541						0.08065056	
Bisphenol A	0.00851211	0.03721471		0.01165452	0.02229873	0.02416276	0.0264438	0.06141333	0.02682249	0.01252891	0.06322067	0.00563881
Dicyclohexyl Phthalate (DCHP)	6.00003042	0.60981705	1.67012309	0.45981949	0.9396114	0.1243401	9.04326021	0.36155028	2.51551329	2.34064572	2.62410118	2.546027
total	6.81313554	20.5632886	11.381436	10.9194319	2.74403627	33.0329664	9.8496887	0.69878105	26.8532513	3.51279671	26.4396518	3.56655081
average	0.17469578	0.52726381	0.29183169	0.27998543	0.0703599	0.84699914	0.25255612	0.01791746	0.68854491	0.09007171	0.67793979	0.09145002

	c	e5ia	e5ib	e5ib2	e6i	e7i	e8i	e9i
Cumene		0.0237183		0.04241427				
Benzaldehyde								
Limonene		0.18455296	0.04888279		0.02965683			
Thymol				0.01093808			0.00824923	0.01803038
Eugenol					0.00895523			
Salicylic Acid		0.08014611		0.02904539		0.0054969		0.01463387
Vanillin		0.36316993	0.02339473	0.30886747	0.03254432	0.79245131	0.6792645	1.49659972
Lilial								
trans-Cinnamic Acid					0.00251361			
Ethyl Vanillin				0.20523596		0.0943393		0.23551777
3,4 dihydroxybenzoic acid		0.1271189	0.10748738	0.17225969	0.06340892	0.11386287	0.11270845	0.17707766
Dibutyl Phthalate				1.29647504	1.34477957			
Bisphenol A		0.03442581	0.02566724	0.04684778	0.03529453	0.01265576	0.03250988	0.0315937
Dicyclohexyl Phthalate (DCHP)		2.71705333	0.52732855	0.71042545	1.48639663	0.61459983	0.61205992	1.11747519
total		3.53018535	28.5963891	15.3131012	28.5961613	1.63340598	1.44479198	3.09092829
average		0.09051757	0.73324075	0.39264362	0.73323491	0.0418822	0.03704595	0.07925457

	c	e10i	e11i	e12i	e13i	e14i(green)	e15i	e16i
Cumene								
Benzaldehyde					0.15822227			
Limonene								
Thymol		0.00903834	0.01234366	0.00981922	0.01302266	0.01557009		0.01325644
Eugenol								
Salicylic Acid			0.00838715		0.00751696	0.00840872		0.00482014
Vanillin		0.78884529	0.80067828	0.52479371	1.28476753	1.35731567		0.8742893
Lilial								
trans-Cinnamic Acid				0.00526998		0.01212454		0.0095154
Ethyl Vanillin		0.18135604	0.20117881	0.19021271	0.18764763	0.24156753		0.38126032
3,4 dihydroxybenzoic acid		0.0605257	0.12181484	0.10680311	0.14065965	0.15865945		0.11201369
Dibutyl Phthalate						0.00753157		
Bisphenol A		0.02515131	0.01806586	0.0310084	0.04026654	0.03038104		0.01240093
Dicyclohexyl Phthalate (DCHP)		0.64003428	0.67874021	0.6410909	1.86387188	5.54890064		0.8477987
total		22.7293251	1.8412088	22.7113544	24.8819408	7.38045925	15.5695667	2.92306209
average		0.58280321	0.04721048	0.58234242	0.63799848	0.18924254	0.39921966	0.07495031

	c	e17i	e18i	e19i	e20i	total	average
Cumene						0.82677457	0.02755915
Benzaldehyde						0.28377667	0.00945922
Limonene						1.20286448	0.04009548
Thymol		0.00540066	0.01498852	0.01955615	0.01511771	0.19754848	0.00658495
Eugenol						0.06636392	0.00221213
Salicylic Acid			0.03823715	0.00094827	0.0071596	0.48702832	0.01623428
Vanillin		0.22968923	0.5088884	0.80680896	0.97913133	15.3094819	0.51031606
Lilial			0.01461719			0.01461719	0.00048724
trans-Cinnamic Acid						0.08700362	0.00290012
Ethyl Vanillin		0.15452364	0.36094021	0.50591977	0.42310629	3.97470604	0.1324902
3,4 dihydroxybenzoic acid		0.06092124	0.10991398	0.08126514	0.03661767	3.07252805	0.1024176
Dibutyl Phthalate						5.15306363	0.17176879
Bisphenol A		0.01938948	0.012326	0.03044876	0.06532919	0.80367306	0.0267891
Dicyclohexyl Phthalate (DCHP)		0.67771394	0.5843511	0.828931	2.46688396	51.7984948	1.72661649
total		19.2327926	20.5155381	23.2371094	3.99334574	403.595681	
average		0.49314853	0.52603944	0.59582332	0.10239348	10.3486072	

Appendix B

Table 3 Station coordinates along with their common names used by other seniors, the station numbers, the samples, and how the samples were processed.

Lat	Long	Station Name	Station Number	Sample	Origin	Location Processed
21.31755	-156.9544	Jim core4	-4	c1o	flow through	ship
21.31755	-156.9544	Jim core4	-4	c2o	CTD	lab
20.5925	-156.478	molokini	-3	c3oa	flow through	ship
20.5925	-156.478	molokini	-3	c3ob	flow through	lab
20.5925	-156.478	molokini	-3	c4o	CTD	lab
18.73917	-158.235	cross seamount	-1	e1oa	flow through	lab
18.73917	-158.235	cross seamount	-1	e1ob	flow through	ship
18.94181	-158.4195	eddy0	0	e2ea	flow through	lab
18.94181	-158.4195	eddy0	0	e2eb	flow through	ship
18.94181	-158.4195	eddy0	0	e3ea	CTD	ship
18.94181	-158.4195	eddy0	0	e3eb	CTD	lab
19.18432	-158.523	eddy1	1	e5ia	CTD	ship
19.18432	-158.523	eddy1	1	e5ib	CTD	lab
19.51249	-158.6751	eddy2	2	e6i	flow through	lab
19.51249	-158.6751	eddy2	2	e7i	flow through	lab
19.75	-158.3666	eddy11	12	e8i	flow through	lab
19.75	-158.3666	eddy11	12	e9i	CTD	lab
19.7515	-157.9353	eddy13	13	e10i	flow through	lab
19.7515	-157.9353	eddy13	13	e11i	CTD	lab
19.92845	-158.0957	eddy15	15	e12i	flow through	lab
20.06146	-158.2636	eddy16	16	e13i	flow through	lab
20.15768	-158.4263	eddy17	17	e14i	flow through	lab
20.22558	-158.5515	eddy18	18	e15i	N/A	lab
20.38192	-158.7397	eddy19	19	e16i	CTD	lab
20.38192	-158.7397	eddy19	19	e17i	flow through	lab
20.41671	-157.8338	eddy20	20	e18i	CTD	lab
20.42642	-157.6567	eddy22	22	e20i	flow through	lab
20.92606	-157.803	eddy23	23	e19i	flow through	lab