A characterization of the Equatorial Undercurrent between 92°00’W and 91°20’W

Kevin Lee Odle

School of Oceanography
University of Washington
Seattle, WA 98105

Running Title: The EUC Between 92°00’W and 91°20’W
NON-TECHNICAL SUMMARY

The Equatorial Undercurrent (EUC) flows from the western Pacific Ocean to the eastern Pacific Ocean within two latitudinal degrees of the equator. The EUC forms because predominantly westward winds near the equator create westward surface currents resulting in the formation of a shallow yet broad ‘pile’ of water on the order of 70 centimeters above average sea level in the western Pacific Ocean. Since there is no Coriolis force at the equator, the EUC forms to partially counteract the effects of the westward wind, ‘draining’ some of this ‘piled’ water eastward along the equator beneath the westward surface currents. The Galápagos Islands exist on and near the equator in the eastern Pacific and thus represent an obstruction to the EUC. Historical observations have found that much of the EUC splits into two branches to circumnavigate the archipelago, one traveling around the northern reach and the other flowing to the south of Isabela Island. In addition to these horizontal deflections, some of the EUC is forced upward and some is forced downward. The upwelling is of tremendous biological importance because it brings nutrients to the surface where photosynthesis can occur. In addition to the higher concentration of chlorophyll at the surface, the upwelled masses of the EUC are detectable at the surface as regions of lower temperature because EUC water is colder than the surface water. During January 2006, this study examines how the EUC was disrupted by the western portion of the Galápagos Islands using an Acoustic Doppler Current Profiler (ADCP), deployed drifters, and discrete water sampling. Along 92°W, the EUC occurred at an average depth of about 100 meters. The EUC flow around the northern portion of the Galápagos was much greater than flow to the south.
ACKNOWLEDGMENTS

Dr. Seelye Martin has been an outstanding guide and mentor throughout this learning experience. I am grateful to the teaching team, especially Llyd Wells, the US Navy, the R/V Thompson crew, and my OCEAN 444 peers. I also thank Robert Drucker and Stephen C. Riser for providing software and hardware support, and Professor Roy Carpenter for working through logistics that has given UW students the opportunity to study oceanography while in the Galápagos Islands.
ABSTRACT

The EUC exhibits seasonality and interannual variations, is important to regional biological activity as well as global climate, but its termination and subsequent distribution is still relatively underdocumented. Interest in these various aspects of the EUC and access to a hull-mounted ADCP, ARGOS and Iridium drifters, CTD, and satellite data allowed for a characterization of the EUC upon its approach to the Galápagos Archipelago. The EUC was found between depths of 28 to about 212 m, had eastward flow as far south as 0.8°S, and exhibited prominent flow around the northern portion of Isabela Island. Maximum velocities were found between depths of 60 to 76 m and between 0.1°N and 0.5°N. These were oriented northeastward, had a speed of about 80 cms\(^{-1}\). CTD casts confirmed that the saline and thermal properties of the EUC agreed with historical data.
INTRODUCTION

Roughly speaking, the EUC is a subsurface current about 200 meters thick with typically maximal eastward velocities at a depth of 75 meters (Feldman 1984). Though the vast majority of the EUC remains subsurface along the western margins of the Galápagos Archipelago, the presence of nutrient-rich upwelled EUC waters is of tremendous biological importance (Feldman 1984). Among the determinants of the location and magnitude of the EUC are seasonal and interannual variations in wind stress, strength of neighboring or adjacent currents, and geostrophic forcings (Cane 1979, Enfield 1981). The EUC has three distinctive hydrographic features (Lukas 1986): (1) a 13°C-14°C thermostad (region of uniform temperature), (2) a high salinity core (34.95-35.20 PSU), and (3) a high dissolved oxygen concentration tongue which decreases at the 100 meter depth from 2.3 ml l\(^{-1}\) along 98°W to 1.8 ml l\(^{-1}\) at 82°W. The thermostad is thickest slightly south of the equator while west of the Galápagos, and is poorly developed along the equator east of the Galápagos, apparently due to convergence with the Southern Subsurface Countercurrent (Lukas 1986). The southward projecting branch of the EUC experiences rapid decreases in dissolved oxygen (Lukas 1986).

Though some meridional fluctuations are evident, once formed, the eastward propagation of the EUC west of the Galápagos is constricted to within two degrees latitude of the equator and exists at depths between 50 and 275 meters (Steger 1998). Upon approaching the Galápagos, Lukas (1986) and Steger (1998) found that at the time of their observations, the core of the EUC (highest flow velocities and deepest subsurface extent) were centered approximately 0.5 degrees south of the equator. Since the Galápagos Archipelago extends roughly from 0.5°N to 1.0°S, it represents an obstacle to the eastward propagation of the EUC. The collision of the EUC flow against the Galápagos Archipelago results in a combination of five subsequent flows along the steep
western bathymetry of Isabela and Fernandina Islands: 1) some is upwelled, 2) some is
downwelled, 3) some is deflected around the northern perimeter of Isabela Island, 4)
some is deflected around the southern perimeter of Isabela Island, and 5) some of the
EUC waters are recirculated in and out of the EUC (Fig. 2). As reviewed by Steger
(1998), several studies have concluded that although most of the EUC flow is around
northern Isabela (Knauss 1966, Chistensen 1971, Pak and Zaneveld 1973), there is also
evidence of significant southern flow (Wyrtki 1967, Lukas 1986).

Steger (1998) used ADCP and CTD data during 8-21 November 1993 to
investigate circulations around the Galápagos Islands and found that the westward
flowing South Equatorial Current dominated the surface waters of the region save a small
region west of Fernandina Island, where some shoaling of the EUC was observed. West
of the Galápagos, he found the EUC centered along 0.5°S at 70 meters with maximum
velocities of about 0.6 ms\(^{-1}\) and transporting 6.6 Sv along 92°W. In contrast to Knauss
(1966), Christensen (1971) and Pak and Zaneveld (1973), Steger found strongest
subsurface flow south of the equator, emphasizing the dynamic and variable nature of this
current.

The goal of the study here was to determine the location and characteristics of the
EUC west of the Galápagos in January 2006 while aboard the \textit{R/V Thomas G. Thompson},
predominantly using the 75 MHz hull-mounted Acoustic Doppler Current Profiler
(ADCP). The ADCP was programmed to use 50 intervals, referred to as bins of eight
vertical meters to measure water velocities between water depths 20 and 420 m. Salinity,
temperature, and dissolved oxygen were profiled along the ADCP transects between
92°00’W and 91°20’W for comparison to historical EUC data. ARGOS and Iridium
Drifters were deployed at 92.00°W and 1.5°S and were parked for at depths of ######
meters, surface every ###### days, and have drifted west-north-westward from their
original deployment position. Four other drifters also provide physical and chemical information of the region, two of which had been deployed by a previous expedition, and two of which were deployed by fellow undergraduate physical oceanographer Xyrone Ocampo. These drifters will not be used to evaluate the subsequent paths of the bifurcated EUC because they are beneath the EUC. However, these drifters can still identify the salinity and temperature signatures of the EUC as they (REFER TO) penetrates to the surface regularly. The top 20 meters of the water column could not be measured by the ADCP due to the turbulence induced by the ship during navigation. In regions with powerful currents, it is possible to gather reliable data while traveling at speeds of up to 12 knots. However, it is known that the accuracy of the data increases with slower ship speeds.
METHODS

Discontinuous transects (to accommodate logistical constraints of the cruise) were undertaken along 92°W (Fig. 1) from January 13 to January 23 of 2006. The length of time between maneuvering away from the equator and 92°W and resuming a northward transect from that point was #####. The ADCP was activated and recording almost continuously throughout the duration of the OCEAN 444 data-collection expedition as the R/V Thompson navigated the Galápagos Archipelago. CTD casts at ####### stations (Fig. 1) profiled the water column to compare salinity, temperature, and dissolved oxygen values to the known signatures of the EUC. One ARGOS and three Iridium floats were also deployed. All ADCP, CTD, and drifter data were shared with the other physical oceanographic student Xyrone Ocampo. The dissolved oxygen readings from the instrument mounted on the CTD were calibrated by manually processing seawater samples collected with the CTD at various depths using the Winkler method (Codispoti 1998). Salinity readings from the conductivity apparatus of the CTD were calibrated by manually processing seawater samples collected with the CTD at various depths using a Portasal salinometer (model 8410).

To calibrate a hull-mounted ADCP, the ship must travel some distance (1 or 2 km) across non-turbulent, steady water flow, and then backtrack over the same transect to confirm that the readings are identical (assuming the water flow has not changed during that time) and to identify artifacts within the data that are due to GPS error, ship speed, and other possible sources of error. This calibration was skipped, primarily due to ship-time concerns.

Steger (1998) estimated alignment sensitivity errors following the method of Joyce (1989) to correct for ADCP error. A navigation misalignment of -0.85/360 was
identified for the data collected aboard the *R/V Thompson*, but correction for ADCP alignment error using Joyce (1989) has not been applied. VmDAS and WinADCP were used to export ADCP data to Matlab, which was used to plot horizontal velocities, one depth at a time, of various portions of the ship track simultaneously. Paintbrush was then used to paste images side-by side.
RESULTS

Our transects along 92°W did not show any evidence of a portion of the EUC branching south of Isabela Island. Yet along the western coast of southern Isabela there is evidence of southeastward along-shore current between depths 20 to 84 meters. The southernmost eastward flow of the EUC along 92°W was measured at a depth of 68 meters at about 0.78°S. The northern extent of the EUC was not measured since it continued north of the ship track’s northern-most reach which occurred at 91.82°W and 1.01°N. Maximum EUC speeds were found along 92°W between 60 and 76 m depths, were northeastward, and had magnitudes of about 1.0 ms⁻¹. The EUC’s maximum height was 192 meters: at 0.15°N it stretched from 28 m to almost 220 m. An EUC signal along the diagonal transect from 92°W and 0.75°N to Roca Redonda and Punta Albemarle was found between 92 and 188 meters, and though this was due west of the thickest and fastest EUC flow, the flow was relatively thin; the top surface of this 96 m thick flow of EUC was about 84 m below that thickest EUC signal, and the bottom surface of this thin flow was 24 m above the thickest EUC signal. Except for the water moving due east in bin three (44m), along the transect from 1.26°S and 91.32°W to 1.26°S and 92°W, at all other depths water is moving northwestward. Beneath the southeastward current along Isabela’s southwestern shore, water seems to flow northwestward along the west coast between 84 m and the 420 m, which was as deep as ADCP measurements were made.

Though along 92°W northward flow was strongest at the surface, At 28 meters, surface flow south of the equator was notable northward. This region, between 44 and 76 meters expressed medium southwestward speed.
CONCLUSIONS AND SUMMARY

During the 13 - 23 January 2006, the EUC was observed to have maximum velocities at depths of 60 to 76 m and between 0.1°N and 0.5°N, were oriented northeastward, and had a speed of about 80 cms\(^{-1}\). At maximum thickness, the EUC was found between depths of 28 to about 212 m, and had eastward flow as far south as 0.8°S. Importantly, the vast majority of the EUC was deflected around the northern portion of Isabela Island and very little was deflected to the south. These CTD casts confirmed that the saline and thermal properties of the EUC agreed with historical data.
REFERENCES


Codispoti, Lou. 1998. One man's advice on the determination of dissolved oxygen in seawater.


University of Washington ARGO Profiling Drifters
http://runt.ocean.washington.edu/argo/

Ocean Color Web
http://oceancolor.gsfc.nasa.gov/
LIST OF TABLES

Table 1: Drifter profile with EUC water pressure and temperature signatures

LIST OF FIGURES

Figure 1    Leg 1 and Leg 2 ADCP transects
Figure 2    Schematic EUC Terminal Flows
Figure 3    92°W ADCP Transects Only
Figure 4    92°W ADCP with Coastal ADCP Transects
Figure 5    CTD EUC confirmation
Figure 7    Drifter EUC confirmation
Figure 8    Satellite SST and Chlorophyll
Table 1: Drifter profile with EUC water pressure and temperature signatures

<table>
<thead>
<tr>
<th>T</th>
<th>p</th>
<th>t</th>
<th>s</th>
<th>theta</th>
<th>sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>21.255</td>
<td>34.438</td>
<td>21.254</td>
<td>23.9985</td>
<td></td>
</tr>
<tr>
<td>10.7</td>
<td>18.771</td>
<td>34.766</td>
<td>18.769</td>
<td>24.9021</td>
<td></td>
</tr>
<tr>
<td>20.4</td>
<td>18.145</td>
<td>34.783</td>
<td>18.141</td>
<td>25.0720</td>
<td></td>
</tr>
<tr>
<td>30.6</td>
<td>16.666</td>
<td>35.005</td>
<td>16.661</td>
<td>25.5991</td>
<td></td>
</tr>
<tr>
<td>39.9</td>
<td>15.347</td>
<td>35.072</td>
<td>15.341</td>
<td>25.9528</td>
<td></td>
</tr>
<tr>
<td>50.2</td>
<td>15.100</td>
<td>35.118</td>
<td>15.092</td>
<td>26.0434</td>
<td></td>
</tr>
<tr>
<td>60.0</td>
<td>14.240</td>
<td>35.036</td>
<td>14.231</td>
<td>26.1667</td>
<td></td>
</tr>
<tr>
<td>69.9</td>
<td>13.987</td>
<td>35.016</td>
<td>13.977</td>
<td>26.2050</td>
<td></td>
</tr>
<tr>
<td>78.1</td>
<td>13.751</td>
<td>34.994</td>
<td>13.740</td>
<td>26.2376</td>
<td></td>
</tr>
<tr>
<td>90.1</td>
<td>13.695</td>
<td>34.985</td>
<td>13.682</td>
<td>26.2426</td>
<td></td>
</tr>
<tr>
<td>100.5</td>
<td>13.646</td>
<td>34.981</td>
<td>13.632</td>
<td>26.2500</td>
<td></td>
</tr>
<tr>
<td>110.0</td>
<td>13.605</td>
<td>34.976</td>
<td>13.589</td>
<td>26.2549</td>
<td></td>
</tr>
<tr>
<td>120.3</td>
<td>13.578</td>
<td>34.972</td>
<td>13.561</td>
<td>26.2576</td>
<td></td>
</tr>
<tr>
<td>130.4</td>
<td>13.529</td>
<td>34.967</td>
<td>13.511</td>
<td>26.2641</td>
<td></td>
</tr>
<tr>
<td>140.1</td>
<td>13.440</td>
<td>34.955</td>
<td>13.420</td>
<td>26.2734</td>
<td></td>
</tr>
<tr>
<td>150.0</td>
<td>13.367</td>
<td>34.948</td>
<td>13.346</td>
<td>26.2832</td>
<td></td>
</tr>
<tr>
<td>160.2</td>
<td>13.328</td>
<td>34.944</td>
<td>13.306</td>
<td>26.2883</td>
<td></td>
</tr>
<tr>
<td>169.8</td>
<td>13.316</td>
<td>34.944</td>
<td>13.292</td>
<td>26.2910</td>
<td></td>
</tr>
<tr>
<td>180.1</td>
<td>13.309</td>
<td>34.944</td>
<td>13.284</td>
<td>26.2927</td>
<td></td>
</tr>
<tr>
<td>190.3</td>
<td>13.300</td>
<td>34.944</td>
<td>13.273</td>
<td>26.2949</td>
<td></td>
</tr>
<tr>
<td>200.3</td>
<td>13.293</td>
<td>34.944</td>
<td>13.265</td>
<td>26.2966</td>
<td></td>
</tr>
<tr>
<td>210.1</td>
<td>13.300</td>
<td>34.947</td>
<td>13.271</td>
<td>26.2977</td>
<td></td>
</tr>
<tr>
<td>220.5</td>
<td>13.256</td>
<td>34.947</td>
<td>13.225</td>
<td>26.3070</td>
<td></td>
</tr>
<tr>
<td>229.7</td>
<td>13.219</td>
<td>34.945</td>
<td>13.187</td>
<td>26.3132</td>
<td></td>
</tr>
<tr>
<td>239.9</td>
<td>13.161</td>
<td>34.937</td>
<td>13.128</td>
<td>26.3190</td>
<td></td>
</tr>
<tr>
<td>250.4</td>
<td>12.840</td>
<td>34.919</td>
<td>12.806</td>
<td>26.3696</td>
<td></td>
</tr>
<tr>
<td>260.3</td>
<td>12.667</td>
<td>34.906</td>
<td>12.632</td>
<td>26.3940</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>Angle 1</td>
<td>Angle 2</td>
<td>Angle 3</td>
<td>Angle 4</td>
<td>Depth</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>270.4</td>
<td>12.370</td>
<td>34.887</td>
<td>12.334</td>
<td>26.4375</td>
<td></td>
</tr>
<tr>
<td>280.2</td>
<td>12.101</td>
<td>34.864</td>
<td>12.064</td>
<td>26.4717</td>
<td></td>
</tr>
<tr>
<td>290.1</td>
<td>11.625</td>
<td>34.836</td>
<td>11.588</td>
<td>26.5401</td>
<td></td>
</tr>
<tr>
<td>300.3</td>
<td>11.358</td>
<td>34.820</td>
<td>11.320</td>
<td>26.5774</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Leg 1 and Leg 2 ADCP transects
Figure 2: Schematic EUC Terminal Flows
Figure 3  92°W ADCP Transects Only
Figure 4  92°W ADCP with Coastal ADCP Transects
Figure 5: CTD EUC confirmation using casts 501 and 601
Figure 7  Satellite SST and Chlorophyll