Upwelling of subsurface water into the rim of the Biobío submarine canyon as a response to surface winds

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Abstract

The submarine canyon of the Biobío River (36°50'S; 73°15'W) is located in the vicinity of a zone of intense seasonal upwelling off Central Chile. This zone conforms a coastal ecosystem that produces more than 50% of the Chilean fish catch and approximately 4% of the world fish captures. As the small- and mesoscale oceanographic processes associated to this canyon are practically unknown, it has not been demonstrated whether the interaction of the canyon with the coastal ecosystem contributes to the high biological productivity. Using horizontal currents and hydrographic variables measured in and around this canyon, this study shows the first evidences of the rise of water through the canyon of the Biobío River. Water velocities were measured using three moorings, deployed near the head and the flanks of the canyon in two periods of the year (March–April and August 1991). During the first period, when the wind conditions were relatively constant, both sides of the canyon had different circulation patterns. The kinetic energy of bottom currents in the northern side, which is associated to the continental shelf, was at least one order of magnitude larger than in the southern side, which is associated to interior waters. During the second period a storm of northerly winds, non-favorable for upwelling, generated a mixing of the water column down to 50 m, approximately. Two days after the beginning of the storm the water column under 60 m depth cooled down. This cooling responded mainly to the northerly and coastward currents that were generated almost at the end of the storm. Cooling was more evident at the northern side of the canyon, with cooling rates of 0.5°C/day. Ascent rates of 0.02 cm/s for the 11°C isotherm and 0.03 cm/s for the 10.5°C isotherm were estimated. The divergence of the currents, calculated at 40 m depth, also indicates the rise of cold waters through the canyon during and after the storm. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Submarine canyons; Vertical water movement; Biobío river canyon; Chile (36°50'S; 73°15'W)
1. Introduction

1.1. General background and objectives of the study

The Chilean continental shelf is relatively narrow, having 11 submarines canyons between Valparaiso (33°S) and Valdivia (40°S), whose sedimentological and structural characteristics have been studied by Thornburg and Kulm (1986), Thornburg et al. (1990), and Pineda (1999). The deepest one is the Biobío River Canyon (36°50'S, Fig. 1), which belongs to a local ecosystem of very high biological productivity that provides between 50 and 90% of the annual Chilean fishing (SERNAP, 1997).

Fig. 1. Biobío submarine canyon and associated coastal region (36.0°S–37.2°S).
On a larger scale, this ecosystem is part of the Peru–Chile Current, which flows northward along the western South American coast, one of the major Eastern Boundary Currents (EBC) of the world. A thorough review of the coastal circulation in this system can be found in Strub et al. (1998). In this EBC region the productivity, very patchy in space, seems to be centered around isolated areas with special topography, like the wide shelf off Peru (Brink et al., 1983) or the shelf off Concepción, Chile, at 36°30'S (Arcos and Salamanca, 1984; Arcos et al., 1987). Along most of the Chilean coast the bottom profile is very steep and the productivity seems to be confined to a very thin nearshore strip or to eddies associated with points, headlands, islands or canyons (Cáceres and Arcos, 1991).

Submarine canyons can influence in several ways the physical processes involved in EBC systems. For example, internal waves can be generated, modified and dissipated there and thus vertical mixing can be driven by energy released by breaking (Hickey, 1997). Another important aspect concerns the adjustment of geostrophic currents and quasigeostrophic motion like coastal-trapped waves to abrupt variations of the bottom topography. This can modify coastal-trapped waves, as their low-frequency energy can be dispersed into higher modes. Besides, it can produce mass exchange between the shelf and the slope, by influencing the upwelling and downwelling of waters in the coastal zone.

Studies by Freeland and Denman (1982), Klinck (1988, 1996), Allen (1996) and others show that the alongshore current in a canyon adjusts to smooth alongshore variations of the topography, i.e. the motion tends to follow isobaths, but if the width of a canyon is smaller than the internal Rossby radius, geostrophic adjustment is no longer possible, as the cross-shore pressure gradient will not be balanced by the Coriolis force within a narrow canyon. The resulting acceleration of water along the canyon axis can only be balanced by friction and will ultimately lead to upwelling or downwelling at the head of the canyon. In consequence, water will be supplied to or sucked off the surrounding shelf (Denman and Freeland, 1985).

Kinsella et al. (1987) and Klinck (1988) have studied the particular case of rise of subsurface waters into the continental shelf through canyons. Freeland and Denman (1982), Freeland et al. (1984), and Denman and Freeland (1985) proposed that the intense upwelling in the Juan de Fuca canyon is caused by pressure gradients perpendicular to the coast, not balanced by the Coriolis force within the canyon. They demonstrated that these pressure gradients could bring waters from 450 m depth into the shelf. According to these authors, the classical theory of upwelling induced by surface winds could not completely explain the kind of upwelling found in canyons.

The mentioned physical aspects have not been studied in the case of submarine canyons in the Chile–Peru current. The present study is an attempt to assess the importance of some of these aspects to the Biobío submarine canyon, using the first continuous current records ever obtained there.

1.2. Study area

The Biobío submarine canyon is located between the Gulf of Arauco and the continental shelf of Concepción, off central Chile (Fig. 2). The area is, apart from the canyon, shallower than about
The canyon lies in the neighborhood of a gulf and two bays, in a geographical zone where the continental shelf is the widest of the country (about 36 nm). On the other hand, it is influenced by a seasonally variable flow of the Biobío River, and it is related to zones of intense seasonal upwelling (Lavapié Point, 37°10′S; Peninsula of Hualpén, 36°46′S). The canyon is narrow (half-width, \( L \), around 5 km) and deep (\( H = 750 \) m). The depth from the rim to the bottom (\( h_m \)) is around 600 m. Thus, the fractional height (\( h_m/H \)) is 0.80 and the aspect ratio (\( H/L \)) is 0.12 — i.e. this is a relatively deep canyon.

The Biobío river, associated to this canyon, has large seasonal runoff variations, with monthly values from about 200 m\(^3\)/s in summer to a maximum of about 2800 m\(^3\)/s during the winter (Sobarzo et al., 1993). The mouth of the river, ca. 1.5 km wide, is almost cut off during the summer by sandbanks which are flushed out by the strong flow in winter.

During the austral summer (September–March) the mean surface wind in the study area is southerly (upwelling favorable), turning to northerly during the austral winter (May–July), with transition periods during April and August (Saavedra, 1980).

The seasonal variation of winds and runoff creates two distinct modes of water circulation in the northern part of the Gulf of Arauco: a summer upwelling with isopycnals sloping upwards towards the coast and a semi-permanent eddy over the canyon (Djurfeldt, 1989) and a winter downwelling situation with a thick surface layer to which is added the large winter supply of fresh water from the river (Sobarzo et al., 1993). The system undergoes large variability.
in very different time scales, from sea breeze (Picarte et al., 1996) to El Niño events (Shaffer et al., 1997).

2. Data

With the aim to sample situations under different meteorological conditions, measurements of currents and hydrography were performed during two time periods in 1991, one during late summer-fall (from March 21 to April 7, hereafter called P-1) and the other during winter (from August 8 to August 23, P-2). Three moorings, each one carrying three current meters, were maintained during both periods. Due to technical problems only 14 of the 18 current meter time series were available for this analysis (see Table 1). Because of the heavy fishing pressure in the study area it is unfortunately difficult to leave moorings out for longer periods. The instrument depths were 10, 40 and 80 m, i.e. not within the canyon itself. The moorings were deployed around the rim of the canyon at a bottom depth of about 100–150 m (Fig. 2). Hydrographic cruises with a total of 19 CTD stations were obtained during both periods. Moreover, data of a cruise carried out during 8–11 August 1991 (Sobarzo et al., 1993), which did not include the deploying of current meters, were also used in the present analysis. Thus, the hydrographic cruises (HC) correspond to the following dates: March 25–27, 1991 (HC1), August 8–11, 1991 (HC2), and August 20–22, 1991 (HC3). Wind data were registered by the meteorological station at Point Hualpén (Fig. 2).

The time-series data from the current meters were filtered with a Cosine–Lanczos filter with a half-power point of 40 h.

Table 1
Statistics of the temperatures and subinertial currents. Biobío submarine canyon zone, during P-1 and P-2. The orientation of the velocity components, the MPA and the mean flow are defined respect to the geographical north

<table>
<thead>
<tr>
<th>Mooring</th>
<th>Depth (m)</th>
<th>Data</th>
<th>(u) (cm/s)</th>
<th>(v) (cm/s)</th>
<th>(T) (°C)</th>
<th>(T_{SD}) (°C)</th>
<th>(u_{SD}) (cm/s)</th>
<th>(v_{SD}) (cm/s)</th>
<th>(K_e) (cm/s)²</th>
<th>Major principal axes</th>
<th>Mean flow</th>
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<tr>
<td>Northern side (P-1)</td>
<td>10</td>
<td>372</td>
<td>-0.8</td>
<td>-5.5</td>
<td>13.9</td>
<td>0.33</td>
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<td>6.53</td>
<td>27.63</td>
<td>153</td>
<td>188</td>
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<tr>
<td></td>
<td>40</td>
<td>372</td>
<td>-1.7</td>
<td>-8.7</td>
<td>11.8</td>
<td>0.20</td>
<td>1.53</td>
<td>4.11</td>
<td>9.60</td>
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<td>191</td>
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<tr>
<td></td>
<td>80</td>
<td>372</td>
<td>-2.9</td>
<td>-10.9</td>
<td>11.4</td>
<td>0.09</td>
<td>1.76</td>
<td>4.21</td>
<td>10.40</td>
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<td>372</td>
<td>-1.9</td>
<td>-0.8</td>
<td>—</td>
<td>—</td>
<td>3.51</td>
<td>3.21</td>
<td>11.30</td>
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<td>247</td>
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<tr>
<td>Head side (P-1)</td>
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<td>-0.3</td>
<td>13.2</td>
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<td>0.74</td>
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<td>6.70</td>
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<td>372</td>
<td>-0.7</td>
<td>-0.4</td>
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<td>Southern side (P-2)</td>
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<td>0.9</td>
<td>12.0</td>
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<td>3.99</td>
<td>13.89</td>
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<tr>
<td></td>
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<td>-1.4</td>
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<td>0.27</td>
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<td>9.35</td>
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<tr>
<td>Head side (P-2)</td>
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</table>
3. Results

3.1. Subinertial wind and currents associated to the canyon

During P-1 winds were mainly from the southwest (Fig. 3a), i.e. upwelling favorable, and rather weak. During P-2, on the other hand, southwesterly winds were interrupted by a northerly storm.

Fig. 3. North–south component of winds and subinertial currents around the Biobío canyon during P-1 (March 22–April 6) and P-2 (August 9–21, 1991).
event that lasted for several days (August 12–14) with a maximum velocity of about 13.7 m/s (Fig. 3b).

The north–south and the east–west subinertial components of the wind and currents in the rim of the canyon (North, South and Head) are shown in the Figs. 3 and 4, respectively. In each figure...
the period P-1 (P-2) is shown on the left (right) side. During P-1 the most intense north–south currents occurred in the northern side of the canyon, directed toward the south (Fig. 3c). Near the Head and in the southern side of the canyon this component is notoriously weaker (Figs. 3e and g). The vertically averaged flow of this component in the northern side presents a quasi-barotropic structure with a weak intensification of the velocity with the depth. The first part of this period presents an oscillation of 6 days related to wind local forcing (Fig. 3a), characteristic of the southern part of the inner continental shelf off Concepción (Sobarzo, 1999) during summer. The east–west velocity component, on the other hand, is weaker than the north–south one, especially near the Head (Fig. 4g).

During P-2 the northerly winds storm (August 12–15) strongly affects the north–south component of the surface flow (10 m) of both the northern and southern sides of the canyon (Figs. 3b,d and f). One to three days after the beginning of the storm, northward subsurface flows were generated (40 and 80 m) north of the canyon (Fig. 3d). The subsurface currents (40 and 80 m) south of the canyon and near its head indicate the same tendency (northward currents some days after the beginning of the storm) but less intensely. On the other hand, the east–west velocity component is comparatively weaker than the north–south velocity in the three sampling places. Although weak, the cross-shore velocities are usually westward. The northerly wind storm produced inshore velocities in the level of 80 m (Figs. 4d and f), with a delay of 1.5 (2.0) days in the northern (southern) part of the canyon, respectively.

A comparative analysis of the statistics of the subinertial times series of currents and temperatures is shown in Table 1. In the northern side of the canyon \( \bar{v} \) and \( v' \) (= \( v - \bar{v} \)) are larger than \( \bar{u} \) and \( u' \) (= \( u - \bar{u} \)) in the two measurements periods. In the southern side and near the head, on the other hand, during P-1 (P-2), \( \bar{u} \) is larger (smaller) than \( \bar{v} \). In the southern side and during P-2, also, \( v' \) are larger than \( u' \) only in the level of 10 m. In 40 and 80 m these fluctuations are of the same order.

The eddy kinetic energy \( Ke \), on the other hand, tends to be greater in the northern side of the canyon, especially during P-2 where, in the level of 80 m, it reaches 137.8 cm\(^2\)/s\(^2\), in comparison with only 9.35 cm\(^2\)/s\(^2\) in the southern side.

### 3.2. 3-D scatter diagrams, major principal axes and mean flow orientations of the subinertial currents

Figs. 5 and 6 show the major principal axes (MPA) and the mean flow orientation for the three sampling levels and during P-1 and P-2, respectively. The MPA have been normalized multiplying by the standard deviation of the respective eigenvalue. The percentage of explained variance is indicated in each case. During P-1, with predominant conditions of southerly winds, the mean flow in each current meter in the northern side tends to be southward, with velocities that increase with depth. The measurements in the 40 m level obtained in the southern side and near the head do not show a similar tendency. The MPA of the northern side tends to align along the isobaths, in a north–south orientation. In the southern side, the MPA in 40 m depth is almost transverse to the isobaths.

During P-2, with predominant northerly winds, the MPA and the mean velocity have approximately the same orientation in the 10 m level on both sides of the canyon (Fig. 6a). In the levels of 40 and 80 m, the MPA and the mean flow tend to align in a north–south (east–west)
The vertical structure of the subinertial circulation measured on the northern side of the canyon during P-1 is consistent with measurements carried out during the Thioploca-1994 experiment (Sobarzo, 1999). It implies a southward quasi-barotropic flow that intensifies with depth, and MPA and the mean flow orientation aligned along the isobaths. This southward incident flow on the canyon is part of the characteristic circulation of the southern part of the inner continental shelf during summer conditions (Sobarzo, 1999). During intense southerly wind this southward flow can reduce its velocity in the surface layer and even be turned into a

Fig. 5. Major principal axes (circles) and mean flows (arrows) around the Biobio canyon during P-1. The variance percent of the major axes are included.
Fig. 6. Major principal axes (circles) and mean flows (arrows) around the Biobio canyon during P-2. The variance percent of the major axes are included.

Fig. 7. Scatter diagrams of the subinertial currents during P-1.
northward current. During P-2, this flow is strongly affected by a northerly wind storm that changes the sense of the flow in the 40 and 80 m levels.

- The orientation of the subinertial circulation of the northern side of the canyon differs from its counterpart on the southern side, particularly in the 40 and 80 m level. The persistent southward flow observed on the northern side is not present on the southern region. This is particularly evident at 80 m, as the MPA and the mean flow orientations on the southern side tend to align diagonally to the coast, following the bathymetry.
- Only on the northern side of the canyon, in the 40 and 80 m levels and during P-1, the mean southward flow is statistically representative. In all other cases the fluctuations dominate, presenting a highly variable coastal system, especially during P-2.

### 3.3. Circulation and the thermal field during favorable wind conditions to coastal upwelling

Fig. 9 shows alongshore wind stress and vertical thermal structure, including the tidal variability, during P-1. From March 22 until March 29 the weak wind from the southwest does not cause upwelling. The temperature of the upper 10 m of the surface layer is modulated by the solar daily cycle. Semidiurnal oscillations are observed near 40 m depth. From March 29 until April 3, the upwelling favorable wind causes a light cooling of the surface layer. In the Head side, the thermal behavior is similar, although with a stronger cooling of the surface layer after the maximum in the wind strength of March 29.

The decomposition of the subinertial currents along of the MPA in the northern and Head sides and its relationship with the temperature are indicated in the Fig. 10. The cooling of the surface layer in the northern side (March 25 and 30) is associated to a flow toward the continental shelf.
In 40 and 80 m the predominant flow toward the canyon does not show large variations in temperature. In the Head side, the surface cooling of March 30 is accompanied by a weak flow toward the shelf.

3.4. Circulation and the thermal field during favorable wind conditions to downwelling

During P-2 the coastal area was affected by a storm of northerly wind that changed the dynamical conditions associated to the Biobio canyon. The alongshore wind stress and the vertical thermal structure, including the tidal variability, are presented in Fig. 11. The storm (August 12–14) mixed the water column on both sides of the canyon up to, at least, 40 m depth. The temperature was homogenized to values between 12 and 12.5°C. On the other hand, starting from
Fig. 10. Subinertial fluctuations of the alongshore wind stress, currents along the major principal axes and temperatures during P-1.
August 14 (around two days after the beginning of the storm), a cooling was observed in 80 m depth that began in the northern side, reaching values between 9.5 and 10°C (August 17).

The decomposition of the subinertial currents along the MPA in the northern and southern sides during P-2 and its relationship with the subinertial temperature are indicated in Fig. 12. The storm of northerly wind causes a surface southward flow in both sides of the canyon, which is associated to a homogenization of the temperatures in 10 and 40 m (Figs. 12c and e). Both the southward flow and the mixing of the temperature in the first 40 m remain more time (almost two additional days) in the southern side. The cooling of the water column under 60 m depth, between 15th and 20th August, is related to northward flow on the northern side and to north-eastward side on the southern side of the canyon.

The temperature time series in 40 and 80 m depth, including the tidal variability, are shown in Fig. 13. The storm suppressed the semidiurnal oscillations in 40 m depth, with a delay of around
one day (Fig. 13b). In 80 m, the temperature begins to descend around 2 days after the beginning of the storm, changing from 11.5 to 9.8°C (Fig. 13c). This cooling is more marked in the northern side, where the temperature changes from 11.5 to 9.8°C in approximately 3.5 days, i.e. with a cooling rate of 0.5°C/day. The semidiurnal temperature oscillations recover some 30 h after the end of the storm in the level of 40 m. At 80 m depth, the temperature recovers its initial values four
days after the end of the storm. The divergence, calculated in the first 40 m, shows coherence between the observed cooling and upward displacements in the water column (Fig. 13d).

3.5. **Hydrographic comparison**

In order to confirm the rise of cold waters (10–11°C) suggested from the divergence of the current measurements, temperature sections along the axis of the canyon and vertical temperature
profiles were plotted. Fig. 14 compares the temperature in the canyon during the three hydrographic cruises. During HC1 a strong surface warming was observed, due to large solar radiation input (austral summer). Between 50 and 150 m depth the temperature remained homogeneous around 11°C, while less than 150 m it decreased gently, up to 10°C at 265 m depth (Fig. 14d). In winter, before the northerly storm (HC2), the temperature at the surface (13°C) was lower than during HC1, and a thermal inversion between the surface and 25 m was observed. Between 50 and 125 m the temperature remained homogeneous, close to 11.4°C. Below this depth the temperature dropped to 10°C at 230 m (Fig. 14b). After the storm (HC3), the thermal inversion disappeared due to the mixing produced by the storm. Between 180 and 300 m depth the temperature of the water column decreased 0.3°C on average (Fig. 14f). In this cruise, carried out almost three days after the temperature decrease was detected by the current meters, the hydrographic section still shows the presence of 10.5°C waters at 130 m (see Fig. 14c). Salinity profiles (not shown) indicate that after the storm the water column below 60 m had salinity, on average, 0.03 lower than before the storm.

4. Discussion and conclusions

According to this study, the Biobío submarine canyon is a topographical factor that permanently modifies the coastal circulation in this zone. This influence results evident in the following ways:

4.1. Effects of the canyon in processes of rise of waters

Freeland and Denman (1982), Freeland et al. (1984) and Denman and Freeland (1985) suggested that the increment of the upwelling in the Juan of Fuca canyon be produced by cross-shore pressure gradients not balanced by the Coriolis force inside the canyon. They demonstrated that such gradients were able to transport waters from 450 m depth into the shelf region. According to Freeland and Denman (1982) the classic theory of upwelling induced by wind was not able to explain completely this rise of waters.

Klinck (1988) indicated that the slope of the ocean free surface produces a pressure gradient in the canyon that induces water motion along its axis. In his case the canyon was narrow compared to the Rossby internal radius and the pressure gradient was not balanced by a circulation perpendicular to the canyon. As a consequence, the circulation in the canyon became non-geostrophic.

Kinsella et al. (1987) and Klinck (1988) have highlighted processes of rise of waters through submarine canyons in connection with the occurrence of storms. The data presented in the present study indicate that the Biobío canyon processes of rise of waters due to storms would also happen. The subsurface northward flow in the northern side of the canyon is associated to temperatures between 10 and 11°C. According to the temperature profiles (Fig. 14e), the isotherm of 10°C was at 230 m depth before the storm of northerly wind. Approximately three days after the storm the same isotherm (10°C) was found at 190 m depth (Fig. 14f). On the other hand, an ascent rate of 0.02 cm/s (0.03 cm/s) for the isotherm of 11°C (10.5°C) was determined from the temperatures measured by the current meters anchored in the northern side of the canyon. These values
Fig. 14. Vertical cross sections and temperature profiles in the Biobio canyon.
coincide with vertical speeds found in upwelling areas (0.02 cm/s or 20 m/day) and they are one order of magnitude smaller to that found by Kinsella (1984) in the Carson canyon (0.7 cm/s).

4.2. Effects of the canyon on the horizontal velocity field

During the last years a number of studies have addressed the effects of cross-shore submarine canyons on the dynamics of persistent flows on continental shelves (Freeland and Denman, 1982; Klinck, 1988, 1989, 1996; Huthnance, 1995; Allen, 1996; Hickey, 1997). These studies have demonstrated the existence of currents in and around canyons that can influence the circulation of adjacent continental shelves (Klinck, 1989).

According to Klinck (1989) there are observational evidences of the influence of a submarine canyon on the circulation of adjacent shelves through geostrophical adjustment to variable bathymetry (i.e. Han et al., 1980; Freeland et al., 1984; Hickey et al., 1986; Hunkins, 1988).

The mentioned coupling between the canyon and the circulation on the shelf is also present in this study. During P-1 the vertical structure of the flow in the northern side of the canyon shows a southward quasi-barotropic mean flow, similar to the case found on the shelf during March 1994 (Sobarzo, 1999). This indicates that the component of the flow along the coast maintains the same sign through the water column, but it intensifies the velocity with depth. During P-2 this vertical structure is altered due to the strong perturbations introduced by the storm of northerly wind.

The subinertial fluctuations of the southward flow have periods between 3 and 10 days, being coupled to the wind local forcing. Here we proposed that this vertical structure is caused by the presence of the submarine canyon. Allen (1996) has modeled this kind of situations. She has demonstrated that in the case of an alongshore flow narrower than the canyon, the deep layer of the incident flow cannot cross the topographic discontinuity, but rather concentrates and intensifies toward the head side of the canyon, following the isobaths. This situation corresponds well with the observations of the present study. The bottom southward flow that impinges on the canyon tends in fact to follow the bathymetry, and to concentrate near the head of the canyon.

On the other hand, the potential vorticity conservation for a non-viscous fluid requires that when the water column is lengthened or compressed, the relative vorticity increases or diminishes, respectively. Considering a layer of thickness $h$ that is lengthened to a thickness $h_c$ when it flows on a canyon, and assuming that the vorticity flow up is negligible (Allen, 1996; Hickey, 1997) and that the potential vorticity is conserved one obtains

$$\frac{f}{h} = \frac{(f + \zeta)}{h_c},$$

where $\zeta$ is the relative vorticity ($\partial v / \partial x - \partial u / \partial y$) and $f$ is the Coriolis parameter. This equation can be rewritten as

$$\zeta = f \left( \frac{h_c}{h} - 1 \right),$$

where the expression ($h_c/h - 1$) corresponds to the lengthening vorticity (Hickey, 1997). In our case, toward the head of the canyon, $\zeta$ varies approximately between $f$ and $2f (-1.75 \times 10^{-4} \rightarrow -8.74 \times 10^{-5} \text{s}^{-1}$, negative in the Southern Hemisphere). This implies that the flow acquires
negative $\zeta$ with an intensification of the current toward the coast. Thus, the flow that passes over
the canyon tends to be adjusted to the bathymetry and to be intensified to the coast (Allen, 1996).

For a better study of this interaction a model will be required that considers the particular
characteristics of the bathymetry of this coastal area, along with an observational study that
improves the space and temporal resolution of the sampling used here. However, this analysis
shows that the persistent southward flow existing in the northern side of the canyon is not present
in its southern side or in its head, indicating an important discontinuity in the alongshore flow. In
this way, the canyon would act as a wall that alters the alongshore subsurface circulation and,
besides, increases the offshore transport of waters coming from the continental shelf. This
hypothesis can have important consequences for the biological productivity of the ecosystem
associated to the continental shelf break. The waters that flow southward in the northern side of
the canyon and then rotate offshore could receive suspended material from the highly
industrialized San Vicente bay and from the Biobio river. The final destination of this material
could be the southern part of the continental shelf break. In this way, the identification and
elucidation of water exchange processes between the coastal zone and the continental shelf break
constitutes an oceanographic and ecological important topic, as it has been recognized for other
places (Church et al., 1984; Huthnance, 1995).

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