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4.2 Circulation regime in the austral Chilean channels and fjords

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Ocean currents are generally produced by the wind, differences in density in the water column, or sea level set-up. Tide influence in currents is not very important since the variations in amplitude in this area are slight compared to those in the coastal areas.

In coastal areas, the currents forced by the tidal oscillation are more important; tidal currents are defined as horizontal movements associated with the elevation (high tide) and depression (low tide) of sea level. In coastal areas, these movements are generally elliptical and rotatory, while in areas where the direction of the circulation is restricted (such as rivers, straits, channels, and fjords), the currents are reversible. This reversible behavior results in a moment in which the magnitude of the current is zero, known as slack water. Given that the decrease (increase) in most cases is progressive, we talk about a “slack water period” and, in this period, the magnitude of the current is near zero. The description of current patterns that characterize the austral channel and fjord region is highly relevant in the biological field, because the determination of the retention or dispersal zones of debris materials can be useful for determining managed or protected areas. Moreover, determining or predicting the slack periods can be very useful for navigation along these areas.

For this reason, tidal currents respond to a pattern that depends on tidal forcing as well as non-linear disturbances associated with shallow water harmonics (Speer *et al.*, 1991), lateral or bottom friction (Cáceres *et al.*, 2003), or variations in the local wind field (Cáceres *et al.*, 2002).

Estuarine circulation is characteristic of a two-layered vertical structure, in which the fresh water coming from rivers and salty ocean water meet, causing less dense fresh water flows near the surface towards the mouth of the estuary. Below this layer, a denser flow, known as estuarine or gravitational circulation, moves in the opposite direction and corresponds to a steady state circulation.

Estuarine circulation assumes an average linear and stationary flow, in which the forces involved in the equilibrium of the movement along the estuary are the pressure gradient and the frictional effect. Some agents that modify the estuarine circulation are the earth's rotation, tidal currents, bathymetry, coastline, atmospheric forcing, river discharge, etc. Moreover, the presence of constrictions and sills in estuarine systems can affect the time of residence of the deep waters within the fjord and influence the transport capacity (Stigebrandt, 1979).

Prior to the beginning of the CIMAR Program, knowledge of the circulation in the interior waters of the austral channels and fjords was scarce and most of the information was obtained from foreign expeditions (Silva *et al.*, 1995). During this program, several studies of currents were carried out using Eulerian and Lagrangian currentometry associated with wind measurements to identify cause-effect relationships. These studies were done in different zones between Puerto Montt and Cabo de Hornos (Salinas *et al.*, 1999; Fierro et al., 2000; Valle-Levinson *et al.*, 2002; Salinas & Hormazábal, 2004), and their main results are summarized in the following paragraphs.

From Puerto Montt to Laguna San Rafael (northern zone), a study was carried out to characterize the tidal and current regimes along Canal Moraleda (Fig. 1). These results showed that the currents in Puerto Ballena and Puerto Nassau did not develop reversible behavior (Fig. 2), since most of the variability at both locations was explained by the subtidal component.

In the Boca del Guafo area, reversible currents were detected related to the tidal fluctuations whose axis of maximum variation was east-west, with maxima of 140 cm·s^{-1} in the northeast direction (Fierro *et al.*, 2000). Moreover, in this same zone, a current mooring was deployed on the Meninea constriction-sill at 25 and 40 m depth, over the isobath of 60 m. In both data records, the current directions were aligned with the channel axis, indicating the bathymetric effects on the flow. Average velocities were estimated to be 15.9 cm·s^{-1} at 25 m north of the channel and 2.0 cm·s^{-1} 40 m south of the channel. At both depths, spectral analysis showed the currents to be modulated by the semidiurnal tide frequency, with a spectral maximum in periods of 12.6, 6.2, and 26.4 hours, in decreasing order of its energetic contribution (Salinas & Hormazábal, 2004).

The Meninea constriction-sill is 60 m deep and separates Canal Moraleda into two microbasins: one to the north and one to the south (Silva *et al.*, 1997). The presence of this sill-constriction is a highly important hydraulic factor, as it can control the estuary's salinity through the transport capacity that is associated with the depth of the surface layer (Salinas & Hormazábal, 2004). This constriction-sill only allows the water between 30 and 60 m in the microbasin to the north of Canal Moraleda to move toward the southern microbasin (Silva *et al.*, 1997). The estuarine system of Meninea has a predominant baroclinic component in which the surface flow is directed northward and the deep flow southward. Moreover, barotrophical events occur in the flow (Salinas & Hormazábal, 2004).

A seven-month residence time was calculated for the south microbasin and the hydraulic control produced by the sill was determined, with a density stratification of 0.002 if the currents in each layer are equal or greater than 77.5 cm·s^{-1} (Salinas & Hormazábal, 2004).

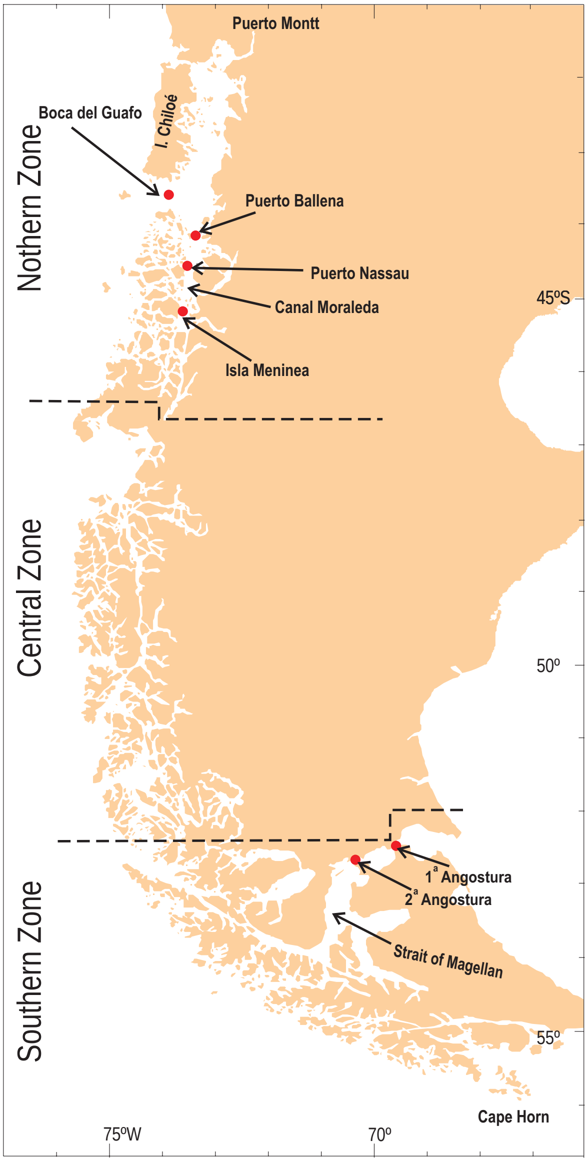

Figure 1: Geographic location of the moorings to measure currents.

Later, in the Meninea constriction-sill area, another current measurement was taken with a fixed ADCP at 50 m depth and time series lasting more than 100 days were obtained, revealing the influence of the hydraulic effects caused by advective accelerations that are in equilibrium with the pressure gradient (Valle-Levinson *et al.*, 2002). During the ebb period, the currents go to 10º from the true north (TN) and during the flow, the direction was 180º TN with magnitudes lower than 40 cm·s^{-1}, whereas the maximum magnitudes were associated with currents flowing toward 125º. In this sector, the typical values correspond to northward surface currents with intensities up to 17 cm·s^{-1} and deep southward currents, with magnitudes of 13 cm·s^{-1} (Valle-Levinson *et al.*, 2002).

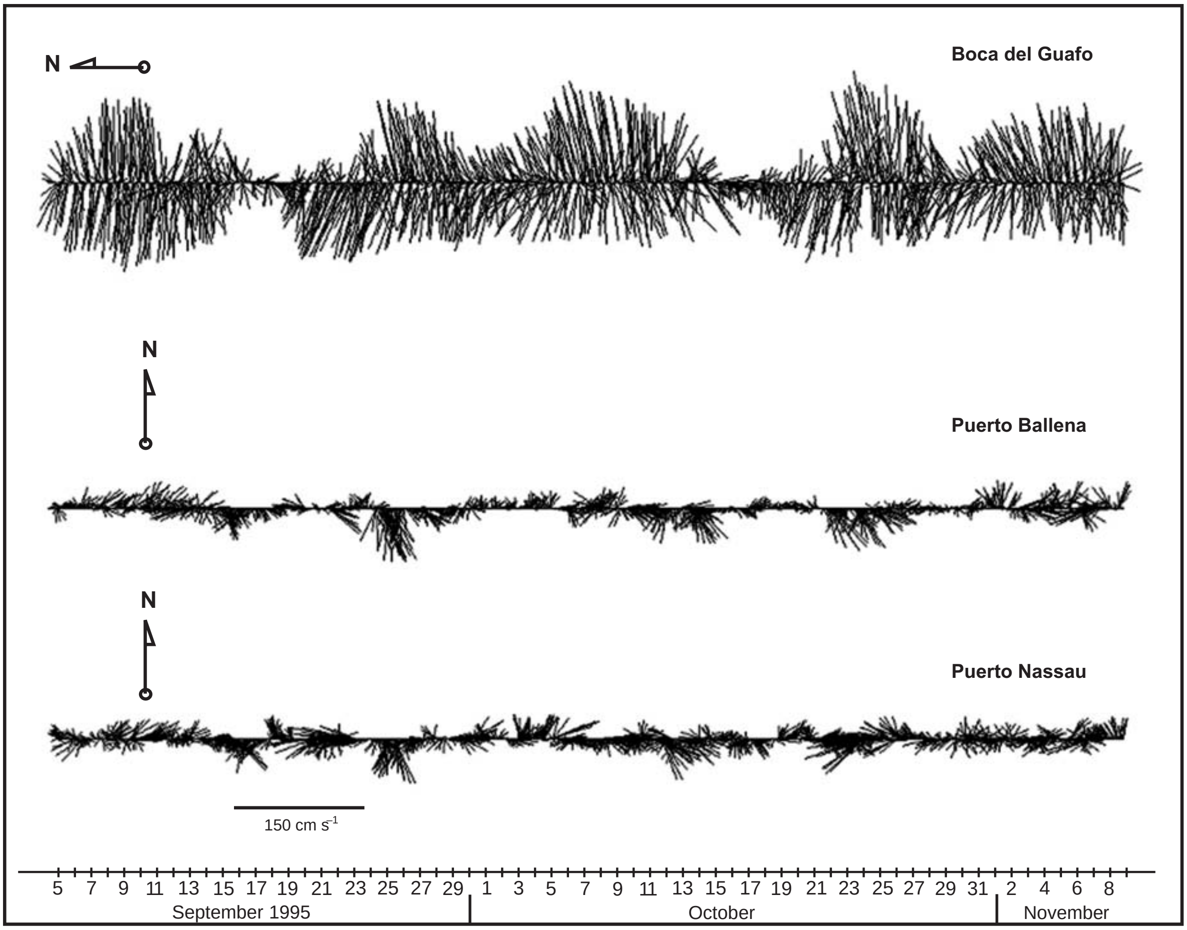

Figure 2: Vector diagram of currents measured in Boca del Guafo, Puerto Ballena, and Puerto Nassau. The diagram of Boca del Guafo was rotated 90º counter clockwise, since most of the variability was associated with the east-west component.

The water exchange in the constriction-sill area is more intense in periods of weak winds. Flow reversals towards the north coincide with a weakening of the flow towards the south near the bottom and with the deepening of the interface between the northward and southward flows. The variability of this interface is related to atmospheric forcing, with the interface deepening during south-blowing wind events. One hypothesis that has been proposed is that the effect of the wind forcing modifies the Bernoulli-type exchange hydrodynamic towards a more frictional balance (Valle-Levinson *et al.*, 2002).

In the Strait of Magellan (southern zone), Lagrangian current measurements were taken in the sector of Primera Angostura and a currentmeter was moored at Segunda Angostura (Fig. 1). At Primera Angostura, currents reached an average velocity of 400 cm·s^{-1}, moving in the direction along the strait axis, and the incremented variability is caused by the tidal wave propagation in this sector (Salinas *et al.*, 1999). This tidal wave propagation interacts with the topography and generates disturbances in the currents and sea level that influence the general circulation patterns in the area. The currents along the strait showed a decrease in the semidiurnal component towards the west and a diurnal component that tends to be constant.

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