The Southern Chilean Fjord Region: Oceanographic Aspects

Marcus Sobarzo Bustamante - Translated from Spanish by Ben Machado.

General Introduction

The region of fjords and channels at the southern end of Chile extends from Puerto Montt down to Cape Horn (approximately between 41.47°S and 56°S and between 76°W and 66°W) constituting a natural obstacle to the Antartic Circumpolar Current (ACC). With this location, further south than Africa and Australia, this region possesses unique characteristics, such as freshwater reserves and particular habitats for a wide range of species that are just being studied.

Its 84,000 km of interior coasts, together with the associated topography of the seafloor, form multiple channels, fjords, submarine canyons, bays and semiclosed areas of irregular shape. In general terms, the motion of the water column in this region is determined by the input of continental waters, the fluctuations of the tides and the wind. These three forces generate, respectively, the so-called density (or buoyant) currents, tidal currents and wind-driven currents. The resultant total current can be modified by the submarine topography, the stratification of the water column, the interaction of these waters with the adjacent coastal ocean and, in some cases, by the rotation of the Earth. In this way, what we call "currents" in this chapter corresponds to a sum of components that respond to different forces that also act on different scales in time and space.

The Adjacent Coastal Ocean

The coastal area adjacent to the southern Chilean Fjord Region extends from Chacao channel (41°46.9'S; 73°38.9'W) to Cape Horn (56°6.3'S; 67°21.7'W) (Fig. 1), linearly comprising some 1,650 km. The area, in general, is characterised by waters of low salinity, sediments of glacial origin, high precipitation rates and also a large tidal range in the Gulf of Ancud, Seno Reloncaví and the Strait of Magellan.

From a geological point of view, in this zone the Nazca, Antarctic and South American Plates unite. The area off the Taitao Peninsula (46°22'S) is therefore known as the Triple Junction. Along with this, the Chile-Peru fault practically disappears as a topographic feature, since it is covered by sediments as result of glacial action.

Little is known of the coastal dynamics in this region. Currents are probably dominated by the southwards deviation of the ACC into the so-called Cape Horn Current. The winds, tides and the local influence of freshwater originating from the continent modulate the temporal variability of this coastal current. The mix between the Subantarctic Surface Water (SASW) and that of the channels zone give rise to the so called Modified Subantarctic Water (MSAAW) of lower salinity. The concept of Subantarctic Water comes from the fact that the ACC is a complex system of circulation and water masses, induced by prevailing winds from the west and composed of the Antarctic region, the Antarctic polar front zone and the Subantarctic region. Because the Polar Front (or the zone that separates the Antarctic region from the Subantarctic one) is situated between 45°S and 55°S, approximately, waters of the Subantarctic region predominate in this coastal zone. The variability of the Polar Front and especially of the Cape Horn Current is not well understood. The SASW is located north of the Polar Front in the surface layer; it is around 150 m thick. During the summer, its highest temperatures lie close to 7°C, salinities near 34.1 psu; and the value of dissolved oxygen is relatively high (about 7 ml/l or more). This water mass moves towards the north along the rim of the subtropical anticyclonic gyre of the South Pacific forming the Eastern South Pacific Transition Water (ESPTW), with temperatures that increase towards the equator. Between 40°S and 45°S, the high precipitation and the contribution of continental waters helps to create waters of low salinity (<34.0 psu), already mentioned as MSAAW. These waters of low salinity spread towards the west from the coast of South America (>150°W), increasing slightly in salinity and creating a tongue of low salinity water to the south of the subtropical gyre. In this way, the influence of the continental waters from the fjord region does not only represent a local coastal effect, but it also influences the hydrography of the South Eastern Pacific on a larger scale.

Below the SASW, which reaches approximately 150 m thickness off Chiloé, remnants of Equatorial Subsurface Water (ESSW) are found between approximately 150 and 300 m depth. Although in its core this water mass is characterised by temperatures between 8 and 12°C, salinities between 34.4 and 34.9 psu and dissolved oxygen amounts between 0.2 and 3 ml/l, off Chiloé the temperature, salinity and dissolved oxygen are typically below 10°C, 34.5 psu and 3 ml/l, respectively. Towards the south, off the golfo de Penas (47°15'S), the SASW continues in the 150 m thick upper layer and the core of the ESSW is found

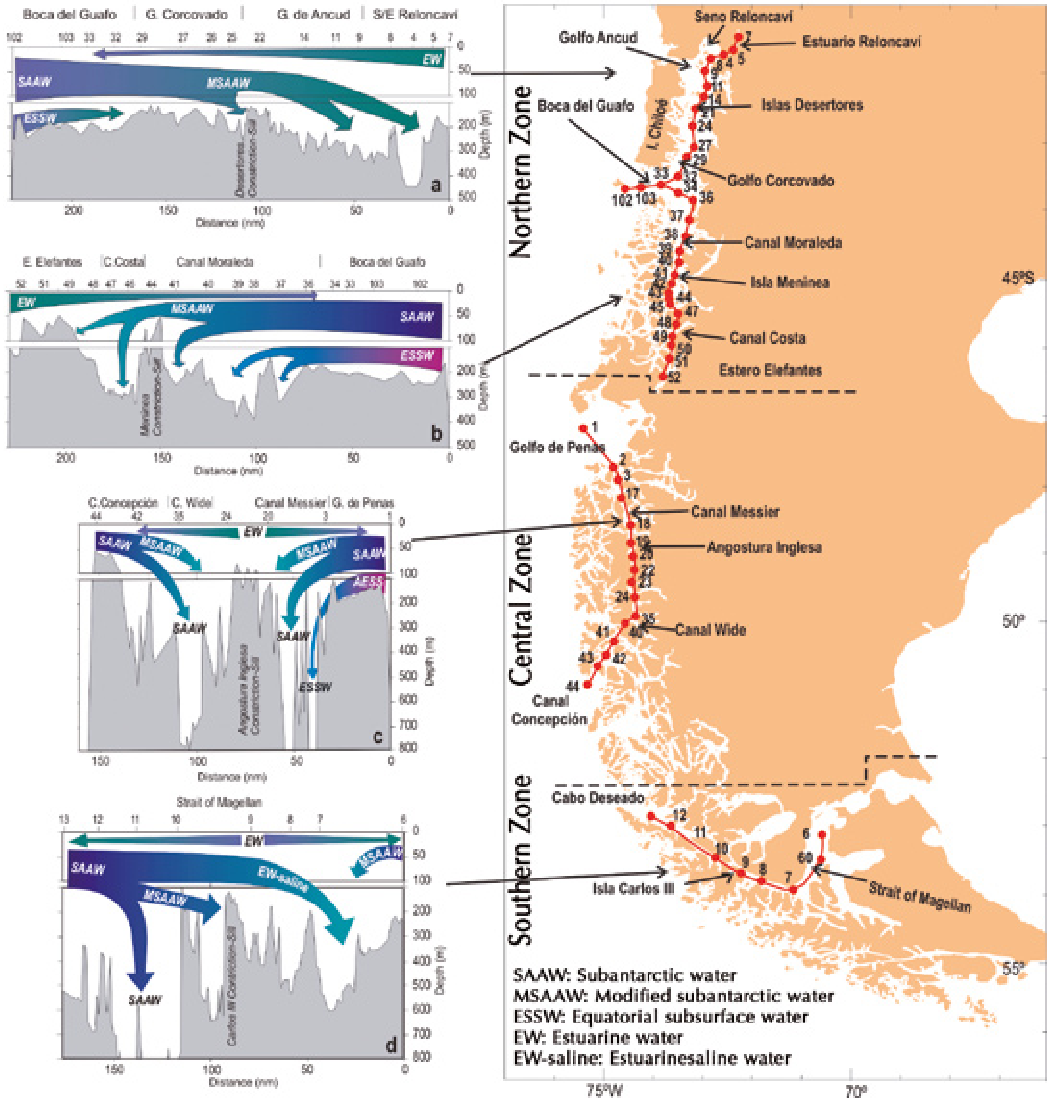

Fig. 1. Schematic vertical circulation model for: a) boca del Guafo to estuario Reloncaví; b) boca del Guafo to estero Elefantes; c) golfo de Penas to canal Concepción; d) Strait of Magellan (adapted from Silva et al.,1998; Sievers et a.l.,2002; Silva & Valdenegro, 2003; Sievers & Silva, 2008).

between 200 and 300 m. Further south of cabo Deseado (52°37'S), the SASW is found in the first 150 m; and below is the Subantarctic Mode Water (SAMW) with a variable thickness between 300 and 700 m. Other water masses in deeper layers of the adjacent ocean (depths greater than 400 m) that do not affect the hydrography of the fjords are the Antarctic Intermediate Water (AAIW) and the Pacific Deep Water (PDW).

The Fjords and the Contribution of Continental Waters

The channels and estuaries of southern Chile are the natural recipients of the freshwater discharges and organic material originating from the rivers and continental run-off. Ice melting and high amounts of precipitation also add to this. The maximum average annual discharges of rivers in this zone fluctuate between 2470, 3480 and 3344 m^3/s, for the latitudes of 42°S, 46°S and 50°S, respectively, with the total quantity of freshwater obtained between 35°S and 55°S being 27.8 x 10^3 m^3/s (based on the data of river discharges). These high values depend on the high amounts of precipitation due to the passage of low pressure subpolar systems associated with high precipitation rates; the Coastal and Andes mountain ranges, which increase the formation of rivers of pluvial regimen on their western sides; and the high altitude of the Andes mountain range, which accumulates precipitated water in the form of ice and glaciers, discharging, eventually, to the sea through rivers characterised by nival regimens.

Depending on the geographical area and the presence of human settlements, these freshwater discharges contain variable amounts of suspended or dissolved material and/or anthropogenic pollutants. From a dynamic point of view, the place of discharge of these substances ("the mouth of the river") can be considered to be the source of momentum and buoyancy, produced by the discharge of a light fluid in a heavier (denser) one. This discharge, manifested as a dynamic structure called the plume of the river (of greater buoyancy than that of the seawater), constitutes the biggest source of buoyancy in the coastal ocean of this region with large effect both on the hydrodynamics and on the marine coastal ecology.

Thus, the structure:

river → fjord → inner channel → outer channel → mouth or gulf → coastal ocean

is one of the sequences that characterises this fractured southern region of Chile. The continuity along this sequence is given by the continental waters. These mix with marine coastal waters already being mixed by *entrainment* (mixed by friction) or by turbulent mixing inducing by the so-called gravity currents, which are modulated by the action of the wind and the tides.

One of the clearest effects of the spreading of low salinity water is the generation of large vertical and horizontal gradients of density. The vertical gradients tend to isolate the surface layer from the deeper ones, diminishing the vertical mixing and the capacity for renewal of the lower waters, thus restricting the vertical flows that are of interest for the biogeochemical balances at the local and regional scale. The horizontal gradients, on the other hand, generate stable or variable fronts of density that influence the transport of dissolved and suspended substances in the water column.

Some studies have demonstrated that the human influence has increased in coastal semiclosed environments (for example, bays, channels, fjords) in the last 200 years, and that the environments dominated by buoyant processes have been among the more severely affected. Strong gradients of density (fronts) often causes restricted exchange of waters or restricted mixing indicating a eutrophicated environment caused by the influence of agriculture, aquaculture, waste water or industrial garbage. This restricted exchange also favours ecological isolation and influences areas particularly sensitive to over-fishing or to the introduction of new species for human activities.

Therefore, these highly stratified systems are particularly important in terms of: i) The discharge of anthropogenic elements to the coastal ocean tends to be associated with the buoyant structure coming from the river. The dilution rate of the discharge indicates if such a substance will have a negative impact on marine life or not; ii) Because some rivers are a valuable source of nutrients for the coastal ocean, the motion of the buoyant plume of the river can be used to infer the initial distribution of nutrients and its potential effect on marine biological productivity; iii) The fronts are, frequently, regions of convergence in which the buoyant material accumulates, constituting zones of retention where biological productivity increases; iv) The rivers constitute the largest source of terrigenous sediments transported towards the ocean, including solid and suspended material. In this way they can intensely influence the dynamics of the sediments in coastal areas. Just like freshwater, the discharge of fine sediments (<63 µm in diameter) can also be associated with pollutants.