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4.3 Tides in the austral Chilean channels and fjords

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The shallow waters over the continental shelf modify the semidiurnal ocean tide. This process intensifies near the coast due to the decreased depths over which the tide propagates and friction from nonlinear effects (Pugh, 2004). Diverse researchers have found that nonlinear effects in coastal environments generate tidal harmonics in shallow waters (Le Provost, 1991; Parker, 1991); these are known as overtides and compound tides of the main astronomic constituents (Lessa, 1996). The frequencies of these additional constituents are greater than those of the main constituents from which they are derived. Because of tidal alteration and deformation during propagation in shallower waters, particularly within estuarine zones, the sea level energy spectrum is different than in oceanic sectors; here, the shallow water harmonics are used to represent and quantify the tidal distortion.

Tides in estuaries are generally believed to receive energy directly from the exterior ocean. The importance of the sun and moon on tidal generation is expected to be lesser in estuarine waters than in oceanic waters because of the lower volume of the former. In turn, the tide propagates at a velocity that is directly proportional to the depth over which it is displaced. This relationship is modified slightly in shallow environments, where the tidal amplitude is comparable to depth. Likewise, interior basins have their own natural oscillation modes that depend on each basin's dimensions. This aspect is particularly important in estuaries with highly variable geometry. The estuary's limits impede the indefinite propagation of the tide as a progressive wave and the tide is reflected with sudden changes in depth and at the edges of the estuaries, where the incidental and reflected waves combine to generate the total wave. Many of the austral fjords are close-ended channels where the reflected wave – without losing amplitude – produces a pattern of standing waves in which the nodes and antinodes have a direct relationship with the intensity of the generated current (Pugh, 1987). Nonetheless, in many estuaries, the tidal energy dissipates before and after reflection, resulting in a standing wave with a progressive contribution of variable magnitude (Dyer, 1997).

Due to the CIMAR program, research has been carried out in the Chilean austral channel and fjord region, increasing the information available on tidal characteristics affected by the mechanisms mentioned above. Tide gauge stations were installed from Puerto Montt to Laguna San Rafael (northern zone), largely in Canal Moraleda, in the area around the Meninea constriction-sill and, later, in the Costa and Darwin channels (Fig. 1). Tide gauge stations were installed in the Wide and Concepción channels between Golfo de Penas and Strait of Magellan (central zone) and at Punta Delgada and Banco Dirección between Strait of Magellan and Cape Horn (southern zone) (Fig. 1). The data collected in both places located in the Strait of Magellan were used to analyze the tidal propagation from the Atlantic (eastern mouth) and Pacific (western mouth) oceans (Salinas *et al.*, 2004).

The offshore tide moves from north to south outside the austral Chilean channels and its ranges are moderate. For example, at syzygy, ranges of 1.62 m were measured at Bahía Mansa (40º 33' S, 73º 46' W), 1.50 m at Puerto Refugio (45º 52' S, 74º 48' W), and 1.58 m at Isla San Pedro (47º 43' S, 74º 53' W). Tidal ranges for the Strait of Magellan, however, were 1.80 m in the western mouth (Bahía Tuesday; 52º 50' S, 74º 29' W) and 10.37 m in the eastern mouth (Banco Dirección; 52º 25' S, 69º 30' W; Fig. 1), highlighting the different tidal characteristics at the two mouths of the strait. The oceanic tide is strongly distorted over the continental shelf of the Atlantic Ocean.

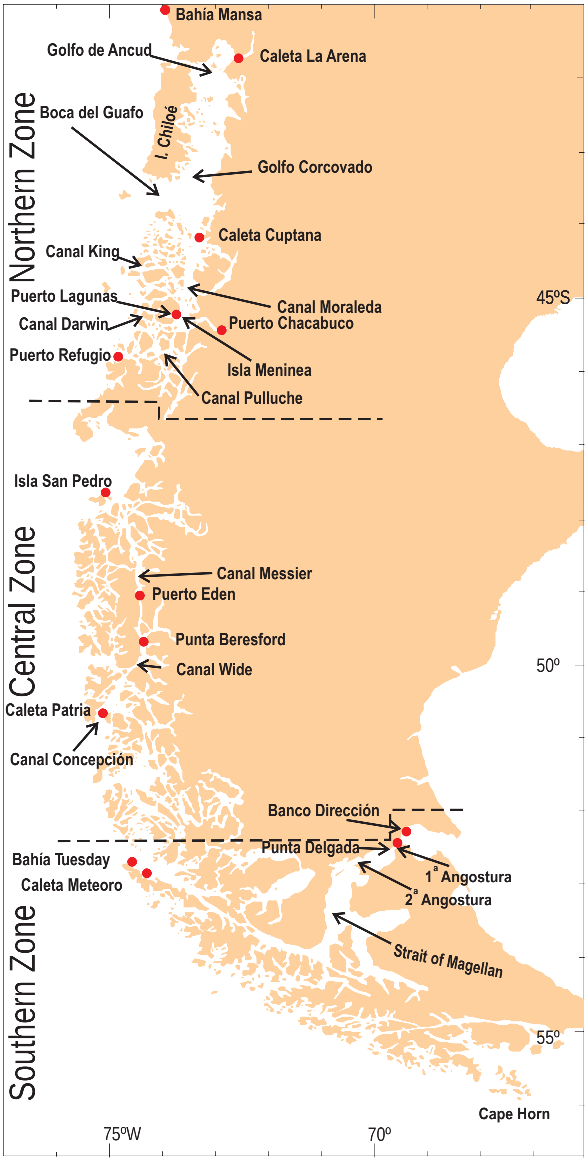

Figure 1: Geographic position of the tidal measuring stations.

The tidal ranges in the interior waters differed from those of the exterior waters. For example, in the northern zone, the tidal height was significantly increased at syzygy to the north of Boca del Guafo, with a range of 6.79 m (Caleta La Arena; 41º 41' S, 72º 39' W). The tidal range to the south of Boca del Guafo in Canal Moraleda was 3.12 m at Caleta Cuptana (44º 39' S, 73º 36' W) and, to the south of the Meninea constriction-sill, it was 2.50 m (Puerto Lagunas; 45º 17' S, 73º 43' W; Fig. 1).

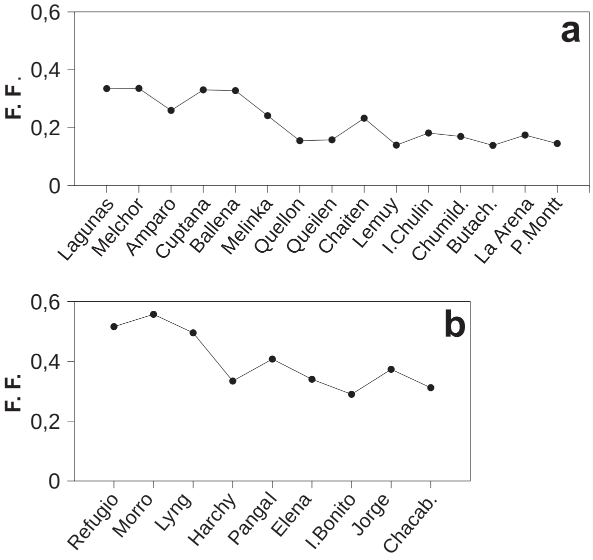

Figure 2: Form factor (F.F.) in a) longitudinal and b) transversal profiles of the channels and fjords in the northern zone.

In the central zone, the tidal range was 1.66 m at Punta Beresford (49º 47' S, 74º 22' W) and 2.05 m at Puerto Edén (49º 08' S, 74º 27' W). The tidal ranges were most variable in the southern zone due to the different characteristics of the waves from the Pacific and Atlantic oceans. Most noticeably, the tidal range was 2.10 m at Caleta Meteoro (52º 58' S, 70º 04' W), increased in the sectors of the narrows Primera Angostura and Segunda Angostura, and peaked at 8.90 m at Punta Delgada (52º 28' S, 69º 32' W; Fig. 1).

The tidal regime along the Chilean coast is mostly mixed semidiurnal (Fierro, 2001). The ocean tide outside of the studied estuarine zones was initially characterized by using a form factor known as the Courtier coefficient over the base of the ratio of amplitude between the main diurnal and semidiurnal harmonic constituents (Pugh, 2004). This parameter was 0.52 in Puerto Refugio (northern zone) and 0.54 around Isla San Pedro (central zone); both values are characteristic of mixed semidiurnal tides (Fig. 2). A similar Courtier coefficient (0.58) was found for Caleta Meteoro in the western mouth of the Strait of Magellan (southern zone); however, at Punta Delgada in the eastern mouth, this parameter was 0.14, characteristic of a semidiurnal tide. Thus it was possible to see the different tidal characteristics in both mouths of the strait.

The Courtier coefficient dropped to around 0.25 at the sites in Canal Moraleda (northern zone) (Fierro *et al.*, 2000), reflecting the lower tide's diurnal inequality. However, in the Messier and Wide channels (central zone), the oceanic values were maintained, increasing slightly to 0.65 in the southern mouth of Canal Concepción (Caleta Patria) (Fierro *et al.*, 2003). Figure 2 shows the modification, expressed in terms of the form factor, that the exterior tide experienced in the northern zone during its propagation through the longitudinal interior channels; in Seno Reloncaví and the Ancud and Corcovado Gulfs, the tide was semidiurnal whereas, in the interior waters to the south of Boca del Guafo, it became mixed semidiurnal. Moreover, an examination of the tidal propagation through transversal channels from the exterior sector (Puerto Refugio) to the head of Fiordo Aysén (Puerto Chacabuco) revealed that the semidiurnal components had greater relative importance in the interior channels and fjords.

The spectral analysis of the sea level time series clearly showed the tide to be the phenomenon presenting the greatest energy of the whole sea level signal. Energy peaks were observed in the diurnal (D) and semidiurnal (SD) bands at different locations in the interior waters of the austral region. Likewise, the decrease in high frequency energy indicates that the tide experienced less distortion due to the effects of friction. Figure 3 shows the spectral estimate for the sectors selected between the northern mouth of Canal Messier and the southern mouth of Canal Concepción, highlighting the energy peaks mentioned, at frequencies of 0.08105 cph (12.3 h) and 0.040245 cph (24.8 h).

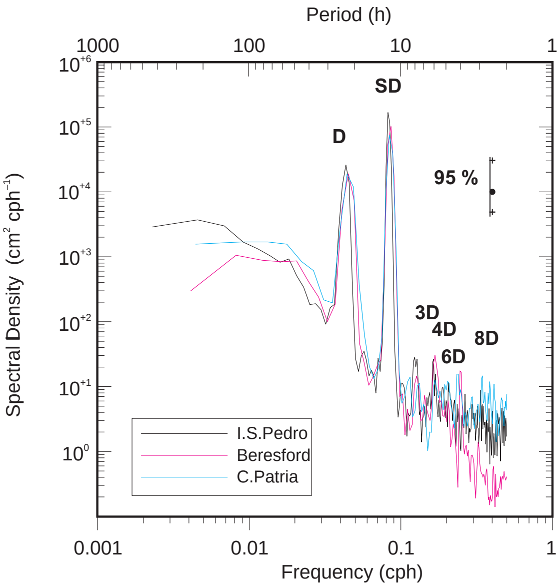

Figure 3: Spectral density estimate in the longitudinal section from Isla San Pedro to Caleta Patria.

These results indicated that Boca del Guafo is an important access way, allowing the tide coming from the Pacific Ocean to penetrate the interior waters. This tide then propagates southward through Canal Moraleda (Fierro *et al.*, 2000) and northward through the interior waters of Isla Chiloé. It should be noted that the important transversal channels such as Tuamapu, King, Darwin, and Pulluche are also important for tidal propagation.

The studies carried out in the southern zone revealed highly variable tidal ranges and variations in the tidal propagation velocity along the Strait of Magellan according to the geographic accidents encountered by the tide; velocities are greatest in the middle sector. In turn, the attenuation of the semidiurnal tide is greatest in the eastern sector of the strait between the narrows Primera Angostura and Segunda Angostura. Also worthy of attention is the low-frequency wave that was identified and determined to have a period of 6 to 10 days, propagating from west to east and distorting the tide coming from the Atlantic Ocean.

References

Dyer, K. 1997. Estuaries. A physical introduction. J. Wiley & Sons, Chichester, 195 pp.

Fierro, J. 2001. Tides in the Chilean coast. Hydro International, 5(1): 7-9.

Fierro, J., M. Bravo & M. Castillo. 2000. Caracterización del régimen de mareas y corrientes a lo largo del canal Moraleda (43º 54' S-45º 17' S). Cienc. Tecnol. Mar, 23: 3-14.

Fierro, J., M. Castillo & C. Valenzuela. 2003. Propagación de la onda de marea en canales adyacentes a Campos de Hielo Sur. Cienc. Tecnol. Mar, 26 (1): 5-14.

Le Provost, C. 1991. Generation of overtides and compound tides (Review). In: B.B. Parker (ed.). Tidal hydrodynamics. John Wiley & Sons, New York, pp. 269-295.

Lessa, G. 1996. Tidal dynamics and sediment transport in a shallow macrotidal estuary. In: Pattiaratchi (ed.). Mixing in estuaries and coastal seas. Coast. Estuar. Stud., 50, American Geophysical Union, pp. 338-360.

Parker, B. B. 1991. The relative importance of the various nonlinear mechanisms in a wide range of tidal interactions (Review). In: B.B. Parker (ed.). Tidal hydrodynamics. John Wiley & Sons, New York, pp. 237-268.

Pugh, D. 1987. Tides, surges and mean sea level. John Wiley & Sons, London, 472 pp.

Pugh, D. 2004. Changing sea levels. Cambridge University Press, Cambridge, 265 pp.

Salinas, S., M. Contreras & J. Fierro. 2004. Propagación de la onda de marea en el Estrecho de Magallanes. Cienc. Tecnol. Mar, 27(2): 5-20.