Climatology of Maipo and Rapel river plumes in Central Chile

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Key Points:

- River plumes in central Chile were modeled
- Seasonal climatology was described
- The influence of wind and river river discharges dominate

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Abstract

River-influenced areas are very important coastal ecosystems, due to their influence on nutrients and the structure of planktonic and benthic communities. Many studies have focused on the interaction between river runoff, wind and river plume characteristics, by means of observations and modeling. This study aimed to improve our understanding about the circulation and seasonal pattern of river plumes in Central Chile, using the Regional Ocean Modeling System (ROMS). Results were in reasonable agreement with observations. The plumes exhibit a minimal area during summer-fall, with a northwest orientation caused by southwesterly winds and lower river discharges. A larger plume area is developed during June-September, as result of higher winter precipitations. The orientation of the plumes during winter is westward, driven by higher river discharge and wind from the northwest. An interesting feature reproduced by the model was the trend to coalesce as observed in satellite imagery.

1 Introduction

River plumes are important for coastal ecosystem, because of their impact on the biogeochemistry and the seasonal and spatial dynamics of planktonic communities (D'Sa & Miller, 2003; Masotti et al., 2018; Mestres et al., 2003). Thus river-influenced areas have comparatively higher nutrients and planktonic productivity (Kudela & Peterson, 2009; Mallin, Cahoon, & Durako, 2005; Peterson & Peterson, 2008). However, the most notorious and evident feature of river plumes is their fingerprint in terms of local (lower) salinity causing a strong stratification, surface currents and higher turbidity associated to suspended solids. The areal extension and shape of the river plumes mostly depend on river runoff (which, in turns, depends on the regime of the local rainfall and/or snow melt), wind and surface currents over the continental shelf (B. Hickey, Geier, Kachel, & MacFadyen, 2005). Some coastal areas, for instance, exhibit a rapid response to large freshwater and sediment discharges, showing a a strong stratification and a rapid sediment settling within 1 km of the river mouth (Warrick, A.k. Mertes, Washburn, & A. Siegel, 2004). The complexity of the "river plume-wind" interplay and its role in the mixing process was modeled by Hetland (2005), who observed that mixing was more intense near the river mouth because of the stronger vertical shear. Wind intensifies mixing in the near and far fields but its efficiency is higher in the far field (far from the river mouth). About time scales, it has been observed that river discharge drives the plume dynamics in a long term (seasonal) scale whereas wind does it in a short term (few days) (Falcieri, Benetazzo, Sclavo, Russo, & Carniel, 2013).

In spite their relevance in terms of local fisheries, ecological processes and sediment supply to nearby beaches, the studies on river plumes in Chile are scarce and mainly focused on planktonic and benthic ecology. Especially, modeling of river plume variability is missing. The low attention payed to river plume dynamics along the Chilean coasts is likely because these rivers are relatively small, given their small watersheds and the short distance between the mountains and the coast (Saldías, Sobarzo, Largier, Moffat, & Letelier, 2012). However, the relative extension of these plumes is quite high when considering the narrow continental shelf of this region. The region encompassed by Maipo and Rapel river discharges is particularly interesting as their catchments have been dramatically modified and in their basin there are several cities that account for the largest part of the population of the country. These snow- and rain-fed rivers move across transverse and longitudinal valleys in central Chile.

The coastal zone of central Chile exhibits a strong seasonal pattern (Strub, Mesías, Montecino, Rutlant, & Salinas, 1998), with intermittent periods of upwelling and relaxation and high levels of stratification and intrusion of oceanic waters during summer (Aguirre, Pizarro, Strub, Garreaud, & Barth, 2012; Letelier, Pizarro, & Nuñez, 2009), and strong storms during winter (Hernández-Miranda, Palma, & Ojeda, 2003). In this sense, it is worth to mention that Central Chile is influenced by the so-called low-level jet off the west coast of subtropical South America (Garreaud & Muñoz, 2005). This feature consists of southerly coastal jets (i.e., a maximum of wind speed) off central Chile (26°S-36°S), that occur year-round but whose intensity and frequency are higher during spring-summer (Muñoz & Garreaud, 2005).

The diurnal variability of the Maipo river plume motion was studied by Piñones et al. (2005), concluding that, whereas the plume was mostly modulated by the river discharge in winter time, the influence of wind was more important during spring-summer. This wind influence, in turns, exhibits a diurnal variation. On the other hand, Vargas, Narváez, Piñones, Navarrete, and Lagos (2006) described the seasonal variation of the Maipo river plume hydrographic conditions. In this study, the river plume was shown to influence the distribution of chlorophyll and barnacle larvae in the inner shelf. Recent studies of river plumes in central Chile have been performed by means of MODIS imagery (Saldías et al., 2016, 2012). In these studies it has been observed a high seasonality in the plumes areal extent and turbidity. In austral winter, a larger areal extent and plumes merging is observed, whereas in austral spring-summer the plumes are smaller, staying individually and close to the coast.

From the above review, it is evident that river plumes in Chile have been studied mostly from ecological perspectives, but these systems are less well-characterized in terms of their physics and the main forcing that drive their dynamics. The objective of this study was to describe the climatology of the circulation and hydrographic conditions in a coastal region strongly influenced by two rivers in central Chile: Maipo and Rapel rivers.

2 Materials and Methods

2.1 Study area

The study area is delimited by 32°30′S-34°S latitudes, where plumes of Maipo and Rapel river are discharged (Fig. 1). These rivers are relatively small, given their small watersheds and the short distance between the mountains and the coast (Saldías et al., 2012). However, they are among the most important rivers in central Chile because of their discharges and their path across several cities that account for the largest population of the country. These snow- and rain-fed rivers move across transverse and longitudinal valleys. In this region, river plumes spread under the influence of tides and topography, with a strong seasonal influence of wind and river discharge.

2.2 Numerical model

The hydrodynamic field and hydrographic conditions were generated with the Regional Ocean Modeling System (ROMS) AGRIF version, an adaptation by the group at Institut de Recherche pour le developement (IRD), France Penven, Debreu, Marchesiello, and McWilliams (2006). This model resolves the primitive hydrostatic equations of ocean dynamics and uses the terrain following coordinate Shchepetkin and McWilliams (2005). The model was configured Debreu, Marchesiello, Penven, and Cambon (2012), with a 2 km resolution and 20 vertical levels with higher resolution toward the surface and bottom levels. This configuration allows to resolve sub-mesoscale features of the river plumes and their interaction with regional mesoscale processes. The model momentum and buoyancy fluxes were forced with the Scatterometer Climatology of Ocean Winds (SCOW)

Figure 1: Study area showing Maipo and Rapel River (Source: https://worldview.earthdata.nasa.gov).

and the Comprehensive Ocean-Atmosphere Data Set (COADS) 25 km resolution climatology. Boundary conditions were obtained from the 10 km resolution Ocean General Circulation Model for the Earth Simulator (OFES), which was forced with National Centers for Environmental Prediction (NCEP) fluxes. After analyzing the global rivers climatological data from (Dai, Qian, Trenberth, & Milliman, 2009) and (Dai & Trenberth, 2002) a time-lag was noted. Consequently, climatological monthly discharges from Maipo and Rapel river were obtained from the General Direction of Waters (Dirección General de Aguas, Chile). The monthly mean wind forcing and river discharges in the study area are shown in Fig. 2. Simulations were replicated ten times so as to reflex the variability of the climatology in the model. The first four years were not considered in the results as this period was the model spinup.

3 Results and Discussion

Climatology showed a marked seasonality in the plume of Maipo and Rapel rivers. Low river discharges predominate between November and April, with an orientation towards northwest, under the influence of summer-spring southwest winds. In June the plumes begin to grow, reaching a maximum area in August and showing a trend to coalesce. The

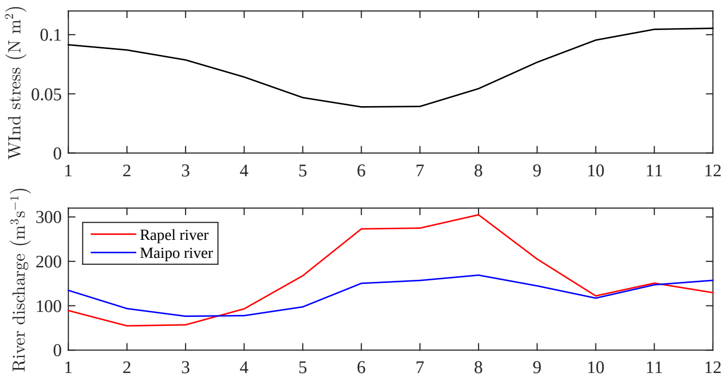

Figure 2: Monthly mean wind stress and river discharges used to force the model in the study area

orientation of the plume during this period is westward, due to the weakening of the south west winds and predominance of wind from the northwest in winter (Fig. 3). This extension offshore along with a plume decrease observed by late winter is in concordance with satellite based studies (Saldías et al., 2016, 2012), where the contrast between winter and summer is remarkably notorious (Fig. 3).

The period of lowest river discharges in central Chile occurs during summer-fall, coinciding with strongest winds from the southwest (Fig. 2). Thi effect of lower river runoff can be observed locally, where the river plumes close to the river discharges exhibit lower temperature and higher salinity from December to April (Fig. 5). On the other hand, the lower momentum flux is observed in the magnitude and direction of current surface velocity U-V components. During winter-spring, relatively higher temperature values are observed, whereas surface salinity is lower, because of higher freshwater discharges. The surface vector components reflect stronger discharges westward, although Rapel river discharge also shows a strong northward component (Fig. 5). This change in the orientation and strength of the plumes as response to the combination of river discharges and upwelling favorable winds has been described by other authors (Saldías et al., 2012; Sobarzo, Bravo, Donoso, Garcés-Vargas, & Schneider, 2007). On one side, southwesterly winds favor coastal upwelling, whereas rivers runoff decreases, facilitating coastal upwelling by decreasing vertical stratification. Moreover, summer hours of sunshine add surface buoyancy, which opposes coastal upwelling. During austral winter, downwelling-favorable winds predominate, along with higher freshwater discharges. Thus, river runoff increases,

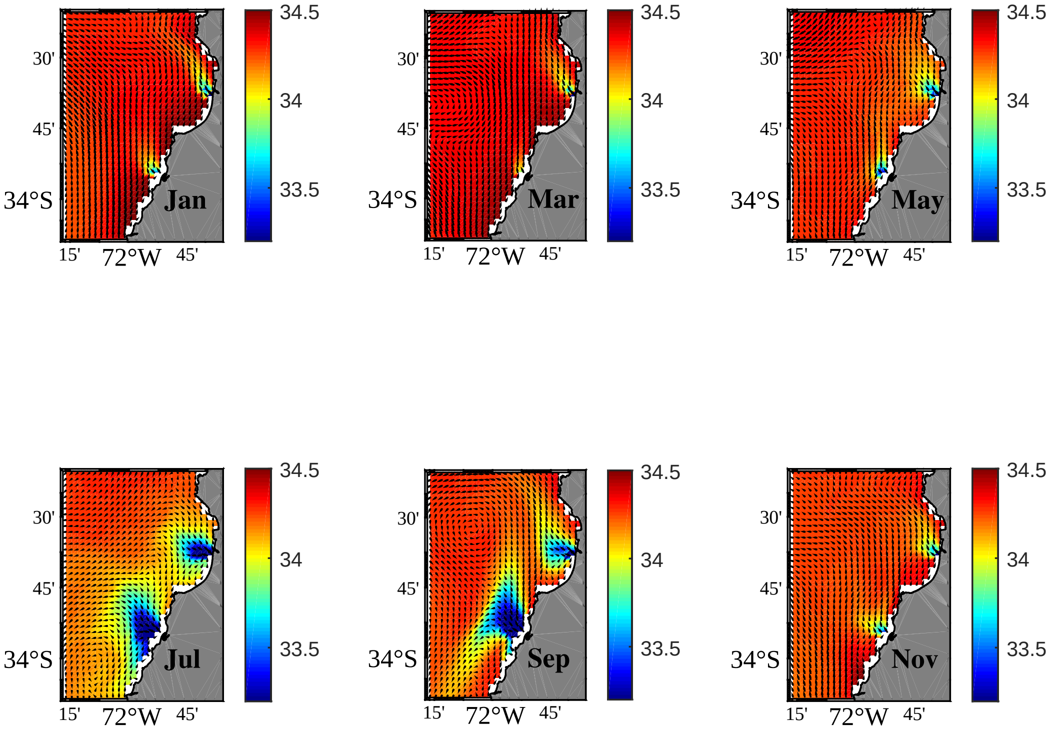

Figure 3: Monthly mean surface currents (vectors) and salinity (color scale) in the area under the influence of Maipo and Rapel river plumes.

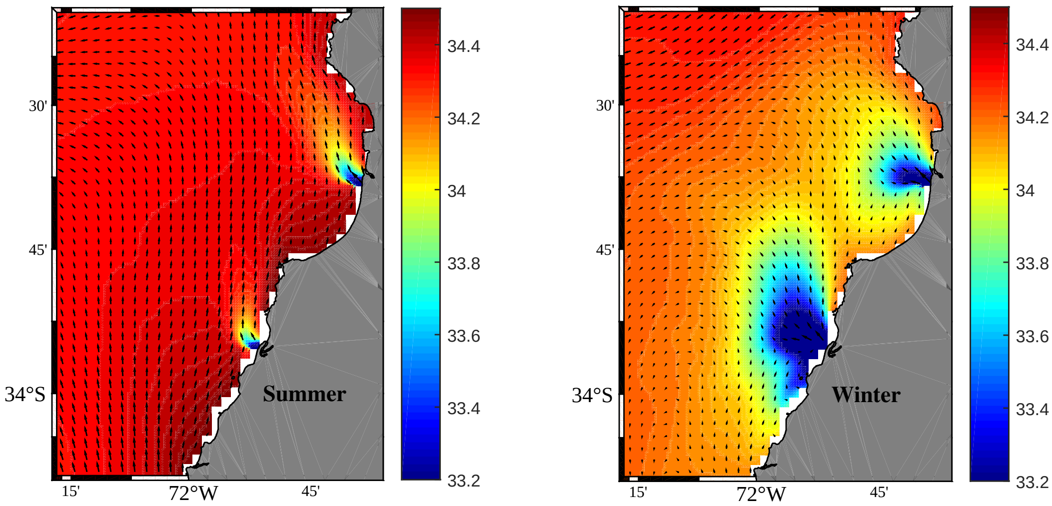

Figure 4: Comparison between winter and summer mean surface currents (vectors) and salinity (color scale) in the area under the influence of Maipo and Rapel river plumes.

introducing buoyancy and increasing the vertical stratification, inhibiting coastal upwelling (Sobarzo et al., 2007). Furthermore, Sobarzo et al. (2007) pointed out that freshwater discharges determine the seasonal pattern observed in the first 20 m of the water column. At the same time, the higher freshwater discharges in austral winter influences on the onset of the coastal upwelling for the coming spring season (Saldías et al., 2016). This seasonal pattern was described by Piñones et al. (2005), concluding that, whereas the plume is mostly modulated by the river discharge in winter time, the influence of wind is more important during spring-summer. This wind influence exhibits, in turns, a diurnal variation.

In particular, the local influence of Maipo river discharge is consistent with description of Narváez et al. (2004), who observed vertically and horizontally homogeneous conditions during winter and a strong stratification and upwelling in summer, with strong effects in surface temperature, salinity, stratification, and chlorophyll-a. Although there is a strong interaction between river plumes and wind-induced upwelling, tides are also important in the evolution of a river plume. Therefore, as MacCready, Banas, Hickey, Dever, and Liu (2009) asserts, a full understanding about mixing and circulation in a river-influenced area must consider the estuary and the shelf, the river discharge and tide forcing.

A strongly wind-influenced system is Columbia River region (Fiedler & Laurs, 1990). Here, similar to Maipo and Rapel river area, the coastal surface circulation is mostly wind driven, under the seasonal fluctuation of the atmospheric forcing (i.e. the plume is oriented according to the predominant winds and, in turn, its size depends on the river discharge). In winter, the plume is directed northward and is colder than the surrounding water. In summer, the plume is oriented southward and is warmer than the coastal water. A confirmation of this description and the wind effect on the plume horizontal and vertical structure was given by B. Hickey et al. (2005) and B. M. Hickey, Pietrafesa, Jay, and Boicourt (1998).

A more complex interaction must be studied in detail, as some other factors can affect the plume behavior. For instance, Nikiema, Devenon, and Baklouti (2007) modeled the Amazonas river plume under realistic conditions and found a permanent influence of the coastal current which can moderated by the wind. Additionally, tides were shown to influence the horizontal position of the plume front. The dependence of the plume

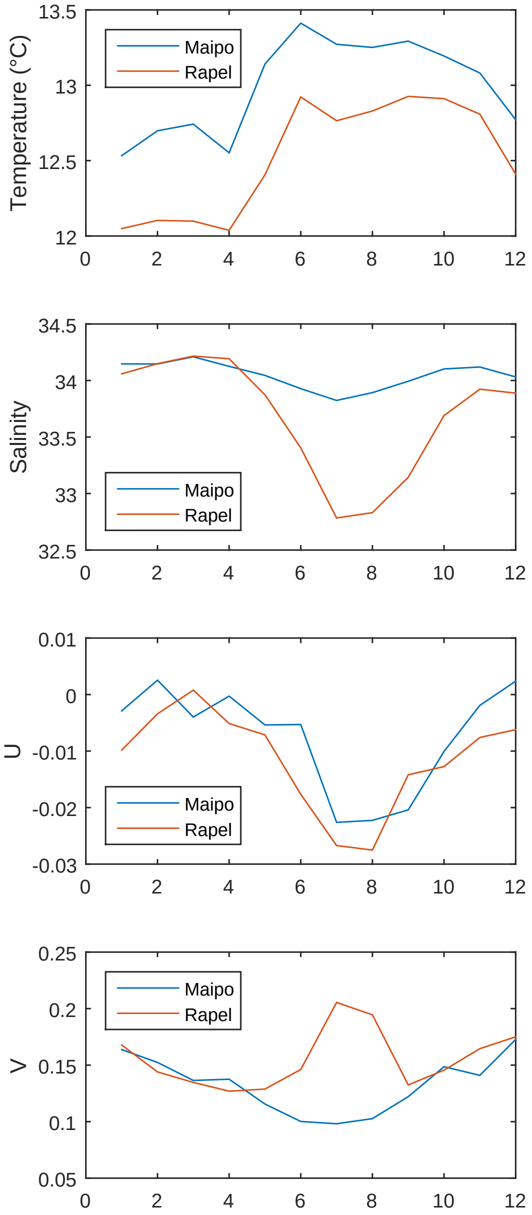

Figure 5: Monthly mean temperature, salinity and surface current U,V components off Maipo and Rapel river mouths.

dynamics and structure on changing river runoff characteristics is another aspect to be further explored (Fong & Geyer, 2002; Yankovsky, Hickey, & Münchow, 2001).

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