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Regional circulation around New Caledonia from two decades of observations

Sophie Cravatte [a,b,*], Elodie Kestenare [b,c], Gérard Eldin [b,c], Alexandre Ganachaud [b,c], Jérôme Lefèvre [a,b], Frédéric Marin [a,b], Christophe Menkes [a,d], Jérôme Aucan [a,b]

[a] Centre IRD (Institut de Recherche pour le Développement), Nouméa, New Caledonia
[b] Université de Toulouse, UPS (OMP-PCA), LEGOS, 14 Avenue Edouard Belin, F-31400 Toulouse, France
[c] IRD, LEGOS, F-31400 Toulouse, France
[d] Sorbonne Universités (UPMC, Univ Paris 06)-CNRS-IRD-MNHN, LOCEAN Laboratory, IPSL, Paris, France

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ABSTRACT

The regional and near-coastal circulation around New Caledonia is investigated using a compilation of more than 20 years of observations. Velocity profiles acquired by Shipboard Acoustic Doppler Current Profiler (SADCP) during 109 research cruises and ship transits since 1991 are analyzed and compared with absolute geostrophic currents inferred from hydrographic profiles and Argo floats drifts. In addition, altimetric surface currents are used to explore the variability of the circulation at various timescales. By making the best use of the strength of these various observations, this study provides an unprecedented detailed picture of the mean circulation around New Caledonia and of its variability in the upper layers. New Caledonia, together with the Vanuatu Archipelago and the Fiji Islands, acts as a 750-km long obstacle to the westward South Equatorial Current (SEC) entering the Coral Sea. On average, the SEC bifurcates against New Caledonia's east coast into a northwestward boundary current, the East Caledonian Current, beginning east of the Loyalty Islands and extending to at least 1000 m depth, and into a weak southeastward current. The latter, the Vauban Current, flows into the Loyalty channel against the mean trade winds where it extends to at least 500 m depth. It is highly variable at intraseasonal timescales; it often reverses and its variability is mainly driven by incoming mesoscale eddies east and south of New Caledonia. West of the Island, the southeastward Alis Current of New Caledonia (ACNC) flows along the reef slope in the 0–150 m layer. It overlays a weaker northwestward current, creating an unusual coastal circulation reminiscent of the current system along the Australian west coast. The ACNC is a persistent feature of the observations, even if its transport is also strongly modulated by the presence of offshore eddies. This study highlights the fact, if needed, that a snapshot view of the currents provided by a single transect can be strongly impacted by mesoscale eddies, and should be put into context, e.g. by using simultaneous altimetric data.

1. Introduction

New Caledonia (165°E, 19°S–23°S) is an archipelago located in the Southwest Pacific, at the entrance of the Coral Sea (Fig. 1). It is mainly composed of the Loyalty Islands and of the main island "Grande Terre", surrounded by a 750 km long barrier reef enclosing a shallow lagoon. Together with the Fiji Islands (178°E, 18°S) and the Vanuatu Archipelago (169°E, 14°S–20°S), New Caledonia acts as an obstacle to the broad-scale oceanic circulation, mainly composed of the South Equatorial Current (SEC) advecting subtropical thermocline waters westward from the Southeast Pacific to the Coral Sea (e.g. Qu and Lindstrom, 2002; Ridgway and Dunn, 2003; Kessler and Cravatte, 2013a). When encountering these islands, the broad SEC forms boundary currents and westward zonal jets at their northern and southern tips (Couvelard et al., 2008; Webb, 2000). In the lee of the islands, recirculations and eastward countercurrents are also produced (Couvelard et al., 2008; Qiu et al., 2009). These interactions between the mean flow and the topography thus render the oceanic circulation quite complex in the Southwest Pacific: the westward SEC cannot be simply described as a broad westward flow, but should rather be considered as a combination of intricate currents. Describing them and understanding their connections is a necessary condition to understand if (and how) anomalies in water masses hydrological properties or transports are transmitted from the subtropical South Pacific to the Coral Sea, and downstream both to the equatorial band and to the Tasman Sea.

Topography around islands creates local circulation features (including coastal currents, upwelling or downwelling conditions) that depend on the island orientation with respect to the main oceanic currents and atmospheric winds. These coastal circulations modify the thermohaline structure and nutrients' supply, and thus the local

* Corresponding author at: Centre IRD de Nouméa, BPA5, 98848 Nouméa Cedex, New Calédonie.
E-mail address: sophie.cravatte@ird.fr (S. Cravatte).

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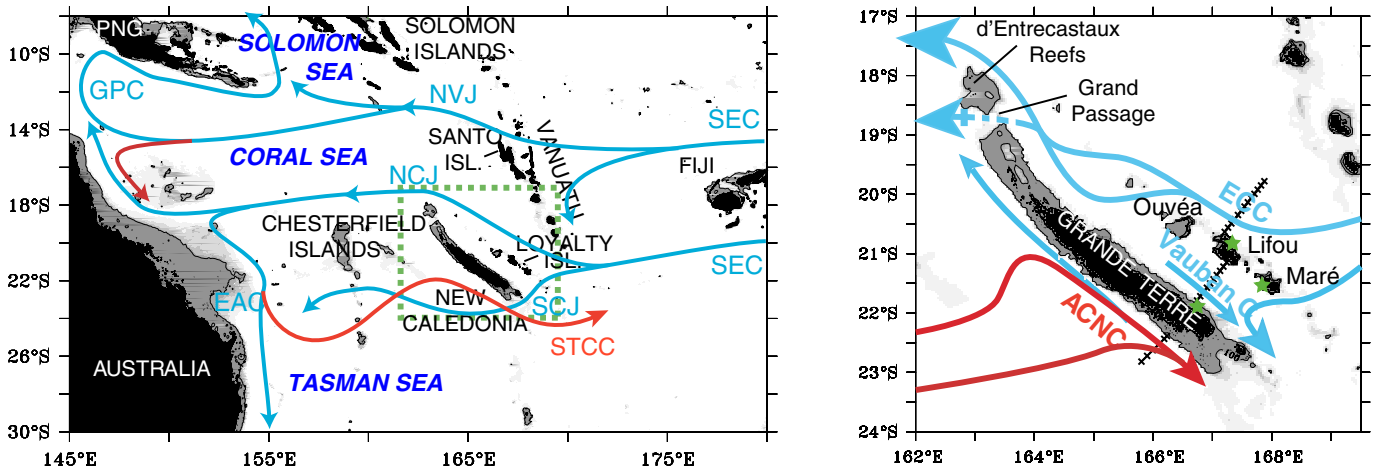

Fig. 1. Reference maps of the southwest Pacific (left) and New Caledonia (right), with names of the main Islands and countries, and schematic of the thermocline circulation (blue lines) and surface circulation, shown when different from the thermocline (red lines). The green dashed lines box in the left panel delineates the area shown in the right panel. Black and gray shading shows bathymetry at depths of 0, 100 and 300 m. «PNG» abbreviate Papua New Guinea. Indicated are the SEC (South Equatorial Current), NVJ (North Vanuatu Jet), NCJ and SCJ (North and South Caledonian Jet), STCC (SubTropical CounterCurrent), GPC (Gulf of Papua Current), EAC (East Australian Current) and ECC (East Caledonian Current). The dashed black lines on the right panel represent the sections used for Figs. 9, 13 and 15, showing the Vauban, ECC and Alis current of New Caledonia (ACNC) structures. Ouvéa, Lifou and Maré are the three main Loyalty Islands. The green stars show the positions of the tide gauges used in this study.

physical and biogeochemical oceanic properties, which impact the ecosystems up to higher trophic levels (e.g.: Ganachaud et al., 2010; Menkes et al., 2014). Yet, these local circulations are poorly known around most of the Pacific Islands. Describing them is an important task, firstly to better understand how the large-scale oceanic circulation and its variations at seasonal, interannual or decadal timescales affect local ecosystems and their connectivity, and secondly to infer with more confidence how climate change predicted at large scale in low-resolution climate models will influence these systems. These downscaling studies are an essential component of the CLIVAR/SPICE project (Climate Variability and Predictability/Southwest PacIfic ocean circulation and Climate Experiment) (Ganachaud et al., 2008b, 2014).

As a first step toward this goal, we investigate here the mean observed circulation and its variability around New Caledonia, with a focus on the coastal currents. We are far from starting from scratch, and it is fair to pay tribute to the work historically done on the circulation in the region, thanks to organized surveys conducted as early as 1956 by ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), which became IRD (Institut de Recherche pour le Développement) (Donguy et al., 1970; Henin et al., 1984; Rotschi and Lemasson, 1967). These pioneer cruises did allow describing the surface regional circulation, but did not allow an accurate description of the small-scale circulation around New Caledonia. The authors pointed out that the observed currents were quite different from one cruise to another, but they were not able to understand this variability. More recently, efforts have been made to better understand the large-scale circulation in the Southwest Pacific, and the jets feeding the Coral Sea. In that context, some aspects of the local circulation have been described from synoptic observations (Ganachaud et al., 2008a, 2010; Gasparin et al., 2011; Gourdeau et al., 2008; Maes et al., 2007). Numerical simulations have also been performed to investigate physical processes (Couvelard et al., 2008; Marchesiello et al., 2010). The knowledge gained from these studies is briefly summarized here.

The southeast–northwest orientation of New Caledonia's main Island is at a small angle to the direction of the mean trade winds, resulting in interesting dynamical structures (Fig. 1). On the west coast, wind driven coastal upwelling events cool the sea surface temperature on the southern half of the barrier reef in austral summer (Alory et al., 2006; Ganachaud et al., 2010; Hénin and Cresswell, 2005; Marchesiello et al., 2010). A southeastward current flowing against the mean winds, named "Alis Current of New Caledonia (ACNC)" after the R/V Alis, a Nouméa-based French research vessel (Ganachaud et al., 2010; Marchesiello et al., 2010), has been observed along that reef (Fig. 1). On the east coast, another southeastward boundary current flowing between the main island and the Loyalty Islands, in a 100 km wide channel, has also been episodically observed. It was named "Vauban Current" by Henin et al. (1984), after the R/V Vauban, another French research vessel formerly based in New Caledonia. Along the southeast coast, downwelling conditions, and southeastward advection of tropical warm waters result in sea surface temperature several tens of degrees warmer than on the west coast (Henin et al., 1984; Marchesiello et al., 2010).

Yet, a comprehensive study relying on observations and describing the coastal currents' structure, extension, persistence and variability is still missing. Furthermore, the dynamics and variability of the currents still remain to be understood. Up to date, the most comprehensive analysis of the mean regional circulation around New Caledonia is provided in the modeling study of Marchesiello et al. (2010). Though very informative, this study has two major drawbacks. First, the model simulation they used is validated against observed surface temperature, but not against observed currents, questioning the validity of the simulated circulation. Secondly, the variability of the coastal currents was not studied.

This paper aims at providing a useful reference database for process studies and numerical model validation, by taking advantage of the large amount of previously accumulated data. In particular, it relies on historical oceanic currents measurements from Shipboard Acoustic Doppler Current Profilers (SADCP) mounted on research vessels cruising in the vicinity of New Caledonia. These particularly valuable historical in situ data (e.g. Cravatte et al., 2011) are available from near surface to 200, 300 or 500 m depth, depending on the frequency of the mounted instrument. Some research cruises recorded currents deeper, but they are too few to be considered for this study. When analyzed together with hydrological and altimetric data, these SADCP data provide a description of the circulation around New Caledonia at relatively high resolution.

This paper has the following structure. Section 2 describes the data and methods used. Section 3 summarizes our knowledge on the large-scale circulation in the Southwest Pacific, and describes the details of the mean regional circulation around New Caledonia. Section 4 discusses the variability of this circulation, while Section 5 focuses on the Vauban Current, the East Caledonian Current and ACNC, which are