The Canary Deep Poleward Undercurrent

Eusebio Romero-García[1], Pedro Vélez-Belchí[2], Ricardo Sánchez-Leal[2], Alonso Hernández-Guerra[1]

(1) Oceanography and Global Change Institute - University of Las Palmas de Gran Canaria, Spain (2) Spanish Institute of Oceanography, Spain

Abstract

Poleward undercurrents are well known features in Eastern Boundary systems. In the California Current Eastern Boundary upwelling system (CalCEBS) the California poleward undercurrent (CalUC) has been widely reported, and it has been demonstrated that it transports nutrients from the equator waters to the northern limit of the subtropical gyre. However, in the Canary Current Eastern Boundary upwelling system (CanCEBS), the Canary deep poleward undercurrent (CdPU) has not been properly characterized. In this study, we use trajectories of Argo floats and model simulations to properly characterize the CdPU, including its seasonal variability, and the driving mechanism. The Argo observations show that the CdPU flows from 26ºN, near cape Bojador, to approximately 44ºN, near cape Finisterre in the northwest Spanish's coast. The CdPU flows deeper than the CalUC. The CdPU shows a marked seasonal variability, with it maximum strength in fall, and the minimum winter.

Material and Methods

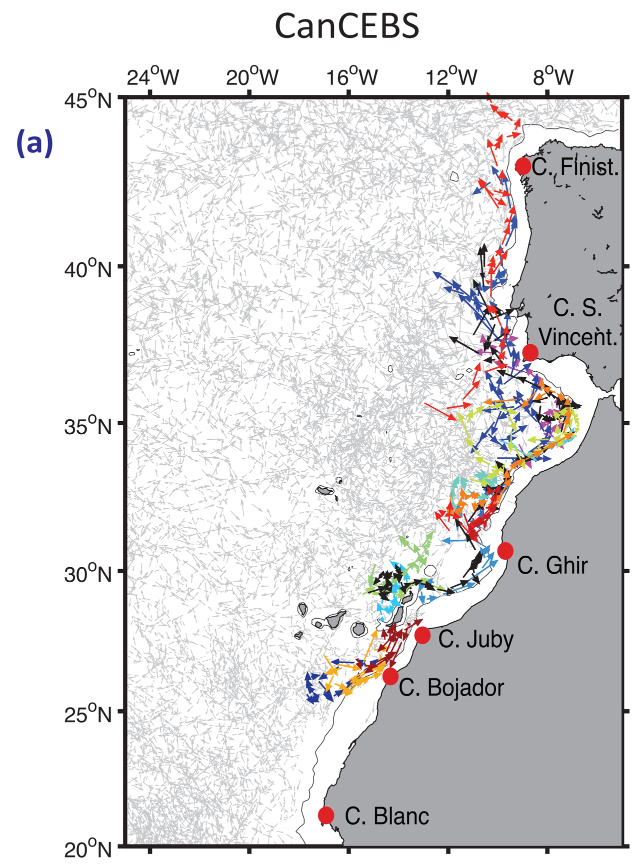
- To realise this study we used *direct measures* and *numeric simulations.*
- *For the Direct Measures we used*:
  - Argo float velocity data from the YoMaHa database (Lebedev *et al.*, 2007). All Argo floats selected drifted at 1000dbar (Fig. 1)
  - The mooring data (EBC4) at 800m of depth located in the Lanzarote Passage (LP) (Fig. 3.a).
- *For the Numeric Simulations we used numerical simulations from the OFES couple ocean atmosphere model, with two different forcings:*

Oceanic model	Wind forcing	Available temporal data	General features
OFES	NCEP	Jan1950-Dec2013	Low resolution (2.5º), smooth winds
	QS	Jan1999-Dec2006	High resolution (0.25º), realistic winds

Table 1. Main features of the numerical simulations employed. Using the same ocean model with different winds forced QS and NCEP (Masumoto *et al.*, 2004).

Results

- *Direct Observations*:



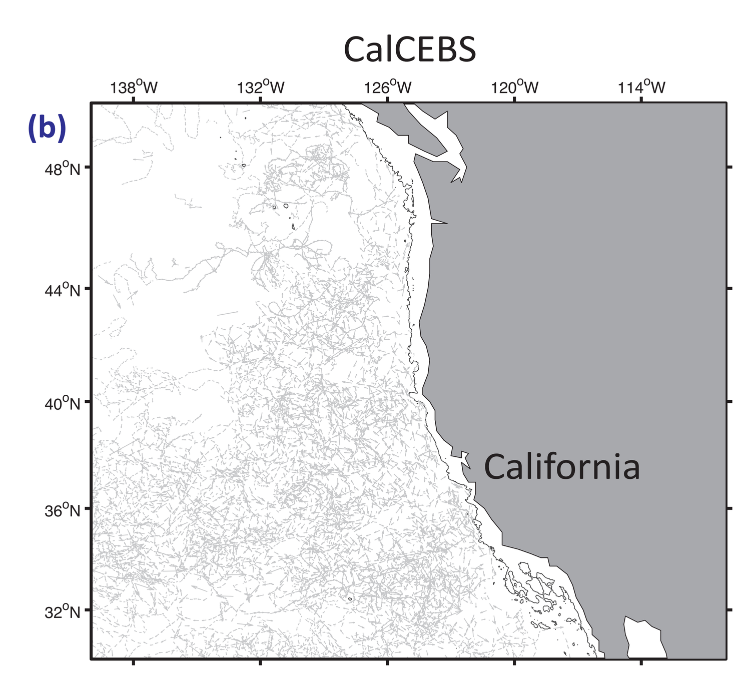


Figure 1. Selected Argo floats trajectories. The parking depth of the floats was 1000dbar. For reference, the 1000m isobaths is presented as a black line. **(a)** The different colored arrows represent individual selected trajectories, while grey arrows represent the trajectories of all Argo floats in the CanCEBS. **(b)** The same before, but any trajectory was seleccted in CalCEBS.

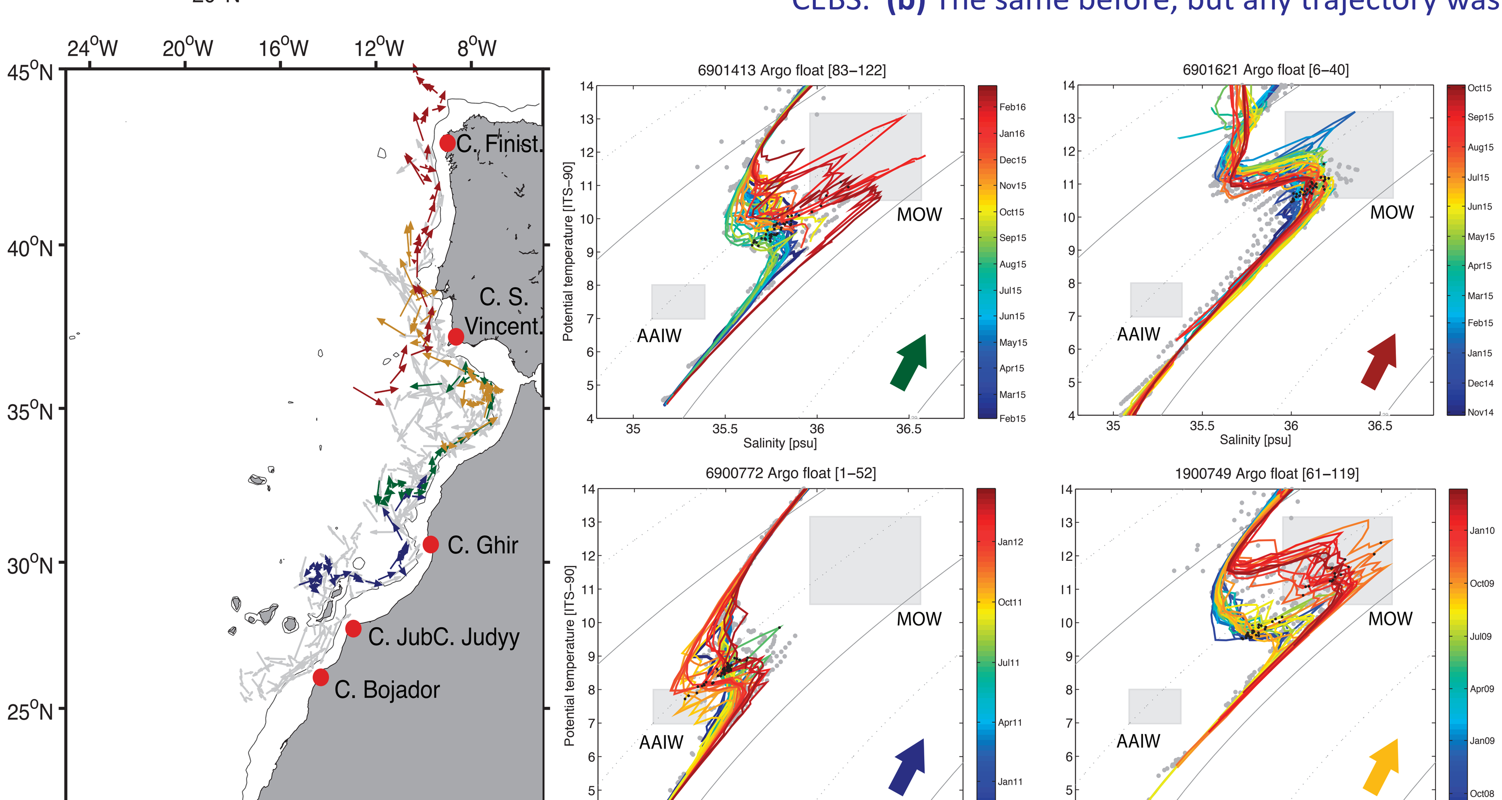
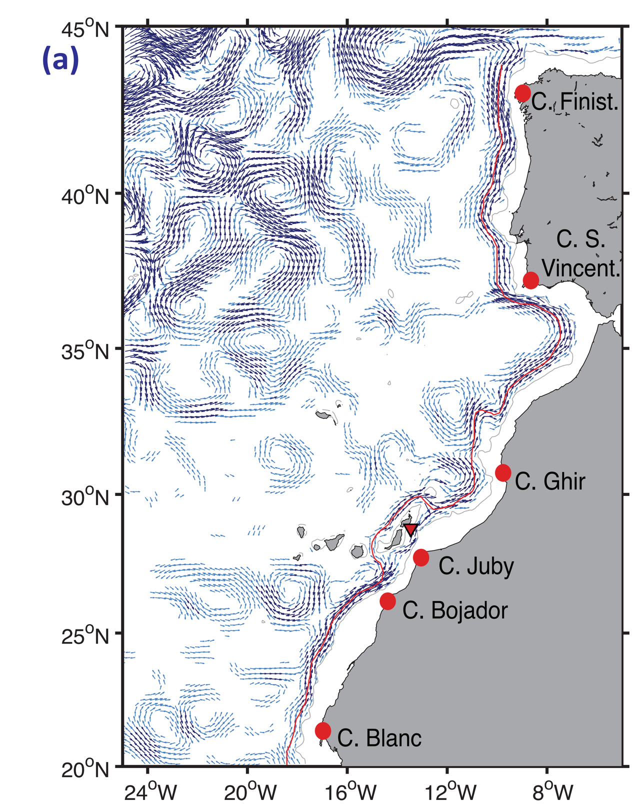


Figure 2. Four trajectories of the 23 available in the CanCEBS are shown in this figure. And it is shown their TS diagrams. Each one has a color arrow located in the bottom right corner, which represents its trajectory in the map. It's shown the typical water masses in the region in grey areas. The black dots represent the value at 1000dbar. The grey dots represent the climatology in the region. And the grey lines the isopycnals.

- There are 20 floats into the CanCEBS that driftted more than 20 days poleward of a total of 157 (Fig. 1.a). In contrast, in the CalCEBS (Fig. 1.b) any float drifted polward during 20 days.
- That there are not any floats south of 25ºN (Fig. 1.a) is becasue the the strong westward superficial current associated to the trade winds in this zone that displace the floats at the surface offshore when rise to send the data up.
- In the four TS diagrams (Fig. 2) it canbe observed that **the CdPU advects different kinds of water masses**, changing with latitude. From less temperature and salinity to more temperature and salinity due to the output of the MOW.
- In the Fig. 1.a it can see the same flow to the North in the 20 floats of a total of 157 in the region. These floats show a continuous flow from 25ºN to 44ºN like shows the model too (Fig. 3.a). Moreover, the velocity data of the mooring (Fig. 3.b) were compared with the data obtained by OFES in the same places and depth (Fig. 3.c). Both data were rotated 51.2º clockwise. The results of this comparison show us that the magnitude of the velocity values from the OFES model is very similar with the observational mooring values. Moreover the average variability is almost equal that the real dynamic in the region (Fig. 3.c). Therefore **OFES model is reliable to use in CanCEBS**.
- Inside the CanCEBS the CdPU demonstrates a continuous and biannual flow (Fig. 4). Both begin in the months of January and June at 20ºN and a depth of 800-1000m.
- The intensity of the CdPU varies by year, not always remains the same (Fig. 5). And it turns varying seasonally.
- The dynamic height (Fig. 6.a) corresponds perfectly with the velocities (Fig. 3.a) by the geostrophy.
- Probably the pressure gradients are the responsible to occur the CdPU. The APF is one of them, which can force to create this undercurrent. These pressure gradients (Fig. 6) are created by a density gradient offshore, which in a geostrophic fluid generates a flow to coast. This flow comes to coast and due to the potential vorticity conservation law creates a poleward flow. This phenomenon has a seasonal variability. And it does not depend of the wind stress. Part of the CalUC is also generates by the APF (Connolly *et al.*, 2014).

- *Model Validation*



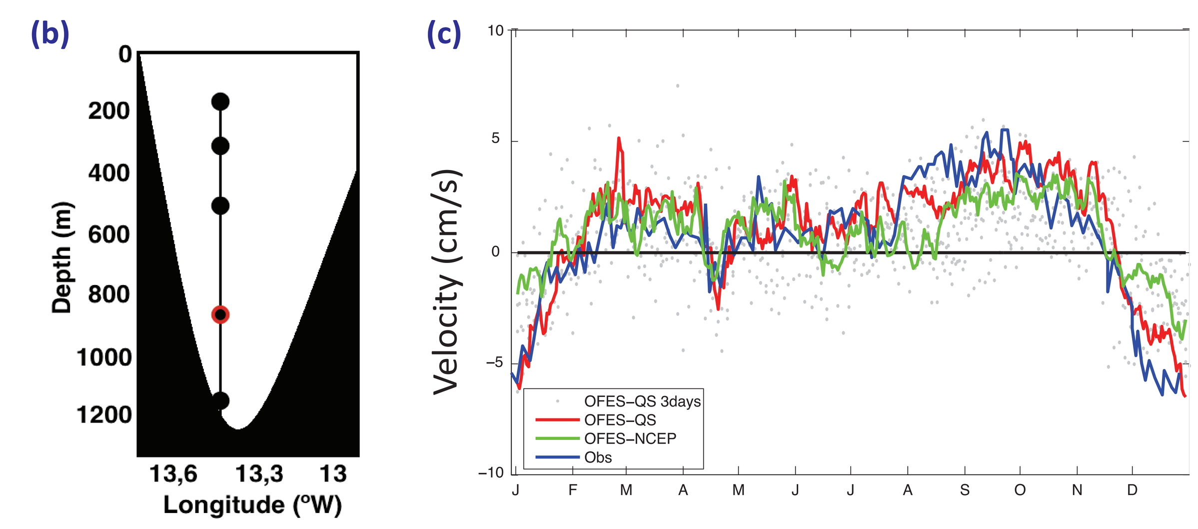


Figure 3. (a) Represents the average velocities between August and September in the CanCEBS at 800m of depth. The light (dark) blue arrows represent velocities between 1-2 cm/s (>2cm/s). The grey (red) line represents the 1000m isobath (ideal CdPU way). Red triangle indicates mooring location. **(b)** Shows the vertical distribution of current-meters (that actually used is colored in red). **(c)** Represents the annual average velocities given by OFES (QS and NCEP) with the real obsvervations by the mooring in the LP, all of them at 800m of depth.

- *Seasonal Variability*:

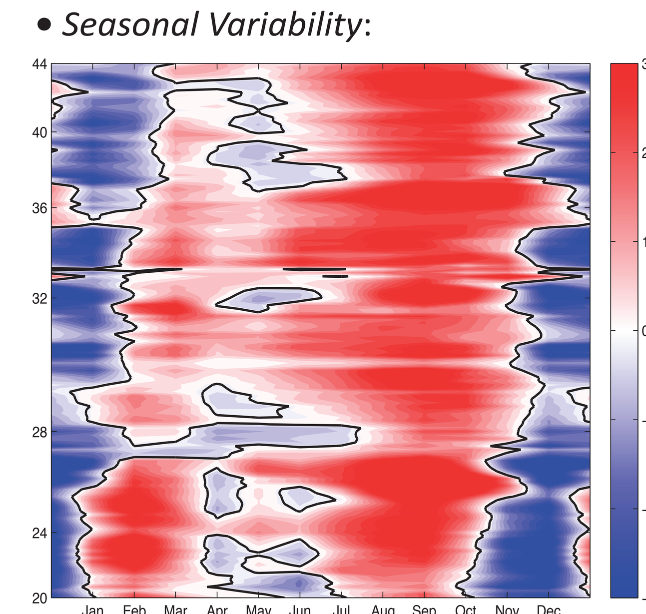


Figure 4. Represents the average velocities (cm/s) alongshore on the red trajectory shown in the Fig. 3.a. Using the OFES-QS data at 800 m.

- *Forcing Mechanisms for the CdPU*:

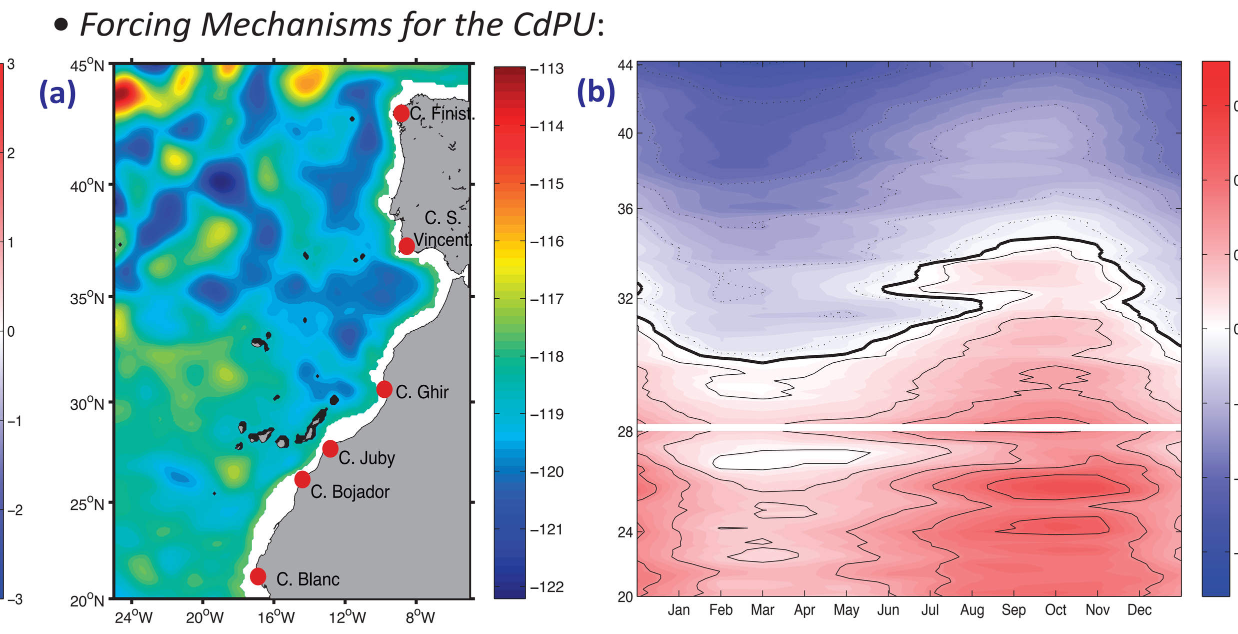


Figure 6. (a) Fynamic height (cm) at 800m of depth from the OFES-QS data. **(b)** Pressure (equivalent to m) anomaly alongshore on the red trajectory shown in the Fig. 3.a from the OFES-QS data.

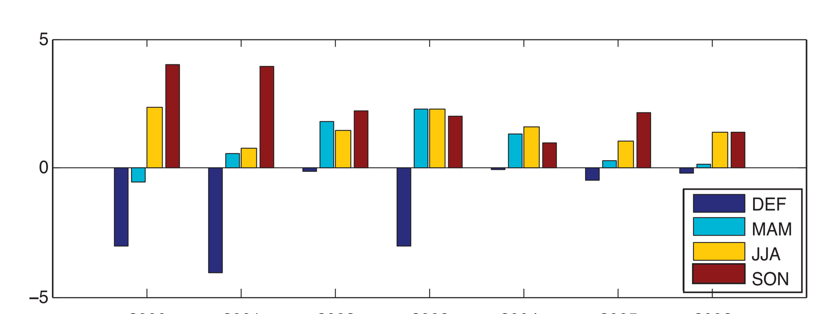


Figure 5. Interannual variability of the average velocity calculated for the CdPU inside the LP at 800-1000m of depth (cm/s). Using the OFES-QS data.

Discussion and conclusions

- **The CdPU flow continuosly from 3ºN to 43ºN** (Fig. 1.a). It shows that is coherent with the model average **circulation at 800m** of depth (Fig. 3.a).
- In the CalCEBS it is different, there are not any poleward trajectory onshore at 800m as long as in the CanCEBS (Fig.1) due to **the CalUC is upper than the CdPU**. The CalUC is found at 400m of depth approximately (Thomson *et al.*, 2010; Connolly *et al.*, 2014).
- **The CdPU advects different kinds of water masses (Fig. 2)**. As occur with the CalUC, which transports Pacific Equatorial Water (PEW) to the North of CalCEBS and is losing PEW concentration with increasing latitude (Thomson *et al.*, 2010). In CanCEBS it wasn't known, it was though the CdPU carried the same water on all the way.
- How it is shown in the OFES model, inside the CanCEBS it can be stated that **the CdPU is continuous**. Beginning from 20ºN in January and June **at 800m of depth**, and it becomes shallower as latitude increases (until 44ºN) in both cases (Fig. 4).
- Therefore we can affirm that **the CdPU and the CalUC are not equals**. Given that the core of the CalUC doesn't vary a lot (Connolly *et al.*, 2014; Thomson *et al.*, 2010), while the CdPU is created two times per year (Fig. 4) and both rise up near the surface.
- There are to have in account the **exchanges of water masses** both South to North and opposite (Fig. 4). **Associated to the CdPU** and the other equatorward current at 800-1000m of depth. Which carry the properties of the different water masses coming from each zone (MOW, AAIW, NACW, etc). And exchanges properties with the other water masses close to it as occur in CalCEBS (Thomson *et al.*, 2010). These properties are very interesting from the biochemical point of view. As it's shown in several studies about the deep poleward copepods transport alongshore in the CanCEBS (John *et al.*, 1997; Stöhr *et al.*, 1997). In these studies the **copepods can be used like tracers of the CdPU**.
- It had never studied the possible physical phenomenon as well as we have done in this study despite there are not enough direct observations. With the results obtained using the realistic oceanic model, it appears that **the main responsible** of this undercurrent **is the APF** (Fig. 6). And moreover the wind stress is not one of the principal factors to produce it (Fig. 3.b), as it can be happen in CalCEBS because is shallower. It appears that the CalUC and the CdPU despite are similar, are not equal and have not the same forcing mechanisms.

Acknowledgements

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IOCAG Instituto de Oceanografía y Cambio Global

INSTITUTO ESPAÑOL DE OCEANOGRAFÍA

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA