FINAL REPORT PROGRAM LEFE

Programs LEFE/ IMAGO and LEFE/GMMC	ZEBRE/CASSIOPEE+ Observation and modeling of intermediate zonal jets in the Tropical Pacific Ocean.	Years 2013-2014 for ZEBRE Years 2015-2017 for ZEBRE/CASSIOPEE+

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Other funding sources : ACI IRD

Context and scientific objectives :

At 1000 and 1500m depth in the equatorial Pacific, the presence of alternating zonal jets has been evidenced at the basin scale. The main goal of the ZEBRE project was to better document the characteristics of these deep extra-equatorial jets in the Pacific Ocean and in the other tropical oceans. The purpose of the follow-on project "ZEBRE/CASSIOPEE+" was to organize a dedicated cruise in the western Tropical Pacific, CASSIOPEE, onboard the R/V Atalante. The objectives of the cruise were to describe the zonal jets 3D structure in the western Tropical Pacific, from below the thermocline to the bottom of the ocean; to understand their water masses properties and associated mixing, and their connection with the western boundary currents.

Main results:

-The CASSIOPEE cruise took place in July-August 2015 onboard l'Atalante.

-The jets vertical structure have been investigated using a compilation of LADCP measurements and 3-D Argo data. The 1000m jets are far from being barotropic, and observations revealed the existence of two systems of jets, the "multiple Tsuchiya jets", found between the thermocline and 700-800m, and the "extra-equatorial intermediate currents" below 800m. They appear as distinct dynamical objects (Cravatte et al., 2017).

- The deep eastward jets found at 2° N and 2° S help to focus small particles around the equator, and may contribute to modulate the transfer of particulate carbon from the surface to the deep ocean (Kiko et al., 2017).

-The hydrological structures of the zonal jets are complex. In the western part of the basin, the eastward jets are associated with frontal structures in oxygen and potential vorticity (Delpech et al., in prep).

-Staircase profiles and fine scale eddy kinetic energy observations support for the first time theoretical hypotheses about the jets formation (Delpech et al., in prep, Menesguen et al., 2019).

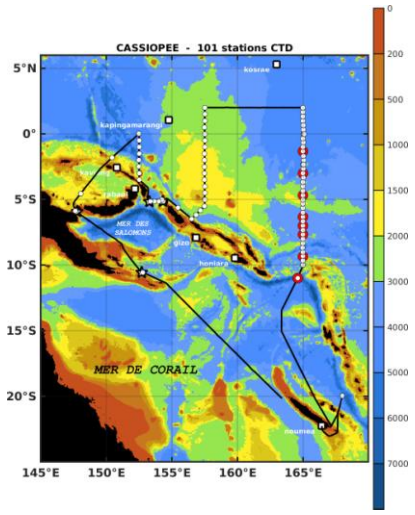

Figure 1 : CASSIOPEE cruise track (July-August 2015) ; the white dots show the positions of the CTD casts, the red dots the Argo floats deployed, the white stars the recovered moorings. Colors show bathymetry (m).

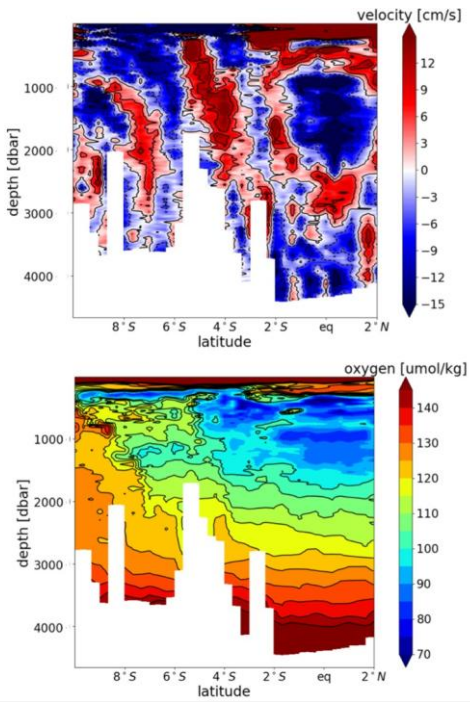

Figure 2 : Upper panel: Zonal velocity section from 10°S to 2°N along 165°E during the CASSIOPEE cruise, from LADCP data (cm/s).
Lower panel: Oxygen concentration along the same section (micromole/kg). From Delpech et al. (in prep).

The CASSIOPEE cruise was carried out on R/V Atalante from July, 19 to August, 23, 2015 (one year after what was initially planned, and on R/V Atalante instead of R/V Alis). Three meridional sections documented the zonal jets structure and their longitudinal evolution from the surface to the bottom, with 101 classical hydrological casts (white dots in Figure 1), including nutrients, neodymium isotopes, biological sampling as well as LADCP, video-profiler (UVP5) and turbulence (chi-pods) measurements (Figure 1). 4 moorings from SPICEMoor have also been recovered in Solomon and Vitiaz straits (white stars in Figure 1). 9 Argo floats have been deployed (7 Arvor, 2 from CSIRO; red dots in Figure 1).

The structure of the currents captured by the CASSIOPEE cruise were investigated using the full-depth LADCP (Figure 2, upper panel). Despite the synopticity of the transect, the zonal jets structures observed during the cruise are consistent with the two systems of jets identified in Cravatte et al. (2017). The differences between these snapshots and the mean structures are mainly explained by the downward propagation of an annual Rossby wave (not shown). Zonal velocities higher than 10 cm/s are observed to the bottom of the ocean.

South of the equatorial band (2S-10S), the striking features on the oxygen section are the existence of meridional fronts extending over more than 2000m (from 500m down to 2500-3000m) following the core of eastward jets at 2°S, 4°S (including the second Tsuchiya jet) and 7°S at 165 E with the same tilt toward the equator with depth. Frontal structures are denoted through a convergence of oxygen isopleths alternating with quite homogeneous regions. The signature of equatorial deep jets alternating vertically right at the equator are also visible in oxygen, suggesting that they contribute to the ventilation of the central/eastern deep basin.

Future of the project :

Two publications on the hydrological structures of the jets, and on their variability at intraseasonal timescales are in preparation. Audrey Delpech, a PhD student at LEGOS, is also collaborating with Claire Menesguen (LOPS) and performs idealized numerical simulations with the CROCO model to better understand the dynamics of the jets.

The mixing data (from chipods, collaboration with J. Moum) also still need to be analyzed.

M. Behrens (Universität Oldenburg) took sample to measure Neodymium concentration and isotopes during the CASSIOPEE cruise, in the core of the zonal jets. These tracers of the continental inputs origin are being currently analyzed and will help to better understand the connection of the jets with the western boundary currents.

Publications, communications and thesis

A. Delpech, PhD student at LEGOS, “Dynamique des courants zonaux subthermoclinaux et intermédiaires dans les océans tropicaux »,Université Toulouse III, *2017-*

5 related Publications:

-Delpech, A et al., Characterization of deep zonal jets properties in the tropical Pacific Ocean from high-resolution in-situ data, in prep.

- Menesguen, C., A. Delpech, F. Marin, S. Cravatte, R. Schopp and Y. Morel, (2019) Observations and Mechanisms for the formation of Deep Equatorial and Tropical Circulation, in press in the special issue "Nonlinear Systems in Geophysics: Past Accomplishments and Future Challenges" in Earth and Space Science

- Cravatte, S., E. Kestenare, F. Marin, P. Dutrieux and E. Firing (2017), Subthermocline and Intermediate Zonal Currents in the Tropical Pacific Ocean: paths and vertical structure, JPO, 47, 2305–2324, https://doi.org/10.1175/JPO-D-17-0043.1

- Kiko, R., A. Biastoch, P. Brandt, S. Cravatte, et al. (2017), Physical focusing and disintegration of marine snowfall feeds deep equatorial carbon export, Nature Geoscience 10, 852–858 (2017), doi:10.1038/ngeo3042.

-Cravatte S., F. Marin and W. S. Kessler (2014), Zonal jets at 1000m in the tropics observed from Argo float’s drifts, Mercator-Coriolis Newsletter, Avril-Mai 2014.

Oral Communications:

Cravatte, S., E. Kestenare, F. Marin, P. Dutrieux and E. Firing (2017), Subthermocline and Intermediate Zonal Currents in the Tropical Pacific Ocean : paths and vertical structure, Euro-Argo meeting, 3-5 July 2017, Paris

Cravatte, S., E. Kestenare and F. Marin (2016) : ZEBRE project: Intermediate Zonal Jets in the Tropical Pacific Ocean, Journées 2016 du Groupe Mission MERCATOR/CORIOLIS, 7-9 juin 2015, Toulon, France