FINAL REPORT PROGRAM LEFE

Program LEFE IMAGO/GMMC	Project Title oceAn Change Over the LAst Decade (AcCOLADe)	Years 2017–2018

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Context

Over the last decade, the Southern Ocean is the main location of the Ocean global heat content (OHC) change. However, the mechanisms driving the local and inter-annual to decadal variability of thermohaline variability, *i.e.* OHC and Freshwater Content (FWC), as well as thermohalosteric Sea Level (SL) change, are still not well understood, and crucial to separate the natural variability from the anthropic forced global change. Over the last decades, the international Argo program have collected consistent and quality controlled time series of temperature and salinity profiles covering the whole global upper ocean (0-2000m). This unprecedented global network of observation is suited to tackle the questions of the interannual and decadal ocean variability at global and local scale.

Objectives / scientific questions

- IMAGO actions: Where is heat and freshwater stored in the Southern Hemisphere ocean? What are the interannual to decadal mechanisms of thermohaline variability in the ocean in the Southern Hemisphere?
- GMMC actions: What are the most appropriate approach and metrics for quantifying thermohaline content? What are their representations in the various analyzes and reanalyses of data available?

Main results

IMAGO actions: Thanks to the Argo data interpolated products (ISAS15, *Kolodziejczyk et al.*, 2017) and ocean reanalyses (ECCOv4), we studied the interannual variation and associated mechanisms of ocean water masses (0-2000 m; modal and intermediate water) over the recent period (2006-2015). Using an isopycnal coordinate decomposition, we revealed that the last decade Southern Ocean heating was marked by a significant redistribution of mode and intermediate water masses: an increase of the volume in the less dense (warmer) layers. This has occurred in few “hot spots” around the southern hemisphere (*Kolodziejczyk et al.*, 2019). To better understand the transformations occurring in the heart of mode and intermediate water masses of the Southern Ocean, we have developed and used an innovative approach based on the transformation of water masses in density/spiciness coordinates. In contrast to the traditional approach (T-S coordinates or density coordinate alone), the density/spiciness approach has the advantage of separating the isopycnal/dyapycnal components of the transformations of the interior water masses. Thus, during the last decade we diagnose the destruction of intermediate Antarctic waters by isopycnal mixing, and the warming and increase of upper-subantarctic mode waters thanks to increased subduction and diapycnal mixing (Fig. 1; *Portela et al.*, 2020).

GMMC actions: Metrics and analyses assessments:

- The net ocean mass contribution to SL has been estimated by assessing the global ocean salt budget (dilution due to melting of continental ice and ice sheet) based on available in situ data over 2005–2015 (Fig., 2; *Llovel et al.*, 2019).
- The OHC and Freshwater metrics have been used for inter-comparing existing in situ reanalyses (CORA, ISAS, Scripps, IPRC, JAMSTEC, EN4) on a global to regional and interannual to decadal bases. The OHC intercomparisons shows a good agreements in term of patterns and amplitude. In contrast, FWC variability inter-comparison have revealed larger differences due to critical level of Quality Control (QC) among the products. Methodological biases among the products (interpolation method) are not significant (M1 training Alex Legal, summer 2017).
- ISAS15 has been used to assess OHC and SL change in WCRP paper and Agro white paper (*WCRP et al.*, 2019; *Roemmich et al.*, 2019).
- Along with development of interpolation and QC tools at Service National d’Observation (SNO) Argo, Argo deep trajectory (1000 dbar) Real Time Quality Control (RTQC) methods and procedure has been

initiated during this project (with C. Cabanes at SNO Argo).

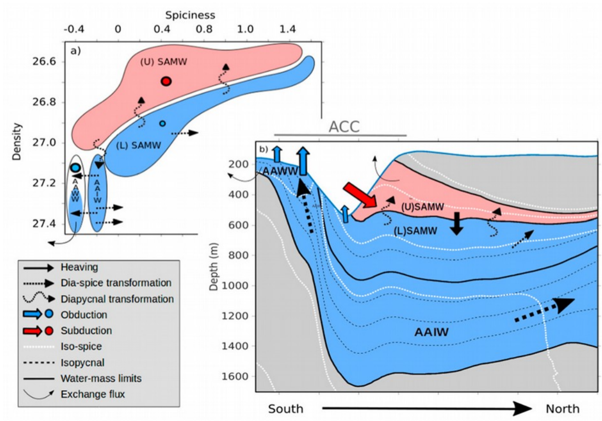

Figure 1: Schematic of zonal average of the upper Southern Ocean (0-2000 m) volume census change and associated water mass transformation over the last decade (2006-2015) computed from ISAS15 and ECCOv4 model in (a) density-spiciness and (b) geographical coordinates (pink=volume increase; blue=volume decrease). The projection in density-spiciness space (a) allows to separate the isopycnal mixing transformation (horizontal) and diapycnal mixing transformation (vertical). Acronyms: Antarctic Circumpolar Current (ACC); Antarctic Intermediate Water (AAIW), Antarctic Winter Water (AAWW), Upper and Lower SubAntarctic Mode Water (U-L-SAMW).(from Portela et al., 2020). Blue (pink) shading indicate water mass loss (gain).

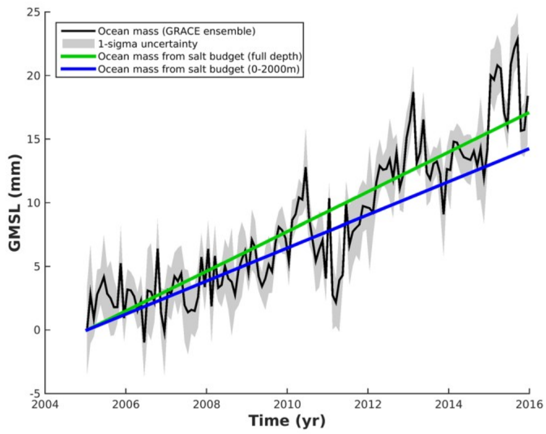

Figure 2: Ocean mass contribution to global mean sea level. Ocean mass change inferred from GRACE data (black curve) and from the global ocean freshening (blue and green curves for the 0–2000 m and full depth, respectively). Seasonal signals have been removed from the GRACE curve. Shading denotes 1-σ uncertainty of the respective estimates. Curves are offset for clarity. (from Llovel et al., 2019)

Future of the project :

- The density-spiciness water mass transformation conceptual framework is suited for any physical passive tracer transformation. In the context of global ocean desoxygenation, this framework applied to oxygen tracers will help to better understand and quantify the mechanisms of oxygen variability in North Atlantic. The post-doctoral project OVAN (Region Bretagne funding, starting end of 2020) will be focus on this question.
- New collaborations between LOPS, CERFACS and IGE (T. Penduff) has emerged during this project. Quantifying the chaotic error in the estimates of OHC, FWC and SL monitored by Global Observing System with our in situ analyses systems is mandatory to ascertain the local to global ocean changes estimates. The 50 members of OCCIPUT (Oceanic chaos – impacts, structure, pre-dictability) synthetics profiles will be interpolated with ISAS OI tools to estimate the spread among the OHC and SL change estimates. New dataset and manuscript are in preparation.
- Progress has been made on Argo trajectory QC methods. On going work is currently led to develop new algorithm of the automatic procedure of RTQC developed. This is a first step to be able to distribute QC Argo trajectory files and displacement products on near real time basis by Coriolis data center to provide Argo trajectory data for research and operational community.

Number of publications and communications:

<u>Five main Peer reviewed publications</u>:
1. Portela et al., 2020, J. Phys. Oceanogr. doi: 10.1175/JPO-D-19-0128.1.
2. Llovel et al., 2019, Nat. Sci. Rep. doi:10.1038/s41598-019-54239-2.
3. Kolodziejczyk et al., 2019, J. Geophys. Res. doi:10.1029/2018JC014866.
4. Rommeich et al., 2019, Front. Mar. Sci. doi.org/10.3389/fmars.2019.00439
5. WCRP global sea level budget group, 2018, Earth Syst. Sci. Data. doi.org/10.5194/essd-10-1-2018

<u>Four main Communications:</u>
1. N. Kolodziejczyk (invited talk), Interannual variability of upper ocean water masses as inferred from Argo ArrayArgo Science Workshop #6, Tokyo, Japan. October 2018.
2. E. Portela (Oral presentation), Southern Ocean water mass transformation in a density-spice space. EGU Vienna, Austria, April 2019
3. E. Portela (Oral presentation), Southern Ocean water mass transformation in a density-spice space.OSM, San Diego, USA, February, 2020

4. W Llovel, S Purkey, B Meyssignac, N Kolodziejczyk, A Blazquez, Sea level change since 2005 (Oral): importance of salinity, AGU Fall Meeting, 2017.

<u>Data set</u>:
Kolodziejczyk Nicolas, Prigent-Mazella Annaig, Gaillard Fabienne (2017). ISAS-15 temperature and salinity gridded fields. SEANOE. https://doi.org/10.17882/52367