Intermediate water masses, a major supplier of oxygen for the eastern tropical Pacific ocean" by Olaf Duteil et al.

Reply to Referee #2

This paper highlights the role of intermediate waters as the O2 supply pathway for the waters of oxygen minimum zones primarily focusing on the Pacific basin. This study consists of three model simulation with different source code, resolution and biogeochemical parameterizations. In general current generation of earth system models tend to have difficulties representing this mode of oxygen supply, thus overestimating the size of low-oxygen waters.

Here are main conclusions;

(1) the O2 concentration of these water masses in the subtropics is biased in models. If restoring is used to correct the model bias in O2 entering into the subtropics, the tropical O2 representation improves significantly.

(2) the ocean jets and eddies play major role for the O2 transport of intermediate water, as supported by the runs with different model resolutions.Coarse resolution models must rely on parameterization for this process.

(3) Due to tropical upwelling, the biases in the deep and intermediate water can impact on the entire upper ocean water column.

I think these points are not really surprising, but the authors have done a detailed, systematic analysis of oxygen responses to model resolution and source water properties to support these conclusions. In my view, this paper is publishable perhaps with a few minor revisions.

We thank the author for her/his positive feedback.

Below are my technical comments. Main text has several typos. It will benefit from a careful proofreading.

The final version of the ms has been carefully proofread.

Fig 2b. If I'm reading this figure correctly, it is remarkable that not a single model can capture the peak of O2 at about 800m. I think this feature should be pointed out more clearly in the main text at about page 6. The caption does not indicate which line is WOA. I think it is obvious that the observation is the thick black line, but it needs to be spelled out in the caption.

The "missing" O2 peak is indeed a remarkable feature in the models. We point that out more clearly in the new version of the ms. The figure 2 has been updated and is reproduced at the end of the reply.

Fig 3 and main text in page 7. I really like this figure and the discussion in the main text, up to panel f. Then I'm confused. The figure caption says the panels g, h, i are zonal mean tendencies of O2. The main text talks about something different about deep O2. It doesn't even mention how these tendencies are calculated. This probably means there is some version inconsistency between Figure 3 and the main text. This obviously needs a revision.

The text L229 (page 7) to which the reviewer refers reads : “The difference NEMO2-30DEG1500M – NEMO2-30DEG (Fig 3f-h) shows a deep positive anomaly in oxygen, as oxygen levels are lower than in observations by 30-40 mmol.m-3 in the eastern tropical regions”. The reference to Fig 3 f-h is wrong. It has been corrected in the new version of the ms.

L284 and in some other places; What is meant by the “upper layer”? I interpreted as the surface, but please be more specific (such as the surface or sigma-theta level or z-level).

The upper layer corresponds to the mixed layer. This is clearly specified in the new version of the ms.

The text related to Fig 4 is confusing, if I read it correctly, the net advective transport divergence is not affected but is not shown (L262-263). Is the change in O2 concentration entirely caused by the eddy parameterization part of the transport? In my opinion this type of budget analysis may be more interesting if it is applied to contrast the low-and high-resolution runs and separate the mean flow and (resolved or parameterized) eddy contribution.

We show below the total advective transport in NEMO2_REF and its anomaly (NEMO2_30S30N minus NEMO2_REF) (Figure 7)

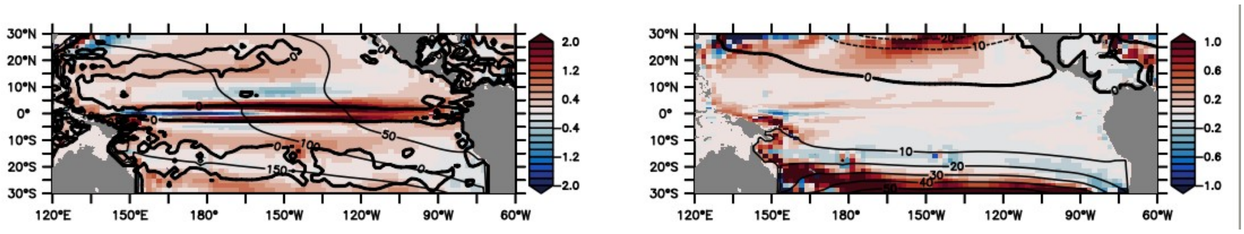

Figure 7: left : total advection term in NEMO2_REF. Right : difference in the total advection term between NEMO2_30S30N – NEMO2_REF

The Fig 7 right panel in our response letter shows clearly that the total advection terms are similar between NEMO2_30S30N and NEMO2_REF at the equator. In contrast, the differences are large in the gyres as the anomaly is advected by the strong westward currents. In the tropics, most of the anomaly is due to isopycnal mixing (or “eddy parameterization” transport as stated by the reviewer), see Fig 4b in the new version of the ms. This is maybe not surprising as the intermediate currents are weak in NEMO2 (coarse resolution). Higher resolutions models will likely be characterized by the imprints of zonal jets. We agree with the reviewer, a similar experiment but performed at high resolution would be very useful to quantify precisely the impact of these jets. Unfortunately a high resolution eddy resolving simulation coupled with biogeochemical cycle was not available due to computational expenses (which is the reason why we compare coarse and high resolution simulations coupled to a single passive tracer in part 4 of this ms)

Updated Figures and Table

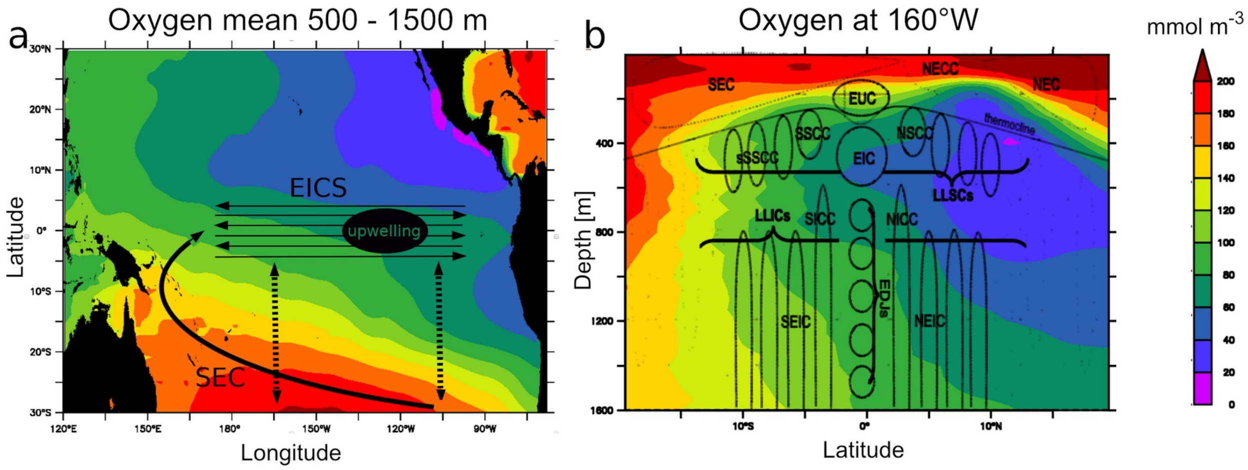

Figure 1 : a- schema summarizing the intermediate water masses (IWM) pathway from the subtropics into the equatorial regions. EICS : Equatorial Intermediate Current System. SEC : South Equatorial Current. Dashed line : isopycnal diffusive processes. Observed (World Ocean Atlas) oxygen levels (mmol.m^{-3}) in the lower thermocline (mean 500-1500m) are represented in color. b - schema (adapted from Menesguen et al., 2019) illustrating the complexity of the EICS, extending below the thermocline till more than 2000 m depth (see section 4.1 for a detailed description). Observed (World Ocean Atlas) oxygen levels at 160°W are represented in color.

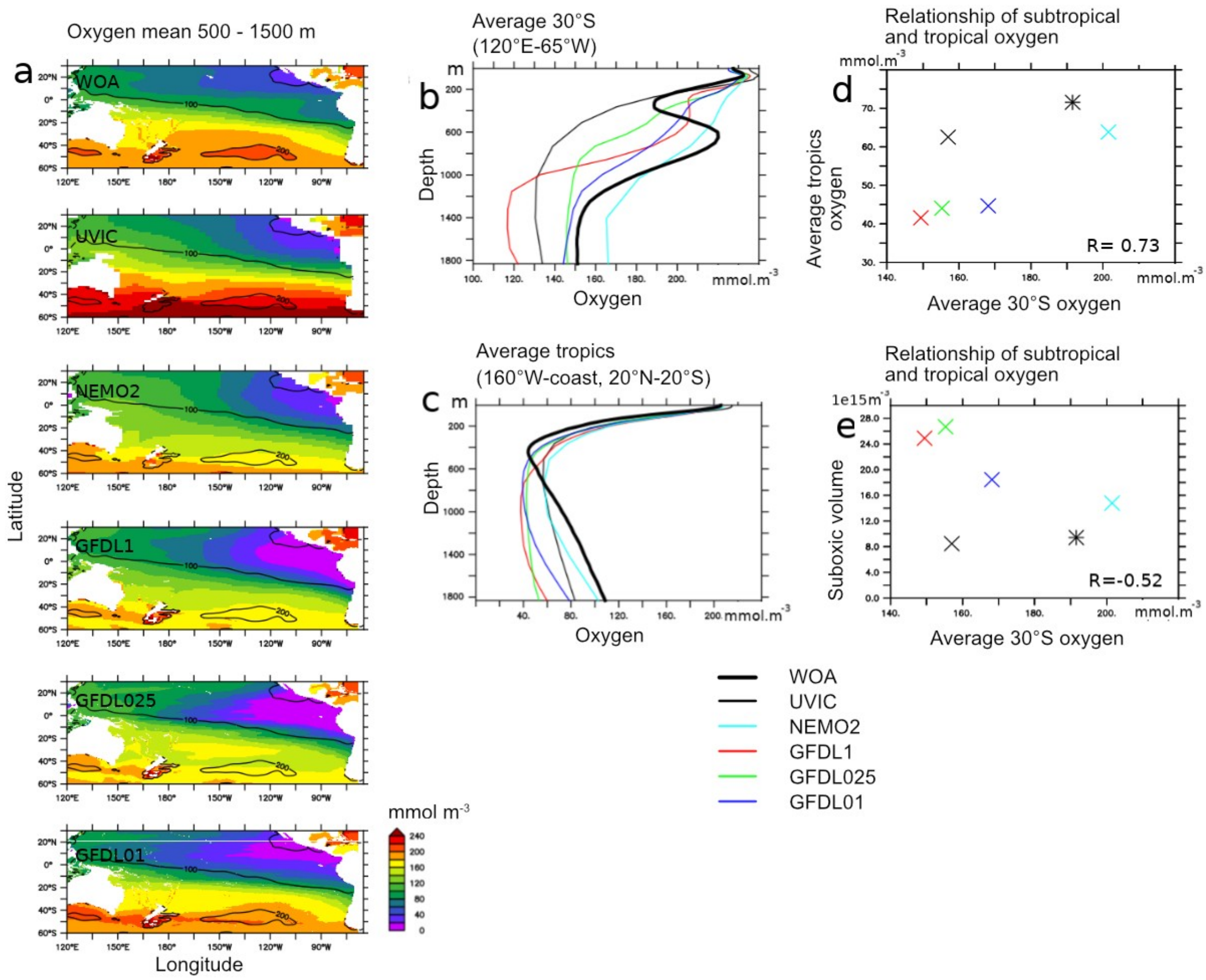

Figure 2 : a- oxygen levels (mmol.m^{-3}) in observations (World Ocean Atlas - WOA) (mean 500 – 1500 m) and models (UVIC, NEMO2, GFDL1, GFDL025, GFDL01). Contours correspond to WOA values. b: average “30°S” (120°E-65°W, 30°S) c : average “tropics” (160°W-coast, 20°N-20°S). d: average “30°S” vs “tropics”. e: average “30°S” vs volume of tropical suboxic ocean (oxygen lower than 20 mmol.m^{-3}) regions (1e15m3). b-e : UVIC : black, NEMO2 : cyan, GFDL1 : red, GFDL025, green; GFDL01 : blue, WOA: bold line (b,c) and star (d,e).

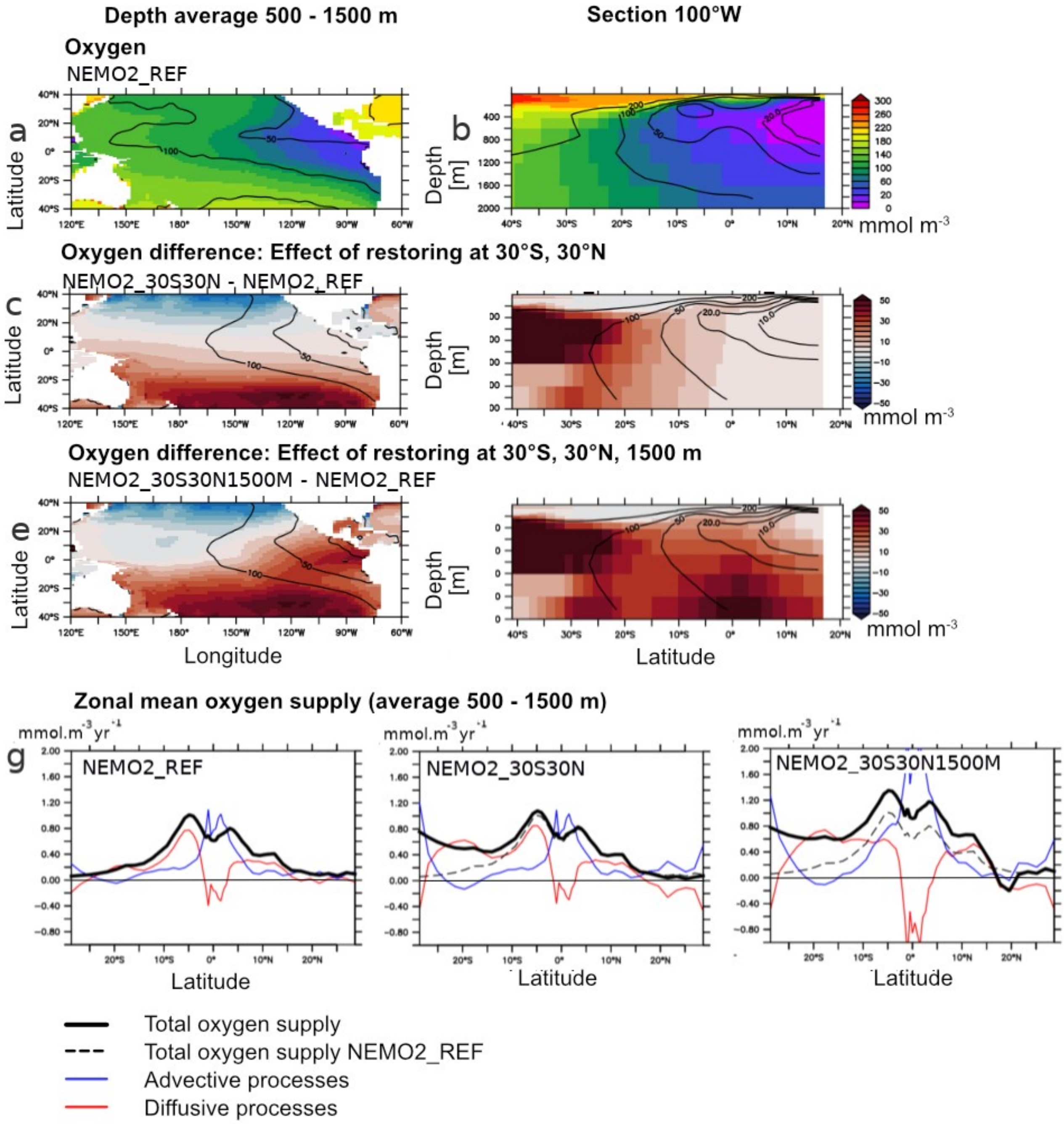

Figure 3 : a,b: Oxygen (mmol.m^{-3}) in the experiments NEMO2_REF (color) and World Ocean Atlas (contour) (a- average 500-1500 m, b- 100°W). c,d: Oxygen (mmol.m^{-3}) difference (c- average 500 – 1500m, d- 100°W) between the experiments NEMO2_30S30N minus NEMO2_REF. e,f : Oxygen (mmol.m^{-3}) difference (e- average 500-1500m, f- 100°W) between the experiments NEMO2_30S30N1500M minus NEMO2_REF. g- basin zonal average (average 500 - 1500 m) of the oxygen total supply (bold) (mmol.m^{-3}.year^{-1}), advective processes (blue) and isopycnal diffusion (red) in NEMO2_REF, NEMO2_30S30N, NEMO2_30S30N1500M. The dashed line is the oxygen total supply in NEMO2_REF.

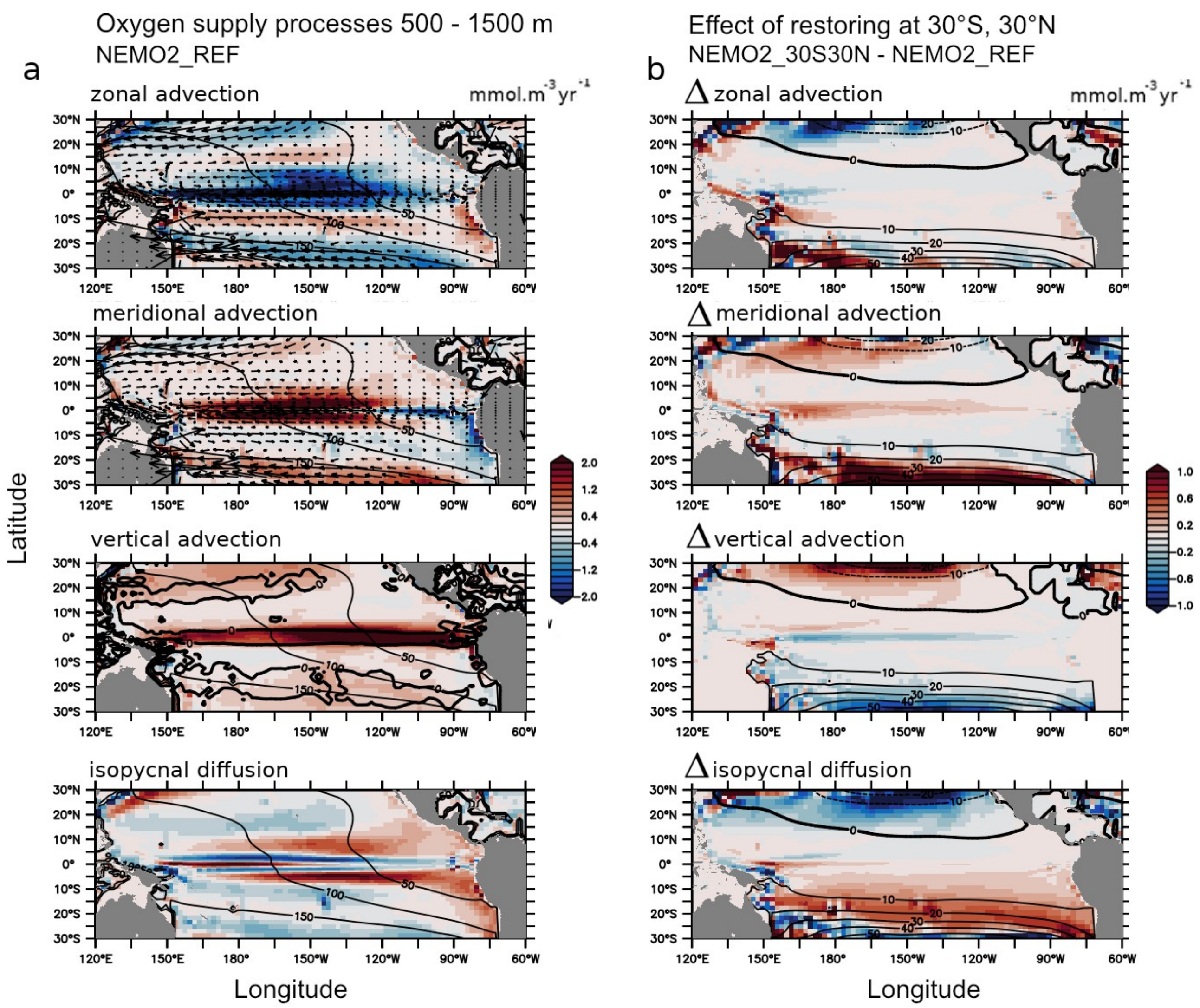

Figure 4 : a- Oxygen supply processes (mmol.m^{-3}.year^{-1} – average 500 - 1500m) in NEMO2_REF : zonal advection, meridional advection, vertical advection, isopycnal diffusion. The mean meridional and zonal currents are displayed as vectors (meridional, zonal advection). The mean vertical current (0 isoline) is represented as bold contour (vertical advection). Oxygen levels (mmol-m.$^{-3}$) are displayed in black contour. b- Difference in oxygen supply processes (mmol.m^{-3}.year^{-1} – average 500-1500m) between NEMO2_30S30N and NEMO2_REF : zonal advection, meridional advection, vertical advection, isopycnal diffusion. The NEMO2_30S30N – NEMO2_REF oxygen anomaly (mmol.m^{-3}) is displayed in contour.

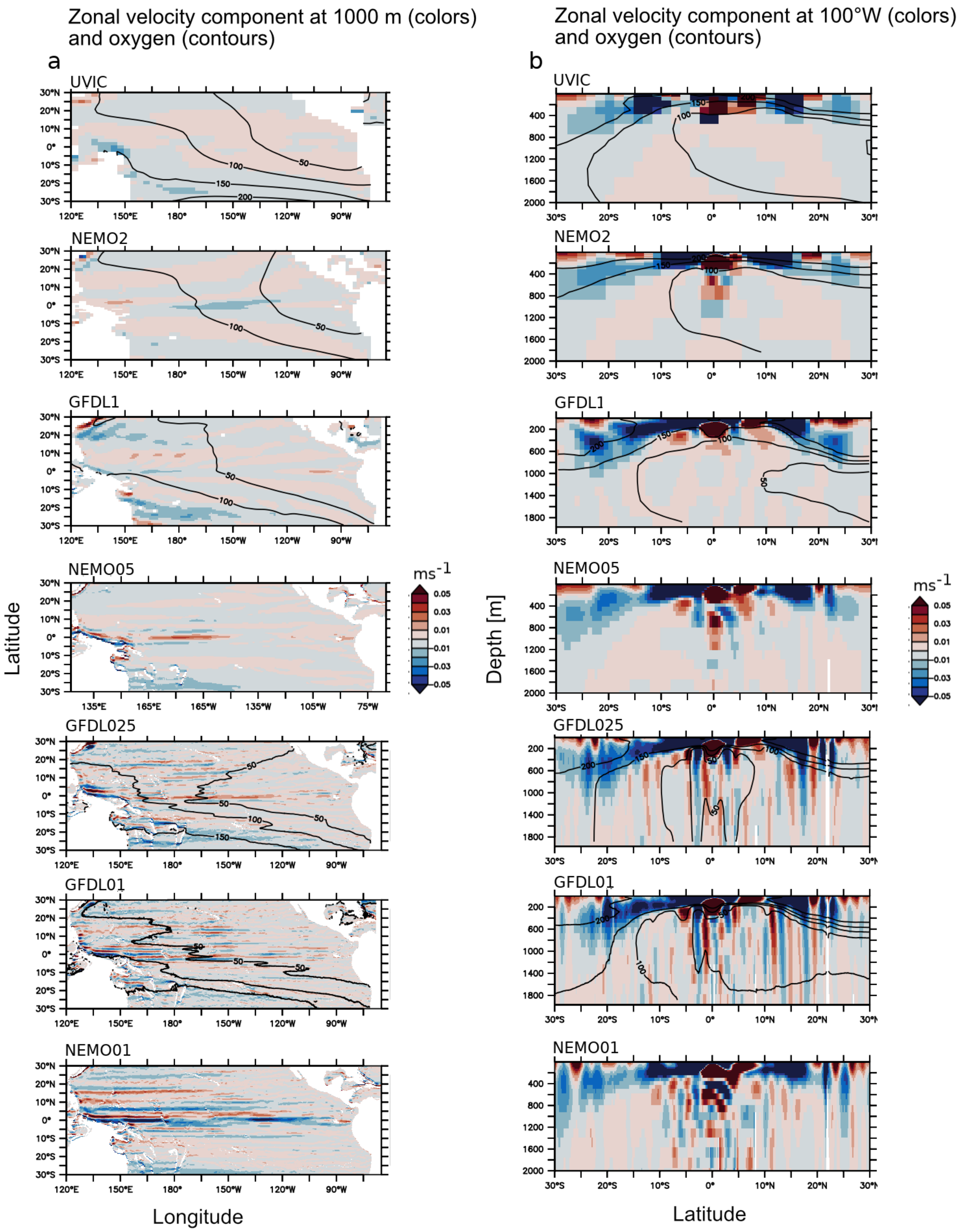

Figure 5 : mean currents velocity (ms^{-1}) at a- 1000 m depth b- 100°W in UVIC, NEMO2, NEMO05, GFDL025, GFDL01, NEMO01. The mean oxygen levels (mmol.m^{-3}) (when coupled circulation-biogeochemical experiments have been performed – see Table 1) are displayed in contour

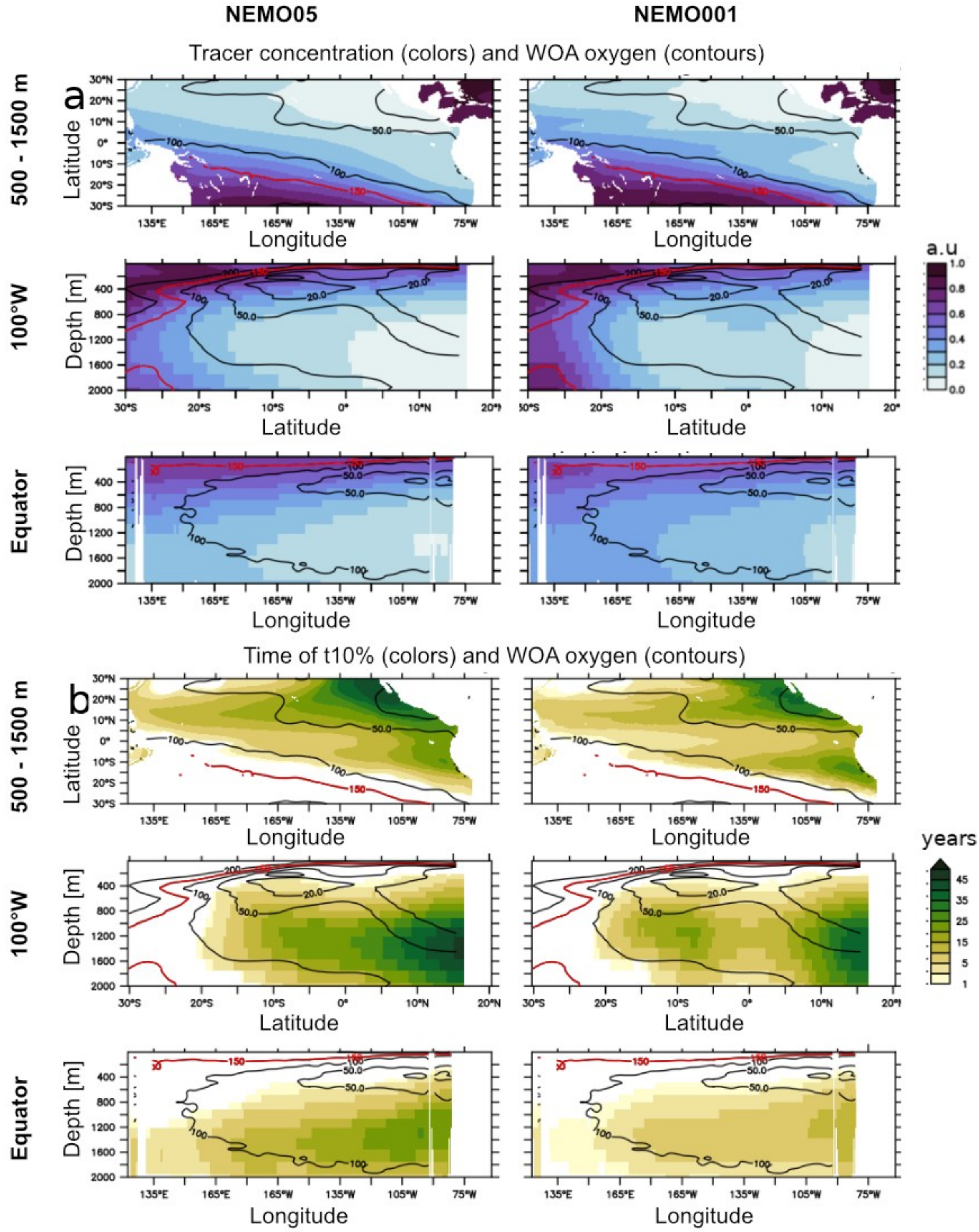

Figure 6: a : tracer concentration (arbitrary unit) after 60 years integration in NEMO05 and NEMO01: average 500-1500m, section 100°W, equatorial section. b: Time (years) at which the released tracer reaches the concentration 0.1 (t10%) in NEMO05 and NEMO01: average 500-1500m, section 100°W, equatorial section. In all the subpanels, the WOA oxygen levels are displayed in contour. The red contour is the WOA 150 mmol.m^{-3} oxygen isoline, used to initialize the tracer level.

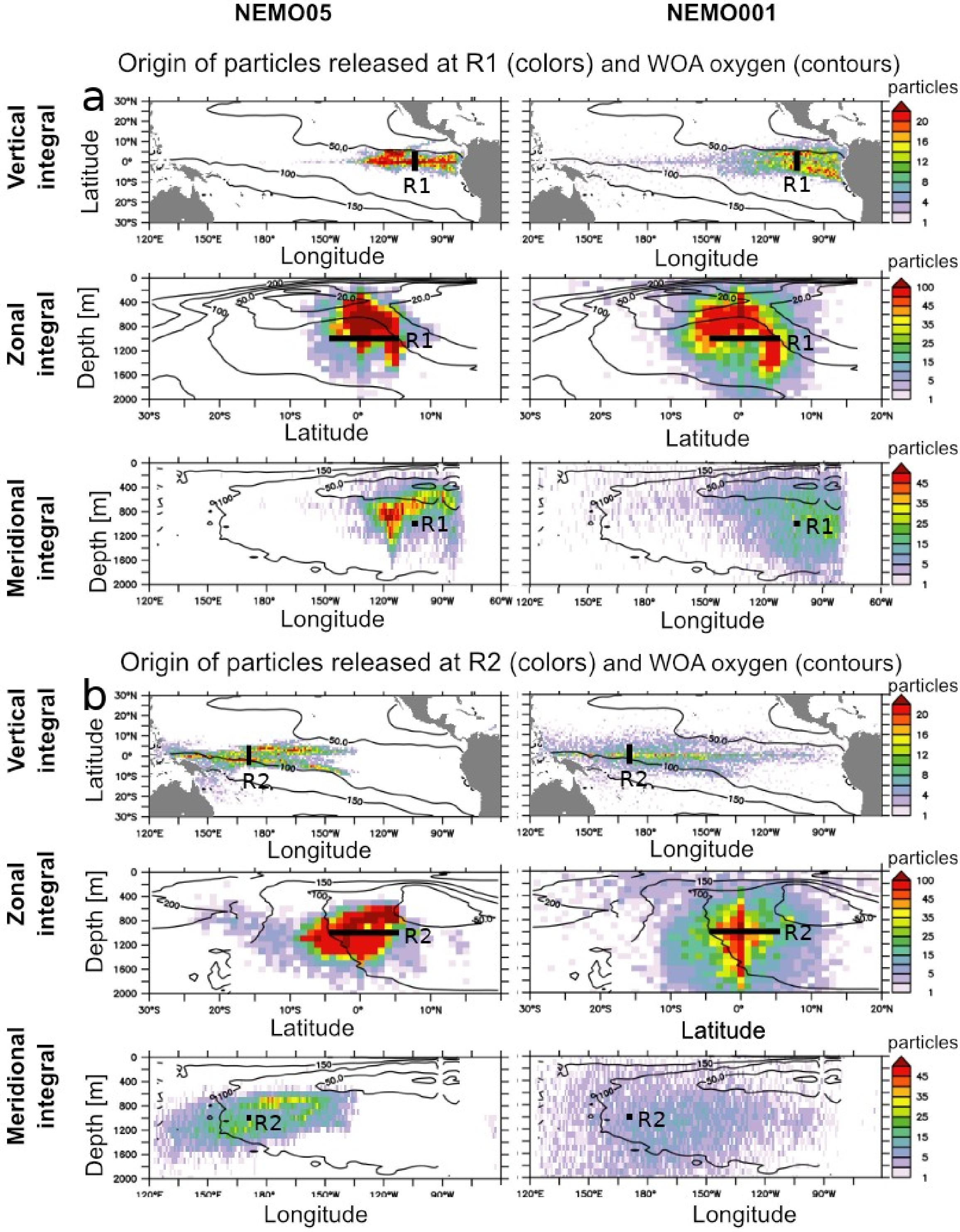

Figure 7 : Density (number of particles in a 1°x1°x100m depth box) distribution of the location of released Lagrangian particles (15 years backward integration starting from the final experiment state) in NEMO05 and NEMO01. The release location is identified in bold and is located a- at 100°W/5°N-5S/1000 m depth (R1). b- at 160°E/5°N-5°S/1000 m depth (R2). The particles have been integrated vertically, zonally and meridionally. The observed mean oxygen levels (WOA) are displayed in contour.

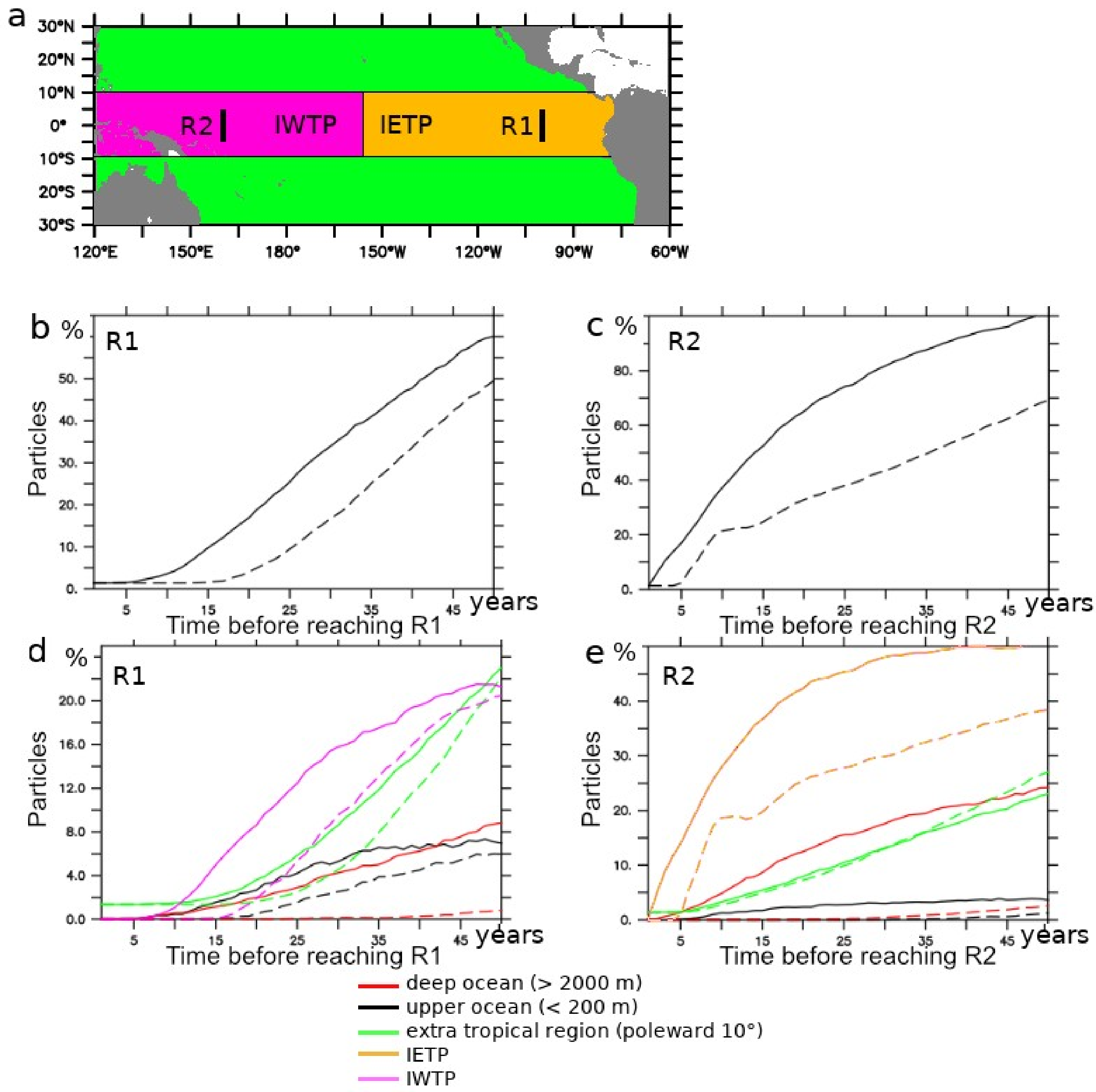

Figure 8 : a- schema summarizing the releases (R1: 100°W / 5°N-5°S / 1000 m , R2: 160°E / 5N°5S / 1000 m) location, the IETP (Intermediate Eastern Tropical Pacific), IWTP (Intermediate Western Tropical Pacific) regional extension. b. percentage of particles (release R1) originating from outside the IETP ocean region. b- percentage of particles (release R2) originating from outside the IWTP ocean region. d- percentage of particles (release R1) originating from the upper ocean (shallower than 200 m), the deeper ocean (deeper than 2000 m), subtropical regions (poleward 10°), the IWTP. e- percentage of particles (release R2) originating from the upper ocean (shallower than 200 m), the deeper ocean (deeper than 2000 m), subtropical regions (poleward 10°), the IETP.

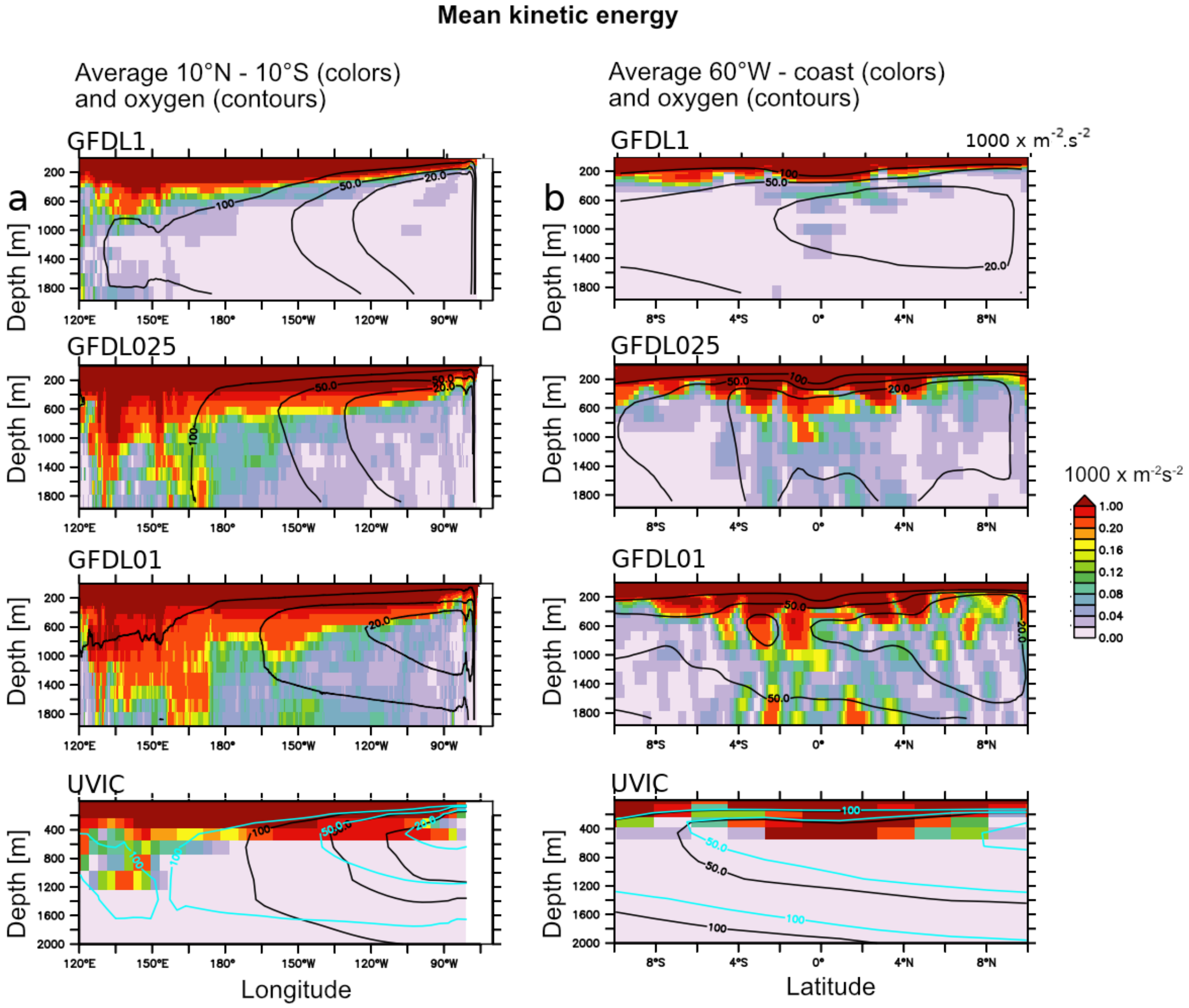

Figure 9 : a - Mean Kinetic Energy (m2.s^{-2} x 1000) (average 10°N-10°S) in GFDL01, GFDL025, GFDL01, UVIC, b - similar to a. but average 160°W- coast. Oxygen levels (mmol.m^{-3}) are displayed in black contour. The blue contour corresponds to UVIC GD13 (Getzlaff and Dietze, 2013, including an anisotropical increase of lateral diffusion at the equator)

Table 1 :

Model	Resolution	Atmosphere	Integration (years)	BGC	Model Reference (circulation)	Model Reference (BGC)
Mean state comparison						
UVIC	2.8°	Coupled (temperature, humidity) Forced (NCEP/NCAR wind stress)	10000	UVIC-BGC	Weaver et al., 2001	Keller et al., 2012
NEMO2	2° (0.5 eq)	Forced COREv2 “normal year”	1000	NPZD-O2	Madec et al., 2015	Kriest et al, 2010 Duteil et al., 2014
GFDL1	1°	Coupled	190	BLING	Delworth et al, 2012, Griffies et al, 2015	Galbraith et al., 2015
GFDL025	0.25 °	Coupled	190	BLING		
GFDL01	0.1°	Coupled	190	BLING		
Process oriented experiments						
Model	Resolution	Atmosphere	Integration (years)	BGC	Characteristics	
NEMO2 -REF -30N30S -30N30S1500M (section 2.2.1)	2° (0.5 eq)	Forced COREv2 1948-2007	60	NPZD-O2	- control experiment - O2 restoring to WOA at 30°N/30°S - O2 restoring to WOA at 30°N/30°S/1500m	
NEMO05 (section 2.2.2)	0.5°	Forced COREv2 1948 - 2007	60	Tracer release	- Tracer initialized to 1 (O2 WOA > 150 mmol.m-3) or 0 (O2 WOA < 150 mmol-m-3)	
NEMO01 (section 2.2.2)	0.1°	Forced COREv2 1948 – 2007	60	Tracer release		