Response to the comments of the Ref. 3

C. 1: The manuscript encompassing a comprehensive introduction of the experimental apparatus and methodology followed by the authors and everything is very well conducted, except the relative role (scale ratio) of the central part of the tank respect to the sloping part. In fact, looking the figure 7 in the manuscript seems that the dynamics driven by the slope domain dominates on those generate in the flat domain, making difficult distinguishing the difference between the two dynamics. This isn't irrelevant to make more realistic the comparison with the northern Ionian Sea circulation in section 4.

Reply: We thank the Referee for the comment on the relative importance of the dynamics in the slope domain with respect to the dynamics of the flat domain. Regarding this, first we bring attention to the fact that Fig. 7 (Fig. 8 in the revised version of the manuscript) shows only the surface layer flow evolution in the tank. The dense water injection occurs over the slope near the interface between the upper and lower layers and begins influencing the stretching and squeezing of the water column in different manner. We recall Fig. 5, in particular Figs. 5b and 5d of the revised version (old Fig. 4) and Fig. 11. These figures show how the averaged vorticity in the slope and flat domains evolves in time, both in the tank and the Ionian Sea. Concerning the relative importance of the slope with respect to the central flat-bottom area, in the Chapter 4 we compare residence times in the Ionian Sea and in the rotating tank. The ratio between the two residence times is of the same order of magnitude as the ratio of the vorticity rate of change in the rotating tank and in the Ionian Sea. This confirms the dynamic similarities of the dense water flow in the two basins making realistic the comparison between the laboratory experiment and the Ionian Sea. Furthermore, this confirms that the relative importance of processes at the slope and in the central part of the basin is similar in the Ionian and the rotating tank. Indeed, our main goal is to show that laboratory conditions are similar to the ocean processes and not to distinguish between the slope and flat-bottom phenomena which are obviously interdependent.

To clarify the question of dynamic similarity, we added the following text at the end of chapter 4:

"The dynamic similarity between the Ionian Sea and the laboratory experiments was discussed in Rubino et al. (2020) by comparing the Burger number in the laboratory and oceanic conditions. Also, as evidenced in the same paper, another important similarity that should exist is between the in situ and laboratory ratios of the topographic slope and the initial geostrophic slope, which means that the non-dimensional number $g's(fV)^{-1}$, must be preserved in the laboratory."

C2 Moreover is very confusing the theoretical and modelling equations that are used to analyze the experimental results: the equation 1 is not the same used by the cited paper of Lee-Lueng, F. and Davidson, R. A. (A note on the barotropic response of sea level to time-dependent wind forcing. J. Geophys. Res., 100, C2, 24955-24963, 1995) that use a classical linear barotropic vorticity equation, may be the authors have to use a different reference.

Reply: As our response to this comment, we simply removed the reference saying that we will be treating the well-known linear barotropic vorticity equation for an f-plane approximation with the sloped bottom in radial coordinates for the surface layer without wind-stress forcing. We also defined the radial coordinate being perpendicular to isobaths and negative downslope.

C3 However, the most relevant matter is related to the stratification that, at the end, is the core problem of the manuscript. It is well know that a good representation of the ocean dynamics is a three-layer system and this is this is confirmed even in this case as is well evident in the figure 2c (experiment 27), specifically around the 75th day in which we see the respond of the pressure to the injection of the density anomaly and subsequence stratification in three layer (or a continuously stratification see references), is very interesting the impact of the redistribution of density and pressure within the water column in the figure 3 (and also figure 5) experiment 27 at the same day (around the 75th). These figures are the most interesting of the manuscript and at the same time are those that demonstrate the weakness of the theory presented in this manuscript: actually, can't demonstrate the opposite vorticity at the 75th day and the corresponding kinetic energy anomaly in the lower layers. However, despite this experimental evidence and the same recognition as the authors themselves that the dynamics follow at least a two-layers system, even so at the end the equation that the authors used is written in a one-layer formulation. This is not irrelevant for physical point of view. Is matter of fact that dealing with one-, two- or three-layer formulation of the QG equation, produce a different vorticity relation between the several interfaces along the water column (see Sokolovskiy paper and all reference herein). This is true either in the flat or in the slope domain and finally on the comparison with the realistic example of the Ionian Sea. In conclusion, the circular rotating tank experiment shows in an impressing way (this could be more impressing with a different scale ratio between the slope/flat domain), the adjustment of the vorticity along the continuously stratified water column (and its dependence from the layers-thickness distribution) when it is subjected to a density anomalies: first along the slope and afterwards during the spreading of the anomaly density flow along the flat bottom; finally is very arduous to do some comparison, in the present version of the manuscript, between the tank experiment and what was observed in the northern Ionian sea in 2012.

Reply: *The Reviewer is right when he argues that the evolution of a 2-layer and 3-layer system differs. However, in the present paper we do not attempt to determine the evolution of the eddying dynamics of the system. Our focus is on the dynamics of two homogeneous layers and the relationship between their thickness and the relative vorticity which is constrained for every layer by the conservation of potential vorticity (PV) in each of them, independently of the dynamics above and below it. So, the conservation of PV is ensured in a single layer, and it does not depend on how many layers stay above or below. In addition, we reduce the effect of the horizontal advection in our analysis by considering horizontal averages over larger areas (central and slope). Please, note also that the flow is not advected from one layer to the other.*

We thank the Reviewer for highlighting the event of the 75th day in experiment 27 which is really a special event. We examined more carefully the flow pattern evolution during that event and added Appendix B with details.

"Appendix B:

The theoretical curve in Fig. 4 obtained from Eq. 3 on the lower layer thickness h fits rather well the experimental data from the single-point density measurements at Cp3 site. Few departures from the theoretical curve are however evident, like e.g. the anomaly seen in the MLD (Fig. 3, reported also in Fig. B1a), in the rate of change of the lower layer thickness (Fig. 4), and in the vorticity evolution (Fig. 6) for EXP 27, around rotation day 75th. Concurrently, at the Cp3 site, the *local maximums are present both in the radial and tangential velocities in the deep layer (Figs. B1 b and c). These features are linked to the passage of a mesoscale anticyclonic eddy. Indeed, the formation and passage of the eddy in the vicinity of Cp3 is clearly evident from the horizontal distributions of the velocity vectors in the lower layer beneath the pycnocline, represented by the level 11 (Fig. B2). Overall effects of the eddy passage are: an anomaly in the vertical density distribution and the transient thickening of the pycnocline layer, an anomaly in the relationship between the vorticity rate of change and the rate of change of the bottom layer thickness (Figs. 3 and 4). This event is however of limited spatial and temporal extent. In fact, it should be kept in mind that such an anomaly has been detected because the mesoscale eddy was passing through the Cp3 site. Moreover, less prominent features are observed at other rotation days, probably generated by similar mesoscale features passing close but not over the Cp3 location. It is plausible that some similar eddies have not been detected at all, because travelling out of range of Cp3 site, during EXP 27, but also during other experiments."*

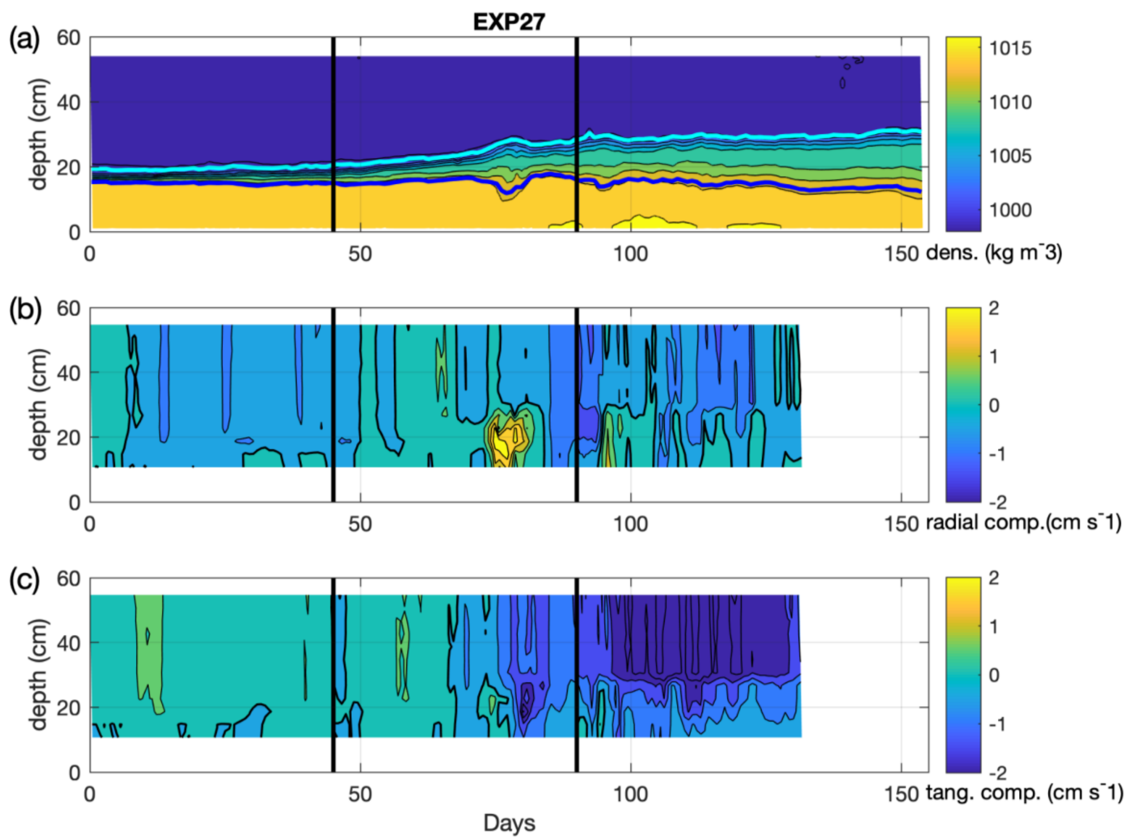

Figure B1: Hovmöller diagram of density (a), radial (b) and tangential (c) velocity components for EXP 27. The black isoline interval in panel (a) is 2 kg m^{-3}, starting from 1016 kg m^{-3} at the bottom; thick cyan and blue lines denote MLD and the base of the pycnocline, respectively. Bold isolines in panels (b) and (c) indicate 0 cm s^{-1}, and the isoline interval is 0.5 cm s^{-1}. Black solid vertical lines indicate rotation days 45 and 90, i.e., the start and end of the high-density water injection, respectively (for reference see Fig. 2 and Tables 1 and 2).

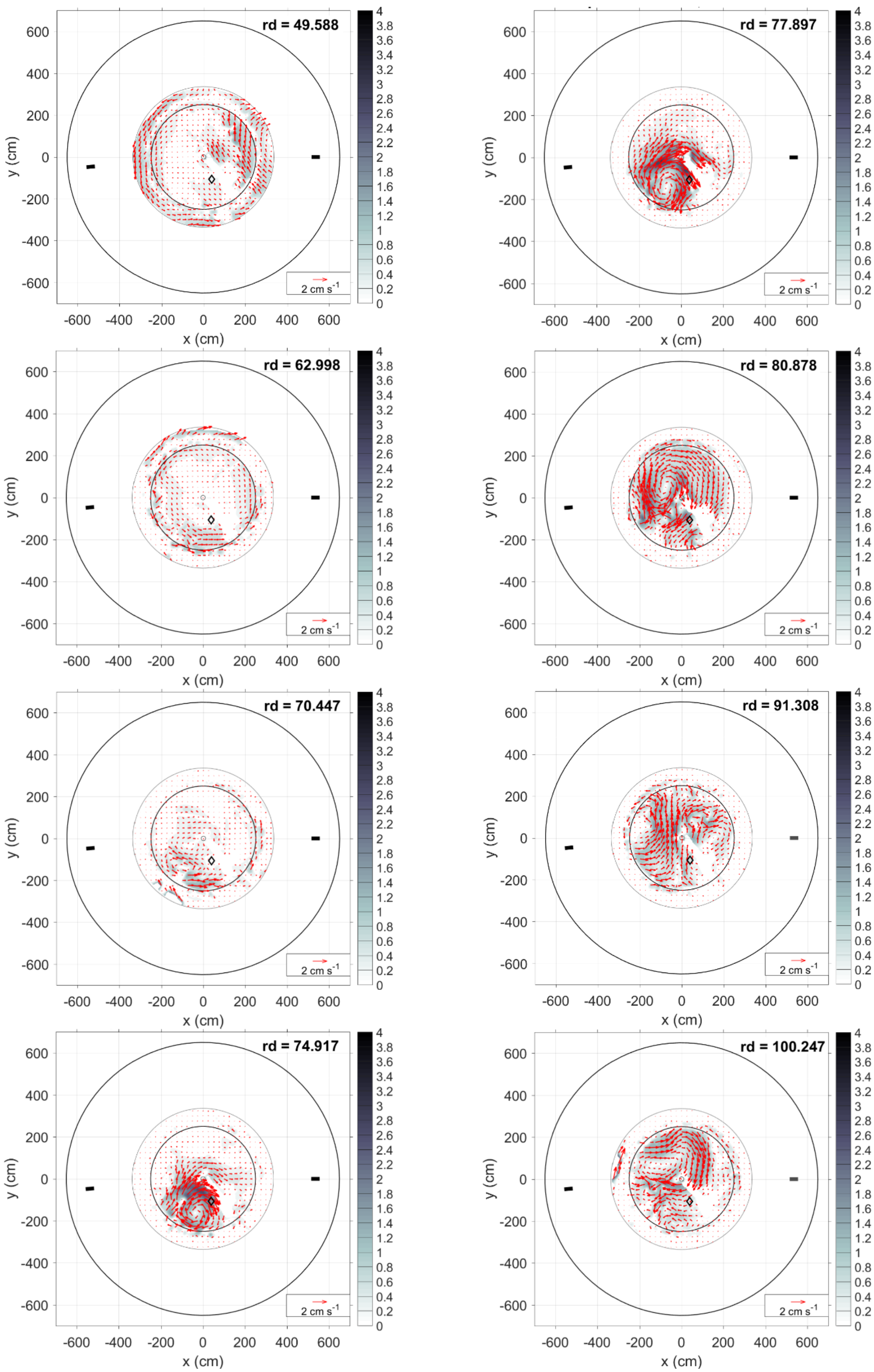
rd = 49.588
rd = 77.897
rd = 62.998
rd = 80.878
rd = 70.447
rd = 91.308
rd = 74.917
rd = 100.247
2 cm s-1
x (cm)
y (cm)

Figure B2: Evolution of the flow field in the lower layer of the rotating tank (represented by level 11) during experiment 27. The rotation days are indicated inside each panel. The diamond shows the location of the conductivity probe Cp3, and the two bars show the location of the two dense water sources. The outer and inner bold circles delimit the tank edge and the central deep area, respectively. Grey circle delimits the extension of the level 11.

Minor revision:

- Line 326 “level 1” is referred to inclined laser sheet levels 1 of the Figure 1?

Reply: Yes, it is.

- Line 451 at which model is referred? Please give more details;

Reply: We clarified this point in section 2 Data and methods:

“We compare the current fields in the rotating tank and in the real ocean for a particular condition when a circulation inversion event was observed in the northern Ionian Sea. Regarding the real ocean, for the surface we use the altimetry data, while for the deep layer conditions we use outputs from the hydrodynamic model of the Mediterranean Forecasting System. The latter concerns the physical reanalysis component, originating from the Copernicus Marine Service MEDSEA_REANALYSIS_PHYS_006_004 dataset (CMEMS Reanalysis) supplied by the Nucleus for European Modelling of the Ocean (NEMO) (Simoncelli et al., 2019). The model has a horizontal grid resolution equal to 1/16˚ (ca. 6-7 km) and 72 unevenly spaced vertical levels. We use the following variables: 3D monthly mean and daily mean temperature, salinity, and horizontal current components (eastward and northward) covering the entire Mediterranean Sea (https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004 https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=MEDSEA_MULTIYEAR_PHY_006_004).“

From then on, we specify everywhere in the text that we deal with the CMEMS Reanalysis fields, including the Line 451:

“By comparing the outputs of the CMEMS Reanalysis (which assimilates the in-situ data) and the vertical profiles of those ARGO floats, that were active in the northern Ionian during 2012, we observe that the Reanalysis absolute density values are typically larger than float densities (not shown). However, temporal variations of both data sets are consistent. Thus, we reconstruct the evolution of the density fields on the continental slope and in the deep area of the northern Ionian Sea using only the data from the CMEMS Reanalysis and compare it with the vorticity variations at the surface and in the deep layer (i.e., 1000 m depth, Fig. 12).”

- figure 1 the word “cp3” is not clear;

Reply: The meaning and location of the Cp3 is now introduced in the new Figure 1 (see below). In addition, the caption of the old Fig. 1 (now Fig. 2) also indicates the meaning of the Cp3.

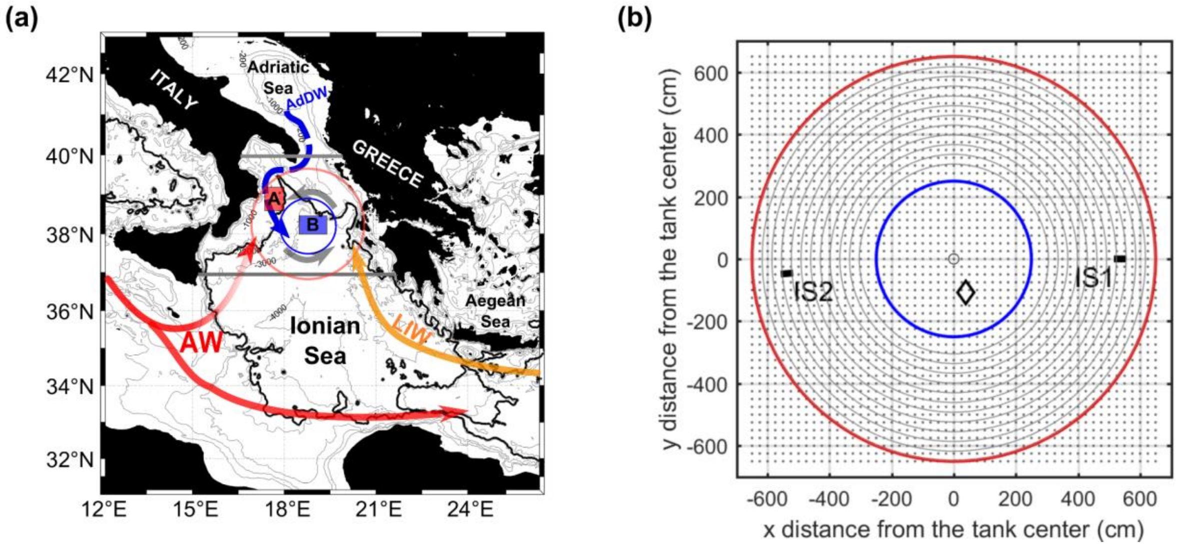

Figure 1: (a) Map of the study area in the Ionian basin with a simplified circulation scheme, which changes according to the BiOS regime. Gray horizontal lines indicate the geographical limits within which the mean vorticities above and below the 2200 m isobath were calculated. Rectangles A and B indicate the areas where density data (CMEMS reanalysis) were averaged. Concentric rings represent the simplified laboratory tank scheme. Acronyms: AW = Atlantic Water, LIW = Levantine Intermediate Water, AdDW = Adriatic Deep Water. (b) Top view of the tank: the slope area is between the red and blue circles, the deep flat-bottom area is inside the blue ring. Dense water injectors are placed at IS1 and IS2. A diamond near the center shows the location of the Cp3 profiler. Concentric gray rings indicate intersections of the laser sheet levels with the slope. Gray dots indicate regular x-y grid nodes for the tank velocity field (subsampled every 5 nodes for clarity). The map in (a) was created from the bathymetry data ETOPO2v2, NOAA, World Data Service for Geophysics, Boulder, June 2006, doi: 10.7289/V5J1012Q) using the MATLAB software.

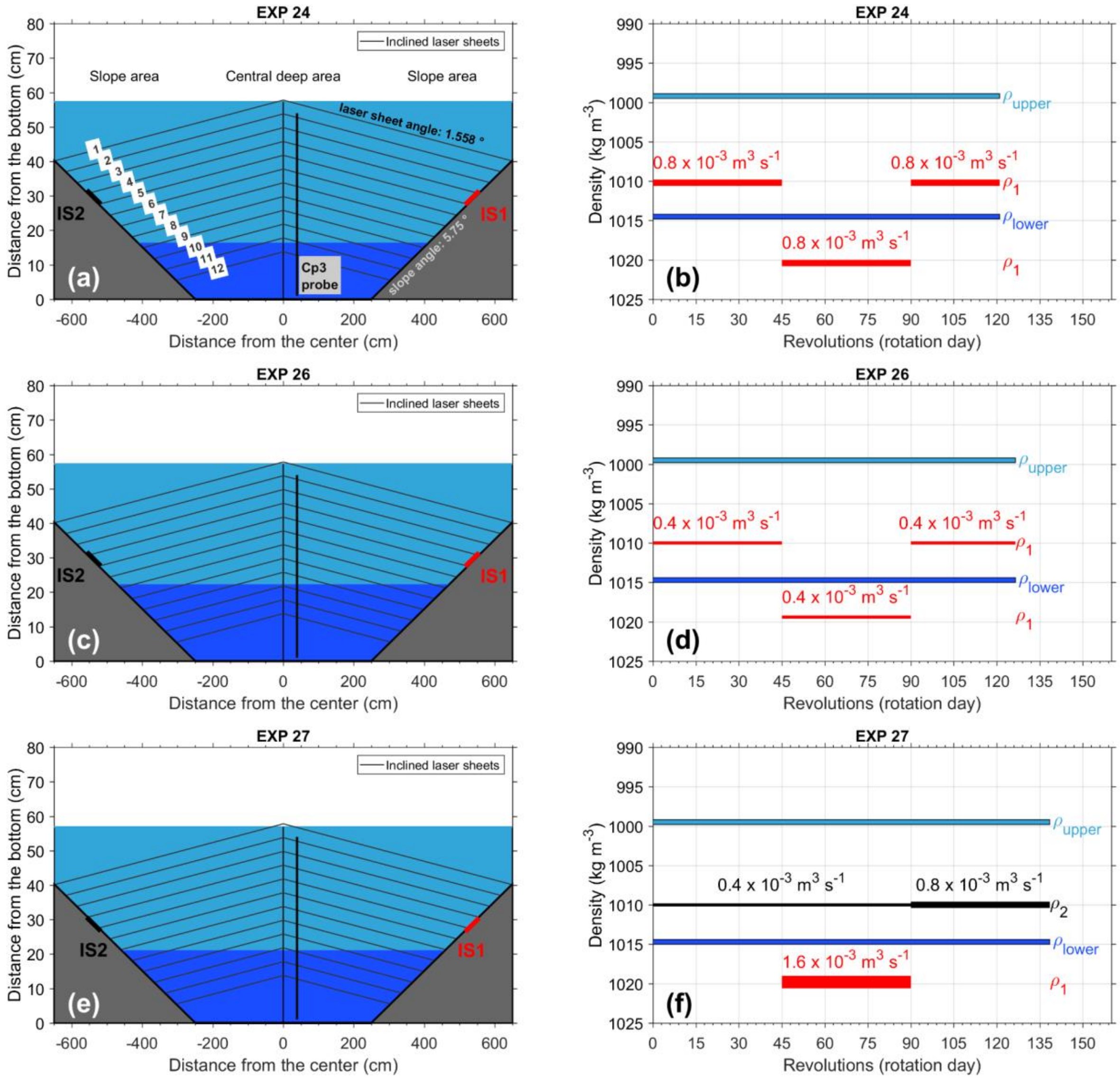

Figure 2: Scheme of the rotating tank (not to scale) and density configuration for the three experiments discussed in the paper, EXP 24, EXP 26, and EXP 27. Cross sectional view with central deep and slope areas, and injectors IS1 and IS2 (a, c, e); a vertical bar near the center of the tank indicates location of the vertical profiler Cp3; blue/cyan patches refer to the lower/upper layers; numbers from 1 to 12 indicate inclined laser sheet levels. Initial density (blue/cyan bars) in the lower/upper layers along with density and discharge rates of the injected water (b, d, e); red/black bars correspond to IS1/IS2; the thickness of the bars corresponds to discharge rates during various phases (for details see Tables 1 and 2). Only in EXP 27 were both injectors active.

figure 2 in the color tab 0-15 means that the range of density is between 1000-1015?

Reply: The Reviewer is right, and figures have been re-done using density instead of density anomalies (see new Fig. 3)