Answer to reviewer 2

This manuscript presents a study on the implementation and evaluation of a high-resolution hydrodynamic model (SYMPHONIE) over the South China Sea (SCS). The authors simulate a 10-year period and successfully replicate observed circulation patterns and water masses in the SCS. The introduction of an online computation method to assess water volume, heat, and salt budgets adds strength to the manuscript. However, there are some areas that require improvement. First, the manuscript should clearly highlight the role and advantages of the 4 km configuration, enhancing the scientific significance of the study. Second, Section 3 needs restructuring to ensure logical flow and provide a more detailed evaluation of the South China Sea Throughflow (SCSTF). Lastly, reconsidering the title to clarify the "scale" aspect would be beneficial. By addressing these issues, the manuscript has the potential to make a valuable contribution to the scientific literature on South China Sea dynamics and ocean modeling community.

We warmly thank the reviewer for the time and attention devoted to our paper, and for those positive and constructive comments. We have carefully considered all the comments and suggestions in the revised version of our manuscript. In what follows, and in the highlighted version of the manuscript, our answers and modifications are highlighted in blue. Line numbers refer to the highlighted version of the revised manuscript.

Major Comments:

1. The title of this manuscript is confusing and could be misunderstood as referring to different spatial scales of ocean dynamics rather than temporal scales. It is recommended to clarify this in the title to avoid confusion.

The initial title was "Studying multi-scale ocean dynamics and their contribution to water, heat and salt budgets in the South China Sea : evaluation of a high-resolution configuration of an online closed-budget hydrodynamical ocean model (SYMPHONIE version 249). Following this comment, as well as the modification done in the revised paper that now includes an evaluation and analysis of water volume budget over the SCS, we changed the title to "**New insights on the South China Sea Throughflow and its seasonal cycle: evaluation and analysis of a configuration at high-resolution including tides of the online closed-budget regional ocean model SYMPHONIE version 2.4"**

2. The manuscript mentions the use of a 4 km resolution, which is an outstanding feature of the configuration. It would be more meaningful to explicitly highlight the role and advantages of this high-resolution approach in the manuscript. This will enhance the significance of the "multi-scale ocean dynamics" concept, incorporating both temporal and spatial scales.

First, following this comment, and based on the literature, we better explained in the Introduction the importance of simulating realistically small scale processes, both at temporal and spatial scales, including tides, for the study of SCS dynamics. These features were not represented in most of the previous numerical studies of SCS water volume, heat and salt budgets, that used models not including tides and using resolution coarser than 10 km: we highlighted the role of small scale topographic features, especially at interocean straits, of submesoscale to mesoscale dynamics, of tides and induced mixing, which play a key role in the transformation and transport of water masses through the SCS: lines 72-73 and lines 114-126.

We moreover quantitatively showed the added-value of our high-resolution simulation compared to simulations at coarser resolution: see the answer to the following comment.

Last, our model computes online each term (lateral oceanic fluxes, surface atmospheric fluxes, river discharges and internal variations) of the water volume, heat and salt budgets. Using available (re)analysis to study those budgets indeed requires to compute them offline, based on daily, weekly or even monthly distributed outputs, thus neglecting the turbulent term of temperature and salinity lateral transports. This is not exactly an advantage of the high-resolution, but it is an advantage of our configuration compared to other products. This is now clearly stated in the introduction (lines 112-114) and explained and assessed in detail in Sectio*n 3 Added-value of the online budget computation.* With offline computation based on daily outputs, NRMSE reaches 10 to 30% for interannual variations of yearly values of heat and salt net lateral fluxes. Moreover, the online method allows to rigorously compute at each lateral strait the total inflowing and outflowing fluxes, contrary to the offline method that induces errors of the same order or even one order of magnitude larger than the values themselves (see Figure 3 and Table 2 of the revised paper).

3. The authors claim that the 4 km configuration in the South China Sea (SCS) is developed, but it is important to explain the advantages of this resolution compared to coarser resolution models. Describing these advantages will enhance the scientific significance of the manuscript.

Several groups indeed develop and distribute global or regional simulations that cover the SCS region from other models. Some of those simulations (for example reanalysis and analysis produced by CMEMS and most of HYCOM simulations used to study the area, e.g. Yang et al. 2019, Zhitao et al. 2021) include assimilation procedures toward satellite sea surface temperature and elevation data and ARGO temperature and salinity profiles. This helps them to realistically reproduce ocean surface characteristics and water masses profiles as well as their variability, but does not let them completely free to produce their own physics. Conversely, simulations without assimilation (e.g OFES simulations produced by JAMSTEC, Sasaki et al. 2020) could show lower performances regarding the representation of ocean characteristics variability, but are free to produce their own physics, making those simulations relevant to study specific ocean processes, for example interocean straits exchanges.

Following this comment, we retrieved four datasets produced from other ocean models, three global simulations (two with assimilation) and one regional simulation (without assimilation):

- CMEMS Global Ocean Physics Analysis and Forecast at 1/12° resolution (~9 km over the SCS region) available over the period 1993-now.

- CMEMS global ocean eddy-resolving reanalysis GLORYS12v1, at 1/12° resolution available over the period 1993-2020.
- OFES (OGCM for the Earth Simulator) version 2 simulation at 1/10° resolution (~11 km) provided by JAMSTEC (Japan Agency for Marine-Earth Science and Technology) over the period 1958-2016, that does not contain assimilation.
- INDESO simulation performed by CLS over the Southeast Asia region at 1/12° over the period 2009-2016, that does not contain assimilation.

We included a description of those coarser resolution simulations in section *2.4 Other global and regional models* and Table 1 of the revised paper. We then included those simulations when comparing our model results with observations data in section 4 : we show over 2010-2016 (the period common to all simulations) the time series of climatological monthly mean and interannual yearly mean of SST, SSS and SLA (Figure 5 of the revised paper), the maps of SST, SSS and SLA bias compared to data for the winter and summer period (Figure 7 of the revised paper), the T and S profiles and seasonal cycle of MLD (Figure 10 of the revised paper) and provide the associated values of bias, RMSE and correlations in Table 3 of the revised paper. The performance of SYMPHONIE is compared to the other models in the revised version of the paper in *Section* 4. *Model performance in representing sea surface and water masses characteristics* : lines 506-515 in section *4.1 Sea Surface Characteristics / 4.1.4 Comparison with other models*, lines 537-545 in *4.2 Water masses characteristics*, lines 583-588 in *4.3 Mixed layer depth*. Those comparisons show that the performance of our high resolution simulation in terms of spatial and temporal variability of sea surface characteristics, water masses characteristics and mixed layer depth is in the upper range of the 5 simulations. In particular, our model performs as well, and sometimes better, as models that include assimilation. We also mentioned this comparison in the short summary (lines 15-16), abstract (lines 25-27), introduction (lines 142-145) and conclusion (lines 788-790).

4. The structure of Section 3 is unclear. The title of Section 3.2 ("surface characteristics") overlaps with the title of Section 3.1 ("tide"), and the title of Section 3.2.3 is inconsistent with other subsection titles. It is recommended to restructure Section 3 to make it more coherent and clear.

Following this comment, and taking into account the other comments of both reviewers, we modified the structure of the paper to improve its clarity: after presenting the methods and data in section 2, we present the added-value of the online computation of budgets in section 3. We then compared our results with available satellite and in-situ data as well as other coarser resolution simulation in section 4. As explained below (comment 6), a whole section 5 was then added to evaluate the representation of water budget and SCSTF.

To make the structure of section 4 clearer, it is now divided in *4.1 Sea surface characteristics*, with *4.1.1 Tides, 4.1.2 Seasonal cycle of sea surface temperature, salinity and elevation 4.1.3,* *Interannual variations of sea surface temperature, salinity and elevation*, then *4.2 Water masses characteristics* and *4.3 Mixed Layer Depth.*

5. The analysis of Mixed Layer Depth (MLD) in Section 3.4 is interesting, revealing a robust shallower bias due to wind speed. However, considering the higher resolution, a deeper MLD might be expected, particularly in winter. It would be valuable to compare the results of the 4 km configuration with a coarser-resolution configuration.

Following this comment, we included the 4 other simulations mentioned above (comment 3, OFES, INDEOSO, COPERNICUS and GLORYS) when comparing the simulated MLD with MLD computed from ARGO in Section *4.3 Mixed Layer De*pth: see Figure 10, Table 3 and lines 583-588 of the revised paper.

All models indeed underestimate MLD (certainly due to the same reason, i.e. underestimation of wind speed in atmospheric forcing datasets), but simulate similar annual evolution of MLD. SYMPHONIE performance is in the upper range: OFES shows the smallest underestimation and NRMSE (7.3 m, 19%), followed by SYMPHONIE (9.1 m, 25%), then INDESO (10.5 m, 28%). The strongest biases and NRMSE are obtained from INDESO (15.6 m, 41%) and COPERNICUS (15.5 m, 40%), even if those models assimilate Argo profiles.

6. Since the South China Sea Throughflow (SCSTF) is mentioned as a major topic at the beginning of the manuscript, a detailed evaluation of all inflows and outflows through different straits would be expected. However, Section 3 (model evaluation) does not address these throughflows. It is recommended to include an evaluation of the SCSTF in Section 3.

Following this comment, and the comment of the other reviewer, we added a whole section about the evaluation and analysis of water volume budget over the domain, examining the contribution of lateral fluxes at the six interocean straits (Taiwan, Luzon, Mindoro, Balabac, Karimata and Malacca), i.e. the SCSTF, of rivers and of atmosphere: section *5 Evaluation and analysis of SCS interocean straits water volume exchanges and SCS water budget*, pages 32 to 42.

We first presented a synthesis of the observational and numerical estimates available from previous studies (section 5.1 and Table 4 of the revised paper). We then examined the climatological average and seasonal cycle (section 5.1.1, Figure 11) as well as the vertical structure (section 5.1.2, Figure 12) of interocean lateral fluxes of water based on the SYMPHONIE simulation. To summarize our results explained in detail in section 5.1, we showed that our model reproduces realistically the interocean water volume exchanges in terms of climatological average, seasonal variability and vertical structure. Surface interocean exchanges, especially at Luzon Strait, are all driven by monsoon winds which favor winter southwestward flows and summer northeastward surface flows. Exchanges through Luzon Strait deep layers show a stable sandwiched structure with vertically alternating inflows and outflows.

Finally, we examined the contributions of atmosphere and rivers in section 5.2 and Figure 11. To summarize our results explained in detail in section 5.2, the SCS receives on average a 4.5 Sv yearly water volume input, mainly from the Luzon Strait. It laterally releases this water to neighbouring seas, mainly to the Sulu Sea through the Mindoro Strait (49%), to the East China Sea via the Taiwan Strait (28%) and to the Java Sea through the Karimata Strait (22%). The seasonal variability of this water volume budget is driven by lateral interocean exchanges, that largely exceed atmospheric gains or losses and river gains.

We modified the short summary (lines 17-20), abstract (lines 31-38), introduction (lines 145-147) and conclusion (lines 802-830) accordingly.

For the sake of conciseness, and since the paper is already long enough, similar analysis for budgets of heat and salt and analysis of interannual variability will be presented in a future paper, as explained in the conclusion (lines 831-840).

Minor Comments:

1. Maintain consistency in the expression of water volume, using consistent terminology throughout the manuscript (e.g., water, volume, or water volume).

→ We chose “water volume” and carefully checked that we used this terminology consistently throughout the manuscript.

2. In Line 218, consider including river fluxes in Section 2.2.2 (lateral fluxes) for better organization.

→ The term “lateral fluxes” actually refers to fluxes through lateral open ocean boundaries, i.e. interocean straits. We corrected our text to make things clearer: in the revised manuscript, we kept separate the sections for lateral oceanic fluxes and river fluxes, since they are computed differently, but added the word “oceanic” with “lateral” throughout the text and moved the section about river fluxes (now 2.2.3) just after the section about lateral oceanic fluxes (now 2.2.2) for consistency.

3. In Figure 2, it is difficult to discern the difference between the simulation and tidal product. Including a column for bias would enhance clarity.

→ Done : we added bias maps in Figures 3 (tide gauges) and 4 (FES2014b).

4. Figure 4 should include the bias information. Adding the bias to the figure will improve interpretation.

→ Done : we added bias maps in Figure 7.

5. In Lines 312, 314, 361, 408, 479, etc., add units for the variables.

→ Units (psu) are added everywhere for salinity in the revised manuscript.

6. In Line 396, consider revising to "Therefore, our simulation accurately represents..."

→ Done (lines 534-535)

7. The numbering in the caption of Figure 7 is incorrect, as "(c)" is used twice. Adjust the numbering accordingly.

→ Indeed, this was corrected. We have verified and adjusted the numbering of all figures in the revised manuscript

8. Maintain consistency in formatting, ensuring that there is either a space or no space between paragraphs throughout the manuscript.

→ We have adjusted the formatting, ensuring that there is a space between each paragraph.

References

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