Answer to reviewer 1

The authors utilized the SYMPHONIE model's kernel to conduct a simulation of higher resolution (4 km) compared to previous studies. They evaluated the performance of this simulation by comparing it with satellite and field measurements. The errors in online and offline computation of lateral fluxes were estimated. The logical flow of the manuscript is clear. However, based on my evaluation, this simulation did not provide new and insightful information about the dynamics of this large-area marginal sea. Therefore, I cannot support accepting this research in its current stage. I would like to highlight the following major concerns for the authors' consideration:

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.

1) The authors claim that this simulation benefits from higher horizontal resolution, but it is unclear how. Were frequently used models like HYCOM, GLORYS12V1 from CMEMS, and OFES simulation shown to perform poorly compared to the regional simulation presented in the manuscript? It is essential to thoroughly compare this simulation with frequently used models, particularly when the circulations in the study area, such as the South China Sea (SCS), are influenced by complex internal and external forces. If these later simulations performed better than the configurated one, I don't think a publication of this manuscript will contribute to the community.

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, Zithao 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 first 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.

Second, 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).

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 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).

2) The circulations in the SCS have not been adequately validated. For instance, the authors mention the significance of the SCS Throughflow, which plays a predominant role in defining the SCS circulation. It is crucial to further validate whether the intensity and structure of this flow are accurately represented in the simulation.

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. To summarize our results explained in detail in section 5.2, we showed that our model reproduces realistically the interocean water volume exchanges in terms of climatological average, seasonal variability and vertical structure.

Finally we examined the contributions of atmosphere and rivers in the water volume budget in section 5.2 and Figures 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 neighboring 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).

3) The simulation covers the period from 2009 to 2018, and the discussion also focuses on this period. Why was there no mention of the simulation requiring time to spin-up to eliminate distortions caused by abruptly imposed forcings?

We thank the reviewer for pointing out this issue. The spin-up of a model involves two time scales: the physical spin-up time scale and the numerical spin-up time scale.

The physical spin-up scale is very long, of the order of several to tens of years depending on the size of the domain. The goal is to establish ocean circulation from an initial state at rest (i.e. zero current). For example, simulations done with the NEMO model at 1/12° over the Mediterranean Sea, i.e. a domain of comparable size, depart at rest from the climatology and apply a 10 year spin-up to activate the Mediterranean circulation (see Waldman et al. 2018). However, this spin-up does not apply in our case since we don't depart from rest: it only concerns the CMEMS analysis (that uses NEMO at 1/12° over the global ocean), which provides the initial state (including currents) and lateral boundary conditions for our model.

The numerical spin-up scale mainly concerns the adjustment of the initial physical fields to the specific constraints of our grid, for example its bathymetry, which is not exactly the same in our model and in CMEMS analysis, although it is close since it is constructed from the same GEBCO database. Moreover, because of the difference in horizontal resolution, the spectrum of wavelengths represented by our grid is slightly broader than that of the CMEMS analysis. There is therefore a physical spin-up at short wavelengths (those represented by our grid but not by the CMEMS grid). This spin-up lasts for a few months, as can be seen on Figure A below that shows the integral of kinetic energy over the computational domain. In the revised version of the paper, we therefore removed year 2009 from the simulation, and analysed it between 01 January 2010 and 31 December 2018. Note that the results and conclusions were not significantly impacted by the removal of the first year of computation: see for example Table A below where we show the comparison between SYMPHONIE outputs and SST, SSS and SLA observations in average over the domain.

Following this comment, we added a paragraph in section 2.1.2 to explain this (lines 180-183), performed all our analysis (evaluation and computation of fluxes) over the period 2010-2018 (or 2010-2016 when comparing with data or other models that were not available after 2016), and modified the figures and text accordingly throughout the revised paper.

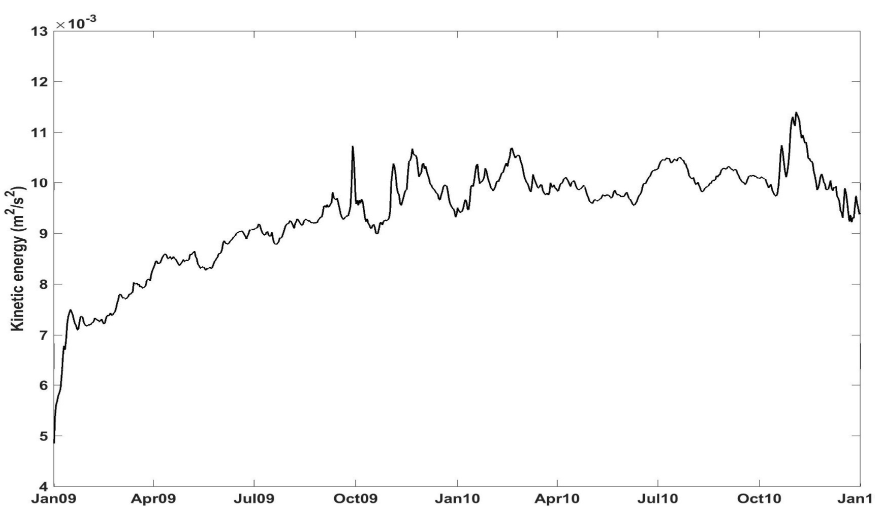

Figure A: Kinetic energy (sum of the square root of u and v - velocity following x and y axis) over the computational domain for the first two year of simulation (2009 - 2011)

Table A : Mean bias, correlation coefficient and NRMSE (for the monthly climatological cycle and interannual time series of yearly average) in SYMPHONIE compared to data (OSTIA for SST, SMOS for SSS and altimetry for SLA) over the periods 2009-2018 and 2010-2018.

Models	Bias			Correlation coefficient R annual cycle / *interannual*			NRMSE (%) annual cycle / *interannual*		
	SST (°C)	SSS	SLA (m)	SST	SSS	SLA	SST	SSS	SLA
SYMPHONIE 2009-2018	-0.18	-0.04	8.6E-5	0.99 $p<0.01$ *0.94* *$p<0.01$*	0.91 $p<0.01$ *0.91* *$p<0.01$*	0.97 $p<0.01$ *0.88* *$p<0.01$*	5.71 *27.3*	18.9 *20.0*	12.0 *18.5*
SYMPHONIE 2010-2018	-0.18	-0.04	-4.5E-4	0.99 $p<0.01$ *0.94* *$p<0.01$*	0.91 $p<0.01$ *0.91* *$p<0.01$*	0.97 $p<0.01$ 0.90 $p<0.01$	5.73 26.2	18.9 20.0	9.92 17.5

4) The computational domain does not include the source region of the Kuroshio current (e.g. the NEC), which extensively intrudes into the SCS through Luzon Strait. Consequently, the dynamics of this important western-boundary current are not adequately addressed. It would be valuable to assess whether the intensity of the Kuroshio intrusion in the Luzon Strait aligns with observations of volume transport.

Following this comment and the previous comment 2), we added a whole section (Section 5, pages 32-42) about the evaluation of water budget of the SCS and of its components, including the six interocean straits, in particular the Luzon Strait. The climatological values, seasonal cycle and vertical structure of fluxes at the interocean straits is addressed in section 5.1 (*Evaluation of water fluxes at interocean straits,* pages 33-41*)* that includes 5.1.1 (*Climatological mean values and seasonal cycle,* pages 37-38*)* and 5.1.2 (*Vertical structure,* pages 38-41*)*. To summarize our results explained in detail in section 5.1, we showed in particular that our model reproduces realistically the interocean water volume exchanges at Luzon Strait in terms of climatological average, seasonal variability (lines 630-643) and vertical structure (lines 694-706). Surface interocean exchanges at Luzon Strait are 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.

We modified the abstract (lines 31-32 and 35-38) and conclusion (lines 807-808 and 827-828) accordingly.

5) Among the widely used numerical simulation kernels, mass conservation is typically replaced by volume conservation under the incompressible assumption. Therefore, volume should be conserved in the computational domain, while salinity and temperature may not be conserved due to additional sources and sinks. I would appreciate it if the authors could explain why "The variation of heat content HC between times t1 and t2 (ΔHC) is equal to the sum of all heat fluxes exchanged within the SCS domain between t1 and t2" is used for heat balance.

   Additionally, why are evaporation-precipitation (E-P) and river discharge excluded from the computation of salt flux? Changes in salinity resulting from E-P and river discharge significantly affect the salinity and, consequently, the budget presented in the manuscript.

The SYMPHONIE model is based on the Navier–Stokes primitive equations under the hydrostatic equilibrium hypothesis, incompressibility hypothesis and Boussinesq approximations (see Marsaleix et al. 2008). Similarly as in other ocean models (e.g. NEMO, ROMS, HYCOM), the discretization of equations ensures the conservation of volume, heat and salt contents. This does not mean that the total volume, temperature and salinity integrated over the domain does not change, but means that during every time step, the variation of volume, heat and salt content over the numerical ocean domain is rigorously equal to the net sum of volume, heat and salt input (sources) and output (sinks) at the boundaries of the domain. This is indeed what we obtain when we plot the net sum of inputs and inputs and the variations : see Figure 2 a,b,c of the revised paper. For water volume and heat, lateral ocean boundaries and atmosphere can be sources and/or sinks, and rivers are sources: precipitation and evaporation, shortwave, longwave, latent and sensible heat fluxes at the air-sea interface, river discharge. For salt, the only source/sink is lateral boundary conditions. The salinity of water going to or coming from to the atmosphere and the rivers is indeed assumed to be zero, i.e. there is no input or output of salt from surface atmospheric fluxes and river runoff since rainwater, river water and evaporated water do not contain salt. It should be noted, however, that evaporation, precipitation and river discharge are not sources/sinks of salt, but are sources/sinks of salinity for the ocean domain: although they do not affect the salt budget of the ocean domain, atmospheric and river fluxes do modify the salinity budget, as they affect the water volume budget. Assuming for example a closed domain with no open oceanic lateral boundaries, precipitation and river discharge alone would result in an increase of the total volume with no variation of the total salt content, i.e. in a decrease of salinity. Similarly evaporation alone would result in a decrease of water volume with no variation of salt content, i.e. an increase of salinity.

Following this comment, we added text in section 2.2.1 to better explain this (lines 206-209 and lines 227-231).

6) The simulation was forced with Harmonic Constants from FES2014b, and then the simulated heat content (HC) was compared to FES2014b itself. I may suggest the authors collect record of tidal elevation from tidal gauges and conduct validation.

FES2014b tidal solution is produced from the FES (Finite Element Solution) tidal model. FES2014b assimilates altimetry and tide gauges data (see Carrère et al., 2016 and https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes/description-fes2014.html), which allows it to reach an unprecedented level of precision and to show accuracy that is superior to the previous versions, in particular to versions without assimilation. We therefore use FES2014b to provide harmonic constants to our simulation, but only at the lateral boundaries of the numerical domain, which are located outside the SCS. We can moreover use it as a reference to evaluate the tidal solution produced by the model over the inner domain, as shown by Piton et al. (2020) over the Gulf of Tonkin. In the open sea, FES2014b is indeed very close to altimetry.

Complementary to that, we agree that comparing our results with tide gauges data is very relevant for the coastal area. We therefore retrieved tide gauges data available from GESLA3.0 (Haigh et al. 2023). Comparing our results with those data and with FES2014b confirms that SYMPHONIE reproduces realistically the tidal solution both over the coast (see Figure 3 of the revised paper) as well as in the open sea (see Figure 4 of the revised paper).

Following this comment, we described tide gauges data in Section *2.3.2 In-situ data*, included the comparison with tide gauges data in section *4.1.1 Tides* (lines 378-385 and Figure 3) and added some text to explain the way we use FES2014b complementary to tide gauges data (lines 390-393).

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