Review of

"Assessing Vertical Coordinate System Performance in the Regional Modular Ocean Model 6 configuration for Northwest Pacific" (https://doi.org/10.5194/egusphere-2025-3211)

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General comments

This manuscript aims at investigating the sensitivity of a regional MOM6-based mesoscale-rich ocean configuration of the Northwest Pacific (NWP) to the type of vertical coordinate system employed. Two configurations differing only on the vertical grid are compared: one, named ZSTAR, adopts a widely used quasi-Eulerian z*-scheme while the second, named HYBRID, employs a flexible hybrid z*-isopycnal Arbitrary Lagrangian-Eulerian vertical coordinate.

The assessment is conducted comparing model simulations against observational and reanalysis data for the surface and vertical structure of the active tracers, MLD, SSH, surface currents and EKE, volume transports and tidal amplitudes and phases. The methodology is quite straightforward, and the analysis includes standard statistics.

Results indicate that at the surface, both configurations present similar biases while at depth the HYBRID configuration is able to reduce spurious diapycnal mixing in the interior of the deep ocean, significantly improving the representation of the North Pacific Intermediate Water in comparison to the ZSTAR configuration. HYBRID shows superior skill over ZSTAR also in simulating tides in shallow regions such as the Yellow Sea. However, HYBRID presents significant biases in representing upper and mid-depth water masses at high latitudes, a problem that the authors attributes to the coarse vertical resolution that the HYBRID configuration tends to have in weakly stratified regions. The latter is also a well-known limitation of classical isopycnal models.

The analysis is solid and the study quite innovative and informative, being isopycnal coordinates (either pure or hybridised) rarely used in regional configurations where the stratification can be quite weak, especially in shallow areas with strong tides. The manuscript is very well written and fits well the scope of the journal. However, I do have few remarks/questions that might require some additional simulations. For this reason, publication is recommended after major revision.

Major remarks

My main criticism concerns the setup of the vertical grid of the HYBRID configuration. As stated by the authors, HYBRID uses the same target densities of Adcroft et al. 2019, a global ocean configuration where the target density range was chosen to fulfil the needs of a model domain covering the entire globe. In the case of a regional model like the one described in this paper, the extension of the model domain is much more limited in the meridional direction, allowing one to use a narrower range of target densities. I think that Fig. S4 and the biases that HYBRID presents at the high-latitudes clearly demonstrate that the chosen target density range was not optimal for the domain of this study – according to Fig. S4, HYBRID seems to have on average ~ 10 active layers less than ZSTAR! Consequently, I believe the comparison between the two vertical coordinate system is not fair, and I think it would be great if the authors could add one more simulation where the target density range is more tailored to the regional domain of this study. This additional simulation could allow us to understand whether the problems that the authors are reporting in the case of HYBRIDS are due to its not-optimal setup or there are intrinsic limitations in the z*-isopyncal vertical coordinate.

Specific comments

L89: MOM6 introduces a "significantly different algorithm" compared to previous versions -> can you be a bit more specific?

L149: "layer thickness of 2 meters extending to a depth of 14 meters in the ZSTAR space." -> does it mean that the thickness of the upper layer is 2m? If yes, I think it could be too thick – e.g. Bernie et al 2005 and Siddorn & Furner 2012 recommend a resolution of ~1m to properly model diurnal SST variability – and this could possibly be one of the causes behind the SST biases you are seeing in both ZSTAR and HYBRID, please clarify.

L151-155: "The transition depth between the isopycnal and ZSTAR coordinates deepened toward higher latitudes (Adcroft et al., 2019)" -> could you please clarify how the hybrid vertical coordinate works – a sketch or plot showing a vertical section with grid layers and the topography would be very helpful.

Also, it is not clear to me what happens on the shelf: because of the shallow depths, the unstratified bottom boundary layer can be quite thick, and is not unusual that it merges with the upper mixed layer, generating a well mixed water column, especially in regions where tides are strong. In such a regime, I see the usage of isopycnal coordinates quite challenging … for example, according to Fig. S4 it seems that in shallow areas HYBRID has much less active layers than ZSTAR …

L148-157: what formulation of bottom friction is used by the two configurations? What type of lateral boundary conditions are used in the case of the ZSTAR model? How is represented the bottom topography with ZSTAR, with full or partial steps?

L251: "where u' and v' represent deviations of the zonal and meridional velocity components from their respective means." -> averages over which period?

L322-324: It seems to me that in the South China Sea and across the open ocean it is actually the contrary - i.e., HYBRID has a slightly larger positive bias than ZSTAR - see Fig 4 – please clarify.

L336: ", with ZSTAR showing stronger positive biases in the open ocean and ..." -> It seems tom me that in the open ocean the two model are in the same ballpark, with ZSTAR sightly better than HYBRID in terms of warm bias ... please clarify.

L341-344: you already said this at L336-337 - you may want to merge and simplify the text here.

L356: "15 m compared to ZSTAR in the open ocean" -> perhaps "Southern open ocean"?

L362: Perhaps you were meaning Fig. S2?

Fig. 9 -> Vectors are not clear (I can not see them), perhaps you may consider avoiding plotting them ...

L456: "HYBRID achieved a slightly lower RMSE (138.46 cm^2/s^2) than ZSTAR (138.86 cm^2/s^2)" -> to me, they are very similar ...

L478: "The Yellow Sea is characterized by the Yellow Sea Bottom Cold Water Mass (YBCWM), a cold and dense water mass that forms near the bottom. However, both configurations showed positive temperature biases exceeding 2°C near the bottom, suggesting limitations in accurately representing YBCWM" -> is this an indication that actually in the Yellow Sea the two models are using a similar vertical discretization – mainly z* levels? Fig. S4 seems to support this conclusion (the difference in active layers in the Yellow Sea is <= 6). This links to the previous comment: it would be great if you could clarify how the hybrid vertical coordinate works in shallow areas (a plot would be very helpful).

Fig. 11: Are the discontinuities in the HYBRID profiles seen in, e.g., panel (b) at around 800m or panel (c) around 400m, due to the transition from z* to isopycnal levels?

L620-622: "Overall, the HYBRID configuration tended to overestimate transport, particularly through the Tokara and Tsugaru Straits, while underestimating it in the Soya Strait. In contrast, ZSTAR generally underestimated transport, as observed in the Korea/Tsushima Strait and Soya Straits." Could the authors try to explain possible reasons for this? Could it be due to the fact that both configurations use the same formulation and coefficients for the bottom friction, but the ZSTAR configuration has some additional drag from the lateral boundary conditions (assuming ZSTAR uses a no-slip LBC, please clarify)?

L652-655: This seems to be in agreement with Wise et al. 2022, that shows that better resolving the bottom topography (terrain following and multi-envelope vertical coordinates versus z*-levels with partial steps) allows for a more accurate representation of the tides. Also, Graham et al. 2018 and Bruciaferri et al. 2022 showed the detrimental impact of the 10m minimum depth approximation on the tidal propagation, especially in shallow areas. This could explain the consistent underestimation of tidal amplitude in both configurations in the Yellow Sea. Please consider discussing here how the two configurations differ in the representation of the terrain and how this could explain the better performance of HYBRID.

L659: “computational efficiency”-> can the authors quantify this for this domain?

L683: “lower salinity biases” -> but the temperature biases seem to me much larger (Fig 12e) – please clarify.

L694-695: “While such processes facilitate surface-to-interior interactions, they likely contributed to the observed temperature and salinity biases (Figs. 12 and 13).” -> could the authors please clarify a possible mechanism for this?

L701-702: “This reduction in active layers likely contributed to the increased temperature and salinity biases observed in HYBRID, underscoring the challenges of using isopycnal coordinates in high-latitude environments.” -> I think Fig S4 shows that HYBRID has fewer active layers not just at high latitudes, but everywhere …. As I mentioned before, are we sure these are intrinsic difficulties of the hybrid z*-isopycnal vertical coordinate and not due to the not-optimal configuration of the HYBRID vertical grid?

L703-704: “modifications to the target density profile could enhance vertical resolution and better capture stratification” -> could the authors clarify why they chose to use a global setup in a regional model?

L725: “HYBRID’s improved tidal amplitude simulation is likely linked to its enhanced representation of stratification.” -> or to a better representation of flow-topography interactions in comparison to ZSTAR?

L729-731: “further investigation is needed to clarify the mechanisms through which different vertical coordinates influence tidal dynamics, particularly the generation, propagation, and dissipation of baroclinic tides.” -> The 10m minimum depth approximation could be one possible candidate (see Graham et al. 2018 and Bruciaferri et al. 2022).

<u>References</u>

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