Response to Reviewer #2

We thank Reviewer #2 for the valuable feedback. We have reviewed all comments carefully and incorporated them into our revised manuscript. Our responses are indicated in blue, and modifications to the text in red. The line numbers correspond to those found in the original manuscript.

General comments:

This study evaluates the seasonal forecast by statistical and model forecast methods. Among the three forecasts, ocean inertia in the ECCO forecast seems to outperform the other two at lead time of four months. It is interesting but not surprised to see the importance of model initial conditions and ocean inertia. One important unanswered question is why the climate model forecast (SEAS5) including both ocean initial conditions, ocean dynamics and full atmospheric forcing has less predictability than the ECCO forecast without atmospheric forcing. It could be better to have seasonal forecasts with ECCO that include both inertial condition and atmospheric forcing to answer the above question. If there is no such ECCO forecast, it is better to think about some method to illustrate how atmospheric forcing act along with or counteract ocean inertia in the ECCO or SEAS5 model.

We appreciate the reviewer's feedback. Long et al. (2021) demonstrated that climate models can produce skillful seasonal sea level forecasts in the tropical and subtropical open ocean, and SEAS5 is one of the best-performing models. In the coastal regions of the Northwest Atlantic, it's challenging for climate models to generate skillful forecasts, and the potential reasons have been discussed in previous studies (e.g., Frederikse et al., 2022; Long et al., 2025). The skill of climate models depends on the accuracy of initial conditions and representation of atmospheric/oceanic processes and air-sea coupling. With a fully coupled model like SEAS5, it is difficult to determine exactly what causes the low forecast skill. This could be biased from poor initial conditions, unrealistic air-sea coupling, inadequate skill in atmosphere forecasts, or some combination of these factors.

ECCO dynamic persistence forecast is an initialized ocean model running with prescribed climatology atmosphere forcing. It provides an opportunity to evaluate the predictable signal due to ocean dynamics while limiting the direct influence from external atmospheric forcing. We hope that reporting indications of improved sea level forecasting skill using the ocean-dynamic persistence framework will encourage further testing of this method, especially by the modeling centers that produce the operational forecasts. For example, it would be interesting to compare SEAS5 with its ocean-dynamic equivalent, should such an experiment be performed.

The potential reasons for the lack of skill in SEAS5 have been discussed in lines 323-326. Additionally, we revised the manuscript to clarify our motivation further.

In line 40, we added “*For coastal sea levels at such locations, seasonal forecast skill is perhaps limited by inaccurate initializations of the climate models (Feng et al., 2024; Widlansky et al., 2023), simulation biases in the coupled atmosphere-ocean system (Meehl et al., 2021; Roberts et al., 2021) and low predictability of the wind stress anomalies (Newman et al., 2003; Obarein et al., 2023).*”

We revised lines 110-111 to “*The atmospheric state variables from the ECCO optimization are used to force the ocean model, with surface fluxes of heat, momentum (wind stress), and freshwater being computed externally.*”

In line 113, we added “*This flux-forced model configuration allows us to isolate the effect of ocean dynamics on the seasonal sea level forecast, while excluding the potential biased atmosphere forecast and ocean-atmosphere interactions.*”

Regarding the suggestion to explore the role of atmosphere forcing in ECCO dynamic persistence forecast, unfortunately, we currently do not have such experiments (i.e., ECCO forced with a realistic or forecasted atmosphere). Such an investigation is planned, should the necessary experiments be conducted.

Specific comments:

One concern is how well ECCO or climate model simulates coastal sea level at the tide gauges along the coast compared to observations, even though the authors shows evaluation at four locations in Fig. 5. For example, both ECCO and SEAS5 have low-resolution so that they may not be able to resolve the coastal sea level variability. It’s not a good idea to use one model that cannot simulate the coastal sea level very well.

Model horizontal resolution impacts how well sea level variability is reproduced, especially in the Gulf and East Coast regions. Feng et al. (2024) showed more realistic U.S. East Coast sea level variability associated with high-resolution reanalyses like GLORYS12 and HYCOM. However, eddy-permitting reanalyses like ORAS5 can still reproduce most of the coastal sea level variability (see Fig. 6 in Feng et al., 2024 and the figure below). SEAS5 is the operational forecast system that uses the same models and configuration as ORAS5. We agree with the reviewer that a higher resolution ocean forecast may have better performance, unfortunately, there is no global ocean forecast available at eddy-resolving resolution for the seasonal lead times considered here.

The ECCO dynamic persistence forecast was produced with a similar ocean model configuration as the ECCO state estimate (ECCO V4r4). The ACC of ECCO V4r4 (see the figure below) shows that it has better skill than ORAS5 along the Gulf Coast, comparable skill along the Southeast Coast, and less skill along the Northeast Coast. Despite the weaker performance along the

Northeast Coast, the ECCO dynamic-persistence forecast achieves a higher ACC than SEAS5 after lead-4 month (Fig. 5 in the manuscript). It is perceivable that more sophisticated dynamic persistence frameworks (i.e., with improved initializations and higher model resolutions) will achieve a better skill.

In line 110, we added two sentences and a new figure to demonstrate the skill of ECCO and ORAS5. "*Despite its coarse resolution, ECCO V4r4 can reasonably reproduce coastal sea level variability (Figure 2). Along the Southeast and Gulf Coasts, ECCO V4r4 shows comparable ACC and RMSE to eddy-permitting ocean reanalyses such as ECMWF's Ocean ReAnalysis System 5 (ORAS5; Zuo et al., 2019).*"

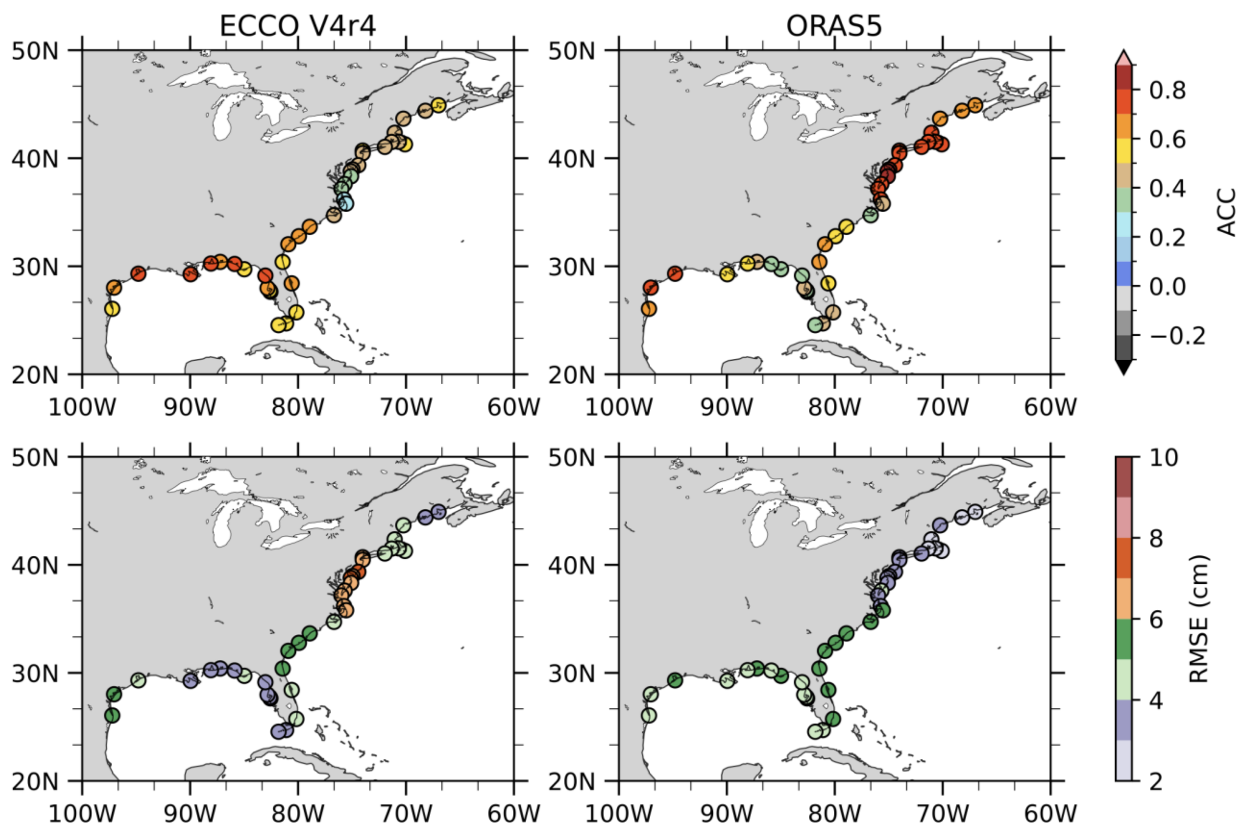

Figure 2. ACC and RMSE of monthly sea level anomalies from the ECCO state estimate and ORAS5 with water level gauge observations. The ORAS5 assessment is modified from Feng et al. (2024).

Atmospheric forcing cannot be neglected in the sea level forecast. Is there ECCO seasonal forecast that includes atmospheric forcing so that you can compare the roles of atmospheric forcing with ocean inertia? If observed wind forcing make the forecast worse, the bad forecast might be related to some deficiencies of numerical models.

Atmospheric forcing clearly affects the coastal sea level variability (Piecuch et al., 2016; Zhu et al., 2023). However, in an operational seasonal forecast model, the atmospheric forcing is predicted from the coupled climate model. Limited predictability of the atmosphere at seasonal lead times, especially near the U.S. East Coast, likely limits the potential predictability of the ocean. Why SEAS5 does not achieve at least the same skill of ocean dynamic persistence using the ECCO model remains an interesting question, which could be answered perhaps by examining the role of ensemble size, erroneous initial conditions, and/or other modeling deficiencies.

Line 171-172. Comparing Fig. 1a with Fig. 1e seems not supportive for this statement. Pointing out the specific region where the climate model has better performance might be helpful.

The sentence was meant to compare the climate forecast to the dynamic persistence. We revised the sentence to "The climate forecast performs particularly well for a broad area of the subtropical Atlantic Ocean, where its ACC values equal or beat *dynamic persistence*."

Line 256-258. Because sea level in the targeted month is derived from previous months, "damped persistence of ECCO or observation" somehow considered all processes including ocean dynamics but in a statistical way.

A damped-persistence forecast at one location does not account for ocean dynamics, meaning it relies solely on local observations without considering remote information when predicting sea levels. For instance, consider a forecast for some location "X" in the future, a damped-persistence forecast is based exclusively on preceding observations at X, while a dynamic persistence forecast takes into consideration the ocean state in all other locations (both open oceans and other coastal regions), as these non-local signals may be dynamically advanced to location X.

Fig. 6 might also suggest that ECCO data with full forcing (damped ECCO) cannot capture coastal sea level very well. Are there other model forecast results with good performances in simulating coastal sea level?

Assessments of ECCO dynamic persistence before Figure 6 are all compared with observations, despite the dynamic-persistence forecast using the initial condition from the ECCO state estimate. As we stated earlier, the skill of dynamic persistence stems from the initial condition being advanced through ocean dynamical processes. Thus, when we compare dynamic persistence skill with damped persistence of observations, the difference in initial condition and non-local ocean memory both contribute to the skill difference. In Figure 6, the skill assessment is based on verification with the ECCO state estimate instead of observations, meaning that we conduct the forecast assessment in the framework of assuming that the ECCO state estimate is reality. This assessment more clearly isolates the benefit of ocean dynamic persistence, compared to damped persistence. Therefore, Figure 6 demonstrates the advantages of including the non-local ocean memory (i.e., ocean dynamics) compared to damped persistence (i.e., local ocean memory), because here the two frameworks use the same initial conditions.

We added "*Here, these forecasts are evaluated against the ECCO state estimate.*" to line 254 to make our point clearer.

Line 270-271. The weak variability in this model's predicted monthly sea level anomalies is expected because atmospheric forcing except the climatology is included in the ECCO forecast and ECCO has coarse resolution to resolve coastal sea level. Again, some numerical models have difficulty to simulate coastal sea level variability.

We revised Section 4 and expanded the discussion about explanations and implications of the weak variability of sea level anomalies from the dynamic-persistence forecast.

Lines 306-310: "*However, the dynamic-persistence forecast only captures seasonally-predicable forcings on the ocean, thereby simulating how oceanic initial conditions evolve according to a climatological atmosphere. As a result, sea level variability predicted by dynamic persistence tends to be much weaker compared to what is observed in the real ocean forced by actual atmospheric conditions. The climatological atmospheric forcing used in the dynamic-persistence forecast tends to restore the ocean toward a seasonally steady state, while friction and mixing gradually dissipate existing sea level anomalies, resulting in reduced sea level variability over time (Sérazin et al., 2014). ECCO's coarse resolution (nominally 1°) may also contribute to its weak variability at all leads, and there is emerging evidence that much higher resolution (i.e., finer than 0.25°) is probably necessary to well resolve sea levels along the Gulf and East Coasts (Feng et al., 2024; Little et al., 2024). Our attempt to scale the dynamic-persistence forecast by its SD did not yield better skill according to the RMSE metric."*

Concerns about "some numerical models have difficulty to simulate coastal sea level variability" are addressed in our response above to Question 1.

Line 301-304. The differences between climate models might also contribute to the forecast differences.

We revised the sentence to clarify the statement:

"The better performance of dynamic persistence compared to damped persistence can be attributed to the ocean's ability to retain the memory of initial conditions, particularly through its high thermal inertia as well as processes such as Rossby waves and horizontal advection, which can influence sea levels over time."

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