

EGUSPHERE-2026-3057

“A dynamical downscaling approach for the improved representation of sub-annual coastal sea level variability: the importance of shelf and slope ocean dynamics”

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Response to Reviewers - RC4 - Referee #4

An analysis of dynamically downscaled seasonal predictions from SPEAR global seasonal predictions using regional MOM6 is presented. The downscaled predictions are compared with the native global predictions to show the benefit of downscaling. Improved spatial resolution in MOM6 allows realistic bathymetry and an enhanced shelf response to overlying winds. These improvements then lead to improved coastal sea level characteristics in the downscaled predictions. The presented analysis shows mechanistic underpinnings of the open-ocean to coastal dynamical transition which I believe adds to our understanding of the added value of dynamical downscaling. The manuscript is well composed and focused. I have only minor comments. It would help the readers if the authors consider the following comments and suggestions regarding their manuscript:

Methodology:

How were the SPEAR seasonal retrospective predictions generated? The authors, at multiple instances (Lines 119-120, 233-234), state that the winds in both SPEAR and the regional downscaled model are the same and hence any improvement in the quality of hindcasts has to be due to other factors or to the differing response to the same wind field. But, I believe the authors are aware that SPEAR is a coupled model and the SPEAR ocean would feed back onto the SPEAR atmosphere. Such feedback is, by design, absent in the regional MOM6 retrospective predictions. The authors point this out in Lines 97-100 but then still assert that both SPEAR ocean and MOM6 ocean see the same winds. I would suggest that the authors be careful about their statement that the atmosphere in SPEAR and the sampled (6-hourly or daily) atmospheric forcing from SPEAR, with which MOM6 was forced, are identical and hence the consequences on their interpretation of results.

Thank you for this comment. We have revised language in the manuscript. As you note, NWA12 is missing atmosphere-ocean feedbacks. We have added detail to further describe this configuration. Our response to Referee 2 is repeated below.

The NWA12 regional model configuration use here calculates the relative wind to determine the stress to apply to the ocean; in other words, the NWA12 ocean surface current was subtracted from the SPEAR winds being applied. We acknowledge that the use of relative wind forcing in a high resolution uncoupled ocean model can often have an overly strong eddy killing effect (e.g., Renault et al. 2020). In recent experiments with a different atmospheric forcing product, we found that using a correction similar to Renault et al. 2016 to make the wind forcing closer to absolute rather than relative to the current increased the eddy kinetic energy in the model. Therefore, we expect that the increased sea level variance in NWA12 would be boosted even further if this correction was included. To address this comment, we have inserted a description of how the wind forcing was applied into the methods (L91-93).

“While surface ocean conditions do not feed back onto the atmosphere, wind stress calculations in NWA12 account for relative air-sea velocity, with NWA12 surface currents subtracted from the SPEAR surface winds.”

Can the authors add an objective analysis to support that five ensemble members are sufficient for their seasonal prediction framework in the context of Figures 10, 11 and 12?

We now show ensemble spread in Figures 4 and 13. Excluding northern stations, the lack of overlap between SPEAR and NWA12 shaded regions suggest distinct drivers of variability. Plans for running forecasts include increasing the number of ensemble members to gain statistical power. Here, we determined five ensemble members was sufficient to identify SPEAR and NWA12 differences relative to internal variability. Comment added (L320-321).

“For single year forecasts, we plan to generate a larger ensemble to enhance statistical robustness. Five ensemble members were chosen here to focus on parent and downscaled model differences relative to internal variability.”

Results:

In Figures 6, 7, 8 and 9, observations-based maps and differences are not shown. The regression pattern in Figure 7 and 8 seems to be same in SPEAR and MOM6 with only the magnitude of the regression coefficients changing. It would help to see how much underestimation does SPEAR have and how much under- or overestimation, if any, does MOM6 have. Is the enhanced response of MOM6 to SPEAR-derived winds realistic?

We have added a new figure (Figure 7) which compares SPEAR, NWA12, and observed variance, including NWA12/SPEAR variance ratios, for each tide gauge station. Figures 4 and 5 highlight SPEAR and NWA12 representation of coastal sea level variability across timescales and relative to observations (comparisons made at nine tide gauge stations). These frequency spectra show SPEAR to have less energy across all but the northern-most stations and at lowest frequencies, indicating the pattern and extent of SPEAR under-estimation. The pattern of these differences is extended to all 15 the tide gauge stations in Figure 7 and assessment of over-/under-estimation relative to observations is included (L189-198).

“At the fifteen tide gauge stations considered here, SPEAR and NWA12 variance differences are explored more closely and alongside station depth differences and observed variance (Fig. \ref{f7}). At nearly all stations, coastline-adjacent NWA12 grid cells are shallower than those in SPEAR (Fig. \ref{f7}, left). These differences, greatest north of Cape Hatteras and along the Florida coastline, contribute to a decrease in SPEAR coastal sea level variance arising from less coastal amplification or shoaling. Diagnosed IB contributions compare favorably to reanalyses and when added to model coastal sea level variance, NWA12 values approach observed values (Fig. \ref{f7}, middle). Ratios of NWA12 to SPEAR variance (Fig. \ref{f7}, right) reveal a five-fold or greater increase in coastal sea level variance in this region that is largely constrained to shorter timescales. Further north, SPEAR and NWA12 stations show comparable variance suggesting more limited downscaling improvements in this region. South of Cape Hatteras, NWA12 increases appear linked to coastal station depth difference. These comparisons reveal the extent and pattern of NWA12 coastal variance increases and show that they approach and better match observed values.”

I am not fully convinced with the reasoning to completely exclude the established deterministic and probabilistic skill metric to evaluate both SPEAR and the downscaled predictions against observations. What information do Figures 10, 11 and 12 convey that can not be summarized into a skill metric at each lead time? Is it the size of your ensemble that would prevent any meaningful estimate of the the skill, for example, of short-term extremes in coastal sea level?

After forecast initialization, synoptic atmospheric variability responsible for much of coastal sea level variance at the timescales considered here decouples from observed variability. As we remove a seasonal cycle, the SPEAR and NWA12 simulated coastal sea levels considered here are shaped by ocean and atmospheric processes that evolve away from observations-informed initial conditions. Model and observed behaviors diverge from initial conditions, with unique phasing of variability, resulting in distinct coastal sea level variability. We feel that focus on a

deterministic skill metric would take away from the manuscript's main consideration of coastal sea level variability as a function frequency, model resolution, and in a distributional assessment sense. Similarly, we do not seek to determine skill in extreme event occurrence, but rather provide a characterization of distribution shape evolution that can be associated with event likelihood (this is information we wish to convey in Figures 11-13).

Figures:

Figure 1: Are the NWA12 maps from the same 30-year ERA-forced simulation from which the initial conditions were derived for the downscaled predictions? Please add this detail in the figure caption.

Clarification added. In this figure, we show annual means of daily averages spanning the year 1999. This comparison is made to give general sense of regional mean SSH structure and variance along the coast and associated with the Gulf Stream.

Mention the frequency band in the caption for Figure 9

Done.

Mention that IB effect is included in SPEAR and NWA12 in Figure 12 caption

Added. Figure 13 has been edited to include ensemble mean 5th and 9th percentile values of SPEAR and NWA12 as well as ensemble spread. In our initial submission we mistakenly did not include IB contributions (original Figure 12).

All figure legends, axis labels are too small to read on an A4 page, which some of us still read from.

We have increased the font size of all figure titles, axis labels, and legends wherever possible.

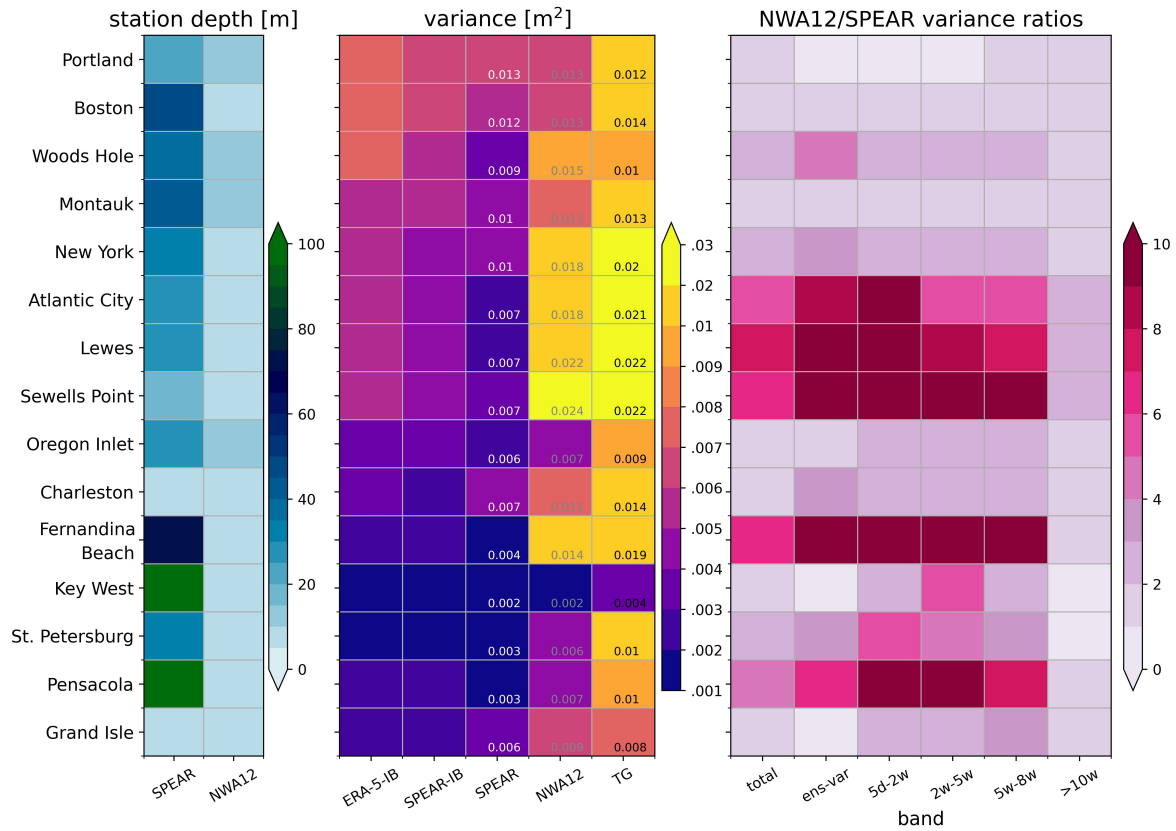


Figure 7 - left) SPEAR and NWA12 ocean depth at 15 tide gauge stations. middle) Coastal sea level variance: ERA-5 inverted barometer contribution (ERA-5-IB), SPEAR inverted barometer contribution (SPEAR-IB), SPEAR, NWA12, tide gauge observations (TG). Text reports model sea level variance with the IB contribution included and observed sea level variance. Note colormap and colorbar are on a log scale. right) NWA12/SPEAR variance ratios: total, ensemble spread (ens-var), and for each frequency bands.

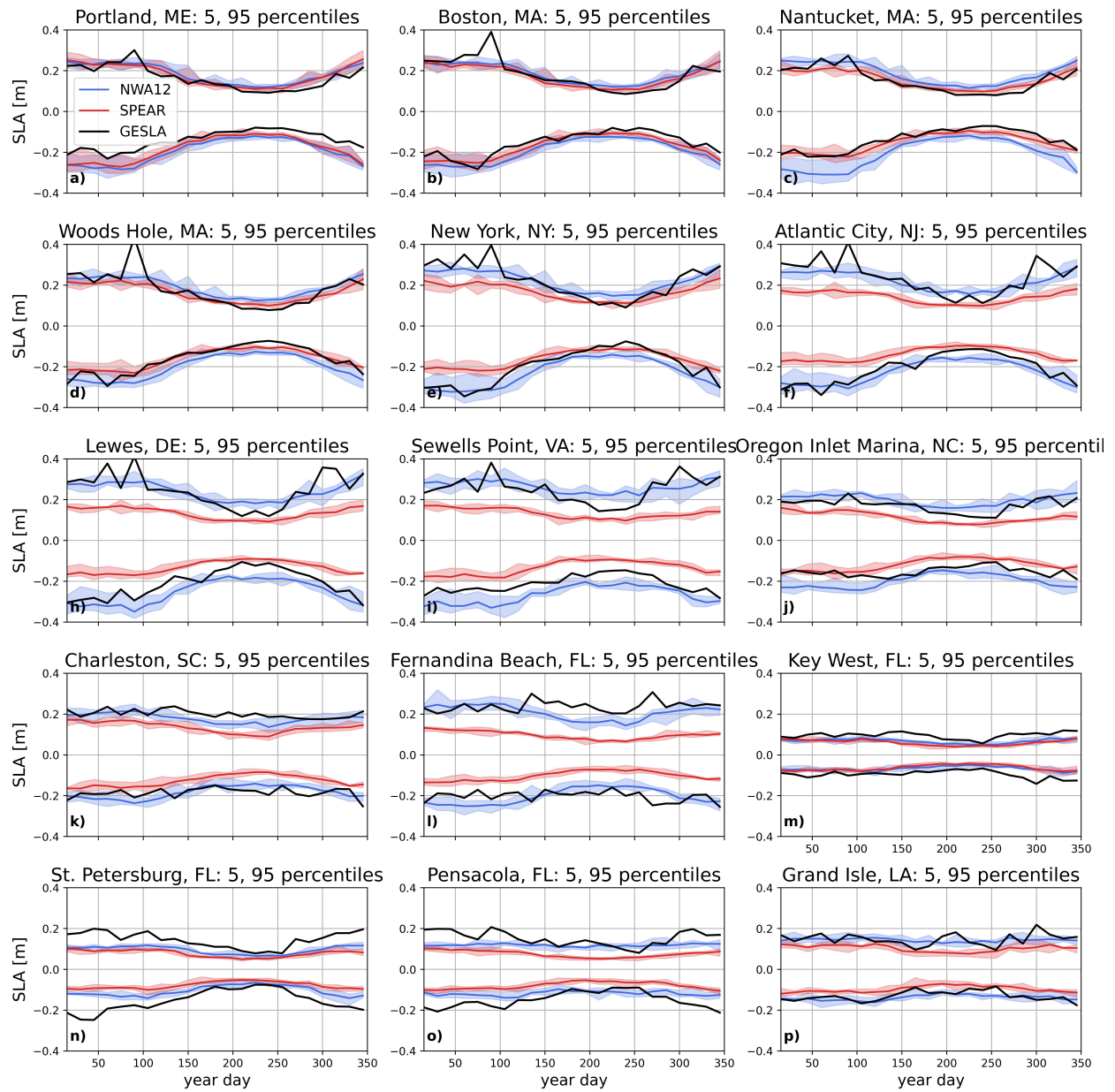


Figure 13 - 5th and 9th percentiles of daily sea level anomaly distributions as a function of simulation lead time (days since model initialization). SPEAR is in red, NWA12 in blue, and observations (GESLA) in black. Red and blue shading shows the mean ensemble spread.