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Seeding Noise in Ensembles of Marginal Sea Simulations—The Case of Bohai and Yellow Sea

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Abstract

As predicted by the stochastic climate model, small disturbances activated in numerical simulations of atmospheric and oceanic systems lead to the formation of unforced variations, named here "noise". This has been demonstrated not only for global systems but also for regional systems. Here, we examine how sensitive this generation of noise is to the mechanism of seeding the internal variability in marginal sea models. The case considered is the circulation of the Bohai and Yellow Sea, as exposed to realistic atmospheric forcing. Two ensembles of simulations were formed. In all simulations, the numerical model is the same—in one, initialization was shifted in time, while the forcing was all the same NCEP CFSv2 in the overlapping time. In the second ensemble, the same code ran on different computer platforms. In both simulations, the intensity of the noise, as well as its temporal development are virtually identical. Thus, the mechanism of how the noise is seeded does not matter—what is needed is just small disturbances; the rest is done by the internal, nonlinear, and high-dimensional dynamics of the system.

Keywords

Noise seeding, the Bohai and Yellow Sea, FVCOM

1. Introduction

The issue of internally generated variability, often named "noise" as it hinders the identification of deterministic signals, is a topic in atmospheric and climate science since the 1970s [1-2]. It has received renewed attention by the Physics Nobel Prize in 2021 [3]. In case of systems, which are steered by a strong and variable forcing, the characteristics of this noise vary in time – sometimes it may be large, but after a while, the forcing will in many cases begin to dominate so that different members of an ensemble of simulations will show little differences. Therefore, the term "intermittent divergence in phase space" had been coined [4].

Such noise with variable intensities and active as well as less active periods has been documented for regional *atmospheric* models, when the lateral boundaries often, but not always dominate [5]. It could be shown that, at least in the case considered, for the formation of such noise seeding very small differences into the simulations suffices to build intermittent macroscale noise, and it does not matter if this seed is introduced by shifting the time of initialization, or if different computer platforms are used.

It has been repeatedly reported, e.g., by Jiang et al. [6] that tracks of drifters, be it bottles or artificial jellyfish, tend to diverge, even if they are released at the same time and at the same location. This may be interpreted that the tracks are subject not only to forced drivers, in particular wind and currents, but that also unprovoked variations are at work. This is no proof for the reality of "noise", but it is evidence consistent with the claim that such noise prevails in the real world.

The subject of this article is not the question if unprovoked internal variability, or in our terminology: noise, exits. Instead, the present study is addressing the technical question of how sensitive the emergence of large-scale noise is to different methods of seeding minuscule disturbances, in particular, if the finding of Geyer et al. [5] for an atmospheric regional model applies also in the ocean context. Nevertheless, we briefly review some of the work, which was done to study and describe this noise: The hydrodynamics noise of marginal seas with numerical simulations has been pioneered by Büchmann and Söderkvist [7], Penduff et al. [8], and Tang et al. [9]. Büchmann and Söderkvist [7] investigated the internal variability in the North Sea-Baltic Sea area with an ensemble of identical model setups with slightly perturbed initial conditions. They found that the stochastic features are attributed to cascading effects from small-scale to larger mesoscale features. Penduff et al. [8] over 17-20% of the global ocean coastal area, in particular along the coastlines of the northwestern Pacific and Indian Oceans, and around the Gulf of Mexico, random sea level trends may blur their atmospherically forced counterpart, such that simulated coastal sea-level trends cannot be unambiguously attributed to atmospheric or anthropic causes. Lin et al. [10] showed the emergence of developments unrelated to forcing, i.e., noise, in ensemble simulations with the Yellow Sea and the shallow Bohai. The generating mechanism is not fully unraveled, but it seems that Hasselmann's stochastic climate model [2], according to which short-term "white noise" is transformed to long-term "red noise" variability, the more so the stronger the memory of the system is. This issue is the subject of a paper in preparation. In this paper, we investigate, in the ocean system, seeded noise by a minuscule disturbance in the initial conditions and by employing the same code on different platforms.

2. Experimental setup and results

The model set-up is the same as in Lin et al. [10]. The 3-dimensional unstructured grid Finite-Volume Coastal Ocean Model (FVCOM) [11, 12] is used in this study. The model domain covers the Bohai and Yellow Sea (31.9°-40.9°N and 117.6°-126.9°E; Fig. 1). We use the Mellor and Yamada level 2.5 (MY-2.5) turbulent closure model [13] and Smagorinsky eddy parameterization method are used for vertical and horizontal diffusion coefficients, respectively. The open boundary across the Yellow Sea extends from Qidong in China eastward to the southern tip of the Korean Peninsula, and a radiation boundary condition is used. In the Bohai, the grid resolution is approximately 4 km and in the Yellow Sea 8 km horizontally and 30 layers vertically. The tides are introduced by adding a time-dependent elevation at the open boundary, which is composed of 8 major tidal components ($M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1$) derived from the TPXO database [14].

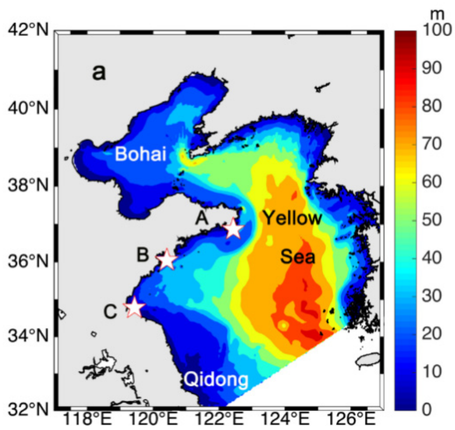

Figure 1. The model area and topography.

Six-hourly surface forcing data are from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Version 2 data, with a global resolution of 0.20°×0.20°, including among others wind and heat fluxes. The model data output interval is three hours, and daily average data are used for calculations.

We will not deal with the validation of the model simulation at this time, as this has been done by Lin et al. [10]. Instead, we focus on the noise seeding process. To do so, we generated two ensembles, named "initialization" and "platform" ensembles.

- The "initialization" ensemble consists of four simulations. They differ by shifted initialization times while all other factors are identical. Each of the simulations covers the year 2019, but the integration time is longer—the first member is initialized on 1 September 2017, thus running 14 months before entering 2019; the second on 1 January 2018, the third on 1 March 2018, and the fourth on 1 November 2018. The initial conditions are taken from the climatological 9-year simulation.

- The "platform" ensemble of three simulations with the same initial conditions was run on different platforms, namely, Deutsches Klimarechenzentrum (DKRZ) in Hamburg, Barkla of Liverpool University, and the China Wuxi cluster. All members of this ensemble are initialized on 1 November 2018.

In climate and ocean science, unprovoked variability, which cannot trace back to external factors, is often named "noise". This definition has been applied in Penduff et al. [15], Penduff et al. [8], as well as Tang et al (2020). In computer science, the term "noise" refers to rounding errors, which lead to small deviations from mathematically accurate solutions (more explanations of the definition of noise in computer science can be found in Geyer et al. [5]). The definition of noise spans different concepts in various fields of science. In this paper, we define "noise" as variability not provoked by external forcing; it is the deviation after subtracting the ensemble mean. Thus, they represent unforced, internal variability, and the curves shown below are such "anomaly" curves, i.e., deviations from the ensemble means.

For platform ensemble, the deviations are initially generated by different computer platforms, which does not represent the noise in the ocean system. But such divergence will last and the divergence grows into intermittent variability between different trajectories through dynamic processes. And this shows the existence of noise in the ocean system.

The temporal developments during 2019 of the depth averaged velocity anomalies at a randomly chosen grid node in the North Yellow Sea (38.14°N, 123.39°E) are shown in Fig.2. The top panel shows the development of the 4 members of the initialization ensemble, the middle the 3 members of the platform ensemble, and the bottom panel the daily standard deviations in both ensembles.

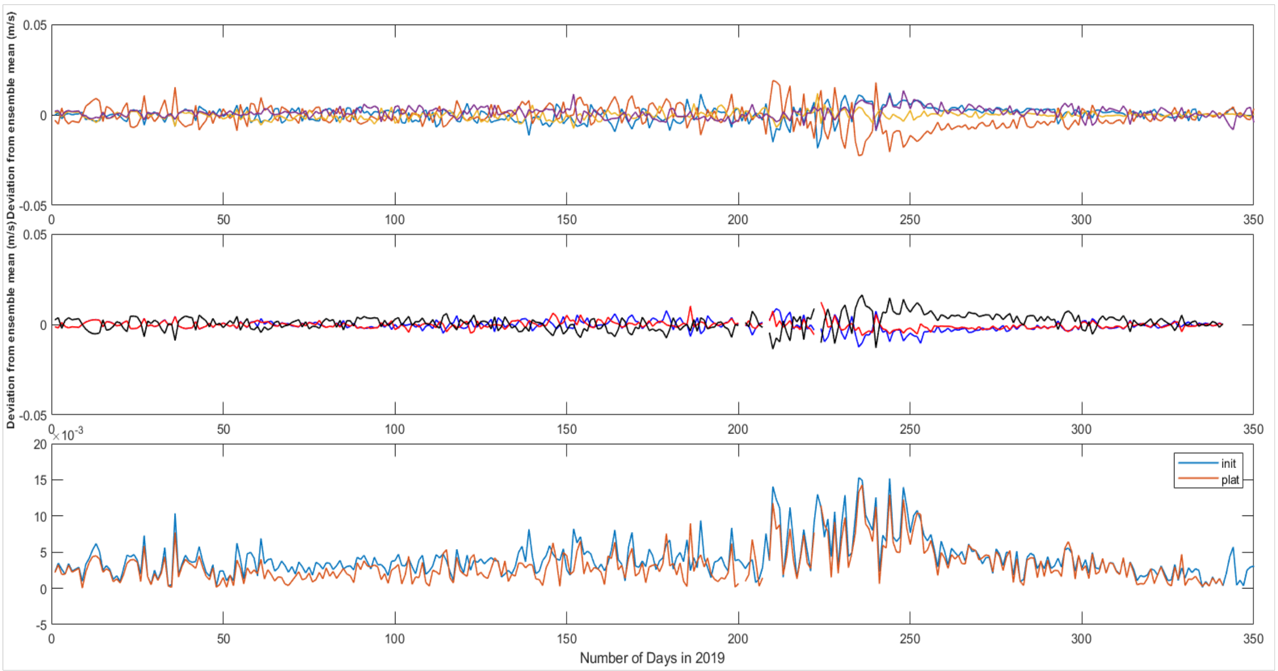

Figure 2. The top two diagrams are the time series of depth averaged velocity anomalies in the almost whole year of 2019 in the grid cell in the center of the North Yellow Sea (38.14°N, 123.39°E) in four realizations of the initialization ensemble and of the platform ensemble. At the bottom the daily standard deviations of the spread in the two top panels are displayed. (For one simulation of the platform ensemble data of the days 201, 207, and 227 are missing).

Obviously, the scatter of time series is similar in both ensembles, in terms of intensity and timing. This impression is confirmed by the comparison of the time series of daily standard deviations (across the different members of the ensembles; Fig. 2): In winter, the trajectories in both ensembles stay close to each other and the hydrodynamical noise is weak. But in late summer, the differences between the trajectories are large. If this is really a seasonal feature, we cannot determine at this time since we could not extend the simulations to cover several years.

3. Conclusion

We conclude that we have - like the result of Geyer et al. [5] for a limited area atmospheric model—intermittently emerging noise irrespective how we seed the minuscule noise, by shifting the time of initialization or by using different computer platforms. Thus, the interaction of minuscule noise and the large-scale dynamics is independent of how the seeding is done, the tendency to get the minuscule small-scale noise grow in amplitude and scale (for details see [10]) depends on the temporal variable configuration of the state of the marginal sea. With the time scales in atmosphere being shorter than in the ocean, Geyer et al. [10] could identify a steering factor, namely the atmospheric zonal through flow, but here, we can only speculate, which features of the changing forcing is responsible for the weak noise in winter of 2019 and the strong noise in late summer 2019. It may be a property of the annual cycle, for instance the stratification, but since we have simulations covering only one year, and cannot prolong these simulations, we must leave the answer to this question open until longer simulations become available.

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