Atmospheric wind and pressure-driven changes in tidal characteristics over the northwestern European shelf

Response to reviewer comments

Reviewers' Comments
Our Response
Changes in revised manuscript

Reviewer #2

The authors work on the driving mechanisms of tide constituent changes (including the highest tide) over a long range of time span (e.g., from 1980 to 2021), especially in year 2009. They design numerical experiments by including one and two factors (e.g., tide only, tide + wind, tide + atmospheric pressure, and tide + wind + atmospheric pressure), and they finally found that the wind effects dominant the shelf locally, while the pressure effect mainly in the deep ocean part). The mean sea level (MSL) changes are related to the resonant effect on the quarter-diurnal tide components. I have no doubt on the literature review and writing, since they are all well-constructed and expressed. My suggestion to this Article is Major Revision considering the following major issue.

Thank you to reviewer #2 for these constructive and interesting comments. We have taken into account the comments below and have revised the manuscript accordingly.

General comments:

1. **The authors have done the model validation with sufficient tide gauges over the studied domain. My major concern is that the root mean square difference (RMSD) of the model-to-data comparison is at several or O (10) cm, while the meteorological effects from other years on year 2009 is only 1 cm. How the model reliability is guaranteed with the factor that the order of model error is higher than the model-induced effect (e.g., ~10 cm versus 1 cm)? Even, the wind and pressure effects are ~15 cm, which is around the model error.**

   The following two aspects should clearly be distinguished to avoid confusion: (1) the model validation/comparison with tide gauge data, (2) the use of the model to undertake numerical experiments and investigate the effect of pressure and wind on tides, in comparison with controlled (simulated) reference scenarios.

   Regarding the model validation, we should remind that tide changes are due to a wide range of non-astronomical factors, and as we account for wind and pressure driven changes only, we do not expect that our model setup will perfectly replicate observations. The aim of the validation step was primarily to ensure that the behaviour of the model setup makes sense and that the differences with tide gauges data (RMSD) are comparable with the ones of other state of the art modelling works of the literature (as stressed in the manuscript).

   Once the validation is ensured, we use this model setup to conduct experiments that are purely numerical experiments, and all variables are therefore controlled. The model was run twice with the same configuration and the differences calculated to ensure that results are consistent, and zero- difference was found over the full spatial domain. We may also notice that it is important to model (as well as possible) the wind and pressure driven hydrodynamics to investigate the

quantitative effect on tidal characteristics. From this perspective, it can be reminded that we use CFSR data (which is one of the best global hindcasts available) and a state of art model formulation (e.g. Charnock for the drag coefficient, which proves to provide good estimates of storm surges for the study area, see e.g. Muller et al., 2014), such that the quantification of tide changes from the numerical experiments may be quantitatively realistic.

To better clarify the distinction between the validation and the numerical experiments:

***Line 131-133 now reads**: "Before using the model for numerical experiments on the effect of wind and pressure on tides, we may ensure that it reproduces water level storm surge and tidal dynamics in the study area to a reasonable degree."*

***Line 215-217 now reads**: "To investigate the effect of wind and pressure on tidal characteristics, we use the model presented above to carry out controlled numerical simulations of a reference scenario, and numerous scenarios involving differing years of meteorological forcing."*

Specific comments:

1. **At P1 in L40: ' … over the period [of] 1960-2021 … ' ;**

   This has been revised.

   ***Line 42 now reads**: "(occurring for the L2 constituent at Saint-Malo over the period of 1960-2021)"*

2. **Introduction: Please add more literature review on the study of the effects of wind and pressure on tides.**

   Edits have been made to the paragraphs discussing tide-surge interaction literature in order to include additional literature, to shorten and clarify the literature review, but also to highlight existing qualitative discussion on the effect of surge on tide.

   ***Lines 51-63 now read:** "In addition, tide and atmospheric storm surges (induced by atmospheric wind and pressure) are also known to exhibit interactions [13–22].*

   These interactions have been investigated in literature through numerical modelling experiments [13–20] and tide gauge data analysis [15,21,22] in many locations over the world. For instance in Canada [16], the Patagonian Shelf [18], the Bay of Bengal [17], the Taiwan Strait [19], Tieshin Bay (China) [20], the English Channel [13], and the Irish Sea [14]. Magnitude orders are found to reach tens of cm up to 1m depending on the location.

   However, the goal of these studies was primarily to quantify a combined tide-surge interaction term or to identify the effects of tides on surge magnitude and timing, rather than to quantify the effect of surge (or wind and pressure) on tide characteristics. Some of these studies (e.g. Rossiter [21]) qualitatively discuss the effect of surge on tide, highlighting that surge changes the phase of the tide."

3. **At P2 in L80, 82 and other places: Please add a space between 2km or 6km etc.;**

   This comment has been taken into account. A careful reread of the manuscript has been conducted and the formatting of units has been corrected.

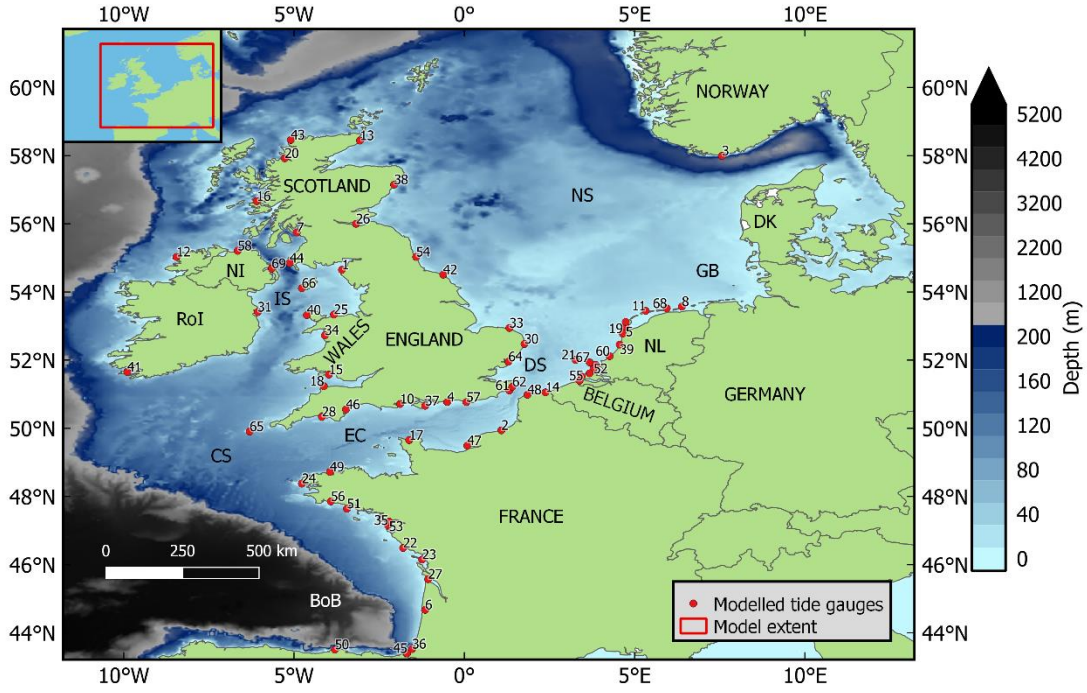
4. **At P3 for Figure 1: It may be better adding more marks of Scotland, Norway, France, Dutch, Irish Sea, Celtic Sea, and Dunkerque etc., since these locations were mentioned and discussed in the following contents.**

Figure 1 has been replaced with a new map that now has labels highlighting discussed areas (such as the Irish Sea, France, Scotland). In regards to Dunkerque, as gauge numbers are already visible on the map, we do not specifically label any gauge names. However instead, where Dunkerque, La Rochelle and Le Conquet are mentioned, we now provide the gauge numbers (from Appendix 1), so that they be easily located on the map.

Lines 178-179 now read: *"…Arcachon-Eyrac (station 6, Figure 1) and Port Bloc (station 27, Figure 1)…"*

Lines 196-197 now read: *"…Dunkerque (station 14, Figure 1), La Rochelle (station 23, Figure 1), and Le Conquet (station 24, Figure 1)…"*

Updated Figure 1 (Line 125):



The caption for Figure 1 also reflects this change.

Figure 1 caption now reads: *"Computational domain of hydrodynamic modelling and the location of tide gauges used for validation. (Note that the shelf break is indicated by a change in colour scale). The inset map shows the full computational domain, whilst the main map shows the studied area. Abbreviations are as follows: BoB – Bay of Biscay, EC – English Channel, DS – Dover Strait, NS – North Sea, and GB – German Bight, DK- Denmark, NL – The Netherlands, NI – Northern Ireland, RoI, republic or Ire-land, CS – Celtic Sea, IS – Irish Sea. (see Table A1 for names corresponding to station numbers)."*

5. **At P4 for Figure 2: It is a nice figure.**

Thank you for the compliment, it is greatly appreciated.

6. **At P7 in L 231 – 235 : 'In the present MARS model setup … with the S2 constituent obtained from T simulations'. I am not quite understanding why the S2 constituent has to be obtained from the tide-only simulation, but not from the tide-wind-pressure simulations? It is mentioned herein, but I just cannot follow the explanation. Please explain it further to the reviewer. Thanks.**

In all tide component data set (such as FES2004, which we use and FES2014 and TPXO9) S2 constituent data contains both the radiational and gravitational information. The regular air pressure changes that correspond to the aforementioned solar heating and cooling are also present in the atmospheric pressure data used to calculate pressure driven tidal effects. This can lead to a 'double counting' of the atmospherically driven effects on solar constituents, leading one to believe that pressure driven changes were responsible for large magnitudes of effect on solar constituents (In this respect we exclude S2 from individual constituent analysis in Section 3.1 & 3.2). When calculating effects on high tide, careful attention must be paid to ensure that this 'double counting' of S2 is not included in the high tide changes, as it will create a misleading results. We therefore substitute the S2 constituent data from the tide, wind and pressure model, with the S2 constituent data from the tide only model, where we know there is no double counting, as there is no meteorological forcing. We specifically only replace S2, over other solar constituents, as S2 is the only solar constituent included in the tidal forcing dataset used for our model setup. The issue of double counting is explained in detail and investigated within the article referenced on line 273-280 (Williams et al., 2018).

7. **At P1 in L 349 : ' … between 200-2003, …'. Is that a typo for '200'? Please double check it.**

This is a typo. 200 should read 2000.

Line 422 now reads: "…between 2000-2003…"

8. **At P12 Discussion. Please indicate it in the figure or some other ways, by specifying the areas of 'shelf'.**

The shelf is represented in Figure 1 as the area coloured in blue, whereas the deeper area (referred to in the article as "off the shelf") is represented in black. 2 short sentences are added in the discussion to clarify this.

Line 508 now reads: *"We find that on the shelf (represented in blue in Figure 1)…"*

Lines 510-511 now read: *"In addition, when moving off the shelf, into deeper water (indicated in black in Figure 1) "*

9. **At P12 in L 391: ' … in the momentum equation of the shallow water equations (see e.g. [33]) …'. Instead of seeing [33], would it be better adding the equation herein or in the Appendix? So that maybe easier for readers to follow it.**

The shallow water equations are now included in the discussion section, at the start of Section 4.1 (Lines 499-507, in the form of Equation 13 and 14), where we directly reference them as numbered equations, allowing readers to better follow the discussion of causes of change.

10. **At P13 in L 429: ' … calculate the (fictional) equivalent pressure field … '. Please double check 'fictional'?**

The use of the term "fictional" has been replaced with the term "simulated" to clarify that this pressure field comes from the results of a simulation.

Lines 309-310 now read: *"…allowing us to calculate the simulated equivalent pressure field..."*

11. **At P14 in L 436: what does this sentence mean ' … a ratio (beta) between the 2 is calculated'?**

The meaning of this sentence is as follows: The wind and pressure driven changes ($\Delta A_{i_{TWP}}$) contain a part driven by the meteorologically induced sea level changes ($\Delta A_{i_{TP(MSL)}}$). We calculate a ratio between these two values, which we refer to as β.

Lines 316-317 now reads: *"a ratio (β) between tide changes induced by the equivalent pressure field and the ones directly induced by the effect of wind and pressure is calculated"*

12. **At P15 in L464: '… we find a strong positive beta [in] in the northern Irish Sea …';**

This comment has been taken into account and fixed.

Line 527 now reads: *"…in the northern Irish Sea…"*

Comments on the Quality of English Language

Minor editing of English language required

Carefully attention has been taken to reread this article, fixing the grammatical errors specifically mentioned in the comment above and any others that were identified.

References stated in this response letter:

Bernier, N. B., & Thompson, K. R. (2007). Tide-surge interaction off the east coast of Canada and northeastern United States. *Journal of Geophysical Research: Oceans*, *112*(6). https://doi.org/10.1029/2006JC003793

Etala, P. (2009). Dynamic issues in the SE South America storm surge modeling. *Natural Hazards*, *51*(1), 79–95. https://doi.org/10.1007/S11069-009-9390-3/FIGURES/12

Johns, B., Rao, A. D., & Sinha, P. C. (1985). Numerical modelling of tide-surge interaction in the Bay of Bengal. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, *313*(1526), 507–535. https://doi.org/10.1098/rsta.1985.0002

Olbert, A. I., Nash, S., Cunnane, C., & Hartnett, M. (2013). Tide-surge interactions and their effects on total sea levels in Irish coastal waters. *Ocean Dynamics*. https://doi.org/10.1007/s10236-013-0618-0

Rossiter, J. R. (1961). Interaction Between Tide and Surge in the Thames. *Geophysical Journal of the Royal Astronomical Society*, *6*(1), 29–53. https://doi.org/10.1111/j.1365-246X.1961.tb02960.x

Wankang, Y., Baoshu, Y., Xingru, F., Dezhou, Y., Guandong, G., & Haiying, C. (2019). The effect of nonlinear factors on tide-surge interaction: A case study of Typhoon Rammasun in Tieshan Bay, China. *Estuarine, Coastal and Shelf Science*, *219*, 420–428. https://doi.org/10.1016/J.ECSS.2019.01.024

Williams, J., Irazoqui Apecechea, M., Saulter, A., & Horsburgh, K. J. (2018). Radiational tides: their double-counting in storm surge forecasts and contribution to the Highest Astronomical Tide. *Ocean Science*, *14*(5), 1057–1068. https://doi.org/10.5194/OS-14-1057-2018

Zhang, W. Z., Shi, F., Hong, H. S., Shang, S. P., & Kirby, J. T. (2010). Tide-surge interaction intensified by the Taiwan Strait. *Journal of Geophysical Research: Oceans*, *115*(6). https://doi.org/10.1029/2009JC005762