The article is a detailed study of the nonlinear dynamics of the tide in the shallow bay of the North Sea, which is characterized by a significant area of the intertidal zone. As a research tool, a relatively new FESOM-c model is used, which approximates the governing equations by the finite volume method and is able to work on hybrid unstructured computational grids. New data on the bathymetry of the bay and tidal currents are also presented. The authors of the study set a rather difficult goal, analyzing the results of observations and modeling for the summary tide instead of effects of nonlinearity for the single harmonic tide. In the latter case, it would be easier to estimate the contribution of the main mechanisms of nonlinearity (shallow depth, advection, and quadratic friction) on the structure of tidal asymmetries. Nevertheless, the results presented in the article are of real interest, since they provide a serious basis for analyzing the features of sediment dynamics and the formation of a variable bottom relief. I would recommend this paper to be published after a little revision. I hope the comments below help improve the manuscript.

Dear Referee 2,

Thank you so much for the very valuable comments! Please, find the answers below. We agree, that further study should be dedicated to the analysis of the separate mechanisms of nonlinearity in the domain based on grids with different structure.

Kind regards, Vera on behalf of the co-authors

Specific comments:

Line 100: Are only 10 sigma vertical layers enough for 3D simulations? In other words, is the numerical solution dependent on the number of vertical layers?

Thank you for the question. The water column in the domain of interests is generally well mixed, weak strain induced periodic stratification only occurs at the end of the flood in some subareas (Villarreal et al., 2005; Simpson et al., 1990; Purkiani et al., 2015). Based on available observations we can conclude that the vertical structure of the velocities and turbulent characteristics are relatively simple (Burchard et al., 2008, Purkiani et al., 2015)

As soon as we have concentrated our attention mainly on the depth-averaged dynamics and near-bottom dynamics (our vertical layers are crowded near the bottom) and the area of consideration is relatively shallow, we have agreed on 10 levels.

Burchard, H., Flöser, G., Staneva, J. V., Riethmüller, R. and Badewien, T.: Impact of density gradients on net sediment transport into the Wadden Sea, J. Phys. Oceanogr., 38, 566 – 587, https://doi.org/10.1175/2007JPO3796.1, 2008.

Purkiani, K., Becherer, J., Flöser, G., Gräwe, U., Mohrholz, V., Schuttelaars, H. M. and Burchard, H.: Numerical analysis of stratification and destratification processes in a tidally energetic inlet with an ebb tidal delta, J. Geophys. Res-Oceans, 120, 225– 243, https://doi.org/10.1002/2014JC010325, 2015.

Simpson, J.H., Brown, J., Matthews, J. et al. Estuaries (1990) 13: 125. https://doi.org/10.2307/1351581.

Villarreal, M.R., K. Bolding, Burchard, H., and E. Demirov, 2005. Coupling of the GOTM turbulence module to some three-dimensional ocean models, Marine Turbulence: Theories, Observations and Models, Baumert, H. Z., J. H. Simpson, and J. Sündermann, Eds., Cam-bridge University Press, Cambridge, 225–237.

Section 2.3 (Open boundary conditions) Please specify the period of model calculations (dates).

The spin-up period for all simulations was three months with a criteria of the stabilization of the energy behavior. Due to the fact that paper considers only the tidal dynamics for the analysis we took last two full tidal periods - 59 days. We simulated the tidal dynamics in 2018, which is expressed in Doodsen correction of the prescribed amplitudes and phases, therefore we were able to compare observed and modeled velocities second to second for end of May 2018.

The additional setup details have been added to the manuscript.

Line 165 (Data. 3.2 Tide gauge (TG) data): VidaTG station is located in the intertidal zone, and so during low tide (when the seabed is exposed) the continuous (quasi harmonic) time series is greatly distorted. (see for example, https://www.emodnetphysics.eu/map/platinfo/piroosplot.aspx?platformid=9015&60days=true). In fact, this is time series with data gaps. Nevertheless, the authors used classical harmonic analysis for this station in the validation of the model. Did authors take into account the peculiarity of the tide in this station when analyzing the results? (see also the comment below on Section 4.5.2).

Thank you for the question. VidaTG station is situated in the intertidal zone, however itself is situated in the quite deep channel, therefore there is no distortion of the time series (Fig. 1).

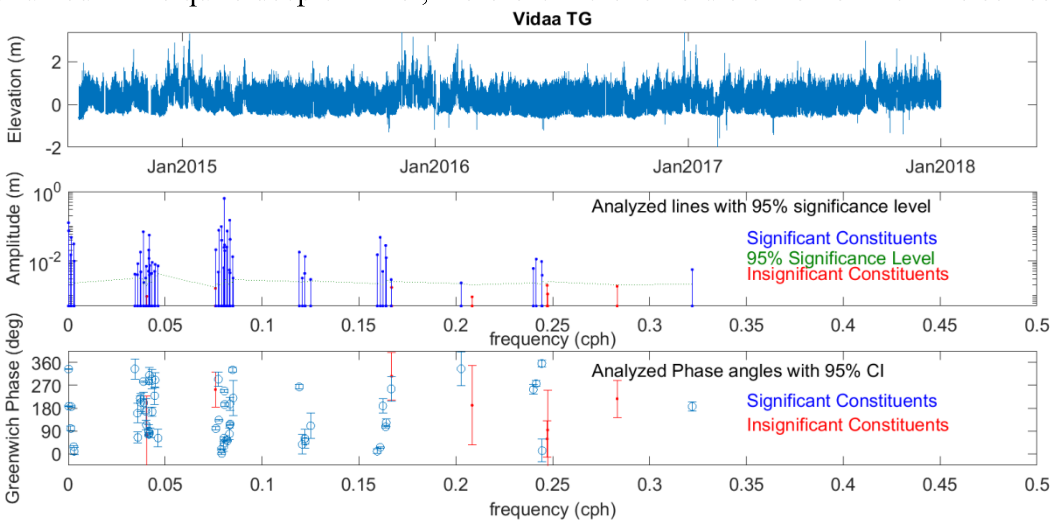


Figure 1. The elevation time series at the Vidaa TG and results of the classical harmonic analysis.

Table 2. The results of the inter comparison show rather large RMSD values (compared with the velocity values themselves). Apparently, this is due to the neglect of wind induced fluctuations in the simulation. The question arises: Is inter comparison in Table_2 appropriate?

Thank you for the question. We think that the wind forcing will add approximately the same contribution to the error for all boundary conditions used based on very high correlation coefficients. In considered zone tides seem to be explained more than 80 % (or 90 % or more in case of a spring tide) of the dynamics in case of absent storm (more than 20 m/s) and blowing continuously in one direction winds. On this basis, we give this comparison in Table 2, the purpose of which is to select those boundary conditions that have the smallest absolute error compared to the observational data.

Line 330: It seems to me that the use of the term "seiche" is not entirely appropriate in this context, since we are dealing with forced fluctuations. It would be more correct to speak about oscillations as near standing wave.

We replaced the term "seiche" with a more general term – "standing wave".

Line 350: It is desirable to immediately emphasize that the results of Fig. 8 relate to the sea level (not currents).

Thank you for the comments. We have put additional notes to the figure caption.

Line 359: Frankly, I do not see indication on degenerate amphidromic point in external area. Yes, there is a slight closeness of phase contours lines (caused by proximity to the strait and refraction of the tidal wave), but there is no decrease in the tide amplitude as it is usually in nodal (amphidromic) zone. The effect of the capture of a Poincare wave is interesting, but requires explanation or reference.

Thank you. Absolutely correct remark, this picture does not clearly show the presence of amphidromic point, because we do not see a concentric decrease in the level. We have excluded this conclusion from the text.

Line 365-370: It is interesting how the authors distinguish between the different duration of the ebb and tide caused by the nonlinearity from the effect of the sum of harmonics of various periods. The last effect is called the Diurnal Inequality of tide, and it is not connected with non-linearity.

Thank you very much for the very useful remarks! The features represented in Fig. 9 (level panel) show the mean pattern for the full tidal cycle (29.5 days). However, we should definitely pointed out that the reason of the variations in Fig. 9 (right panel) is not only non-linear effects, but also Diurnal Inequality of tide. The additional comments have been added to the text.

Line 405-410: To explain the effect of the dominance of tide velocities over ebb ones, it is not necessary to use phase speed inequality (SQRT (gh)). There is a simple explanation for this effect: the bottom friction dampens the flow more efficiently in smaller depth (during low ebb).

We agree to the comments. However, in this zone, the depth is relatively large and residual circulation is smallest compared to the surrounding area.

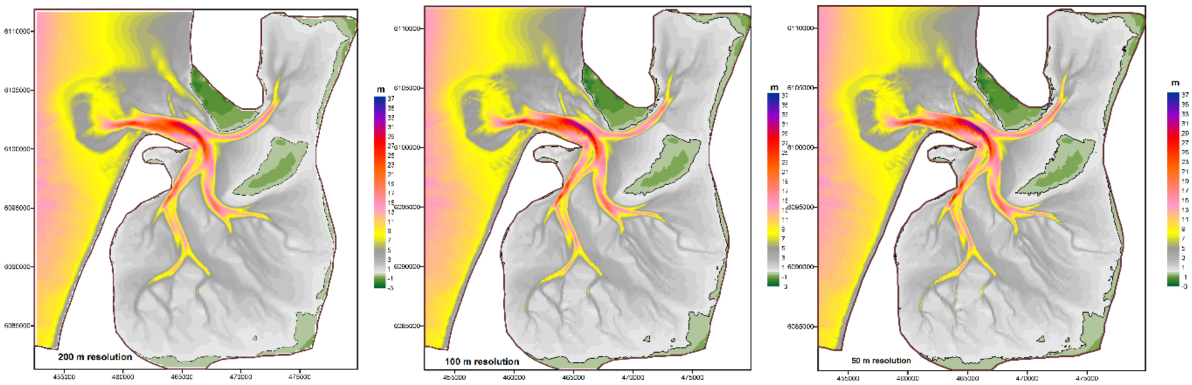
The mentioned effect induced by bottom friction can be traced in the zone 2, where we have an extensive intertidal zone and maximum amplitudes of the semidiurnal tides compared to other zones, here the flood dominance can be explained by the major role of non-linear friction effects and non-linearity in changes of the water-layer thickness.

Section 4.5.2 (Line 412). Again about the accuracy of harmonic analysis in the intertidal zone. Indeed, in this zone, at low tide, the bottom is exposed, and this means that data gaps appear in the model time series. In this case, the classical harmonic analysis can give inaccurate results for the amplitudes and phases of the waves. It seems that it would be more logical to exclude intertidal zones from the analysis of results (at least in terms of the results of harmonic analysis). How was this fact taken into account? Otherwise it's necessary apply special procedures to avoid mistakes.

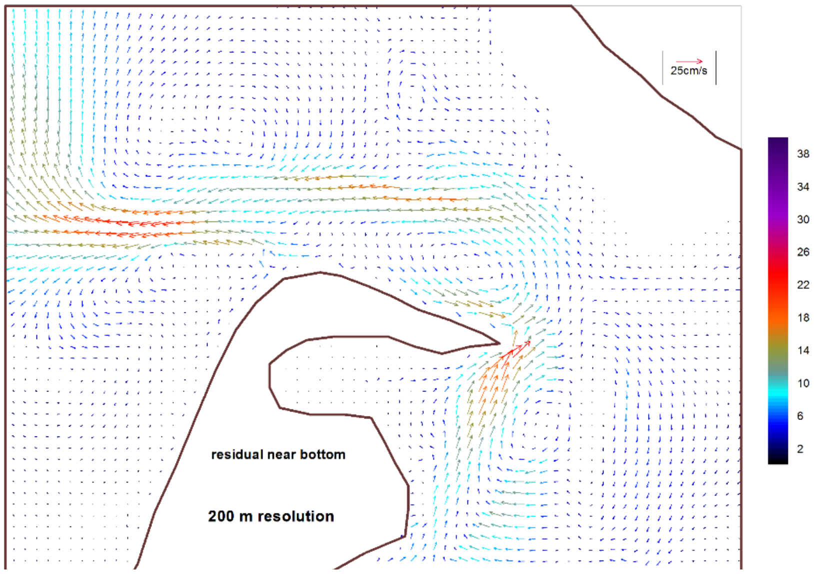
Thank you a lot for the comment. We agree with the remark. We have decided to consider intertidal zone, because it occupies at about 40% of the whole considered area. We performed our simulations with time step of about 1 second, we did not do any averaging and used output every couple of seconds to perform the analysis. Therefore, analyzing last two full tidal cycles (29.5*2 days), we had large time-series. Also we have performed sensitivity test (modifying the analyzed period), which showed that the results of the analysis are justified.

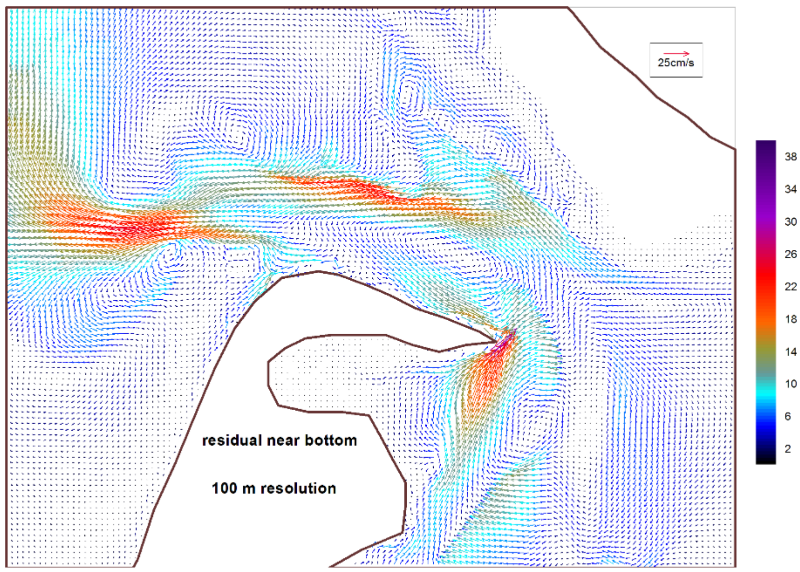
Section 6 (Summary). Unfortunately, the question of the sensitivity of the numerical simulation to the accuracy of bathymetric data remained outside the discussion. In particular, how important is the effect of new bathymetric data in the strait on simulation results. A comparison of the solutions with the old and new bathymetry would answer this question, and perhaps provide a serious justification for the need for new good bathymetry for the whole area.

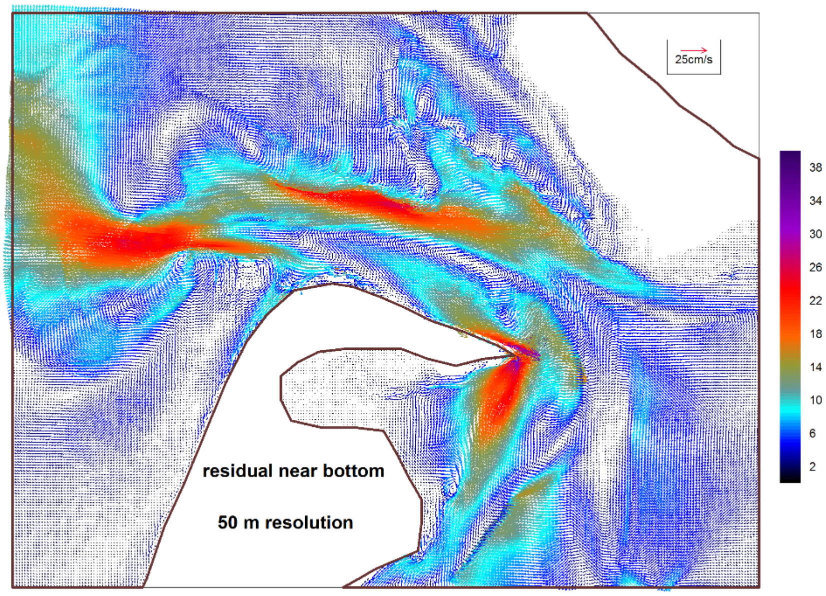
Important note. Thanks. At a preliminary stage, comparison analysis of results of the computation for three bathymetric databases is carried out: 200 m (H. Burchard, personal communication), 100 m and with a resolution of 50 m (L. Sander, personal communication). The meshes used in this analysis have a rectangular structure and the spatial resolution corresponding to the bathymetry info. Note, that 200m bathymetry is largely smoothed compared to 50m bathymetry product. Results were analyzed on fields of residual circulation in a tidal cycle of M2 wave. The residual circulation based on high quality bathymetry data considerably differs from one based on a coarser bathymetry (figures below). Vortex structures have some space shift, a considerable intensification on detailed bathymetry in comparison with smoothed one (figures below).



Bathymetry. Left – 200 m resolution; middle – 100 m; right – 50 m.







Residual circulation near bottom. M2 wave. Upper panel – 200 m bathymetry resolution; middle panel – 100 m resolution; bottom panel – 50 m.

Technical corrections:

Lines 175 and 182: Two paragraphs contain the same information.
Line 245: 29.5 days is rather a lunar (synodic) month than a tidal cycle
Line 335: Direction of rotation (not orientation) of the tidal ellipse is determined by the sign of the ellipticity. (Orientation is rather the inclination of its main axis of the ellipse).
Line 372: Replace "(level panel)" by "(left panel)"
Figure 5. Please explain what the following sentence means: "The length of vectors on the maps is scaled based on the square root method."
Figure 8 .: "The dark blue color indicates zone, where topography features are above sea level." .... above the highest sea level ???

Thank you a lot! Done