Ocean Science Discussions

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Reply on RC2

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Author comment on "Flow separation, dipole formation, and water exchange through tidal straits" by Ole Anders Nøst and Eli Børve, Ocean Sci. Discuss., https://doi.org/10.5194/os-2021-30-AC1, 2021

Many thanks for good and challenging comments from the reviewer. We have had special focus on investigating the effect of mesh resolution and done some new simulations with finer resolution. This has led to interesting results and deeper insight into the processes. We have answered the questions and comments of the reviewer below. Figures is presented in a supplementary pdf.

Specific comments:

The Coriolis effect is vital for our setup to work, as the forcing comes from a Kelvin wave propagating with the coast to the right. A Kelvin wave cannot exist without the Coriolis effect. We have chosen this setup for two reasons: 1) It is an idealized model of the tides through straits in the Lofoten peninsula in Norway (I see that we have not mentioned this in the manuscript, but this will be corrected in a revision). 2) We wanted a setup where the pressure difference across the strait is not dependent on the flow through the strait. In our setup the pressure difference is mostly caused by the phase difference between the northern and southern part of the peninsula. This is setup by the Kelvin wave propagating around the peninsula, and less dependent on the flow through the strait. This is in contrast to, for instance, the entrance into a fjord, where the water flow through the entrance determines the water level in the fjord. The idea is that for theoretical considerations we can assume that the pressure difference across the strait is independent on strait flow. This is important when discussing friction and strait length (see below), where we can assume that the pressure difference over the strait (deta) is independent of the tidal velocity in the strait.

Vertical layering:
We regard this as a 2D barotropic study. The actual reason for having two vertical levels in the model is that our tracer model did not work within a 2D model and the simplest solution to this was to include two levels. However, all our analysis is done using vertically averaged velocities.

Mesh discretization:
Vorticity is extremely sensitive to mesh resolution, and it is clear that the processes of separation and vortex formation is affected by mesh resolution. In our case the spatial

scale of the initial vortices is close to the smallest scale the model can resolve. Will this affect our conclusions of tracer transport, dipole propagation velocity and separation time?

Vorticity is created in the velocity front formed by flow separation. The simulated vorticity in the velocity front will probably depend strongly on model resolution. However, the total production of vorticity with time is probably less dependent on resolution. This can be shown by integration the vorticity over an area containing a segment of the velocity front. During a time t, a velocity front with length U * t is formed, where U is the tidal velocity in the strait. An area integral of the vorticity in the front segment equals U^2 * t. This is obtained using Stokes theorem and assuming that the velocity on one side of the front is U while it is zero on the other side of the front. This result suggests that if the model resolution is sufficient to correctly represent the strait velocity and a flow separation, the vorticity production is likely to be correct. Since the vortices are formed from segments of the front, the total vorticity in the vortices and the circulation are likely to be similar between models of different resolution. Based on this analysis, we will argue that local vorticity is extremely sensitive to mesh resolution, but the circulation is less sensitive to resolution as long as the model produces a flow separation, and the strait velocity is correct.

To study the effect of resolution, we have repeated a number of the simulations using finer mesh resolution. In the new simulations, the resolution at the coast is set to 10 m inside the strait. The simulations presented in the manuscript has 50 m resolution at the coastline. We have selected 7 strait configurations which are simulated with higher resolution. These are the three simulations shown in figures 4-6 in the manuscript plus four others of different strait width and length.

The figures that we refer to in this text is presented in the supplementary pdf. In the new fine resolution simulations, we see that the size of the initial vortices is smaller than in the coarser simulations presented in the manuscript. Figure 1 shows the core radius at time t=Ts, for the old (50 m resolution) and new (10 m resolution) simulations. A similar plot of the time Ts is presented in Figure 2. Vorticity is very sensitive to resolution and as a consequence of this, the method of finding the separation time from the maximum vorticity within the strait exist does not work with the new simulations. From Figure 3 we see that the separation time does not correspond to the maximum vorticity for all the three straits presented in the figure. Strait velocity is slightly lower in the new simulations but corresponds well to the old simulation results (Figure 4). The dipole velocities are not significantly affected by the resolution of the simulations (Figure 5), and as a result the effective transports are also very similar in the old and new simulations. Thus, the main conclusions of the paper are not affected by model resolution.

Friction and strait length:
Section 8.1 is not invalid as it stands now, because it is not only the effect of friction that will increase with strait length. In our case it is the linear acceleration term that is the main cause of the length effect seen in Figure 3. However, we agree that, for straits with shallower depth, friction may play an important role with increasing strait length.

The relation between the different terms in the momentum balance can be illustrated by scaling:

2U/T + U^2/L = g deta/L + Cd U^2/H

The first term is the linear acceleration, where the timescale used equals T/2, and T is the M2 tidal period. The second term is the non-linear acceleration, the third term is the pressure force (deta is the sea surface height difference over the strait) and the last term is bottom friction. U is a velocity scale, H is depth and L is strait length. From this it is clear the pressure force and non-linear acceleration terms decreases with strait length, while the linear acceleration and friction are both independent of length. If it is friction or linear acceleration that determines the length effect seen in Figure 3, depends on the relation between these two terms. In our case, where H=100m, Cd~0.001 and T~45000, the acceleration is about 4 times larger than the friction term for U=1m/s. For L<10 km, the non-linear acceleration dominates the linear and frictional terms.

When non-linear acceleration dominates, this will balance the pressure term which gives a velocity scale, U~sqrt(g deta), which is independent of length (here we assume that deta is independent of strait dynamics, see discussion on importance of Coriolis effect). However, if it is the linear acceleration or friction that balances the pressure force, the result is a velocity scale that decreases with length. The relation between linear acceleration and friction does not depend on length. In our case, where H=100 m, it is mainly the linear acceleration that leads to the length effect seen in Figure 3. For shallower depth, it is likely that friction will cause a similar effect and we will include this in the analysis in a revised manuscript.

Determination Γ

Γ was determined by the Lamb-Oseen equations (Equation 11 in the manuscript) to the simulated vortices. Through the fitting, we find the core radius a, and the maximum vorticity. When these two variables are known Γ can be determined from Equation 11b.

u_θ (in Equation 11a) is the azimuthal velocity of the vortex. In the manuscript we determine Ts by finding the maximum (or minimum) vorticity within the strait exit. We see by visual inspection that this corresponds well with the time of separation. However, in the new simulation with finer resolution presented above, the maximum (minimum) vorticity method does not work, and Ts is then determined by visual inspection of the simulation results.

Please also note the supplement to this comment:
https://os.copernicus.org/preprints/os-2021-30/os-2021-30-AC1-supplement.pdf