What a drag! A numerical investigation of tidal energy dissipation due to flow over rough topography within an estuary

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1. Abstract

Tidal flow over topography in estuaries and coastal regions has been identified as a key mechanism for mixing stratified water and dissipating the ocean's energy (Munk and Wunsch, 1998). When currents and topography interact, the amount of barotropic tidal energy that is converted to baroclinic features such as internal waves or directly dissipated depends not only on the size and shape of the topography, but also the depth of the water-column above the topography. In order to explore this relationship between topography, tidal flow, and energy dissipation, a series of numerical experiments were performed using ROMS, the Regional Ocean Modeling System. The goal of these numerical experiments was to calculate drag coefficients that can be used in larger scale models to more accurately parameterize mixing and dissipation in coastal regions and estuaries. The work may also help predict changes in estuaries that will occur due to rising sea level brought on by climate change.

2. Form drag

+ What is drag? Drag is a force on a moving fluid that tends to slow it down.

+ Two types of drag:

1. Friction drag

| smooth surface | small drag |
| rough surface | large drag |

2. Form (pressure) drag

| small wake | small drag |
| large wake | large drag |

+ Form drag in the ocean:

In the ocean, form drag works to dissipate tidal energy, generate internal waves and eddies, and produce turbulence and mixing. Unlike frictional drag, from drag is not well resolved in coastal and larger scale models.

3. Methods

ROMS is used extensively by oceanographers to model both small and large scale domains. It is a free-surface, hydrostatic, terrain-following vertical coordinate model in which barotropic and baroclinic momentum equations are resolved separately.

The model is forced on the left hand side with a progressive wave. Max tidal amplitude is 1 m, max tidal velocity is 0.2 m/s.

Both a leftward-propagating and a rightward-propagating internal wave are generated during each tidal cycle as can be seen in the salinity plot. The numerical experiment involving changing the bump height and width to various sizes and slope criticalities. The bump shape remains constant in the across-channel direction.

4. Results

+ Power loss:

In this experiment, equal-width bumps with heights ranging from 3% to 95% of the total channel depth were tested. The power loss in the system can be calculated in two ways:

1. Power = form drag x velocity (black dots)
2. Power = difference between pressure work at the left and right (red crosses).

As seen in the figure, losses calculated using the different methods coincide for most of the bump heights. These losses also compare relatively well to losses near similar topography observed in the actual ocean. The power loss from frictional drag (blue diamonds) is orders of magnitude smaller than losses due to form drag.

+ Energy budget:

In addition to power loss, full energy budgets can be calculated. The important terms in the energy budget include barotropic pressure work which accounts for the tidal energy flux into the domain, baroclinic pressure work which accounts for the wave energy leaving the domain, and mixing and dissipation within the domain. Other terms, such as potential and kinetic energy storage and advection are smaller, but must not be neglected.

In the case of tidal flow, the velocity switches direction every six hours, which causes the form drag to switch sign also. The power that the form drag can extract from the tidal flow is the product of velocity and form drag, as seen in red above. Power has a non-zero tidal average.

5. Future goals and connections to climate change

+ Future Goals

The main goal of this project is to parameterize the drag resulting from tidal flow over rough topography like that found at Three Tree Point, Puget Sound, Washington. These parameterizations can be used by larger scale numerical models to more accurately model energy conversion and dissipation over topography.

+ Connections to Climate Change

By looking at estuaries that have already seen the effects of tectonically induced sea level rise, scientists have been able to predict some of the consequences of sea level rise resulting from climate change.

- Less energy dissipation: “The increase in water level in an estuary channel means that the drag on the tidal wave as it progresses inland is decreased and, as a consequence, the wave tends to move further landward and with an increased amplitude and associated current velocities.” (Petrick 1993)

- Higher tidal energy: “The increased landward penetration of the tidal wave also leads to increased salinities in the inner estuary and a landward migration of the turbidity maximum.” (Petrick 1993)

- Higher tides up-estuary: “Tidal amplitudes are increased in the landward section of the estuary as a result of the decreased drag on the tidal wave.” (Petrick 1993)

- Channel widening: Increased energy in the water column “leads to erosion of the upper section of the channel banks — that is the upper intertidal mudflats and salt marsh edge — while the decreased drag on the channel bed leads to deposition here.” The result is a wider and shallower channel. (Petrick 1993)

- Increased frictional drag: In response to a widened channel “such a shape will provide increased frictional drag on the tidal wave so that the estuary moves back toward morphodynamic equilibrium with the new tidal regime.” However, in steep-sided estuaries like Puget Sound, this will be less influential. (Petrick 1993)

- Changes in sedimentation: “Areas presently experiencing low wave energy and consequently characterized by fine-grained sediments will become high energy sandy environments while adjacent beaches will gradually silt up and form mudflats.” (Petrick 1993)

- Landward migration of ecosystems: Due to changes in wave energy and up-estuary propagation of salt, landward migration of mudflats, salt marshes and brackish marshes will occur. (Petrick 1993)

- Biological Impacts: “There will be ecological changes as areas that were previously fresh or slightly brackish become more saline, with die-back of freshwater vegetation and its replacement by halophytes, and changes in the distribution of fauna with increases in marine and estuarine species as freshwater communities are displaced up-stream. Freshwater fisheries will be reduced, and replaced by brackish and marine species.” (Bird 1993)

6. References

