Tidal boundary layer flow in coastal zones

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Objective

The main objective of the thesis is to investigate the applicability of a specific one-dimensional hydrodynamical model with a two-equation turbulence scheme on a shallow-water tidal flow over a complex bottom.

Introduction

Tides are generated by gravity forces from the moon and the sun, together with the relative motions of the earth, the moon and the sun. As the tides rise and fall, water is transported horizontally, giving rise to tidal currents. These currents can be quite strong, especially over shallow grounds and in narrow inlets. Tidal currents are important for transport of e.g. plankton, larvae, contaminated ballast water, oil spills and sea bottom material. They may also be of interest in design and operation of offshore structures. In coastal zones, the interaction of the tidal currents with other phenomena is stronger than anywhere else in the ocean.

Many different numerical models have been applied in studies of tidal flows. Three-dimensional models have extensively been applied to grids representing either specific ocean areas or idealized grids. The methods used require large amounts of computational power. Therefore, simpler models may often be advantageous.

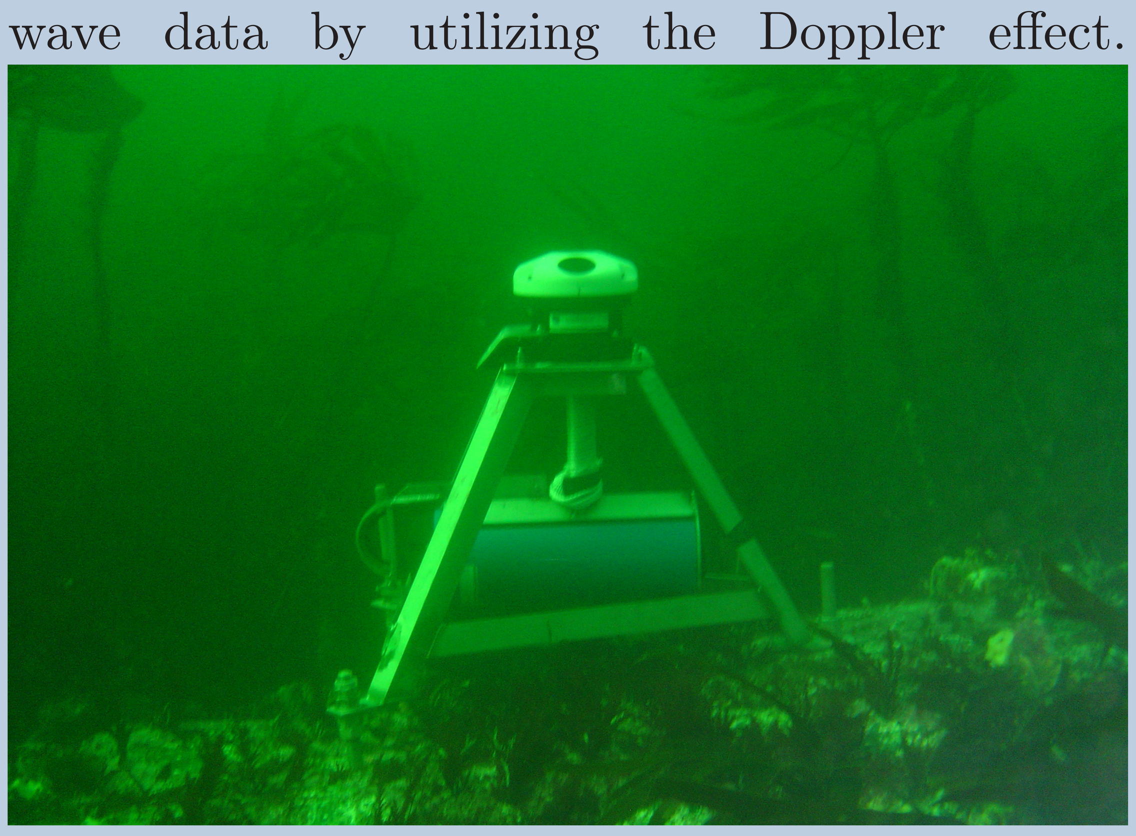
The choice of turbulence model is essential. In modern works, two-equation turbulence closures are commonly used.

Modeling

A one-dimensional numerical model, in the sense that the grid points are located along a line from the sea bed to the surface, is used. The model is based on the Reynolds-Averaged Navier-Stokes (RANS) equations, with the simplifications given by the boundary layer approximation. The turbulence closure is provided by a $k-\epsilon$ model, which is a frequently used two-equation turbulence model.

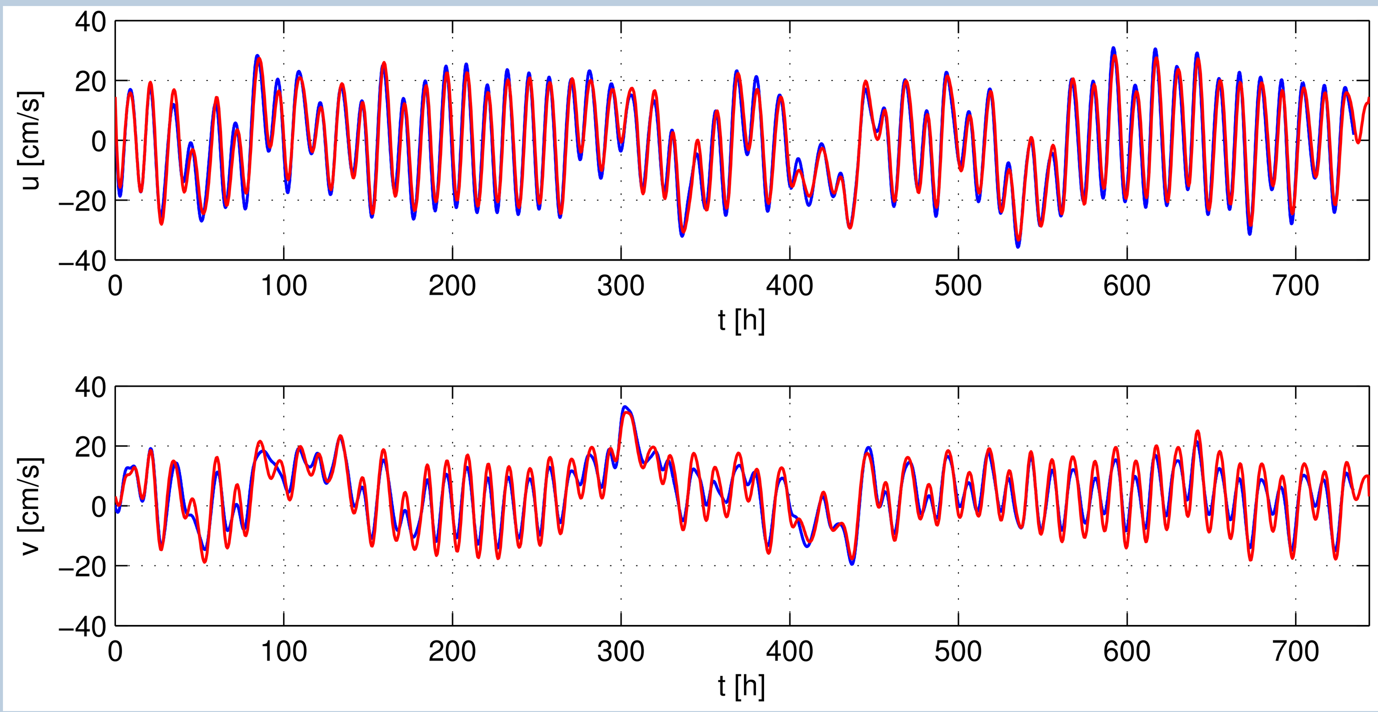
Field data

Current measurements made by a research team at the University of the Highlands and Islands (UHI) in Scotland are used as input for the model and for comparison with the results. The measurements were made using an acoustic AWAC (Acoustic Wave And Current) system placed at the bottom about 700 m from the shore, at a mean depth of approximately 13 m. The system records current and wave data by utilizing the Doppler effect.

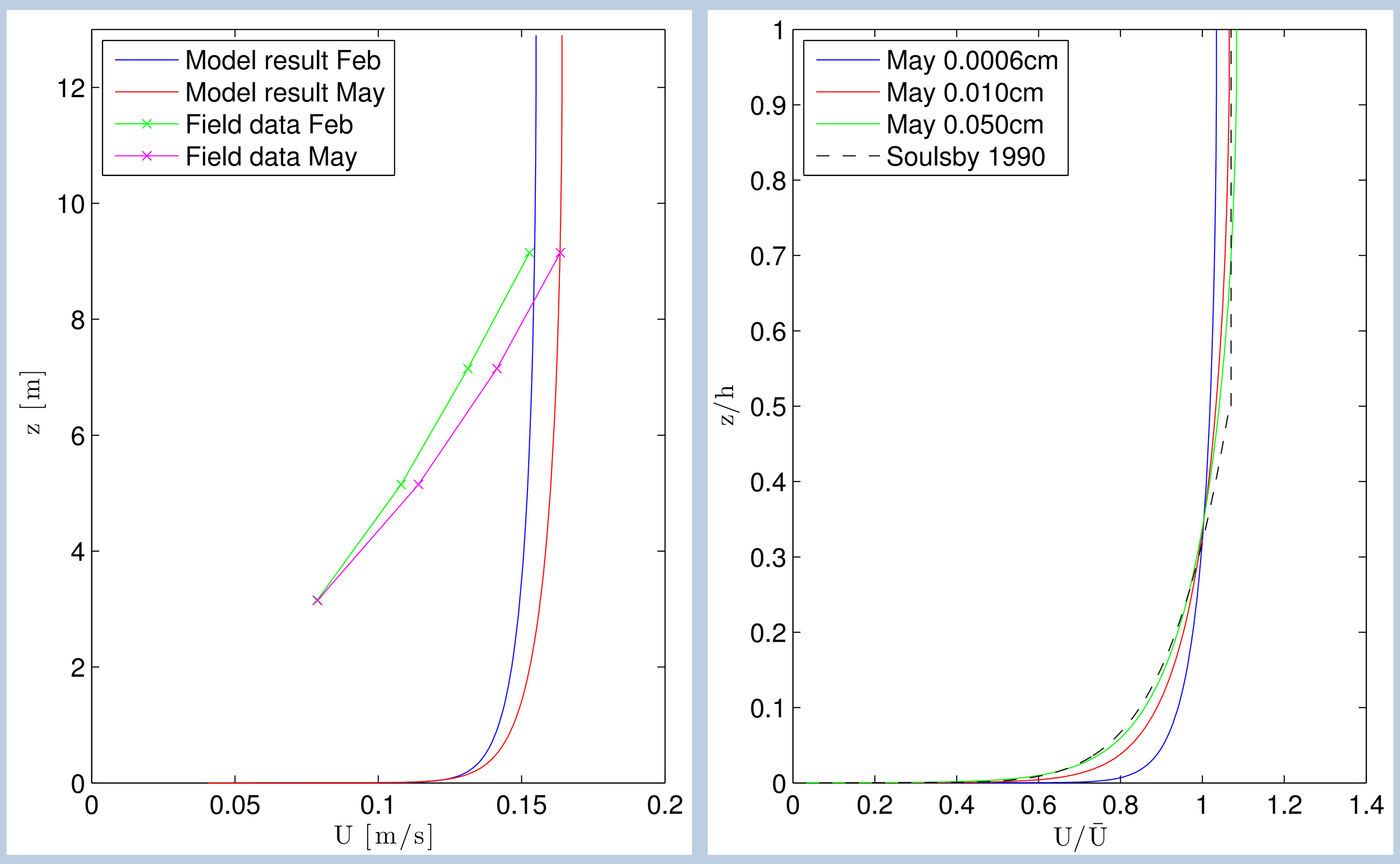


Results

The model was tested with several different bottom roughnesses. The best reproduction of the velocities close to the surface was obtained with a roughness value of $z_0 = 0.0006$ cm. Model results obtained with this value (blue lines) are compared to corresponding field data (red lines) in the below figure, over a period of one month. The vertical position of the shown velocities is 9.15 m.



In the following figures, time-averaged vertical velocity profiles are shown. In the first figure, dimensional profiles of the model results are compared to the field data. In the second figure, non-dimensionalized model results for different bottom roughness values are compared with an empirical formula for tidal flows presented by Soulsby (1990). The formula is verified against several field measurements of tidal flows, including measurements in shallow water, in Soulsby (1990). We see that the graph for $z_0 = 0.050$ cm is a very good fit to the empirical formula. With this roughness, the flow was found to be hydrodynamically rough, while $z_0 = 0.0006$ cm gave a hydrodynamically smooth flow. This indicates that $z_0 = 0.050$ cm gives a more realistic boundary layer.



Further, the effect of wind and wave conditions was investigated. A significant increase of the horizontal velocities was found in periods of high wave activity. An increase in kinetic turbulent energy and shear stress through the water column was also found. This is assumed to be a direct result of increased velocities. The results indicate a slightly better agreement between model results and field data in periods of little wave activity, but the tendency is too small to conclude. A similar analysis was performed for the effect of tidal range, i.e. the difference in mean depth between low tide and high tide. No difference in the accuracy of the model for low and high tidal ranges was found.

Conclusions

The model is able to reproduce the velocities in a certain height above the bottom with very good accuracy. It is not, however, able to replicate the damping of the flow towards the bottom. The shape of the boundary layer predicted by the model is (especially for a given bottom roughness) very similar to the more general tidal flow boundary layer, where the velocities in the upper part of the water column are close to constant. The reason for the very strong damping of the flow in the field data is believed to be the complex bottom conditions, perhaps especially the tall seaweed at the measuring site. The results indicate that the model might be able to model shallow-water tidal flow with better results than found here, if the flow is less complex. Effects of wind and wave conditions, if there are any, on the accuracy of the model, are small. The same applies for effects of tidal range.

References

Soulsby, R. (1990) *Tidal-current boundary layers*, The Sea, Ocean Engineering Science, 9:523-566.

Picture of AWAC system: Courtesy of Arne Vogler, UHI.

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