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On the Tidal Resonance of the Bristol Channel

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The Bristol Channel has one of the largest tidal ranges in the world. A key cause for this is the resonance with the dominant semidiurnal tides. In this paper we use numerical simulations to investigate this resonance. We first vary the frequency on the boundary of the model and examine at which frequency the model is excited. Second, we apply a disturbance to the model and analyse the frequency at which it resonates. We examine the sensitivity of these results, finding them sensitive to the bed friction used (with possible implications for energy extraction) but insensitive to small changes in the tidal amplitude on the boundary or the mean-water level.

INTRODUCTION

The Bristol Channel and Severn Estuary constitute one of the largest, semienclosed water basins in the United Kingdom. The Bristol Channel is located in the southwest coast of Great Britain. The Severn Estuary is situated at the upper reaches of the Bristol Channel, which has the second-largest semidiurnal tidal ranges worldwide. The typical mean spring tidal range is 12.2 m, with the high spring tidal range approaching 14 m at the Severn mouth. The large tidal ranges observed in the Bristol Channel and the Severn Estuary are driven by two main mechanisms (Robinson, 1980; Xia et al., 2012; Serhadlıoğlu, 2014). One is the funnelling effect at the upper reaches of the Bristol Channel due to its wedge-shaped geometry and shallow bathymetry. However, it has long been pointed out by Marmer (1922) that this effect is not enough to produce the observed tidal range. The other mechanism is the quarter wavelength resonance of the Bristol Channel with the incident North Atlantic tidal wave (Fong and Heaps, 1978).

Despite a number of previous model studies having been undertaken for the Bristol Channel, its complex hydrodynamic system is not yet fully understood, particularly given its resonant nature. Resonant systems are typically very sensitive to small changes, and these responses are highly site dependent (Adcock et al., 2015). In this study we seek to improve the understanding of the resonance in the Bristol Channel. A simplified 2-D model has been developed from the model of Serhadlıoğlu et al. (2013) to investigate the resonances in the Bristol Channel.

In this paper, the model equations and the model parameters used for the Bristol Channel region are first considered. Then, the model is tested by comparing its results with previous model studies and observations. Two methods have been used to determine the resonant periods of the Bristol Channel. A frequency sweep is used by varying the forcing frequency on the open boundary of the model to find the peak response of the semidiurnal tidal amplitude. Next, the key properties that influence the resonances are investigated. Finally, wind disturbances are applied to examine the oscillation periods of surge response.

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KEY WORDS: ADCIRC, tidal resonance, shallow-water equations, numerical modelling, Bristol Channel.

RELATED WORK

Systems that are forced by oscillations close to their natural period have large amplitude responses. This phenomenon is called resonance (Pugh, 1996). In oceanography, a tidal resonance occurs when the tide excites one of the resonant modes of the ocean. This occurs when a continental shelf is about a quarter wavelength wide. The whole global ocean system seems to be near resonance at semidiurnal tidal frequencies, and the observed tides are substantially larger than the equilibrium tide (Baker, 1991; Pugh and Woodworth, 2014).

In some studies, the phenomenon of quarter-wavelength resonance was explained by standing wave theory (Pugh, 1996; Pugh and Woodworth, 2014). Consider the simplest case of a wave travelling in a long channel being reflected without loss of amplitude at a closed end. The superposition of incident and reflected waves can resemble a standing wave; standing waves have alternate nodes, positions where the amplitude is zero, and antinodes, positions where the amplitude is a maximum, each separated by a distance of $\lambda/4$ where λ is the wavelength of the original progressive wave (Pugh, 1996). A model of an open box approximates to the tidal behavior of many shelf sea basins (Pugh, 1996). If we describe the movement of water in a box whose length is a quarter wavelength with one closed end and one open end, and the water is driven by oscillatory in and out currents at the open end, then the open end is at the first node and currents at the entrance could produce large changes of level at the head. Although exact quarter-wave dimension would be very unlikely, the possibility of tidal amplification still exists.

Model Setup

The model was built from Serhadlıoğlu's study (Serhadlıoğlu, 2014) whose modelling region includes the Irish Sea, the Celtic Sea and the Bristol Channel. An unstructured mesh was developed by the ADvanced CIRCulation model (ADCIRC) with Surface-water Modelling System (SMS). A mesh convergence study has been conducted to evaluate the necessary level of resolution required in the numerical model to obtain a converged M_2 response using five unstructured triangular finite element meshes (Serhadlıoğlu, 2014). On the open boundary, the water depths were prescribed and were the best estimates based on previous work (Serhadlıoğlu et al., 2013), and no current was specified on the boundary.

As seen in Fig. 1, the model domain stretches from the outer Bristol Channel, close to Lundy Island, to Caldicot and thereby