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High-resolution survey of tidal energy towards power generation and influence of sea-level-rise: A case study at coast of New Jersey, USA

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A R T I C L E I N F O

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A B S T R A C T

The first and a crucial step in development of tidal power, which is now attracting more and more attention worldwide, is a reliable survey of temporal and spatial distribution of tidal energy along coastlines. This paper first reviews the advance in assessment of tidal energy, in particular marine hydrokinetic (MHK) energy, and discusses involved challenges and necessary approaches, and then it makes a thorough survey as an illustrative case study on distributions and top sites of MHK energy within the Might-Atlantic-Bight (MAB) with emphasis on the New Jersey (NJ) coastlines. In view of the needs in actual development of tidal power generation and sensitivity of tidal power to flow speed, the former being proportional to the third power of the latter, a high-resolution and detailed modeling is desired. Data with best available accuracy for coastlines, bathymetry, tributaries, etc. are used, meshes as fine as 20 m and less for the whole NJ coast are generated, and the unstructured grid finite volume coastal ocean model (FVCOM) and high performance computing (HPC) facilities are employed. Besides comparison with observation data, a series of numerical tests have been made to ensure reliability of the modeling results. A detailed tidal energy distribution and a list of top sites for tidal power are presented. It is shown that indeed sea-level-rise (SLR) affects the tidal energy distribution significantly. With SLR of 0.5 m and 1 m, tidal energy in NJ coastal waters increases by 21% and 43%, respectively, and the number of the top sties tends to decrease along the barrier islands facing the Atlantic Ocean and increase in the Delaware Bay and the Delaware River. On the basis of these results, further discussions are made on future development for accurate assessment of tidal energy.

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1. Introduction

Currently, energy demand in the world is primarily met by combustion of fossil fuels. In global energy consumption in 2007, the share of fossil fuels is 88%, which includes 35.6% oil, 23.8% natural gas, and 28.6% coal, and the remaining consists of 5.6% nuclear materials and 6.4% hydropower [1]. The heavy dependence on fossil energy now results in a difficult situation that challenges the whole world; burning of fossil fuels produces CO_2 and has led to the greenhouse effect and thus global warming and climate change [2]. A direct consequence of global warming and climate change is sea-level-rise (SLR), which will apparently impact coastal regions worldwide by posing dangers such as coastal flooding, imbalance of ecosystems, and infrastructure damage [3-5]. In addition, at the current rate of consumption, fossil energy is expected to be exhausted in a near future. According to an estimate for the inventory and with the exploitation rate in 2008, reserves for oil, gas, and coal can only last 40, 60, and 265 years, respectively [6].

In recent years, attention has been shifted from using fossil fuels as the primary source of energy generation to utilizing various types of clean and renewable energy to supply power [7–9]. Tidal energy is such a type of energy, and it has a significant amount imbedded in oceans. Recently, various plans and pilot projects have been implemented for tidal power generation, and there is an emerging resurgent of its development in many countries [8–10]. For instance, aiming at producing 20% of its total energy from renewable resources by 2020, which corresponds to about 35% of its electricity demand, UK is aggressively exploring renewable energy from tidal sources [11]. In US, tidal energy development is also growing rapidly with efforts from private, public, and government sectors [12,13]. New Jersey (NJ) State has set goals to achieve 20% renewable energy generation by 2020 and considers tidal energy as an important part of it. It is estimated that if only 1% of the NJ shoreline is utilized for tidal energy production, it could contribute 500 MW or more power based on presently available technology during the next two to three years, while adding over one billion US dollars to its economy in the next decade [14]. In 2012, the Federal Energy Regulatory Commission has issued a pilot commercial license to Verdant Power's RITE project in the Eastern River in New York City, which is the first commercial license for tidal power in US [15].

The first as well as a crucial step in actual tidal power development will be a reliable survey of spatial distribution and temporal variation of tidal energy along coastlines and, on this basis, selection of the best sites for tidal power generation. For this purpose, in recent years, many countries around the world are making surveys on tidal energy along their coastlines, and databases for potential regions for power generation have been created. For example, an investigation has been made on tidal current energy along the entire coast of Ireland, and its total tidal power was assessed at 230 TWh/y [16]. It was computed that UK had 95 TWh/y in theoretical tidal stream energy, and recently another project of a complete survey has been initiated in the country [17,18]. An analysis was made to review tidal energy at more than 100 sites of Norway, and it estimated that they yielded a theoretical resource on the order of 17 TWh/y [19]. On the basis of studies at a big portion of its coastal zones, it was projected that the average power available from tidal currents in China exceeded 122 TWh/y [10]. An inventory was presented on tidal energy in each of states in US, and it was stated that totally the nation had 250 TWh/y in tidal current energy [20,21]. Additionally, a number of investigations have been made to assess tidal energy at local sites. Among many such local sites, examples are the Alas Strait of Indonesia [22], the Kinmen Island of Taiwan [23], the Cook Strait of New Zealand [24], the Rı´a de Muros on the north-western coast of Spain [25], the Severn Estuary in UK [26], the Minas Passage in the Bay of Fundy in Canada [27], and the Beaufort River of South Carolina, US [28].

Nevertheless, above and other existing surveys are preliminary and cannot meet the needs of actual projects, and more advanced techniques and approaches are necessary and detailed investigations with desired resolution and accuracy are yet to be made to serve the development of tidal power generation and also the evaluation of its

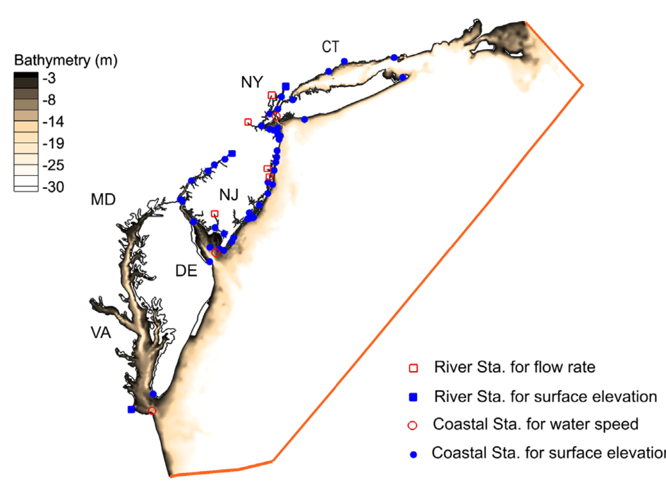

Fig. 1. Region of study. Symbols are observation stations, and the red line is an open boundary where astronomic tide conditions will be imposed. (For interpretation of the references to color in this figure and those hereafter, the reader is referred to the web version of this article.)