【Report】

Ocean renewable energy: Tidal power in the Yellow Sea

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Abstract

Ocean renewable energy sources are briefly introduced in this review article. Special focus on tidal energy from ocean renewable energy in the Yellow Sea and its practical utilization in South Korea are illustrated with several examples. Among them, the Sihwa Lake tidal power plant, the Garolim Bay tidal power project, the Incheon tidal power project, and the Uldolmok tidal current power station were introduced with more details. A numerical modelling system, Regional Ocean Tide Simulator, is introduced for now- and forecast of tidal regime to evaluate the potential tidal power, to provide operational information for practical purpose of tidal power, and to assess the environmental impacts caused by a change of tidal regime due to large-scale development of tidal barrage.

1. Introduction

Global warming in climate change has been the key issue everywhere. CO_2 emission due to fossil fuel usage and its reduction using advanced technology is leading issues in many science and engineering subjects.

In order to ensure healthy air and a stable climate for our children and grandchildren, we must make responsible decisions about our energy sources. Existing technologies and forward-thinking policies offer practical and affordable solutions to reduce our dependence on the fossil fuels that currently dominate America’s electricity system. This system threatens the health of our communities by polluting the air and contributing to global warming. If left unchecked, heat-trapping emissions, such as carbon dioxide (CO_2), are expected to cause irreversible damage to communities throughout the United States and around the world. This damage will likely include increased urban air pollution and emerging infectious diseases such as West Nile Virus (Epstein and Rodgers, 2004); sea-level rise causing flooding and erosion in coastal communities; extreme weather including more intense droughts and hurricanes; reduced productivity of some agricultural regions; and loss of many treasured landscapes and species from coral reefs to polar bears (IPCC, 2001).

Practical solutions do exist. For example, more than half of U.S. states have adopted a renewable electricity standard—a policy that requires electricity suppliers to gradually increase their use of renewable energy such as wind, solar, geothermal, and bioenergy (Scientists, 2010). These states are demonstrating that renewable standards are an affordable solution to reduce CO_2 and other unhealthy air emissions, while alleviating the harmful impact

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that fossil fuel extraction, transport, and use have on land and water resources.

There are several kinds of renewable energy sources around us. Some examples of renewable energy are hyrdropower (water), wind power (wind), solar power (the sun), geothermal power (the earth), and biomass (plant matter, animal wastes, and organic contents). They are not described in detail in this paper since the ocean renewable energy is the main theme; however they are easily accessible on the web or in the materials including the literatures for their definitions, current status, advantages and disadvantages, etc.

This is a brief review article on ocean renewable energy, in particular focusing on what kind of efforts is going on from the ocean to tackle the global warming by reducing CO_2 emission. A couple of examples of tidal power generation in the Yellow Sea from Republic of Korea are provided to show the current status and problems of tidal power because it is the most vigorous region in the world in its kind. In Section 3, the introductory parts are largely based on Hodgson, (2010) unless mentioned specifically.

2. Ocean Renewable Energy

The ocean can produce two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves.

Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. Just a small portion of the heat trapped in the ocean could power the world.

Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy, while ocean thermal energy is fairly constant. Also, unlike thermal energy, the electricity conversion of both tidal and wave energy usually involves mechanical devices.

A barrage (dam) is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator. For wave energy conversion, there are three basic systems: channel systems that funnel the waves into reservoirs; float systems that drive hydraulic pumps; and oscillating water column systems that use the waves to compress air within a container. The mechanical power created from these systems either directly activates a generator or transfers to a working fluid, water, or air, which then drives a turbine/generator (Renewable energy world National Renewable Energy Laboratory, 2010).

2.1 Tide in the oceans

This sub-section is largely based on Park et al. (1999).

The longest oceanic waves are those associated with the tides, and are characterized by the rhythmic rise and fall of sea-level over a period of half a day or a day. The rise and fall result from horizontal movements of water (tidal currents) in the tidal wave. The rising tide is usually referred to as the flow (or *flood*), whereas the falling tide is called as *ebb*. The tides are commonly regarded as a coastal phenomenon, and those who see tidal fluctuations only on beaches and in estuaries tend to think of the tide as 'coming in' and 'going out'. However, it is important to realize that the ebb and flood of the tide at the coast is a manifestation of the general rise and fall in sea-level caused by a long-wavelength wave motion that affects the oceans as well as shallow coastal waters.

The rhythmic rise and fall of sea-level are a result of the *gravitational force* and *relative motions* of the Earth, Sun and Moon. The Moon and the Sun both exert a gravitational force of attraction on the Earth, however the Moon exerts a larger gravitational force on the Earth because, although it is much smaller in mass, it is a great deal closer than the Sun. Actually, the tidal-generating force is proportional to $1/R^3$, where the R is the distance between the objects, the Earth and the Moon/Sun. This force of attraction causes the oceans, which make up 71% of the Earth's surface, to bulge along an axis pointing towards the Moon (lunar tide). Tides are produced by the rotation of the earth beneath this bulge in its watery coating, resulting in the rhythmic rise and fall of sea-level.

The Earth and the Moon behave as a single system, rotating about a common center of mass, with a period of 27.3 days. In this single system, the period of Earth's rotation, which is 24 hours in the Earth system, with respect to the Moon is 24 hours 50 minutes. This is the *lunar day*. The orbits of the Moon around the common center are in fact elliptical and the consequent variation in distance from Earth to Moon results in corresponding variations in the tide-generating forces. When the Moon is closest to the Earth, it is said to be in *perigee*, and the Moon's tide-generating force is increased by up to 20% above the average value. When the Moon is furthest from Earth, it is in *apogee*, and the tide-generating force is reduced to about 20% below the average. The difference in the Earth-Moon distance between apogee and perigee is about 13%, and tidal ranges are greater when the Moon is at perigee. The Moon's elliptical orbit takes 18.6 years to complete a full precessional cycle. One more factor, which has significant effect on the lunar tide, among a number of interacting cycles due to the relative motions of the Earth and Moon is the declination of the Moon's orbit relative to the equatorial plane of the Earth with 28.5º. The result of the declination is that the Moon appears rise and fall over the 27.3-day period to the observer on the Earth, producing the inequalities of the lunar tide at same latitude of the Earth with the time interval of 12 hours 25 minutes.

The gravitational force and relative motion of the Earth and the Sun affects the tides in a similar manner as the Moon, but to a lesser degree. The oceans also bulge towards the Sun causing the sola'r tide. When the Earth, Moon and Sun are positioned in a straight line (a full or new Moon), the gravitational attractions are combined, resulting in very large *spring* tides. At half Moon, the Sun and Moon are at right angles, resulting in lower tides called *neap* tides.

However, the real tides observed in the coasts and oceans are not following the *astronomical tides*, which can be determined and predicted by the abovementioned gravitational force and relative motions of the Earth, Sun and Moon. The reasons why actual tides do not behave as astronomical tides are 1) the wavelength of tidal waves is long relative to depth in the oceans. The propagation speed is slow relative to the rotating Earth and governed by the depth of oceans since they are shallow-water waves due to long wavelength. 2) The Earth's rotation is too rapid for either inertia of the water masses or the frictional forces at the sea-bed to be overcome fast enough for astronomical tides to occur. Therefore, there is a tidal lag, such that high tide commonly arrives some hours after the passage of the Moon overhead. 3) The presence of the land mass interrupts the tidal bulge's directing circulation of the globe. The shape of ocean basins constrains the direction of tidal flows. 4) The Coriolis force affects the water movements to the right or clockwise in Northern Hemisphere and to the left or counter-clockwise in Southern Hemisphere except at equator.

The dynamic theory of tides was developed to understand the actual tides by considering that the factors such as the depths and configurations of the ocean basins, the Coriolis force, friction forces and inertia might influence the behavior of water mass subjected to rhythmic forces resulting from the orbital relationships of the Earth, Moon and Sun. Even though the dynamic theory of tides is complex, it computes theoretical tides, which are very close to the actual observed tides. In real tide system, the combined constraint of ocean basin geometry and the influence of the Coriolis force results in the development of amphidromic systems. In an amphidromic system the crest of tidal wave at high water circulates around an amphidromic point once during each tidal period. The tidal range is zero at an amphidromic point, and increases outwards away from it. Co-tidal (co-phase) lines in an amphidromic system is the link of all the points where the tide is at the same stage (or phase) of its cycle. The successive co-tidal lines radiating outwards from the amphidromic point thus indicate the passage of the tidal wave crest around it. Co-range (co-amplitude) lines, approximately at right angles to them, are the link of all places that have the same tidal range (amplitude). Co-range lines are more-or-less concentric circles about the amphidromic point, representing larger and larger tidal ranges the further away they are from it. (See Figure 1 for an amphidromic system)

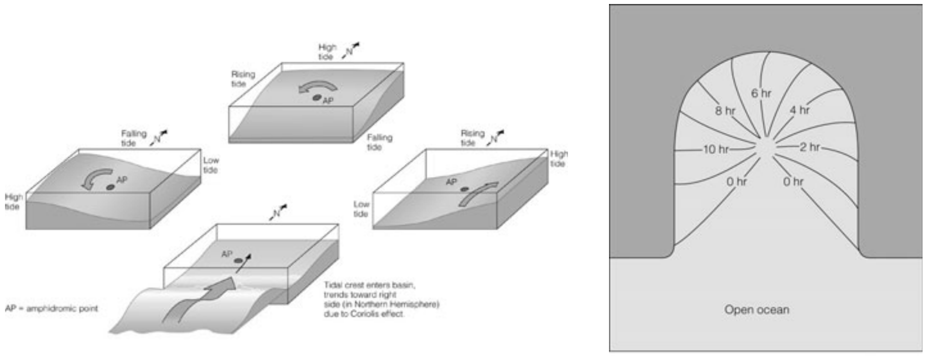

Figure 1. The movement of tidal crest creates a sloshing in the basin, and the Coriolis effect spins the water about the basin. This creates an amphidromic point at its center, where the tidal range is zero. (Copyright 2005 Brooks/Cole Thomson)

The harmonic method is the practical application of the dynamic theory of tides and is the most usual and satisfactory method for the prediction of real tidal heights. It makes use of the knowledge that the observed tide is the sum of a number of harmonic constituents or partial tides, each of whose periods precisely corresponds with the period of some component of the relative astronomical motions between the Earth, Moon and Sun. For any coastal location, each partial tide has a particular amplitude and phase. The actual observed tide at a particular place is the resultant or sum of all of the partial tide at that place. Therefore, in order to make accurate tidal predictions for a location such as a seaport, the amplitude and phase for each partial tide that contributes to the actual tide must first be determined from analysis of the observed tides. This requires a record of measured tidal heights obtained over a time that is long compared with the periods of the partial tide concerned. There are 390 harmonic constituents or partial tides identified so far. Table 1 shows the most important nine harmonic constituents among the 390 with their symbols, periods, and coefficients: four are semi-diurnal, three are diurnal and the other two are longer-period constituents.

Table 1. Some principal tidal constituents. The coefficient ratio is the ratio of the amplitude of the tidal component to that of M_2

Name of tidal component	Symbol	Period in solar hours	Coefficient ratio (M_2=100)
Semi-diurnal:			
Principal lunar	M_2	12.42	100
Principal solar	S_2	12.00	46.6
Larger lunar elliptic	N_2	12.66	19.2
Luni-solar	K_2	11.97	12.7
Dinrnal:			
Luni-solar	K_1	23.93	58.4
Principal lunar	O_1	25.82	41.5
Principal solar	P_1	24.07	19.4
Longer period:			
Lunar fortnightly	M_f	327.86	17.2
Lunar monthly	M_m	661.30	9.1

2.2 Tidal energy

Tide

The tide rise and fall in eternal cycles. The waters of the oceans are in constant motion. The tidal energy from the constant motion is the most promising source of ocean energy for today and the near future. Tides are changes in the level of the oceans caused by the rotation of the earth and the gravitational pull of the moon and sun. Near shore water levels can vary up to 12 m, depending on the season and local factors. Not many locations have good inlets and a large enough tidal range about 3 m to produce power economically. Important sites for potential tidal barrage development include the world's largest tidal range in the Bay of Fundy, Europe's largest, the Severn Estuary and in Alaska (Cook Inlet), Argentine (San Jose), Australia (north west coast), Brazil (north coast), China (Yellow Sea), France (lles de Chausee), India (Gulf of Cambay, Gulf of Katchch), South Korea (west coast) and Russia (Okhotsk Sea, Jugursk Bay) (THEIET, 2007).

Tidal power plants capture the energy in the changing tides. A low dam, called a barrage, is built across an inlet. The barrage has one-way gates (sluices) that allow the incoming flood tide to pass into the inlet. When the tide turns, the water flows out of the inlet through huge turbines built into the barrage, producing electricity. The oldest tidal plant, La Rance in France, has been successfully producing electricity since 1966 (Hodgson, 2010).

The electricity from tidal power plants costs about twice of that of a conventional power plant. It is very expensive and takes a long time to build the barrages to be operated. Tide is periodic; therefore the tidal power has intermittent nature. However, it is predictable and is to maintain.

Tidal power is a renewable energy source. The plants do affect the environment, though they produce no air pollution. During construction, there are major short-term changes to the ecology of the inlet. Once the plants go into operation, there can be long-term changes to water levels and currents. However, the plants in operation have reported no major environmental problems. The key factors are to lower the construction cost, increase output, and protect the environment (Project, 2010).

Tidal currents

Tidal currents power is another possibility by using the underwater turbines where the current velocity is larger than about 3 m/s. This would not have many of the disadvantages of tidal power and be reliable. One of examples of potential tidal currents power is the large installation of underwater turbines near the Cook Strait in New Zealand. It plans to consist of 7000 turbine units anchored 40 m below the surface and has capacity for providing all New Zealand's electricity requirements (Avery, 2007).

2.3 Wave energy

There is also tremendous energy in waves. Waves are caused by the wind blowing over the surface of the ocean. In many areas of world, the wind blows with enough consistency and force to provide continuous waves. The west coasts of the United States and Europe and the coasts of Japan and New Zealand are good sites for harnessing wave energy (Hodgson, 2010).

There are several ways to harness wave energy. The motion of the waves can be used to push and pull air through a pipe. The air spins a turbine in the pipe, producing electricity. In Norway, a demonstration tower built into a cliff produces electricity for about four cents a kWh using this method.

Another way to produce energy is to bend or focus the waves into a narrow channel, increasing their power and size. The waves then can be channeled into a catch basin, like tidal plants, or used directly to spin turbines.

There are not many big commercial wave energy plants, but there are a few small ones. There are wave-energy devices that power the lights and whistles on buoys. Small, on-shore sites have the best potential for the immediate future, especially if they can also be used to protect beaches and harbors. They could produce enough energy to power local communities.

Many devices, however, have to be very large and therefore costly, and they are subject to corrosion by sea water and buffeting by the waves. Also the price of wave-generated power is about six times the current price, for example Portuguese government pays subsidy six times the current price. Therefore, the keys are again the low cost for production and increased output (Project, 2010).

2.4 Ocean thermal energy

The energy from the sun heats the surface water of the ocean. In tropical regions, the surface water can be 40 or more degrees warmer than the deep water. This difference can be used to produce electricity. Ocean Thermal Energy Conversion (OTEC) has the potential to produce more energy than tide, wave, and wind combined, but it is a technology for the future. There are no large-scale OTEC power plants in use today (Hodgson, 2010).

There are three types of OTEC technologies: closed-cycle, open-cycle, and hybrid. Closed-cycle systems use the ocean's warm surface water to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. In an open system design, the steam is turned into fresh water, and new surface water is added to the system. The hybrid systems combine both closed-cycle and open-cycle systems. In Hawaii, the OTEC plant with 50MW has been constructed since the 1970s (Renewable energy world National Renewable Energy Laboratory, 2010).

An OTEC system is only 2.5% efficient. The difficulties lays on the corrosiveness of the sea water, the problem of anchoring the device, and the transmitting the power generated to where it needed (Project, 2010).

3. Tidal power extraction in the Yellow Sea

The Yellow Sea is a shallow inland sea lying between northeastern China and the Korean Peninsula, with depths in its central north-south trough in excess of 60 to 80 m (Figure 2). It serves as the oceanic outlet for the Han, Yellow, Yalu, and Yangtze Rivers from the surrounding Korea and China, which drain much of the north-central China landscape, carrying large amounts of sediments into the sea-thus its name. Placing in a range of latitudes between roughly 33ºN to 40ºN, its dynamics are those expected of a large, shallow, mid-latitude estuary on the eastern boundary of a continent. The tides are dominantly semidiurnal. Tidal forcing is variable in space and time, but is very significant. Peak tidal currents among the shores of western Korea are often 1 to 1.5 m/s and reach a maximum in the passage off the southwest tip of Korean peninsula near Uldolmok of 4.4 m/s. In the central basin, the speeds are of order 0.5 m/s. Tidal ranges along the Korean coast are 4 to 8 m, while those along the China coast are 1 to 2 m (Jackson, 2004).

Figure 3 shows a map of co-phase (constant phase relative to the passage of the Moon overhead) and co-amplitude (constant range in meters) lines of the semidiurnal lunar M_2, S_2, K_1 and O_1. The currents circulate counterclockwise around the amphidromes (Choi and Lee, 2003a).

In the winter, northerly winds from the Asian mainland are strong and the resultant convection and wave mixing render the water column isothermal and isohaline to the bottom, with essentially no density gradients. In the late spring, summer, and early autumn, the southwesterly monsoon brings warm, wet air to the region with attendant rainfall and riverine runoff of fresh water. Solar heating combines with the fresh water outflow from the rivers to strongly stratify the upper layers of the water column. This results in strong temperature, salinity, and density gradients near depths of approximately 25 to 30 meters depending on wind mixing.

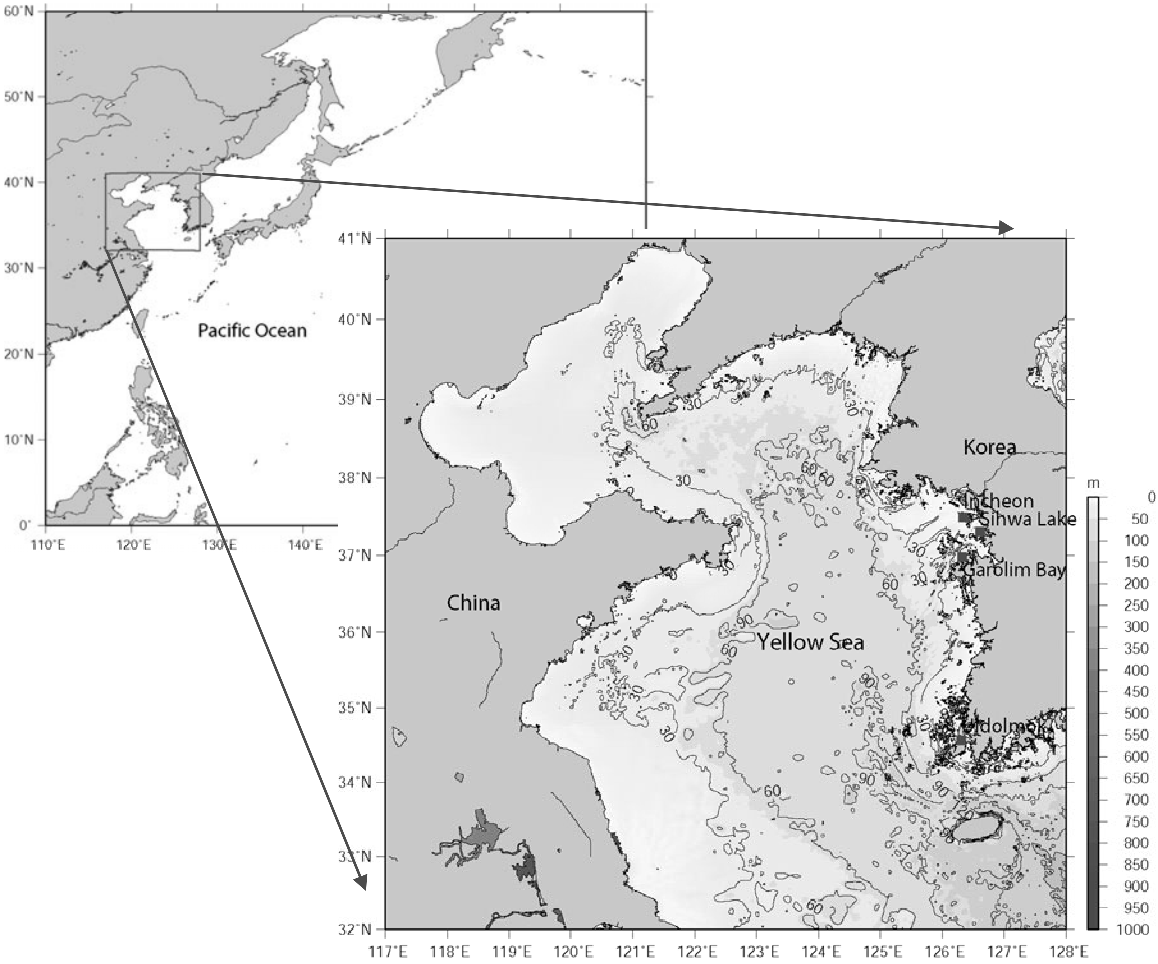

Figure 2. The Yellow Sea and locations of tidal power plant and on-going projects such as Sihwa Lake, Garolim Bay, Incheon, and Uldolmok along the west and south coast of Korea.

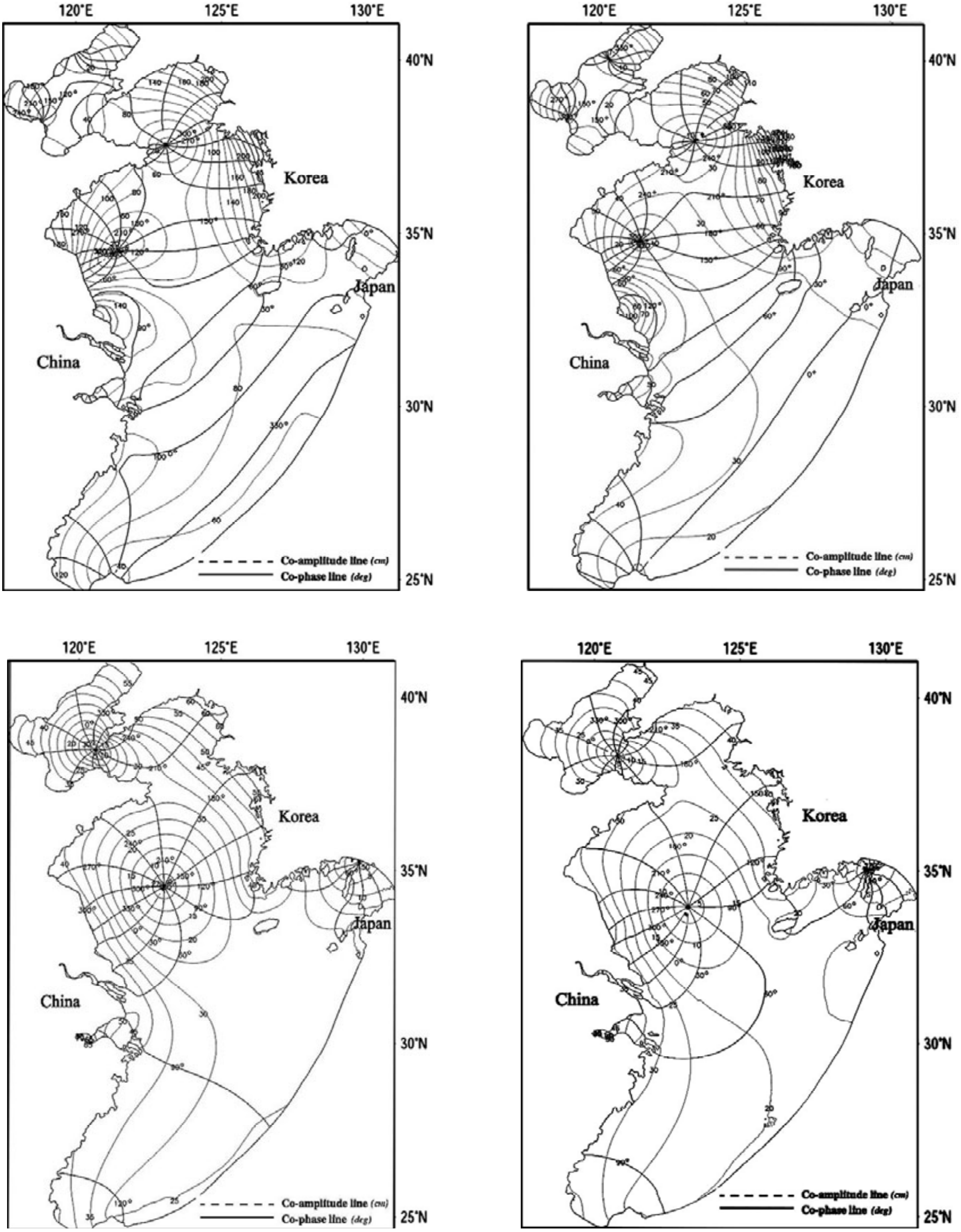

Figure 3. Reproduced tidal distributions using Regional Ocean Tide Simulator (upper left plate - M_2 tide; upper right plate - S_2 tide ; lower left plate - K_1 tide; lower right plate - O_1 tide).

3.1. Sihwa Tidal Power Plant

Sihwa Lake Tidal Power Station (Figure 4) is a large tidal power station currently under construction. Due to be completed in August 2010 (Bae et al., 2010), it will operate with a total power output capacity of 254 MW, surpassing the 240 MW Rance Tidal Power Station in France to become the world's largest tidal power installation.

The tidal barrage makes use of a seawall constructed in 1994 for flood mitigation and agricultural purposes. The 25.4 MW submerged bulb turbines are driven in an unpumped flood generation scheme; power is generated on tidal inflows only and the outflow is sluiced away. This slightly unconventional and relatively inefficient approach has been chosen to balance a complex mix of existing land use, water use, conservation, environmental and power generation considerations (Park, 2007; Construction, 2009).

The tidal power station should provide indirect environmental benefits as well as renewable energy generation. After the seawall was built, pollution built up in the newly created Sihwa Lake reservoir, making its water useless for agriculture. In 2004, seawater was reintroduced in the hope of flushing out contamination; future inflows from the tidal barrage are envisaged as a complementary permanent solution (Park, 2007).

Cost of the project is being met by the South Korean Government and at present totals 313.5 billion won (Bae et al., 2010). Mean operating tidal range is 5.6 m, with a mean spring tidal range of 7.8 m. The working basin area is 43 km^2 (Lee, 2006). The test operation was scheduled from Dec. 2010 while gradually opening the shield protection for construction works.

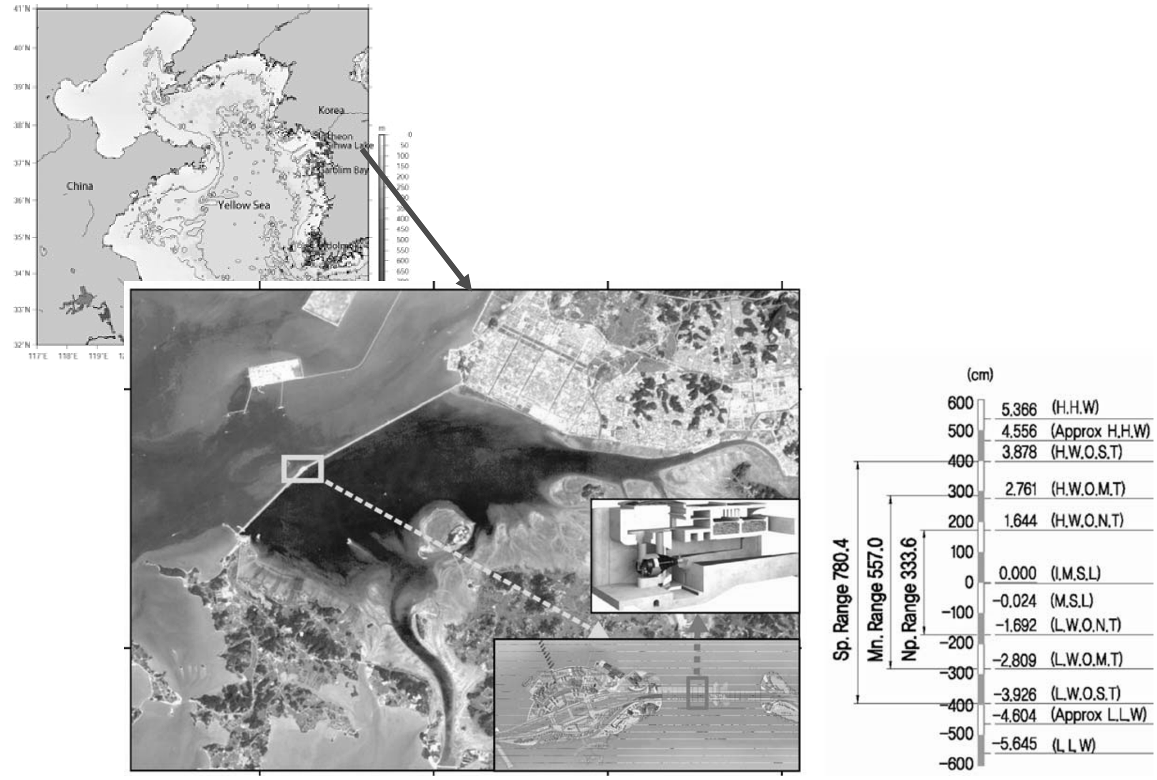

Figure 4. The location of Sihwa Lake and the tidal power plant.

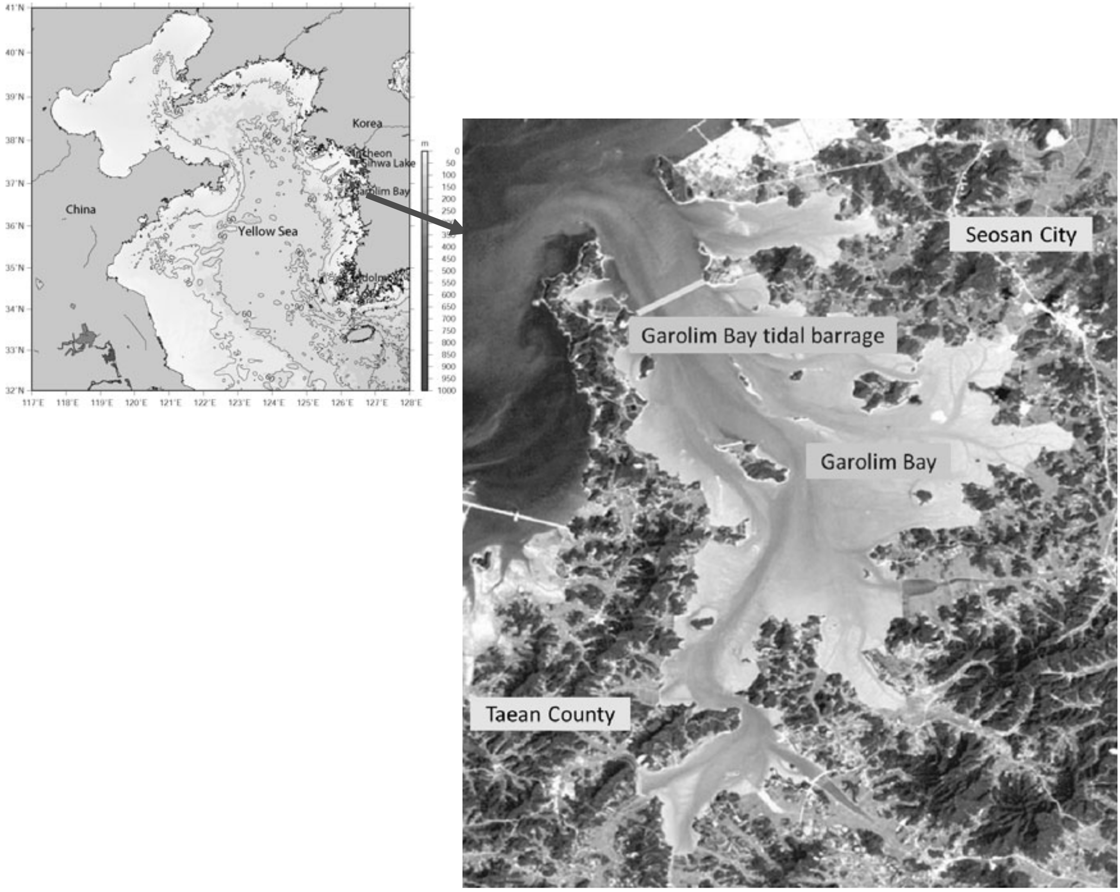

Figure 5. The location of Garolim Bay and a tidal barrage for tidal power plant.

3.2. Garolim Bay Tidal Power Project

Garolim Bay Tidal Power Station (Figure 5) is a planned tidal power plant in Garolim Bay, on the west coast of South Korea. The project is developed by Korea Western Power Company Limited and was in the process of receiving government approval as of November 2008 (Station, 2010a).

Garolim Bay is located between Seosan City and Taean County of Chungnam Province, South Korea, at the western seashore of South Korea with the mean tidal range of 4.7 m and the spring tidal range of 6.6 m. The length of planed tidal barrage is 2.0 km and the basin area is 45.5 km^2. The electric power generation capacity of the plant will be 520 MWh per day (26 MWh×20 sets) using one-way during ebb tide (Station, 2010a). Estimated annual output is 880 GWh. This is more than twice the capacity of the Rance Power Plant in France, which is the biggest tidal power plant in the world as of 2007. According to an announcement made by the power company, construction cost was estimated to be 1 trillion Korean won (1 billion US dollars) as of 2005 (Lee, August 29 2008).

Garolim Bay Tidal Power Plant Project is now being included in the South Korean government's renewable energy strategy. The Korean government classifies tidal power as renewable, and the Garolim Bay Project is included in the renewable energy plan which the government announced in September 2008 (Station, 2010a).

On the other hands, the concerns on environmental impacts are rising at Garolim Bay. Garolim Bay is regarded as one of the important tidal flats in South Korea. The Korean government included this bay in the National Wetland Inventory (Korea, 2008). The Yellow Sea Large Marine Ecosystem (YSLME) Project, managed by the United Nations Development Programme and the Global Environment Facility, also surveyed the ecology of this bay (Park et al., 2008).

The Korean Federation for Environmental Movement (Friends of the Earth Korea) has criticized the project, arguing that the power plant is contrary to the purpose of renewable energy, because it would destroy the valuable tidal flats in the area, thus accelerating global warming (Station, 2010a).

According to a survey on fishery resources in 1981, supported by the Korean Ocean Research and Development Institute, this bay is an important spawning ground for many species of fish. The study predicted that the plant's construction would cause critical damage to the bay's ecology (Hur, 1984). The bay is one of the most important fish farming sites in Korea, composed of about 2000 fishery households (Station, 2010a).

3.3 Incheon Tidal Power Project

The Incheon Tidal Power Station (Figure 6) is a large tidal power station currently proposed to be built at the Incheon Bay, South Korea. The mean tidal range at Incheon Bay is 5.3 m and the spring tidal range is 7.3 m. The length of planed tidal barrage is 20 km and the basin area is 106 km^2. The facility is expected to top 1,320 MW in generating capacity with the help of 44 water turbines rated at 30 MW each using one-way generation scheme during ebb tide, making this facility one of the largest of its kind in the world. The construction and developments costs are expected to reach KRW 3.9 trillion (USD 3.4 billion), of which would be entirely covered by private funding. The station is expected to generate up to 2.41 TWh of energy annually upon its completion in June 2017 (Joongangdaily, 14 Jan. 2009; Koreatimes, 20 Jan. 2010).

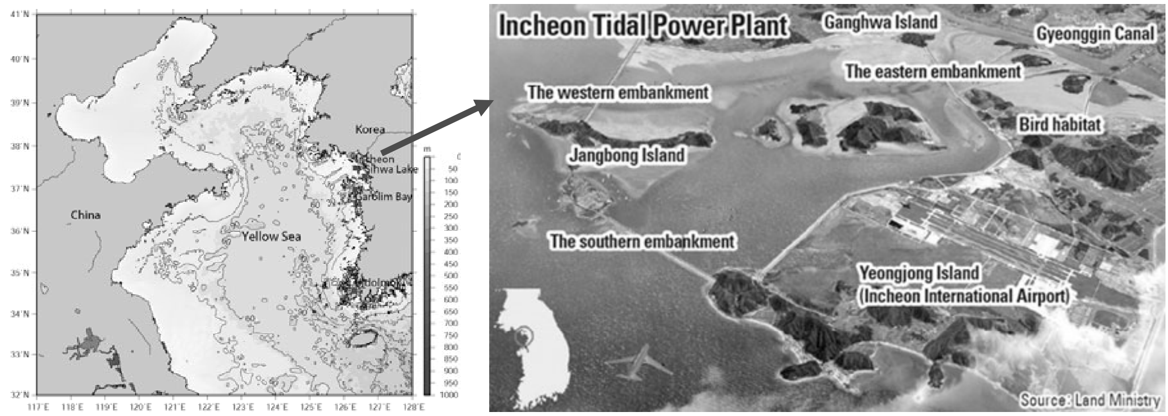

Figure 6. The location of Incheon tidal power plant.

3.4. Uldolmok Tidal Current Power Project

Uldolmok Tidal Power Station (Figure 7) is a tidal power station in Uldolmok, Jindo County, South Korea. The Uldolmok Strait experiences tidal water speeds that exceed 6.5 m/s with the width of the strait being approximately 300 m due to the average tidal range of 3 m over the entire channel and the tidal phase difference of 100 min between both ends. The water level difference through the Uldolmok Strait is 2 m (Lee, 2006).

The plant was commissioned in May 14, 2009 by the South Korean government. The plant cost US$10 million and has an installed capacity of 1,000 KW (1 MW), generating 2.4 GWh annually, sufficient to meet the demand of

430 households (News, 1 Jun. 2009; Station, 2010b).

The South Korean government plans to increase this capacity of 1 MW to 90 MW by the end of the year 2013, increasing the demand cover to 46,000 households, while simultaneously working on the 254 MW Sihwa Lake Tidal Power Station as a part of the goal of generating 5,260 GWh through tidal power by 2020 (News, 1 Jun. 2009; Station, 2010b).

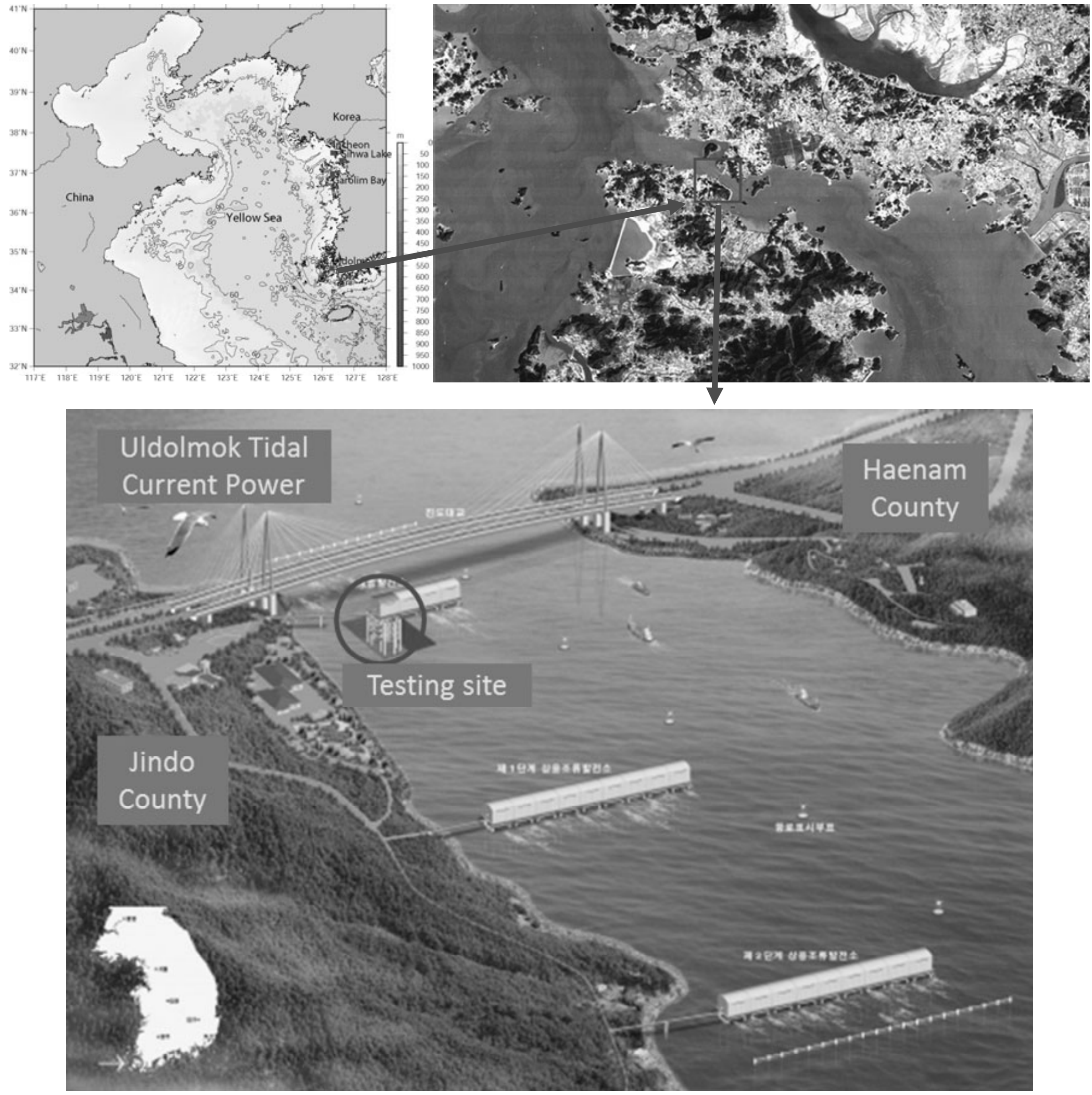

Figure 7. The location of Uldolmok tidal current power test plant and its plan.

4. Now- and Forecast of Tidal Regime: Regional Ocean Tide Simulator

The necessity of predicting changes in tidal regime caused by large coastal engineering developments has led to increased numerical modeling of ocean tides on the continental shelf since the 1970s (Flather, 1976; Choi, 1978; Greenberg, 1979). In view of practical concerns related to pollutants, oil spill dispersal, and search and rescue operations at sea, and navigation, demands for accurate tidal predictions with respect to both time and space are increasing. Tidal power plant usually requires large scale tidal barrage construction to utilize the exchange of the sea water and water level differences in river mouth or estuary. Therefore it is very important to know the present and future states of tidal regime not only for the construction and operation of tidal power plant but also for the environmental impact assessment. The only practical way of obtaining effective solutions is to construct a mathematical model that simulates the behavior of the tidal system, which plays a central role in the shelf sea, involving a set of equations of motion for the sea that are solved numerically to yield the tidal variation. An ocean tide simulation system, Regional Ocean Tide Simulator (ROTS) for accurate modeling of the ocean tides in the regional seas of bordering the Korean Peninsula and Japan including the Yellow Sea was introduced (Choi and Lee, 2003b) and brief explanations are in the following sub-section.

4.1. Regional Ocean Tide Simulator

The main part of the ROTS is a modeling technique that converts the model equations to a discrete form and allows computation over spatially unstructured meshes, allowing more accurate representations of the coastlines, man-made dikes, coastal structures, and topographic features (ADCIRC, http://www.nd.edu/~adcirc/ manual.htm). Rather than refining dynamic grid nesting technique retaining the finite difference scheme, ROTS adopts the finite element technique. This method permits more flexibility in fitting irregular coastlines and allows bathymetry to be fitted with elements of an arbitrary size, shape and orientation (in particular, tidal barrier positioning). GUI based code for partitioning of unstructured meshes in semi-automatic manner was also developed to resolve the detailed variation of bottom topography and coastline topography. It permits easy editing of the unstructured meshes and merging them into larger domain of base models, of which the open boundary conditions were prescribed previously with a series of adjustment runs. Considering the importance of setting up an appropriate model area, two versions of base models were created: one covering the Yellow Sea and the East China Sea (YS/ECS) continental shelf; and the YS/ES/WNP (the Yellow Sea, the East/Japan Sea and the western North Pacific) extending to the outer eastern Japanese coast. These models were helpful for focusing on different coastal regions of interest, as seen in Figure 8 for the YS version. With this simulator design, detailed meshes in the coastal and estuarine regions can be resolved and computations can be managed with parallel structures, demonstrating the ease of relocatablity within the base model regions. Applications of this system for the simulation of barrier effects perturbing the tidal regime due to the construction of tidal dikes in the eastern Yellow Sea and Isahaya Bay in the Ariake Sea can be found (Choi et al., 2010).

This technique can also be extended to three-dimensional flow computations and can be used for such now- and forecast of tidal regime of interests for the construction and operation of a tidal power plant.

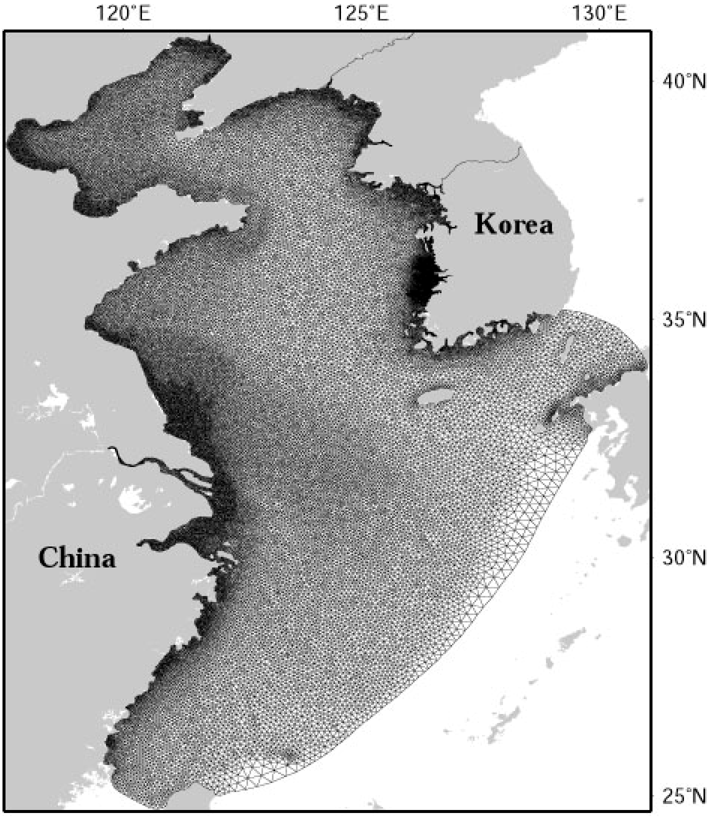

Figure 8. Overall meshes of Regional Ocean Tide Simulator covering the Yellow Sea and a part of the East China Sea.

5. Concluding Remarks

Ocean renewable energy described above has still many requirements to be practically utilized in power generation in cost, technology, and environment. However the current advance of technology in some part shows the feasibility of practical use in tidal energy in significant level such as in South Korea. Finally, with regards to the tidal energy in the oceans, Figure 9 shows the tidal energy dissipation of semi-diurnal M_2 tide implying the potential tidal energy in marginal seas such as the Yellow and East China Seas, the Timor and Arafura Seas, and the Patagonian Shelf.

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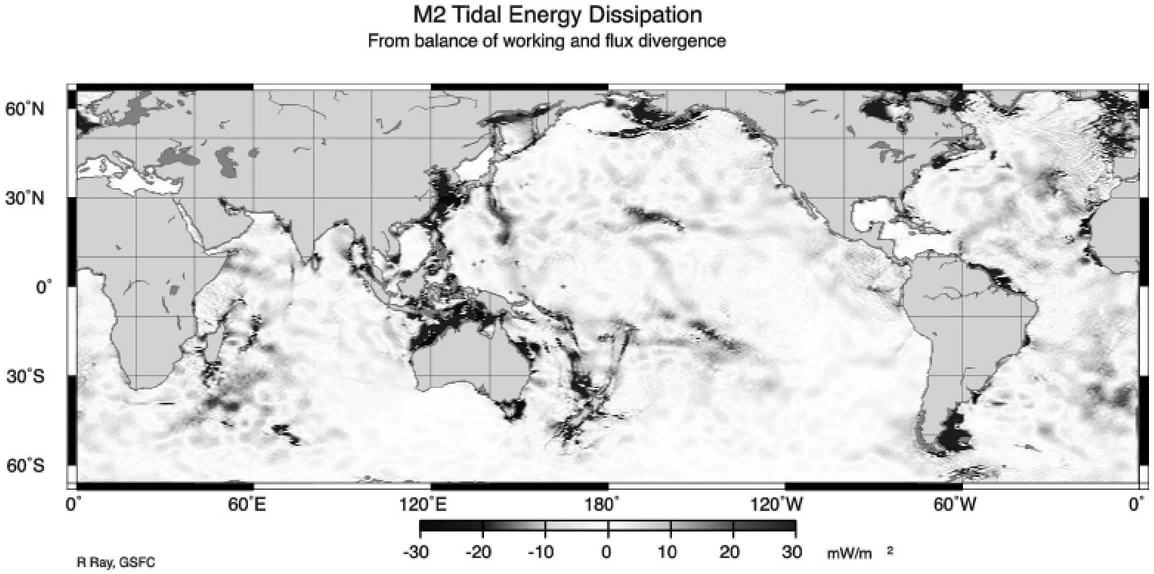

Figure 9. Tidal energy dissipation map of semi-diurnal M_2 tide in the oceans. (from NASA's Goddard Space Flight Center) Empirically drawn tidal dissipation map from six-year altimeter data from the TOPEX/Poseidon satellite. About 1 terawatt, or 25 to 30% of the total tidal energy dissipation, occurs in the deep ocean. The remainder occurs in shallow seas, such as on the Yellow and East China Seas. Red areas indicate tidal energy dissipation areas implying that the dark-red areas have high potential for tidal energy.

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