論 文

VULNERABILITY OF KOREAN COAST TO THE SEA-LEVEL RISE DUE TO 21ST GLOBAL WARMING

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ABSTRACT: The present study intends to assess the long-term steric sea-level change and its prediction, and potential impacts to the sea-level rise due to the 21st global warming in the coastal zone of the Korea in which much socioeconomic activities have been occurred. The analysis of the 23 tide-gauge data near Korea reveals the overall mean sea-level trend of 2.31 mm/yr.In the satellite altimeter data (Topex/Poseidon and ERS), the sea-level trend in the East Sea is 4.6mm/yr. Both are larger than those of the global average value. However, it is quite questionable that the sea-level trends with the tide-gauge data on the neighboring seas of Korea relate to global warming because of the relatively short observation period and large spatial variability. It is also not clear whether the high trend of altimeter data in the East Sea is related to the acceleration of sea level rise in the Sea, short response time of the Sea, natural variability such as decadal variability, short duration of the altimeter. The coastal zone of Korea appears to be quite vulnerable to the 21st sea level rise such that for the 1-m sea level rise with high tide and storm surge, the inundation area is 2,643 km2, which is about 1.2% of total area and the population in the risk areas of inundation is 1.255 million, about 2.6% of total population. The coastal zone west of Korea is appeared to be the most vulnerable area compared to the east and south. In the west of the Korea, the North Korea appears to be more vulnerable than South Korea. In order to cope with the future possible impact of sea-level rise to the coastal zone of Korea effectively, it is essential to improve scientific information in the sea-level rise trend, regional prediction, and vulnerability assessment near Korean coast .

KEYWORDS: Sea-level, sea-level rise, sea-level rise impact, coastal zone

1. INTRODUCTION

The coastal zone has been extensively used worldwide such as a high density of population and considerable portion of GDP production. The development in the coastal zone - population growth, high GDP production, and strong urbanization - still exhibits upward trend. This trend is no exception in the coastal zone of the Korea. A variety of the coastal zone development in Korea has brought adverse effects such as wetland destruction, coastal erosion and pollution. In addition, the coastal zone of Korea has already been threatened by coastal hazard such as inundation due to extreme high tide and storm surge, and saltwater intrusion into freshwater. Such physical stresses in the coastal zone will be expected to increase with the superposition of the steric sea-level rise due to the human-induced climate change-global warming.

The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) concluded that the global warming due to the enhanced greenhouse effect since the Industrial Revolution would be accelerated in the 21st century. The projected warming will increase the steric sea-level rise of ocean which has large adverse effects such as coastal lowland inundation, wetland displacement, coastal erosion, saltwater intrusion into estuaries and freshwater aquifer, altered tidal range in rivers and bays, change in tide and wave patterns, change in sedimentation on the coastal zone in which rich natural ecosystem is exhibited and active socioeconomic system has been already occurred. Thus the vulnerability assessment of the potential impact to future sea-level rise is essential for developing response strategies and then sustainable development of coastal zone. This study intends to review the sea-level change and its prediction, and to assess potential impacts to the future sea-level rise in the coastal zone of the Korean Peninsula in which much socioeconomic activities have been already occurred.

2. SEA-LEVEL CHANGES AND ITS PREDICTION NEAR KOREA

The long-term sea-level trends at the Korean coast have calculated based on 23 tide-station data near Korea from permanent service for mean sea level (PSMSL). The method of analysis is a simple linear regression fit over the monthly mean sea level of record length at each tide station. The calculated sea-level trend is correctedfor the postglacial rebound component at each station with the ICE-4G(VM2) model (Peltier and Jiang, 1997) to remove the vertical land movement component due to the PGR. We find that the PGR corrected sea-level trend near Korea is 2.31 mm/yr 2.22 mm/yr (Fig. 1), which is higher than the global average, 1.0~2.0 mm/yr, assessed by the IPCC (2001). The regional distribution of the long-term sea-level trend near Korea reveals that the East Sea is in the low trend of 0.57 mm/yr than those of the South Sea (3.13 mm/yr) and the West Sea (2.64 mm/yr).

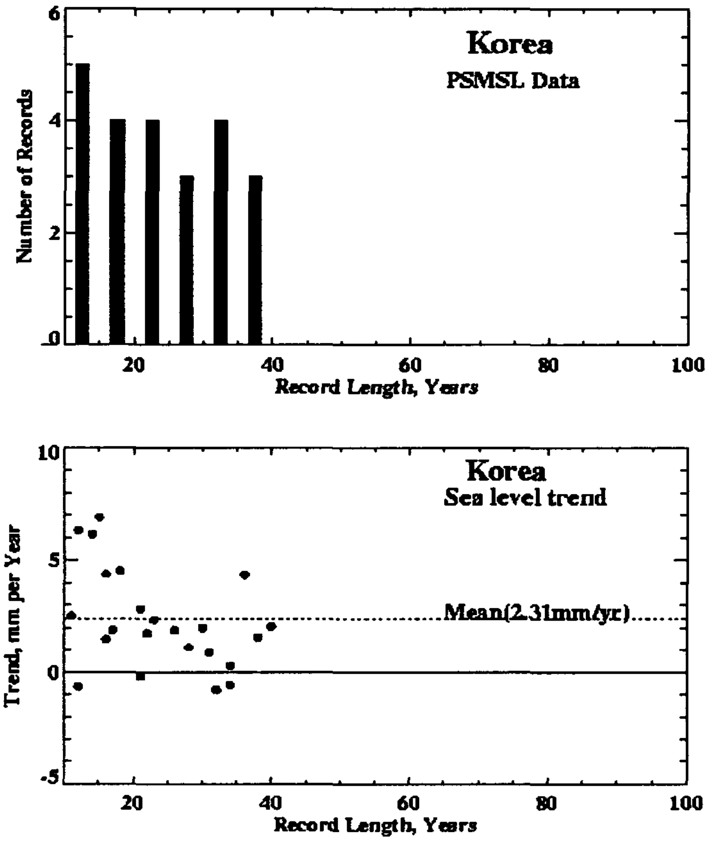

Figure 1. Frequency of the record-length of the tide stations near Korea(top) and sea-level trend according to the record-length(bottom)

Figure 1 also shows the frequency of the record length in years for the 23 PSMSL tide stations used in the present study. The record length of all tide data near Korea is less than 40 years. The regional distribution of sea-level change can be quite complex because of the regional distribution of thermal expansion, heat transport into ocean interiors, ocean circulation changes by the change of density structure with temperature and salinity changes, horizontal heat transport changes due to the ocean circulation changes, wind field changes to climate change, various geological effects in the coastal zone, etc. Also the interannual and decadal variability of the ocean are superposed with the long-term steric sea-level change due to the global warming in the mean sea-level time series from tide-gauge data. From these reasons, the long-term sea-level trend calculated in the present study based on the tide-gauge data with relatively short record length can be much biased with the weak signal of steric sea-level change due to the global warming in spite of the PGR corrections. In addition to the temporal sampling problem on the tide-gauge data near Korea, there exists spatial sampling problem in the calculation of the long-term sea-level trend near Korea. Most data are concentrated in the southern part of the Korean peninsula.Also the data are mainly located at the coastal zone rather than island. The coastal zone has a wide range of physical and geological processes. The large spatial variability near Korea is also shown in the standard deviation of the sea-level trend, which is comparable to the mean value.

In order to overcome the spatio-temporal sampling problem and a variety of errors in the tide-gauge data of Korea, satellite altimeter data are used to estimate the sea-level trend near Korean waters. The altimeter data used include Topex/Poseidon and ERSs data, and observation period spans from May 1992 to April 2001. The sea surface height anomalies in the Eastand South Seas of Korea are produced with standard corrections from Topex/Poseidon measurements and resampled at a degree in space and every month in time through optimal interpolation. Figure 2 represents the monthly time series of sea-level anomalies in the East andSouth Seas of Korea with a linear trend of 4.6 mm/yr (East Sea) and 4.8 mm/yr (South Sea). The sea-level trend in the East Sea, 4.6 mm/yr, is larger than that of the global average values, 1.0 - 2.0 mm/yr, by IPCC assessment (2001) based on tide gauge data and 3.1 mm/yr, by the Topex/Poseidon data (Nerem, 1999). It is not clear whether the high trend with altimeter data in the Sea is related with the acceleration of sea-level rise in the Sea, short response time of the Sea, natural variability such as decadal variability, short duration of the altimeter. Further studies are required to clarify the mechanismon the long-term sea-level change in the EastSea.

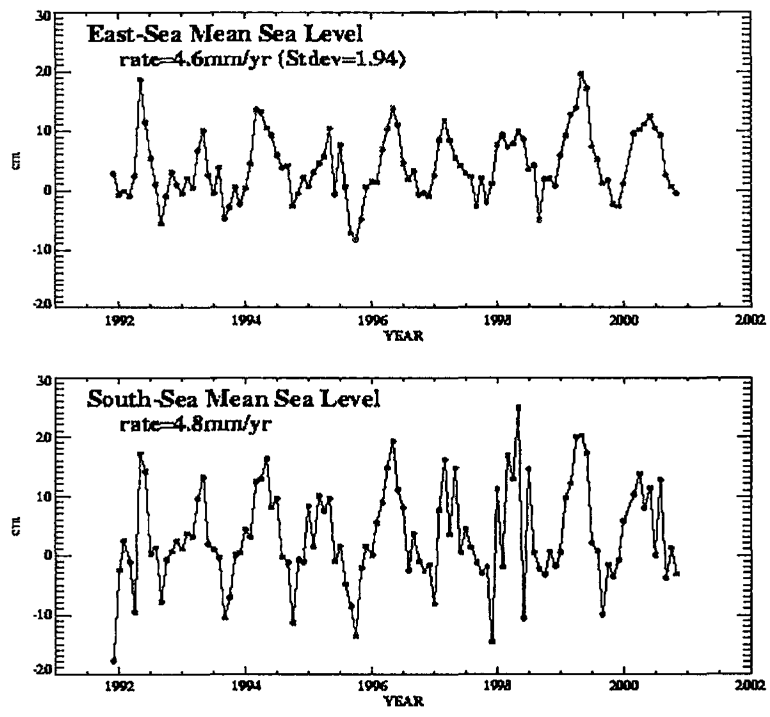

Figure 2. Sea-level change in the East and South Seas of Korea estimated from the Topex/Poseidon and ERS saltimeter measurements.

In the 21st century, the global mean sea-level rise will be accelerated due to the acceleration of the global warming. Based on the 35 IPCC emission scenarios, the sea-level rise in the 21st century will be in the range of 9~88cm with a median value of 48cm. The projected range of the sea-level rise is 2.2~4.4 times higher than that of 20th century. It is projected that the regional variation will be large compared to the global mean value. The state-of-the-art climate model predictions in the regional distribution of the 21stsea-level change show little similarity between models except the Arctic Ocean and Antarctic Ocean. This implies the confidence of current climate model is low in the prediction of the regional distribution of sea-level change (Gregory et al., 2001).

In spite of the low confidence in the regional prediction of current GCM, one GCM prediction (HadCM3 of Hadley Centre, UK) is introduced here to estimate the future sea-level trend near Korea compared to theglobal trend. The HadCM3 include components of the sea-level change due to thermal expansion, ice melting, and the mass balance of the Greenland/Antarctica ice sheet (Gregory and Lowe, 2000). Table 1 represents the prediction of the sea-level change by the HadCM3 to the A2 and B2 emission scenarios, respectively. The prediction of sea-level change represents 10-year averages relative to 1990. As seen in Table 1, the prediction of sea-level rise near Korea appears to be higher than global average for both scenarios. In the northwestern Pacific, the HadCM3 prediction shows the high rise of sea level in the region of Kuroshio and its branches such as Tsushima Warm Current in the Korean waters. The high trend of the sea-level change in the region also appears in other climate model such as NCAR CSM (Choi et al., 2001). The high prediction of sea-level rise in the 21st century could induce serious impacts in the region.

Table1.Predictions of sea-level rise due to the global warming by HadCM3 climate model for the emission scenario of A2(top) and B2(bottom). The unit is cm.

Region \ Year	2030	2060	2090
global	8.0	17.0	28.0
region A	8.8	18.2	31.6
region B	10.6	21.8	36.3
region C	9.7	20.2	35.3
Korean waters	8.2	18.4	33.9

region A: 100o ~ 160oE in longitude, 0o ~ 60oN in latitude
region B: 100o ~ 160oE in longitude, 20o ~ 60oN in latitude
region C: 100o ~ 160oE in longitude, 31o ~ 54oN in latitude
Korean waters: East, South and West Sea of Korea among region C

3. VULNERABILITY OF THE KOREAN COAST

We focused on the socioeconomic system for the vulnerability assessment of the coastal zone in the Korean Peninsula to the future sea-level rise. The questions we asked in the present study are as follows: Is the coastal zone of Korean Peninsula vulnerable to the 21st sea-level rise? If yes, how much and where? What are future tasks in Korea? To answer these questions, we chose inundation area and inundated people as the vulnerability index for the assessment. The sea-level rise scenario for the impact assessment can be classified into two ways in general. One is to use the steric sea-level rise due to global warming (Titus and Richman, 2000) and the other is to include sea-level change due to tide and storm surge as well as the stericchange by global warming (Mimura et al., 1999). The present study adopted the latter method for the vulnerability assessment in the coastal zone of Korea because tide and storm surge give an actual effect on the coastal zone of Korea and the impact will be superposed with the steric sea-level rise due to global warming.

Fourteen sea-level rise scenarios are computed with a combination of steric sea-level rise, tide, and storm surge as follows: Firstly, the global mean sea-level projection by the IPCC (2001) was selected for the steric sea-level change due to global warming along the Korean coast. The global mean sea-level projection by climate model seems to be the only alternative in the sea-level scenario due to the global warming for the Korean coast because of the low confidence of the regional prediction in sea-level change of the current climate model and the difficulty of downscaling based on the observation data. Then the sea- level scenarios are converted into the relative sea-level scenarios with the tide and storm surge effects along the Korean coast. The high tide is adopted into the scenario using the Tide Table (2002) and the storm surge is computed with historical typhoon data (Mimura et al., 1999). The inundation area along the coastal zone of Korea isproduced with the 1-degree resolution of coastal topography adjusted to the local mean sea level (Choi and Ko, 1999) for each of the 14 relative sea-level scenarios. The population inundated is calculated using the LandScan2000 data (Oakridge Nat'l Lab., 2001). The target year for the assessment is 2100.

Table 2 represents the inundation area and population to the 14 sea-level rise scenarios. For the 1-m sea-level rise scenario with high tide and storm surge (S10), the maximum inundation areas appear to be 2,643 km2, which is about 1.2% of total area of the Korean Peninsula. The population in the risk areas of inundation is 1.255 million, about 2.6% of total population. This result suggests that the coastal zone of Korean Peninsula be quite vulnerable to the 21st sea-level rise. The west coastal zone is appeared to be the most vulnerable area compared to the east and south (Fig. 3). In the western side of the Korean Peninsula, the North Korea appears to be more vulnerable than South Korea (Fig. 4). The vulnerability assessment in the present study assumes the maximum emission scenario of IPCC SRES (Special Report on Emission Scenario) and does not consider the retention time of the typhoon, and coastal dike and seawalls. Thus the inundated area and population in the present study represent the possible maximum area and population, which indicates the degree of a potential vulnerability in the coastal zone of Korea.

Table 2. Inundation area (top) and population (bottom) in the coastal zone of Korea due to the 21^{st} sea-level rise. The unit is km2 in area and 1,000 in population

SLR Scenario	East	South	West	Overall
S1	21.304	45.396	1373.859	1440.560
S2	64.111	90.644	1873.167	2027.923
S3	50.384	51.088	1471.403	1572.875
S4	134.890	104.782	1990.205	2229.877
S5	39.855	11.362	337.618	388.835
S6	86.792	65.232	1512.503	1664.527
S7	166.481	110.414	2073.918	2350.813
S8	65.823	25.542	365.075	456.439
S9	181.713	70.887	1664.645	1917.244
S10	237.872	130.302	2274.642	2642.816
S11	163.250	39.759	461.041	664.050
S12	240.328	82.194	1830.086	2152.608
S13	311.325	135.991	2494.212	2941.528
S14	234.853	53.931	585.771	874.556

SLR scenario	East	South	West	Overall
S1	41.597	4.882	649.289	695.768
S2	46.785	10.178	832.080	889.043
S3	44.400	6.740	678.936	730.076
S4	155.525	20.271	920.851	1096.647
S5	43.852	0.155	35.931	79.938
S6	131.653	9.851	694.019	835.523
S7	163.607	20.272	944.460	1128.339
S8	117.812	1.881	38.231	157.924
S9	171.714	9.968	778.425	960.107
S10	181.480	30.939	1042.760	1255.179
S11	163.690	4.367	117.580	285.636
S12	181.640	19.404	891.797	1092.841
S13	198.245	32.573	1256.075	1486.893
S14	181.640	9.237	139.374	330.251

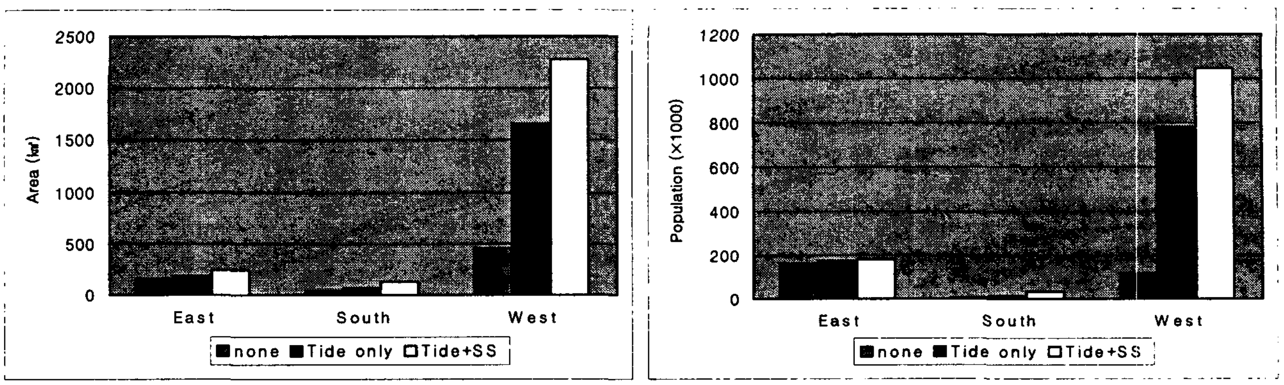

Figure3. Inundation area(left) and population(right) in the East, South, and West coast of Korea to 1-m sea-level rise.

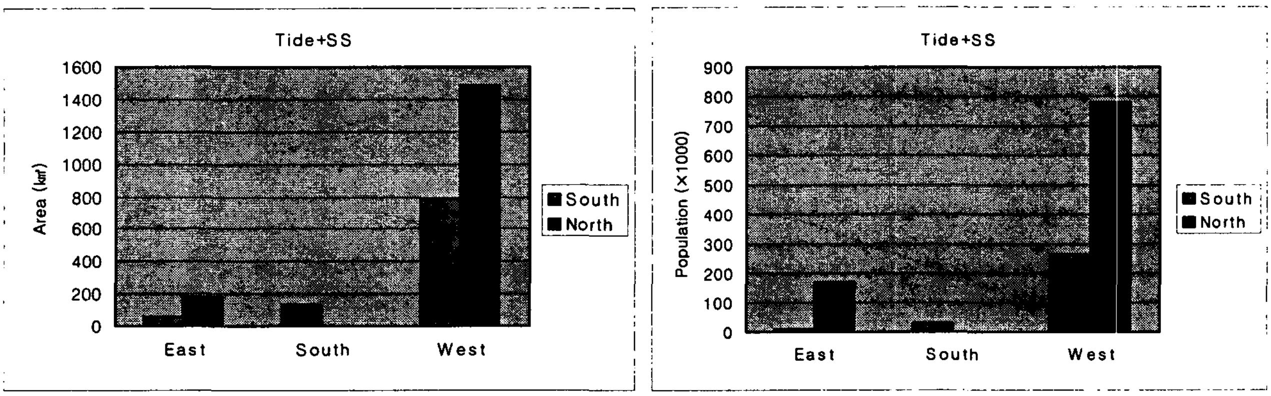

Figure 4. Inundation area(left) and population(right) in the East, South, and West coast of South and North Koreas to 1-m sea-level rise.

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