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Modern sea level changes of the Eastern China Seas and their influences on coastal areas*

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Abstract—The statistics of tidal gauging records showed that the mean sea level of the China Seas has risen for 14 cm in past 100 years. The annual mean sea levels of the Eastern China Seas have been rising at a speed of about 0.21 –0.23 cm/a since 1960. The annual mean sea levels of the Eastern China Seas in 1989 were 1.45 cm higher than that in 1988 on average.

The sea level rise may cause the damage of the dynamical balance of the natural environments in the coastal areas and form or strengthen many coastal disasters, such as storm-tide catastrophic events, sea water invasion landward, soil salinization in coastal lowland and plains, and beach erosion retreat.

Keywords: sea level; Eastern China Seas; coastal area.

INTRODUCTION

In the past 100 years, the climate of the earth has been warming up gradually, which has caused the sea levels of the globe to rise. Sea level rise had formed an extreme menace to the coastal industries, agricultures, seaports and towns or cities that occupy important positions in the world economy. As a result, the research and prediction of sea level changes have attracted general attentions of the scientists and governments of various coastal countries of the world, and a considerable amount of research achievements has been acquired. This paper analysis modern sea level changes of the Eastern China Seas and their influences on the coastal areas.

MODERN SEA LEVEL CHANGE OF THE EASTERN CHINA SEAS

The term sea level is referred to the mean sea level, i. e., the average value of the hourly tidal level records of tidal gauging stations. The average annual sea levels over the years at long-term tidal gauging stations vary in the range of millimeter grade.

1. Sea level changes of the Eastern China Seas in the past 100 years

According to the report on the sea level of China Seas in 1989 published by SOA (1990) among 48 long-term tidal gauging stations along the coasts of China, there are 39 stations at which the annual mean sea level tended to rise (accounting for 81% of the total stations), 7 stations where sea level tended to fall (amounting to 15% of the total stations) and 2 stations

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around which sea level has maintained basically stable (accounting for 4% of the total stations). The statistics of tidal gauging records of more than 1200 station-years showed that the average rate of sea level rise of Eastern China Seas was 0.14 cm/a, at which the mean sea level of the China Seas has risen for 14 cm in the past 100 years. For examples, Bohai Sea has risen for 5 cm, the Huanghai Sea has fallen for 2 cm, the East China Sea has risen for 19 cm, and the South China Sea has risen for 20 cm (Table 1).

Table 1 Change and prediction of sea level of the China Seas

Mean amount of sea level rise, cm	Bohai Sea	Yellow Sea	East China Sea	South China Sea	Average
In last 100 years	5	−2	19	20	14
From 1988 to 1989	1.01	2.56	0.5	1.91	1.45
From normal year* to 1989	2.81	2.44	1.69	3.32	2.55
From 1989 to 1990	0.20	−0.76	1.43	0.53	0.55
From normal year to 1990	3.01	1.69	3.12	3.85	3.09
From normal year to 1995	3.00	−0.85	4.27	4.75	3.32

* The normal year is referred to mean amount of sea level rise from 1975 to 1986.

The tendency of sea level changes along the coasts of China in the past 100 years is the same as that of the globe, and the average annual sea level rise rate is almost equal. SOA has made a statistics on the records of tidal level gaugings of more than 3400 station-years collected from 102 tidal gauging stations all over the world, and found out that the average rate of sea level rise of globe was 0.15 cm/a. Intergovernment Panel on Climate Change (1990) reported that the global sea level has been rising at 1.0−2.0 mm/a over the last 100 years.

2. Sea level changes of the Eastern China Seas since 1960

The annual mean sea levels of the Eastern China Seas have been rising at a speed of about 0.21−0.23 cm/a since 1960. Yu Daoyong (1986) made a statistical analysis on the tidal level data recorded at 16 tidal gauging stations from 1960 to 1980 concluded that the average annual sea level rising rate was 0.21 cm/a all over the country. Zhao Mingcai *et al.* (1986) analysed the tidal level records of 9 stations in the stage from 1960 to 1980. They calculated each ten-year-period mean sea levels, and found out that the average annual rate of sea level rise in China was 0.23±0.09 cm/a. Chen Xiqing (1990) made a statistical analysis on the tide-level records conducted by Wusong Tidal Gauging Station in Shanghai since 1950. After eliminating the influences of the ground subsiding and the variation of annual runoff of the Changjiang (Yangtze) River, he thought that the sea level along the coast of Shanghai had been rising at a

rate of 0.25 cm/a since 1950. In the past 30 years, the characteristics of sea level changes varied from place to place. For example, the sea level along the coasts of Shandong Peninsula and the adjacent southward area has been basically stable, because of the crust of Shandong Peninsula slight uplifting, while the annual mean sea levels along the rest coastal areas tended to rise obviously.

3. Sea level changes of the Eastern China Seas in 1989

The difference in altitude between the annual mean sea level of a specific year and the average annual sea level of many years varies in the range from millimeters to centimeters, because the former is controlled by local and transiently accidental factors. The annual mean sea levels of the Eastern China Seas in 1989 were 1.45 cm higher than that in 1988 on average. The amplitudes of sea level rise from 1988 to 1989 in the Bohai, Huanghai, East China and South China Seas were 1.01, 2.56, 0.5 and 1.91 cm, respectively (Table 1). The annual mean sea levels of China Seas were 2.55 cm higher than that the average sea level of the period from 1975 to 1986. The annual mean sea levels along all the coasts of China in 1989 tended to rise as compared with those in 1988, and the amplitudes of sea level rise were considerable high.

4. Prediction of sea level changes along the coasts of China in the next five years (1990 – 1995)

With the rising of industrialization levels all over the world and the intensification of the influence of human activities on the natural environments, a great amount of fossil fuels has been burned, and the areas of forests in the world have been diminished. As a result, the content of CO_2 in the atmosphere has been greatly increased in the past 50 years, which has formed the "greenhouse effect", causing the climate of the world as a whole to become warmer and the global sea level to rise. That is the dominating factor to control the sea level changes in the future tens of years. The predictions by IPCC (1990) is that: for the Business-as-Usual Scenario at year 2030, global-mean sea level is 8 – 29 cm higher than today with a best estimate of 18 cm, at the year 2100, the rise is 31 – 110 cm, with a best-estimate of 66 cm.

According to the facts mentioned above, it is undoubtable that the annual mean sea levels along the coasts of China tend to rise, and that the rising rate is increasing gradually.

The sea level changes area comprehensive reflection of many environmental factors such as the astronomical, hydrological and meterological factors, tectonic movements and human activities and so on. It is hard to distinguish the effect of a specific factor on sea level changes from those of the others. As a result, it is still difficult to make a precise quantitative prediction of sea level changes in the future. SOA 1990 has predicted that the sea levels along the coasts of China in 1990 would be 0.55 cm higher than those in 1989, and 3.09 cm higher than that of the normal year (1975 – 1986). And by 1995, the sea levels along the coasts of China would be 3.32 cm higher than that of the normal years. The prediction of sea level changes of China Seas are listed in Table 1. The sea levels of the East China Sea and the South China Sea will obviously rise, the sea level of the Bohai Sea will be stable, and the sea level of the Yellow Sea will fall.

THE INFLUENCES OF SEA LEVEL RISE ON THE COASTAL AREAS OF CHINA

The sea level rise may lead to the intensification of erosional processes in the coastal zones, which may cause the damage of the dynamical balance of the natural environments in the coastal areas and form or strengthen many coastal disasters, such as storm-tide catastrophic events, coastline retreat by erosion, soil salinization in coastal lowlands and plains, beach erosion and coarsening of beach materials along the mountainous and hilly coasts, and the raising of river beds of the lower reaches in the estuarine areas, which make the estuarine regions vulnerable to flood disasters.

1. The influences on low coasts

There are vast lowlands and delta plains along the eastern coasts of China, such as Zhujiang (Pearl) River delta plain, the Changjiang (Yangtze) River delta plain, the North Jiangsu coastal plain, the Laizhou Bay coastal plain, the Yellow River delta plain, the Tianjin-Eastern Hebei plain to the west of the Bohai Sea, the Lower Liaohe River plain and the Donggou plain in the lower reach area of the Yalujiang River and so on. The common characteristics of these coastal lowlands and plains are as follows : (1) the elevations of the plain surfaces are all lower than 5 meters, e.g., the elevation of the ground surface of urban area of Shanghai City is 1.8 m with a minimum of 0.91 m ; (2) the plains are flat and vast with very gentle slopes, e.g., the ground slope of the Yellow River delta plain varies from 1/7000 to 1/10000 that of the coastal plain at the head of the Laizhou Bay varies in the range from 1/10000 to 3/10000 ; (3) the plains are all composed of incoherent sediments, especially the river delta plains where the compaction of sediments under the gravitational forces of themselves has caused a slow subsiding of the ground, which has relatively increased the amplitude of sea level rise.

These coastal lowlands and plains are vulnerable to seawater transgression. If the sea level raised for 10 cm, sea water would go landward into 1 km according to the calculation of ground slope of 1/10000. Most of the low coasts in China have undergone slow retreat by erosion, only those around the river deltas have maintained stable and accumulated seaward because of the sediment supply from the rivers. For example, the coast of the abandoned Yellow River mouth in North Jiangsu Plain has retrograded for over 20 km and as much as 1400 km^2 of land have been eroded away in the range of 150 km from north to south along the coastline since 1855 when the estuary of Yellow River migrated away from Jiangsu to Shandong where it emptied into the Bohai Sea. In addition, owing to the excessive pumping of ground water, the grounds of Shanghai and Tanggu have subsided obviously. According to the statistics, the maximum average annual subsiding amplitude in the urban area of Shanghai City was 110 mm.

The sea level rise causes sea water to invade landward through rivers and streams, or to penetrate inland through the underground permeable strata, forming a seawater wedge underground to prograde landward. As a result, soil salinization in the coastal plains become more and more

serious, and the areas of soil salinization increase gradually. For example, seawater invasion underground has been accelerated in the coastal plain to the south of the Bohai Sea because this area is short of precipitation, and the groundwater is excessively pumped. Along the 200 km coastline from Shouguang County to Longkou Town, underground seawater invasion has covered an area of 430 km^2, and the annual landward invading distance of seawater amounts to 150−200 m in average. The scale and speed of underground seawater invasion in this area rarely seen both at home and abroad.

Storm tide is the largest catastrophic event in the coastal zones. Sea level rise has enhanced the intensity and frequency of storm tide in the recent years. The smooth and low coastal plain to the southwest of the Bohai Sea is the most frequently occurring area of storm tide in the Moderate Zone in China. In the transitional period between spring and summer seasons, especially in the period when astronomical spring tide happens, the southeastern strong wind dominates in this area for a long time at first, which causes water level rise all over the Bohai Sea, then the wind direction suddenly changes into northeast. The northeastern strong wind of over scale 7 drives the piled-up seawater toward the southwestern coastal area of the Bohai Sea, causing the water levels along the coast to rise rapidly, and hence seawater transgresses the lower part of the plain, forming seawater flood disasters. The maximum water level rise caused by storm tide in this region on April 23, 1969 amounted to 3.55 m, the tidal level at Yangjiaogou Station reached 6.64 m, which is 1.74 m higher than the local warning water level. Sea water encroached for 22−27 km landward from the coast, with a maximum of 40 km in the Laizhou Bay region, and a lot of houses and salt pans were destroyed.

2. The influences on mountainous and hilly coasts

The influence of sea level rise on the mountainous and hilly coasts of China has manifested mainly in the form that a lot of excellent beaches underwent erosion . Today , prevention of beach erosion has become a general problem all over the world . Phenomena of beach erosion have occurred along the coasts of Liaoning , Hebei , Shandong , Fujian and Hainan provinces . In some coastal sections where serious beach erosion has occurred , seawater transgressed inland for hundreds of meters . The stability of beaches relies on the balance between marine hydrodynamic factors and beach materials . If the hydrodynamic factors become stronger or the amount of beach sediment is diminished , the beach will be subjected to erosion . Since the foundation of the People's Republic of China , many rivers have been dammed at their upper or middle reaches to reserve water for irrigation . These dams or reserviors have trapped great amounts of river sediments from being transported into the sea , thus causing the decrease in sediment supply of the beaches , and which , associated with the strengthening of marine hydrodynamics caused by sea level rise , has intensified beach erosion processes . And what was the worst was the exploitation of beach materials by local peasant workers , which has caused direct loss in beach sediments and serious effect of beach erosion . For examples , the bathing beaches of Weihai City have been abandoned, some bathing beaches in Beidaihe have

been narrowed by nearly 100 m in the past ten odd years , and the beach sand has become coarser , thus the conditions of the bathing beaches became worse , and the section of Qingdao-Laoshan Highway near the Baishahe River has been forced to move landward twice and the beach shoreline has retreated for nearly 100 m mainly because of beach sand exploitation by local people..

In the coastal regions to the south of the Yangtze River mouth, storm tides caused by tropical revolving storms and typhoons are the main catastrophic events. In 1989, such kind of disasters were very serious (SOA, 1990). There were 10 times of typhoons reaching the mainland of China during the period of high sea level between July and October. This number is larger than that of the normal year. Because the amplitudes of sea level rise in the East China Sea and the South China Sea is relatively large in past 100 years, the storm tide disasters have increased largely. If the typhoon reaches the mainland at the same time when astronomic spring tide occurs, wind disasters, tidal disasters and flood disasters happen simultaneously, causing extremely serious destructions in the coastal areas. For example, when the No. 23 typhoon reached the mainland in Zhejiang Province on September 15, 1989, the high tidal level at Haimen Tidal Station in Jiaojiang City reached 6.98 m, which is 1.48 m higher than that the local warning water level, and this case occurs only once in 200 years. In this catastrophic event, the seawalls were collapsed under the washing action of tidal flood, sea water encroached the inland areas, houses were collapsed, power plants ceased operation, and nearly 1000 people were killed and wounded and a great deal of economic loss was caused.

3. The influences on estuarine areas

As sea level rise, the erosional basis of the rivers is raised correspondingly, which in turn accelerates sediment accretion in the lower-reach river courses, hence raises the river beds, greatly increasing the dangers of flood disasters. This problem is especially prominent in the lower reach area of the Yellow River. According to the estimation by Professor Yang Huanren, by the year of 2050 A. D., the river bed of the lower reach of the Yellow River would be raised to a position 1.5 m higher than the present one. If this estimation become true, the Yellow River will be extremely dangerous to the people living on both sides of the lower reach of the river.

The amounts of sediment discharges of the Yangtze River and Pearl River are relatively smaller. As a result, the influence of sea level rise on the lower-reach river beds is not obvious. Because the both estuaries are located in the areas of frequent influence by typhoon, and the typhoon seasons are the same time of flood water period of rivers. The main disasters are still storm-tide catastrophic ones. In 1989, both the estuarine areas of the Yangtze and Pearl rivers experienced serious calamities of storm tides.

From the mentioned above, it can be seen that the storm tides, landward seawater encroachment and beach erosion are the three major calamities occuring in the coastal areas of China that are relevant to sea level rise. Sea level rise has enhanced the destructional effects of the calamities. With the sea level rising, its influence on the coasts is increasing gradually, especially

in the area where amplitude of sea level rise is even high. It is estimated that in the further the coastal calamities in the areas along the south of the Bohai Sea and southeastern coasts in China would be intensified even more.

SUGGESTIONS

The facts mentioned above showed that many of the disasters occurred in the coastal areas were related to human activities that were contrary to scientific laws, even sea level rise in the recent tens of years was closely related to human activities. As a result, in the exploitation of coastal resources, we must follow scientific laws and pay attention to the coastal protection and improvement environments for the purpose of preventing and diminishing the destructive effects of coastal disasters.

1. Scientific management of the coasts

As human kind are going to develop and utilize the golden coasts in even great scales, we must strictly follow scientific laws in our activities, and pay attention to coastal protection. For example, the development of groundwater in coastal cities and areas must be controlled in a moderate degree, and in areas where ground subsiding or seawater encroaching landward might occur, the exploitation of groundwater must be prohibited. For examples, the measure of pouring water into the wells has successfully controlled ground subsiding in Shanghai City. And in order to fundamentally solve the problem of water supply of the city, Tianjin City successfully set up the canal to divert water from the Luanhe River to Tianjin City.

The exploitation of beach sand must prohibited. And in the tropic and subtropic coasts, coral reefs which is natural seawall must not be excavated, because they have the function of sheltering the coasts from wind and waves. We must take effective measures to protect the coral reef coasts.

2. Afforestation and planting trees

Afforesting the coastal areas widely is an effective measure to shelter the coasts from wind disasters and to stabilize beaches. In the tropical and subtropical coastal areas, planting mangroves can protect the coasts well. However, improving the natural environments and diminishing the loss caused by coastal disasters are long-term tasks for the human kind. Here we suggest that the governments of all countries in the world protect the existing forest resources and arouse all the people to plant trees and afforest the inland areas as well as the coatal zones of the whole earth, in order to increase the area of forest cover on the earth and inhibit the overquick increase of the content of CO_2 in the atmosphere , and hence slow down the speed of sea level rise.

3. Building and reinforcing tidal barriers and seawalls

According to statistics, the direct economic loss caused by larger storm-tide disasters in the southeastern coastal areas of China in 1989 excessed 5 billion RMB Yuan. If we had spent such amount of money on reinforcing seawalls, would not have suffered so much from the disasters.

For example, Shanghai reinforced the tidal barrier of 208 km-long in the urban region in 1987. Therefore, although the tidal level at the Huangpu Park in Shanghai reached 4.76 m on October 16, 1989, which was 2.63 m higher than mean sea level and above the ground level of the city in general, there was no serious problem happened.

4. Improving the prediction methods of coastal disasters

Predicting the disasters of storm tides exactly in time is very important to take effective measure to prevent the disasters in advance. For example, the No. 8908 typhoon was one of the extraodinary catastrophic ones in the past three years that reached the mainland of China. Because it was predicted exactly and in time, effective measures had been taken to prevent the disaster, such as dispersing the residents from the dangerous areas and so on, the personnel casualties were diminished to the lowest degree, and the economic loss was also relatively low. While the No. 8923 typhoon had caused heavy personnel casualties and economic loss because the predicted water level was lower than the actual one and hence the preventive measures were not sufficiently effective, altough its strength and scale were much smaller than that of the No. 8908 typhoon.

5. Changing the structure of energy resources

Enthusiastically developing and making use of atomic energy, solar energy, hydraulic energy, wind energy and ocean energy resources, and increasing the proportion of non-fossil fuel energy resources in our energy resources structures are of a long-term project to improve the natural environment in which we live.

6. Intensifying the international cooperations on research of sea level

Because the sea level change is a great matter to human being, we suggest that marine offices of all countries should try to find a way to unitize the monitoring of sea level. For example, to make the unitized base points and instruments for monitor, so that precision and the reliability of monitoring data could be guaranteed. And that the data and research results should be exchanged between the countries in a fixed period time.

Human activities upset balance of natural environment and speeded up sea level rise, and the latter in harmed turn human kind, which were the historic lessons and natural retaliation to us. Now the great nature has sounded the alarm to us, the whole mankind must pay attention to this problem.

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