CHINESE GEOGRAPHICAL SCIENCE
Volume 8, Number 1, pp. 1- 11, 1998
Science Press, Beijing, China

FACTORIAL ANALYSIS OF ANNUAL EROSION-ACCRETION CYCLES OF TIDAL FLATS IN THE FRONT AREA OF THE SOUTHERN CHANGJIANG RIVER DELTA

Yang Shilun(杨世伦)　Chen Xiangfeng(陈祥锋)　Zhang Zhengti(张正惕)
State Key Laboratory of Estuarine & Coastal Research, East China Normal University, Shanghai 200062, *P. R. China*

(Received 15 August 1997)

ABSTRACT: Based on surveyed data from seven coastal sections and the collected data of wind, sea level, tide, nearshore suspended sediment concentration and river flux from adjacent stations, this paper deals with regressive correlation between monthly average flat elevation and monthly average figures of the influential factors. All sections except one which is located within the river mouth showed negative correlation between flat elevation and sea level and between flat elevation and tidal range, with correlation coefficients being -0.53--0.91(-0.77 on the average) in the former condition and -0.56--0.97 (-0.80 on the average) under the latter. Each of the sections with available suspended sediment concentration (SSC) data shows a positive correlation between flat elevation and SSC, with correlative coefficients being 0.35-0.97 (0.66 on the average). Only two sections (one in the Changjiang River Estuary and the other in the Hangzhou Bay) which are similar to beaches in sediment grain-size and slope gradient showed a negative correlation between flat elevation and onshore wind frequency and between flat elevation and average wind velocity, with correlative coefficients being respectively -0.57 and -0.69 (-0.63 on the average) in the former situation and -0.61 and -0.75 (-0.68 on the average) in the latter. Other sections did not show uniform relationship between flat elevation and wind conditions. Due to local marine factors the nearshore SSC in the studied area is negatively correlated with the Changjiang River sediment flux (r= -0.78), which results in false negative correlation between flat elevation and river sediment flux. The paper also gives sediment dynamic and morphodynamic explanation for the above correlations. Sea level rise results in the spread of breaker zone from subtidal area to intertidal area and then increases the intertidal water energy. The larger the tidal range, the stronger the tide currents and the easier for the flat to be eroded. The higher the SSC of flood water, the easier for the sediment to deposit down. Because of correlations among the influential factors, it is difficult to give the prime one which dominates the erosion and accretion processes in tidal flats.

KEY WORDS: tidal flat, erosion-accretion cycle, the Changjiang River delta, factorial analysis

I. INTRODUCTION

The study of seasonal erosion-accretion cycles in beaches has a history nearly half a century. The description of Shepard (1950) about the seasonal changes in the Southern California beach profiles is classic in this field. The theory that wind (wave) is the controlling factor in beach cycles has been broadly accepted (Komar, 1976). The factors affecting the annual erosion-accretion changes in tidal flats are more comprehensive than in beaches. Anderson (1983) found that annual variation in northern tidal flats was controlled not only by wave and tide, but also by activities of organism, glacier and precipitation, etc. In the study of the Zhejiang tidal flats, China, Li Yan *et al* (1987) proved that tide, wave and sediment condition were all the controlling factors. In the research on seasonal cycles in the Changjiang Delta coasts, Yun Caixing (1983) thought that relationship between wind direction and the trend of coastline was most important. Zhang Keqi *et al*. (1994), through spectrum analysis, revealed the short-term cycles of 30 days, 15 days and 2 to 5 days in the northern coast of the Hangzhou Bay. Chen Weiyue (1991) made a meaningful comparison of processes between storm period and normal wave period in his study of the tidal flats along the southern coast of the Changjiang River Estuary and the northern coast of the Hangzhou Bay. Yang Shilun (1991) and Yang Shilun *et al*. (1994) pointed out that wave was the controlling factor in short-term (from a few days to a few weeks) variation on the naked flats which face the open sea, but in a marsh, the upper part of the tidal flat, the luxuriant-withering cycles of vegetation was the key factor. Ji Zixiu *et al*. (1993) drew on a regressive analysis and found a negative correlation between monthly-averaged flat elevation and monthly-averaged tidal level.

The studied area has considerable tides (with mean tidal range of 2.5– 2.7 m along the front of the river mouth and 3.2– 4.0 m along the northern coast of the Hangzhou Bay) and a substantial fine-sediment source from the Changjiang River. So the coastal erosion-accretion processes differ not only from beaches but also from normal tidal flats as in Europe and Jiangsu Province. Here natural factors such as sea level, tidal range, wind(wave), river water and sediment flux, marsh vegetation and coastal suspended sediment concentration (SSC) show an annual cycle. None of them can be ignored in the study of erosion-accretion cycles in tidal flats.

II. METHODS AND MATERIALS

For a wide representation, profiles were selected as the follows: one respectively at the north, east and south side of the Chongming Island, one at the east side of the Nanhui Spit, and one separately at the east, middle and west sections of the northern coast of the Hangzhou Bay (Fig. 1). Most of the elevation data were computed from the primary material stored up in the Shanghai Coastal Comprehensive Survey, only those in the profiles of Zhonggang and Jinhuigang came from Ji Zixiu *et al*. (1993). The method for elevation was “rod-height read

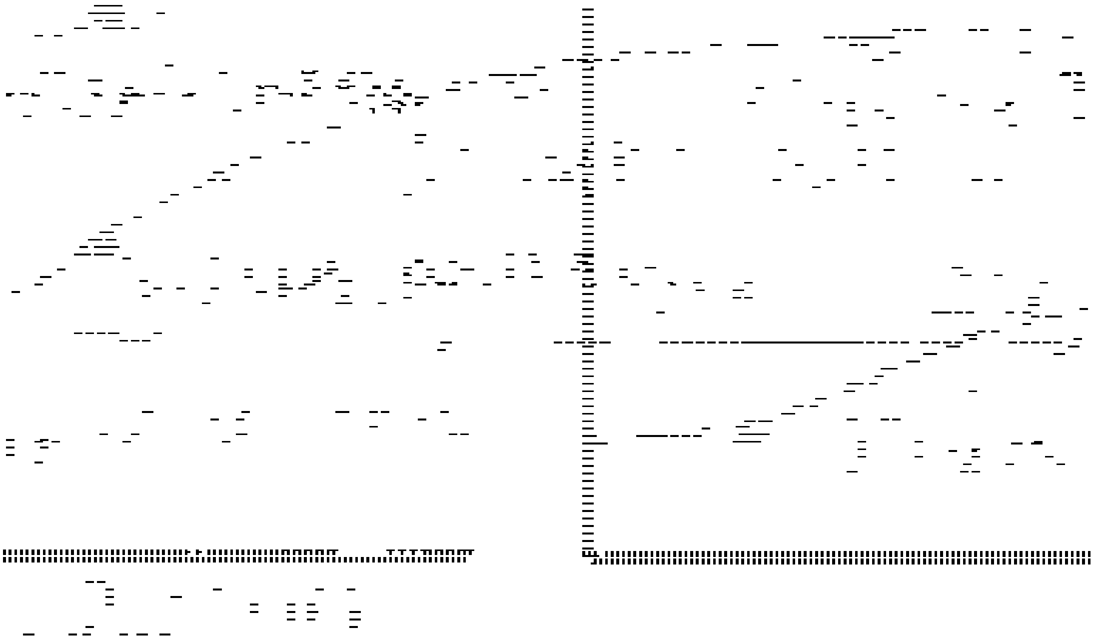

Fig. 1 The studied sections and survey stations for dynamics and sediment data

ing". The "average elevation" represents the mean result from some rods located between the mean low tidal level and the high level of spring tide (the distance between two rods was 200 m in the Dongwangsha profile and 100 m in the other profiles, the lowest rod location was changeable because of the wave actions). The primary records above the spring tidal level was not used because the flat surface there was seldom submerged and the surveyed error may be larger than the accretion rate. So it can be found that the "average flat elevation" reflects a relative concept, and not an absolute one.

Due to the difficulties in getting wave data, wind records were utilized to substitute waves. They are useful in view of the following facts: a) waves in the studied area is dominated by wind-driven ones (more than 90% of them are wind-driven waves); and b) there is a positive correlation between wind direction and wave direction as well as between wind velocity and wave height (Yang, 1991). Data on wind and SSC were from the nearest survey stations shown in Fig. 1 The separation of onshore and offshore wind was made by a) first removing the two directions from the total 16 directions (each with 22.5 degrees) which had smallest angle with the shoreline trend; b) defining the 7 directions from the sea as onshore winds and the other 7 directions from the land as offshore winds. A concept of onshore (offshore) wind coefficient was introduced by making a product between onshore (offshore) frequency and onshore (offshore) wind velocity.

In consideration of the long distance (620 km) between the Datong Station and the river mouth as well as the net velocity in the river channel, the monthly water and sediment flux was made by averaging the Datong Station data of the present and the last month. The data of elevation and SSC was one-year period, but the others were multi-year period.

III. ANNUAL EROSION-ACCRETION CYCLES IN TIDAL FLATS

In the studied area, tidal flats reflected a law of seasonal erosion-accretion cycle which can be proved by the successive three-year period of surveyed data from 1984 through 1986 at Tangjiaozui (Fig. 2). The characteristics resembled one another in different years. In Fig. 2a, the dotted lines show same accretion rates between different years. In the same months of the three years, the flat elevations is nearly in a same rising line. Due to the random effects of wind-driven waves on short term cycle (Yang, 1991) the curves in different years have subtle discriminations. The law can also be proved by the same feature between the eastern Nanhui coast (e.g. Tangjiaozui) and the eastern Chongming coast (e.g. Dongwangsha, Fig. 3). In order to fully reveal the nature of the annual cycle, net vertical accretion rates, 8 cm/a at Jinhuigang, 32 cm/a in Dongwangsha, 43 cm/a in Beibayao, -7 cm/a in Xijiagang and 5 cm/a in Jingshanwei, were taken off. Results after this processing are shown in Fig. 2b and Fig. 3. The cyclic models can be divided into four types: a) the highest and lowest elevation respectively happens in spring and autumn (in eastern Chongming and eastern Nanhui); b) the highest and lowest elevation respectively occurs in winter and autumn (at Jianhuigang and Zhonggang); c) the highest and lowest elevation respectively occurs in winter and summer (at Beibayao); and d) the cycle is not typical (at Xijiagang). The annual differences between the highest and the lowest is 47 cm in eastern Chongming, 25 cm in eastern Nanhui, 22 cm at Beibayao, 24 cm at Jinhuigang, 20 cm at Zhonggang, 14 cm at Xijiagang and 14 cm at Jingshanwei.

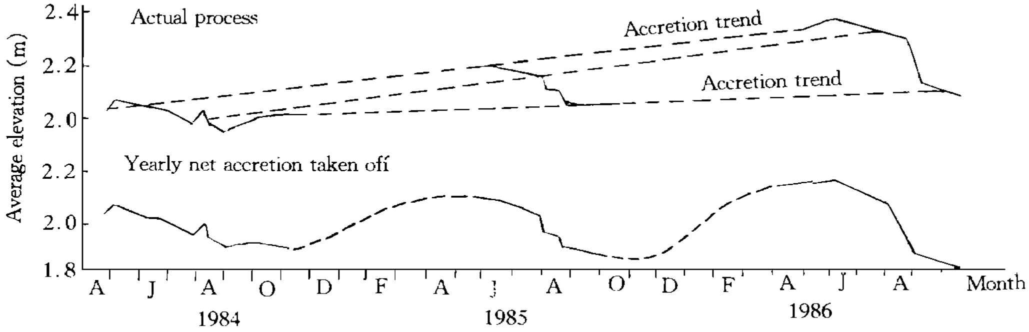

Fig. 2 Annual erosion-accretion cycles for a period of three years at the section of Tangjiaozui

IV. RESULTS AND DISCUSSION

1. Variation in Sea Level

Since Bruun (1962) Rule was issued, scientists have made a widespread discussion about it. The theory came from research in beaches and fits to the condition that there is no sediment transportation along the shore. Based on the appraisal (50 cm rise in the world sea level in the 21 st century) of the Earth Sciences Division of the Chinese Academy of Sciences, Wang Ying *et al*. (1995) adopted the rule and worked out the effect of sea level rise on erosion of the major tour beaches in China. They concluded that the rule was fundamentally applicable. Ji Zixiu *et al*. (1993) deemed that the rule suited in principle for erosive and stable muddy coasts after some proper alteration was made according to sediment scalar and gradient.

$X_1 \ldots X_{14}$ respectively represents monthly river water discharge, river sediment discharge, sea level, tidal range, onshore wind frequency, onshore wind velocity, onshore wind index (the product of X_5 and X_6), offshore wind frequency, offshore wind velocity, offshore wind index (the product of X_8 and X_9), average wind velocity, days of strong winds (which velocity is more than 10.8 m/s), nearshore SSC and river SSC, $Y_1 \ldots Y_6$ respectively represents the monthly flat elevation at Dongwangsha, Xijiagang, Beibayao, Zhonggang, Jinhuigang and Jingshanwei.

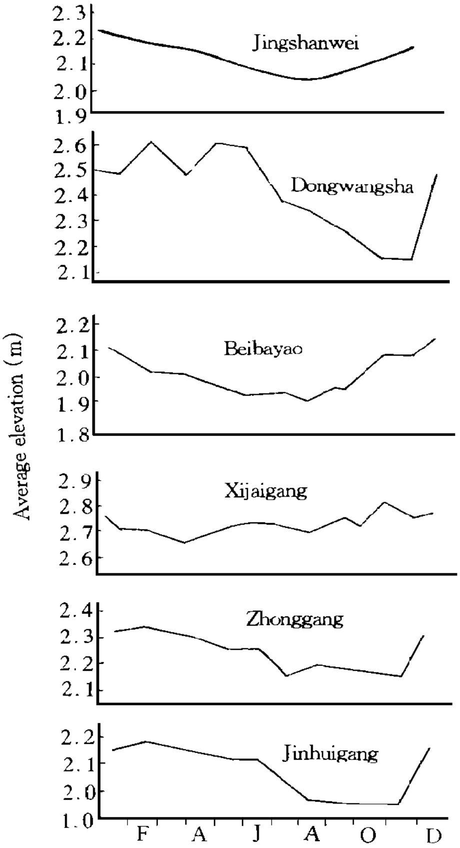

Fig. 3 Annual erosion-accretion cycles (net changes of the year was eliminated) in six sections

Table 1 shows that each profile reflects a negative correlation between monthly average elevation and monthly average sea level except Xijiagang which is located inside the river mouth. These correlations reveal the fact rising sea level was accompanied by erosion, which is consistent with the Bruun Rule. But there was a significant divergence between tidal flat erosion and the Bruun Rule. The divergence is that coastline did not retreat when erosion in the main part of intertidal zone (Yang *et al*., 1995). It was for the benefit of the protection of marsh vegetation (reed and *Scirpus*) growing in the upper part. The marsh vegetation helps reduce the water energy and promote accretion (Yang *et al*., 1995). Fig. 4 shows the net effect of seasonal sea level rise (22 cm rise in average sea level, 45 percent of the yearly variation) on the intertidal profile in a period of three months. The strongest erosion (about 20 cm) occurred in the middle part and there was no erosion in the top marsh. During this time, the average tidal range increased by 9 cm (only 21 percent of the yearly variation). Both measurement was in spring tide, so the spring-neap tide effect can be ignored. The effects of wind and sediment application can also be neglected because both of the conditions were nearly the same in June as in September and no storm happened before the measurements. It can be concluded, therefore, that the effect in Fig. 4 was mainly caused by the seasonal sea level rise.

Table 1 Correlative coefficients of linear regressive analysis between monthly flat elevation and influential factors

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
Y_1	-0.11	-0.57	-0.53	-0.74	0.02	0.57	0.11	-0.03	-0.06	-0.02	0.14	0.10	0.35	-0.84
Y_2	-0.25	0.13	0.07	0.28	-0.57	-0.71	-0.57	0.58	-0.35	0.37	-0.75	-0.43		0.51
Y_3	-0.94	-0.67	-0.77	-0.56	0.83	0.51	0.88	-0.83	-0.77	-0.81	-0.13	0.15	0.72	-0.33
Y_4	-0.63	-0.85	-0.82	-0.91	-0.23	-0.13	-0.23	0.27	0.80	0.41	0.42	0.61	0.69	-0.75
Y_5	-0.46	-0.82	-0.83	-0.84	0.02	0.17	0.03	0.02	0.72	0.14	0.57	0.59	0.57	-0.94
Y_6	-0.91	-0.94	-0.90	-0.97	-0.69	-0.80	-0.72	0.66	0.67	0.72	-0.61	-0.91	0.97	-0.80

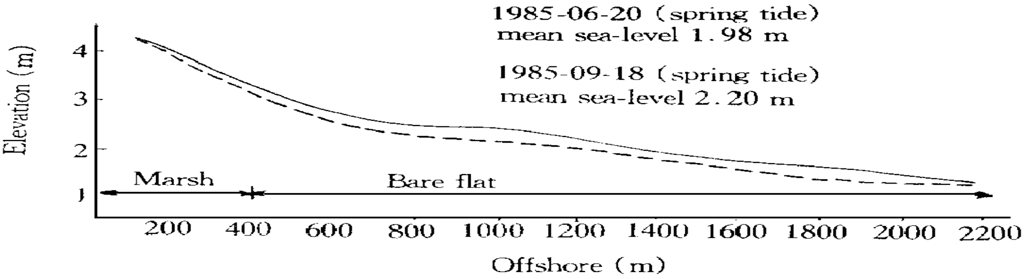

Fig. 4 Seasonal change of Tangjiaozui profile under the effect of sea level rise

Bruun Rule was in fact a deduction of geometry and was not explained in terms of dynamics. The writers of this article consider that sea level rise strengthens hydrodynamics in the tidal flat. Bohssinesq, Mclowan, Gngther, Davies and Dackham seperately considered the ratio between wave height and water depth as 0.73, 0.78, 0.83 and 1.03 when a wave broke in nearshore (Wang and Huang, 1989). The average of these five figures is 0.84. The monthly average wave height varied from 1.0 m to 1.4 m at the Yingshuichuan station, which required a water depth of 1.19– 1.67 m for the waves to break. In the condition of average water level, 1.84 m above the Theoretic Lowest Tidal Level (TLTL), the waves would break within a zone from 0.18 m to 0.64 m in elevation. In the case of mean high water level, 3.39 m above TLTL, the breaker zone would be between 1.72 m and 2.18 m in elevations. Thus it is clear that waves break in the low and the middle flats in normal conditions. In the studied area, difference between the highest and the lowest monthly sea level is 50– 56 cm. Based on the slopes of different profiles, the seasonal fluctuation in sea level would make the breaker zone migrate for 500– 1200 m. In other words, from the month of low sea level to that of high one, breaker zone would migrate onshore for a considerable distance on the flat and promote erosion.

2. Variation in Tidal Range

In the studied field, the annual difference in monthly tidal range is 24– 45 cm, and the ratio between the maximal monthly tidal range (in September) and the minimal one (in January) is 1.1– 1.2. Giving an example in the Southern California, Lafond (1939) described the effect of tide change on beach profile. Above the mean tidal level, maximal elevation occurred immediately after neap tide and minimal one after spring tide. Tide variation affects current capacity for sediment load and then erosion-accretion processes in a tidal flat. The larger the tidal range, the stronger the currents and the greater the capacity to transport sediments. So the increase in tidal range has an effect to erode sediment surface in tidal flats. According to the survey in March 1997, at the branching point of the North and South Passage in the Changjiang River Estuary, SSC in spring tide is 6.9 times as that in neap tide. Calculated results from the data of the Shanghai Coastal Zone Comprehensive Survey carried out in the 1980's revealed that the ratios of spring SSC to neap SSC varied from 1.8 to 3.5. It is important to realize the following a) The annual variation in tidal range is much less than that of spring and neap, and so is the currents. But the effect of the former may not be neglected b) While the tidal range was larger in summer than in winter, the SSC off and near the gate of the Changjiang River mouth was less in summer than in winter. This phenomenon can not be understood as a contradiction to tidal sediment dynamics. It may be caused by the increase in gale frequency in winter (1.3 time as in summer) and the intrusion of the 'clear' sea water under the blow of the prevailing S– SE winds.

As shown in Table 1, good negative correlation existed between tidal range and flat elevation at every profile except Xijiagang. This relationship perhaps revealed that the mechanism that increase in tidal range would result in erosion although it can also be caused by the good correlation between tidal range and sea level, etc.

3. Variation in Wind

(1) Wind direction. The correlative coefficients between onshore wind frequency and flat elevation was 0.83 at Beibayao, – 0.57 at Xijiagang and – 0.69 at Jingshanwei with others being negligible. Similarly, the correlative coefficients between offshore wind frequency and

flat elevation was − 0.83 at Beibayao, 0.58 at Xijiagang and 0.66 at Jingshanwei also with others being negligible. It is reasonable that contrary marks of coefficients existed between onshore and offshore wind conditions because the correlative coefficient between these two kinds of wind frequency is − 0.999. The theory, formed from beach studies, that onshore winds cause erosion and offshore winds result in accretion, can not be supported by the sections except Xijiagang and Jinshanwei.

(2) Wind velocity. Correlative coefficients between wind velocities (onshore velocity, offshore velocity, average velocity and the days of strong wind) and flat elevation were unanimously positive only at Xijiagang. As wind direction, wind velocity did not have identical correlation with flat elevation in the sections.

(3) Contrary to the theory arisen from beach studies. as shown above, the theory that wind is the controlling factor in seasonal erosion-accretion beach cycles has been extensively accepted. But it is necessary to demonstrate that whether this theory is suitable for muddy tidal flats. There are at least three aspects of diffeence between beaches and tidal flats. a) While beach morphodynamics is dominated by waves which gain energy from wind, tidal flat morphodynamics is usually controlled by tide. b) The gradient of sandy beaches is from 1% to 10% (Bascom and Wiegel, seen in Komar, 1976), but that of tidal flats normally less than 0.5%. In sandy coasts, somewhere there are two breaker zones somewhere: one lies in the submerged bar and the other in foreshore. In many circumstances, only one breaker zone which lies in the foreshore exists. Waves often remain high power as they reach the foreshore. But in muddy coasts, the breaker zone frequently migrates within a broad scope due to low slope and frequent vibration in tidal level. As a result, the distribution of wave energy is disperse in tidal flats in contrast with beaches where wave energy concentrates in a narrow zone. When waves break in the subtidal zone, it may cause erosion there and subsequently result in accretion in the intertidal zone. Similarly when waves break in the low flat, the erosion there may lead to accretion in the middle and high flats. Because of these complex processes, the net subsequence of average flat elevation during a strong wind is difficult to forecast. It variably depends on the site of the breaker zone. c) Contrast with beaches, tidal flats are made up of finer, more viscous sediments. These sediments are not so active as sands when they response to the change of hydrodynamics. In conclusion, the effect of wind on a tidal flat perhaps can not be obviously reflected because of the complexity of the physical processes and the interference of other influential factors such as sea level, tidal range and sediment supply, etc.

It is necessary to notice that the sections of Xijiagang and Jingshanwei suggested a law of erosion in onshore wind condition and accretion in offshore wind circumstances just as in beaches pointed out by King(1953). This can be contributed to the sedimentary and geomorphologic features which are similar to beaches. Xijiagang was an eroded profile. Its average slope was 2.0% above the − 10 m contour and the middle grain-size d_{50} was larger than 1.0%, and the d_{50} of sediment was 0.07 mm. It is rational that these two profiles well responded to winds due to their beach characteristics. Differently the other profiles had relatively low slopes and finer sediments. The average gradients of offshore and inshore zones was 0.056% in Jinhuigang, 0.04% in Zhonggang, 0.04% in Tangjiaozui, 0.038% in Dongwangsha and 0.11% in Beibayao. The sediment category in these profiles were mainly silt, clayey silt and silty clay, with sandy silt and silty sand occurred only in the low part of the Dongwangsha section.

4. Variation in Suspended Sediment Concentration (SSC)

Each section had a positive correlation between nearshore SSC and flat elevation except Xijiagang. The coefficients in Jinshanwei, Beibayao, Zhonggang and Jinhuigang were respectively 0.97, 0.72, 0.69 and 0.57. The annual SSC cycle in Xijiagang differed from those in other sections. According to the Shanghai Coastal Zone Comprehensive Survey, SSC feature inside the estuarine gate was determined by the river conditions which had the maximal in summer and minimal in winter. On the contrary, near and some distance out of the gate as well as in the Hangzhou Bay, SSC cycle has its peak in winter and trough in summer, influenced by the sea conditions. This law, in contrast with the river flux, is very important in the estuarine processes. As shown above, it may be attributed to the outside-delta wave conditions and the movement of the Yellow Sea– East China Sea longshore currents. In summer, the littoral ‘clear’ water of Zhejiang Province flows northward under the blow of prevailing S– SE winds and the northward extension of the Taiwan Warm Current. When the ‘clear’ water passes the mouths of the Hangzhou Bay and the Changjiang River Estuary, it ‘dilutes’ the turbid water there and make the SSC lower. Oppositely in winter, the Jiangsu muddy coast is eroded and the sediments are transported southward under the effect of prevailing N– NE winds and the withdrawal of the Taiwan Warm Current. When the ‘turbid’ water goes by the Changjiang River Estuary and the Hangzhou Bay, it make the SSC there higher. The section of Xijiagang is special. It is located in a site near the gate of the river mouth. So it belongs to a transitional type between the two basic categories shown above. Its SSC figure can not be substituted either by the river conditon or by the stations out of the river mouth. Because there was no surveyed data for a period of 12 months near the section, a blank space occurred in Table 1. Beibayao is near the mouth of the North Branch. There is sediment transportation from the offshore area to the North Branch just as in the Hangzhou Bay, so the SSC feature at Beibayao is similar to that at Dongwangsha.

The positive correlation between SSC and flat elevation, as shown in Table 1 (X_{13}), reflect sediment dynamic mechanism as follows: under a condition of high SSC as in winter, the flood water is easy to reach and surpass saturation state for sediment load and lead to deposition on the tidal flat. On the contrast, when the flood water has a low SSC as in summer, it will maintain the state of not saturated for sediment load and cause erosion on the flat.

The negative correlation between the river sediment flux (X_2) and flat elevation as shown in Table 1 was a false appearance, which can not be explained as increase in sediment supply results in erosion. The negative correlation ($r = -0.78$) between the coastal SSC and the river sediment flux conceals the contribution of the river sediment to the accretion of tidal flats. In fact, while the tidal flats in the studied area are eroded in summer, about half of the sediments from the river source deposited in the submerged delta. In winter, the accretion of the tidal flats is supplied by the sediments from the erosion of the submerged delta and the southward Jiangsu longshore current.

V. CONSLUSIONS

Annual erosion-accretion cycles broadly occurred in the outside part of the Changjiang River Estuary and the northern coast of the Hangzhou Bay. These cycles were caused and controlled by the comprehensive effect of the annual variations in sea level, tidal range, winds (waves) and sediment conditions. Sea level rise resulted in the migration of breaker zone to the middle and high parts of the tidal flat, which strengthened hydrodynamics and caused erosion on the flat. Due to the protection of marsh vegetation, erosion usually happened only on the bare flat. This is different from the Bruun Model in which upper beach was eroded away as a response to sea level rise. Annual variation in tidal range resulted in the change in current velocity and then in the capacity for sediment load, which would influence the processes of erosion and accretion. Though storm cycles of erosion and accretion are important in the studied area, they are short term changes differentiated from annual cycles. The beach-originated law that onshore winds cause erosion and offshore winds cause accretion were well reflected only in two sections with features of sandy coasts in slope and grain-size. Normally in muddy coasts, the effect of winds (waves) on morphodynamics in annual cycle was concealed by other influential factors and could not be fully reflected. The positive correlation between flat elevation and nearshore suspended sediment concentration revealed the process in which submergence of 'clear' water cause erosion and 'turbid' results in accretion through the balance between SSC and the capacity for sediment load.

The correlation between influential factors makes this study complicated. It is difficult to give the prime factor though all of the listed ones all have influence on tidal flat cycles in the view of sediment dynamics and morphodynamics. Further work is needed. The methods of multifactor correlation analysis and prime-component analysis may be in the good measures.

REFERENCES

Anderson F. E., 1983. The northern muddy intertidal: seasonal factors controlling erosion and deposition——A Review. *Can. J. Fish. Aquat. Sci.* 40(Suppl. 1): 143- 159.

Bruun P., 1962. Sea-level rise as a cause of shore erosion. *Journal Waterways and Harbours Division*, (88): 117- 130.

Chen Weiyue, 1991. Sediment transportation and dynamic environment in tidal flats——take the northern coast of the Hangzhou Bay and the southern coast of the Changjiang Estuary as examples. *Acta Oceanalogica Sinica.*, 13(6): 813- 821. (in Chinese)

Ji Zixiu, Jiang Zhizhuan, Zhu Jiwen *et al.*, 1993. Possible impacts of sea level rise on coastal erosion in the Changjiang Delta and the coastal plain of northern Jiangsu. *Acta Geographica Sinica*, 48(6): 516- 526. (in Chinese)

King C. A. M., 1953. The relationship between wave incidence, wind direction and beach changes at Marshden Bay, Co. Durham. *Trans. Inst., Brit. Geog.*, 19: 13- 23.

Komar P. D., 1976. *Beach Processes and Sedimentation*. New York: Prentice-Hall Inc, 429.

Lafon E.C., 1939. Sand movement near the beach in relation to tides and waves. *Proc. 6th Pac. Sci. Cong.*, 795- 799.

Li Yan, Zhang Liren, Xie Qingchun, 1987. Cycles of tidal flats in Damutu, Xiangshan, Zhejiang Province. *Acta Oceanologica Sinica*, (6): 725- 734. (in Chinese)

Shepard F. P., 1950. Beach cycles in Southern California. *U. S. Army Corps of Engrs, Beach Erosion Board Tech Memo*, (20): 26.

Wang Baocan, Huang Yangsong, 1989. *Coastal Dynamic Geomorphology*. Shanghai: East China Normal University Press. 31. (in Chinese)

Yang Shilun. 1991. Effect of wind-driven waves on short term changes in eastern Nanhui tidal flat——a case study for open muddy coasts. *Marine Science*, (2): 59- 63. (in Chinese)

Yang Shilun, Chen Jiyu, 1994. On the role of vegetation in the physical processes of tidal flats. *Oceanologia et Limnologia Sinica*, 25(6): 631- 635. (in Chinese)

Yun Caixing, 1983. Erosion and accretion of tidal flats and sediment exchange between shore and channel in the Changjiang Estuary. *Journal of Sedimentation Research*, (4): 235- 244. (in Chinese)

Zhang Keqi, Jing Qinxiang, Wang Baocan, 1994. A spectrum analysis of dynamic system of the tidal flat at Zhangjiaku, the northern coast of the Hangzhou Bay. *Oceanologia et Limnologia Sinica*, 25(4): 446- 451. (in Chinese)