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Decadal link between longitudinal morphological changes in branching channels of Yangtze estuary and movement of the offshore depocenter

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Appendix A. Supplementary Material

Decadal link between longitudinal morphological changes in branching channels of Yangtze Estuary and movement of the offshore depo-center

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Table SI Data sources [†].

Type	Name	Period(s)/Year(s)	Source(s)
Hydrodynamics	Observed daily river water discharge series	1950-2017	Changjiang Water Resources Commission
	Ebb partition ratios of inland branching channels	1958-2015	Yun, 2004; Yang, 2014; Dai *et al*., 2016; Wu, 2017; Dao *et al*., 2018
Morphology	Bed-elevation point data for North Branch	1978, 1991, 1998, 2001, 2007, 2013	Nanjing Normal University and Changjiang Waterway Bureau
	Channel volumes below 0 m isobath of sub-reaches A, B and C in the North Branch	1986, 1991, 1998, 2001, 2003, 2005, 2008, 2011, 2013	Yang *et al*., 2016
	Bed-elevation point data for South Branch	1997, 2002, 2007	Changjiang Water Resources Commission and Shanghai Estuarine & Coastal Science Research Center
	Riverbed erosion/deposition rates for sub-reaches D, E and F in the South Branch	1958-1973, 1973-1986, 1986-1997, 1997-2002, 2002-2010, 2010-2016	Zhao *et al*., 2018
	Bed-elevation point data for North and South Waterways of Baimao Shoal	1992, 1999, 2003, 2007, 2010	Nanjing Normal University, Changjiang Water Resources Commission, the Shanghai Estuarine & Coastal Science Research Center and Changjiang Waterway Bureau
	Mean water depths at cross-sections 1-1′, 2-2′ and 3-3′ in the North Channel	1977, 1982, 1986, 1992, 1995, 2001, 2006, 2010, 2013	Guo *et al*., 2016a
	Riverbed erosion/deposition rates for sub-reaches G and H in the South Channel	1997-2001, 2001-2004, 2004-2006, 2006-2011	Zhu and Luo, 2015
	Bed-elevation point data for North Passage	2006, 2009	Shanghai Estuarine & Coastal Science Research Center
	Position of sedimentary body in the North Passage	2000, 2001, 2002, 2003, 2004, 2005, 2006	Liu *et al*., 2009
	Mean water depths at cross-sections 4-4′, 5-5′ and 6-6′ in the South Passage	2002, 2007, 2009, 2011, 2013	Guo *et al*., 2016b
	Depo-center position in the offshore area	1958-1978, 1978-1989, 1989-1997, 1997-2002, 2002-2004, 2004-2007, 2007-2009, 2009-2011, 2011-2013, 2013-2015	Dai *et al*., 2014; Chen *et al*., 2018
	Areas of land reclamation along the North Branch	1958-1978, 1978-2001, 2001-2013	East China Normal University

[†] The South Branch in this study is defined as the whole channel between Xuliujing and the river mouth at the south of the Chongming Island, which is comparable to the North Branch in terms of length, rather than the shorter channel between Xuliujing and the head of Changxing Island defined previously (Luan *et al*., 2016; Zhao *et al*., 2018). The intention is to obtain fair comparisons between the two branching channels in the present study. Sub-reaches (A, B, C, D, E, F, G, H) and cross-sections (1-1’, 2-2’, 3-3’, 4-4’, 5-5’, 6-6’) are the same as those displayed in Figure 1b.

Text S1

Figure S1 shows that deposition areas and rates in the upper/lower sub-reaches of the North Branch did not experience obvious decreases/increases (and that the erosion areas and rates did not undergo significant increases/decreases) as multi-year average ebb partition ratios and $D_{\geq 60,000}$ increased from dry to flood periods. This implies unobvious downstream sediment transport occurred contemporaneously in the North Branch, which is the north branching channel of the first bifurcation. Similarly, changes in erosion/deposition areas and rates of the two sub-reaches under lowering multi-year average ebb partition ratios and $D_{\geq 60,000}$ from flood to dry periods imply contemporaneous upstream sediment transport.

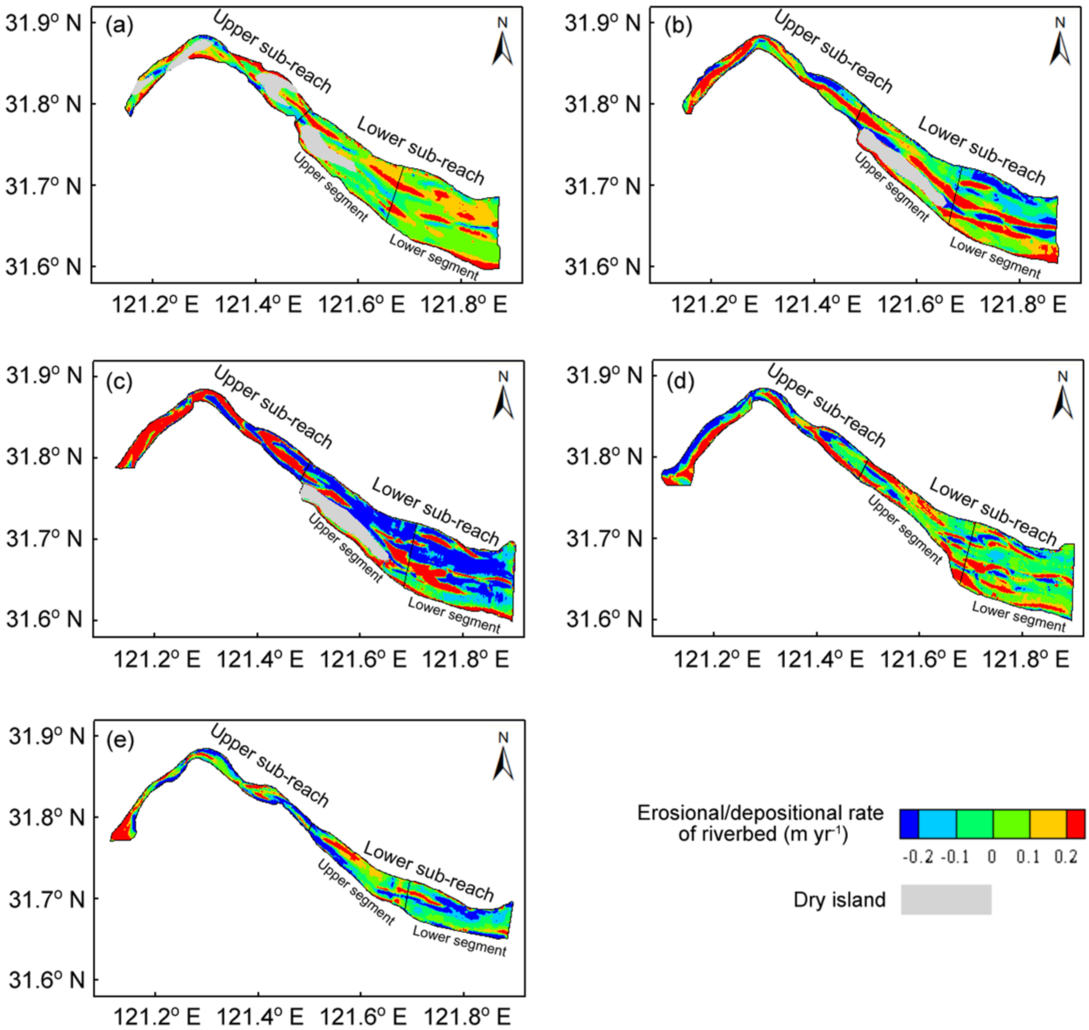

Figure S1. Plan distributions of riverbed erosion/deposition rates in the North Branch during (a) 1978-1991, (b) 1991-1998, (c) 1998-2001, (d) 2001-2007 and (e) 2007-2013, when the multi-year average ebb partition ratios of the North Branch were 0.27, 3.66, 3.66, -10.30, and -10.30 % and the multi-year average $D_{\geq 60,000}$ values were 6, 26, 36, 3, and 5 days yr^{-1}. Positive and negative values represent deposition and erosion.

Nevertheless, variations in erosion/deposition areas and rates in the upper and lower segments of the lower sub-reach exhibited better behavior. During the dry periods of 1978-1991, 2001-2007 and 2007-2013 (especially the latter two periods) that corresponded to relatively low values of ebb partition ratios and $D_{\geq 60,000}$, deposition was predominant in the upper segment. However, during the flood periods of 1991-1998 and 1998-2001 (especially the latter period) associated with higher values of ebb partition ratios and $D_{\geq 60,000}$, obvious erosion occurred in the upper segment, suggesting that sediment in the lower sub-reach was transported downstream during flood periods unlike in dry periods.

Text S2

Figure S2 shows that erosion prevailed in the two sub-reaches of the South Branch during the flood period of 1997-2002 (with lower value of ebb partition ratio and higher value of $D_{\geq 60,000}$), whereas deposition dominated the two sub-reaches during the dry period of 2002-2007 (with higher value of ebb partition ratio and lower value of $D_{\geq 60,000}$). Nonetheless, deposition was more significant in the lower sub-reach during the latter period, indicating that more sediment in the South Branch was deposited in the lower sub-reach during this dry period, and implying attribution to the south branching channel of the first bifurcation.

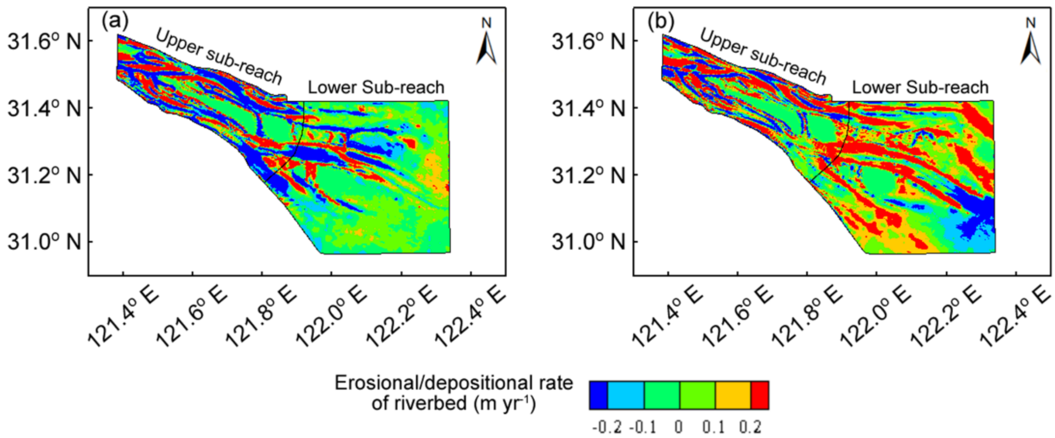

Figure S2. Plan distributions of riverbed erosion/deposition rates in the South Branch during (a) 1997-2002 and (b) 2002-2007, when the multi-year average ebb partition ratios of the South Branch were 96.34 and 110.30 % respectively and multi-year average $D_{\geq 60,000}$ values were 29 and 4 days yr^{-1}. Positive and negative values represent deposition and erosion.

Text S3

Figure S3 shows that the depositional areas and rates in the upper sub-reach of the North Waterway of Baimao Shoal were always larger than those in the lower sub-reach during the four periods, implying that sediment in the North Waterway of Baimao Shoal was mainly deposited in the upper sub-reach during these periods. Moreover, the most severe erosional area and rate occurred in the lower sub-reach, in obvious contrast with dominant depositional features in the upper sub-reach that appeared during the driest period of 2003-2007 for the lowest value of $D_{\geq 60,000}$. This implied that sediment was transported further upstream during 2003-2007 than during 1992-1999, 1999-2003 and 2007-2010 when $D_{\geq 60,000}$ was higher, suggesting attribution to the north branching channel of the second bifurcation.

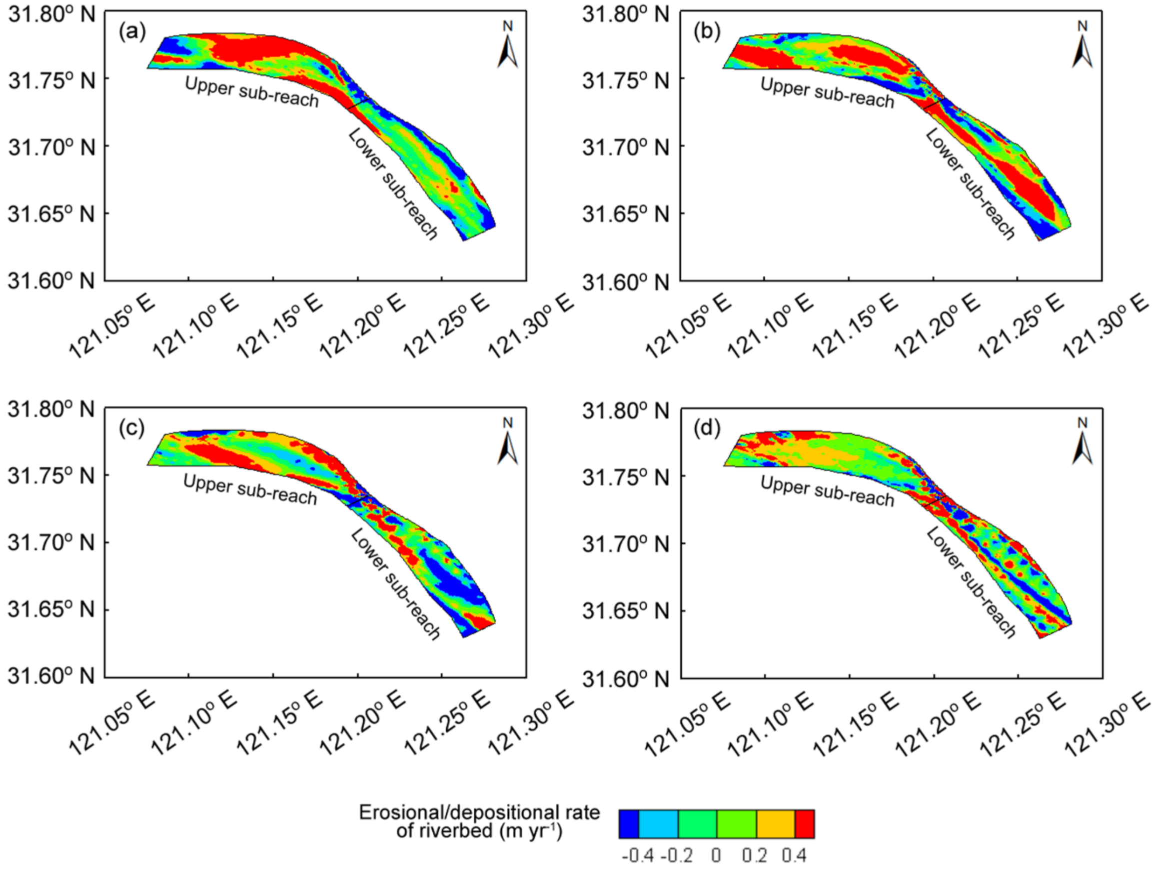

Figure S3 Plan distributions of riverbed erosion/deposition rates in the North Waterway of Baimao Shoal during (a) 1992-1999, (b) 1999-2003, (c) 2003-2007 and (d) 2007-2010. Multi-year average ebb partition ratios of the North Waterway during the latter two periods were 35.81 and 32.90 %, and multi-year average $D_{\geq 60,000}$ values during the four periods were 31, 15, 0, and 9 days yr^{-1}. Positive and negative values represent deposition and erosion.

Text S4

Figure S4 illustrates the predominance of erosional areas and rates in the upper sub-reach of the South Waterway of Baimao Shoal and of depositional areas and rates in the lower sub-reach during the flood periods of 1992-1999 and 1999-2003 associated with higher values of $D_{\geq 60,000}$. Sediment was mainly deposited in the lower sub-reach in the South Waterway of Baimao Shoal during these two periods. However, erosional features occupied both sub-reaches during the dry periods of 2003-2007 and 2007-2010 (with low values of $D_{\geq 60,000}$), implying that sediment was transported further downstream into the channel downstream of the South Waterway during these two periods.

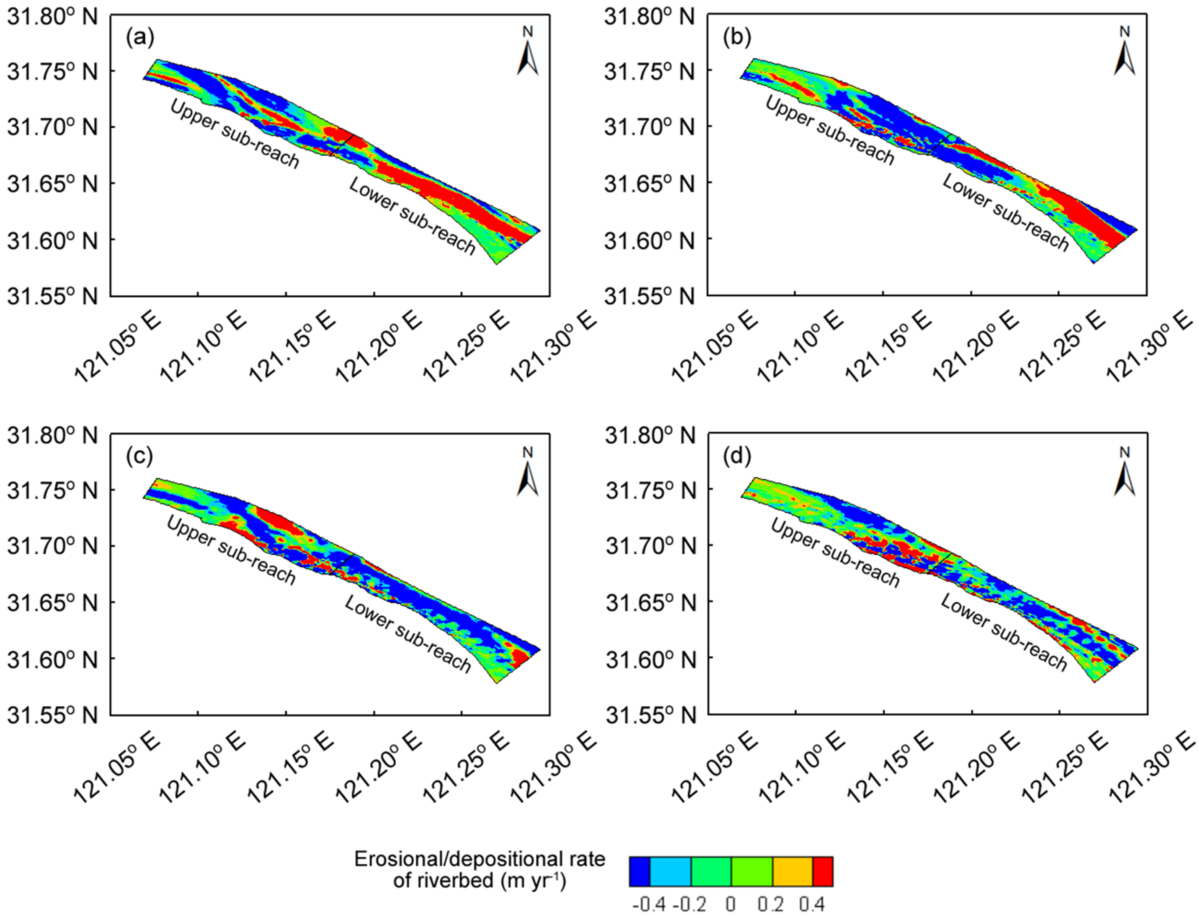

Figure S4. Plan distributions of riverbed erosion/deposition rates in the South Waterway of Baimao Shoal during (a) 1992-1999, (b) 1999-2003, (c) 2003-2007, and (d) 2007-2010. Multi-year average ebb partition ratios of the South Waterway during the latter two periods were 64.19 and 67.10 %, and multi-year average $D_{\geq 60,000}$ values during the four periods were 31, 15, 0, and 9 days yr^{-1}. Positive and negative values represent deposition and erosion.

The depositional area and rate were most significant in the lower sub-reach during the most severe flood period of 1992-1999, corresponding to the highest values of $D_{\geq 60,000}$. This suggested a most remarkable upstream transport of sediment from the downstream channel into the lower sub-reach of the South Waterway. Meanwhile, the erosional area and rate were greatest in the lower sub-reach and also distinct throughout the whole South Waterway during the driest period of 2003-2007, corresponding to the lowest value of $D_{\geq 60,000}$, signifying a notable downstream transport of sediment from the South Waterway into the downstream channel.

These longitudinal erosion-deposition patterns are attributed to the south branching channel of the second bifurcation.

Text S5

Figure S5 shows that erosion areas and rates dominated both sub-reaches of the North Channel during the flood period of 1997-2002, associated with higher values of ebb partition ratio and $D_{\geq 60,000}$, suggesting that sediment was mainly deposited in the offshore area downstream of the North Channel during this period. Furthermore, erosional features were more recognizable in the upper sub-reach than in the lower sub-reach during this flood period. Nevertheless, deposition occurred in both sub-reaches during the dry period of 2002-2007, associated with lower values of ebb partition ratio and $D_{\geq 60,000}$; depositional features were more obvious in the lower than the upper sub-reach, implying that sediment was transported upstream from the offshore area into the lower sub-reach of the North Channel during this period. These longitudinal morphological changes can be attributed to the north branching channel of the third bifurcation.

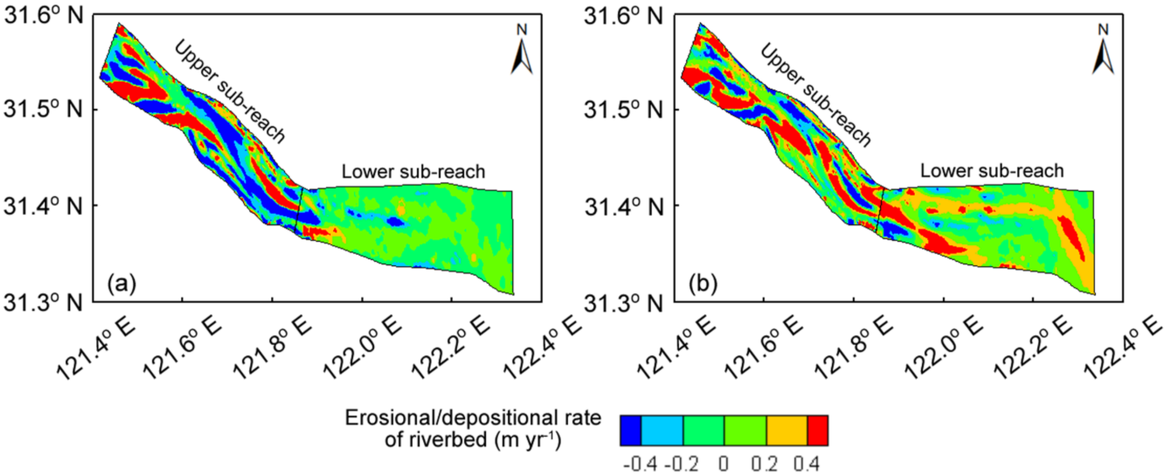

Figure S5. Plan distributions of riverbed erosion/deposition rates in the North Channel during (a) 1997-2002 and (b) 2002-2007, when the multi-year average ebb partition ratios of the North Channel were 52.17 and 49.12 % and the multi-year average $D_{\geq 60,000}$ values were 29 and 4 days yr^{-1}. Positive and negative values represent deposition and erosion.

Text S6

Figure S6 shows that erosion dominated both sub-reaches of the South Channel during 1997-2002 and 2002-2007, with sediment deposited in the channel downstream of the South Channel during these periods. Nonetheless, erosional features were more obvious in the lower sub-reach than in the upper sub-reach during the flood period of 1997-2002, corresponding to a lower value of ebb partition ratio and higher value of $D_{\geq 60,000}$. Erosion was larger in the upper sub-reach than in the lower sub-reach during the dry period of 2002-2007, with a higher value of ebb partition ratio and lower value of $D_{\geq 60,000}$, implying downstream transport of sediment from the former flood period to the latter dry period. These longitudinal morphological changes are attributed to the south branching channel of the third bifurcation.

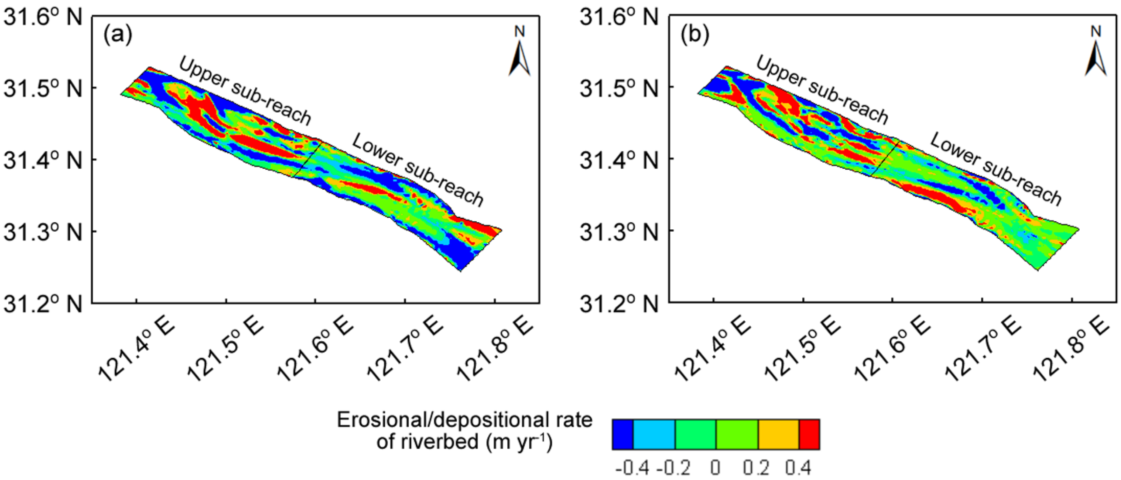

Figure S6. Plan distributions of riverbed erosion/deposition rates in the South Channel during (a) 1997-2002 and (b) 2002-2007, when the multi-year average ebb partition ratios of the South Channel were 47.83 and 50.88 % and multi-year average $D_{\geq 60,000}$ were 29 and 4 days yr^{-1}. Positive and negative values represent deposition and erosion.

Text S7

Figure S7 shows that erosion was prominent in the upper sub-reach of the North Passage, and deposition was slightly dominant in the lower sub-reach during the flood period of 1997-2002 (with higher values of ebb partition ratio and $D_{\geq 60,000}$), indicating that sediment was mainly deposited in the lower sub-reach of the North Passage during this period. However, depositional features occupied both sub-reaches during the following dry periods of 2002-2006 and 2006-2007 (corresponding to lower values of ebb partition ratios and $D_{\geq 60,000}$), with more severe deposition occurring in the upper sub-reach, implying that sediment was transported upstream and deposited in the upper sub-reach during these two dry periods. Erosional features occupied both sub-reaches during the dry period of 2007-2009 (Corresponding to the lowest values of ebb partition ratio and $D_{\geq 60,000}$), with slightly more erosion occurring in the lower sub-reach, suggesting that sediment was transported further upstream so that it deposited in the channel upstream of the North Passage. These longitudinal transports of sediment are attributed to the north branching channel of the fourth bifurcation.

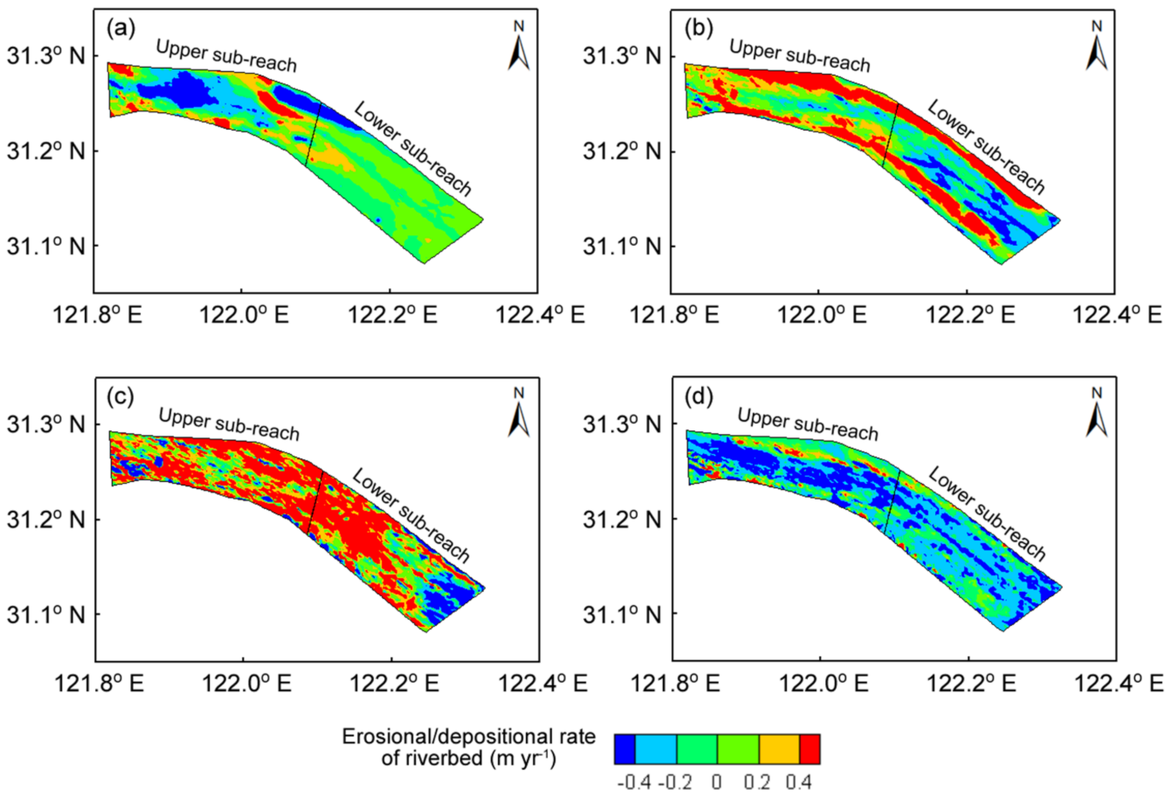

Figure S7. Plan distributions of riverbed erosion/deposition rates in the North Passage during (a) 1997-2002, (b) 2002-2006, (c) 2006-2007 and (d) 2007-2009, when multi-year average ebb partition ratios of the North Passage were 54.83, 49.14, 45.65, and 43.30 % and multi-year average $D_{\geq 60,000}$ were 29, 4, 0, and 0 days yr^{-1}. Positive and negative values represent deposition and erosion.

Text S8

Figure S8 illustrates that erosional areas and rates in the upper and lower sub-reaches of the South Passage did not obviously increase and decrease respectively, as the multi-year average ebb partition ratio rose and $D_{\geq 60,000}$ lowered, from the flood period of 1997-2002 to the dry period of 2002-2007. This indicated an unobvious contemporaneous downstream transport of sediment in the South Passage, even though it is the south branching channel of the fourth bifurcation.

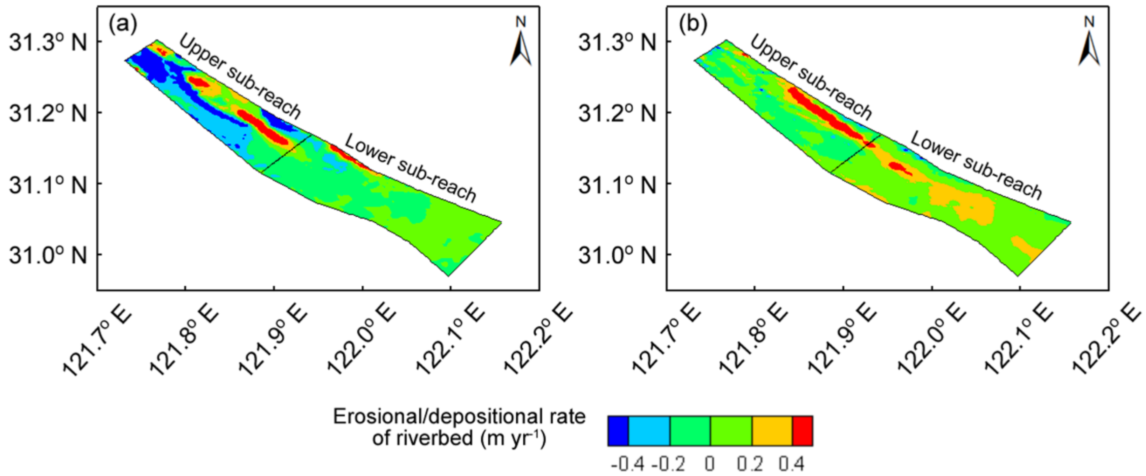

Figure S8. Plan distributions of riverbed erosion/deposition rates in the South Passage during (a) 1997-2002 and (b) 2002-2007, when the multi-year average ebb partition ratios of the South Passage were 45.17 and 51.52 % and multi-year average $D_{\geq 60,000}$ were 29 and 4 days yr^{-1}. Positive and negative values represent deposition and erosion.

Table SII. Original data for Figure 7.

Region between adjacent isobaths (1 m interval)	Channel volume change rate in upper sub-reach (10^8 m^3 yr^{-1})					Channel volume change rate in lower sub-reach (10^8 m^3 yr^{-1})				
	1978-1991	1991-1998	1998-2001	2001-2007	2007-2013	1978-1991	1991-1998	1998-2001	2001-2007	2007-2013
0 ~ -1 m	-0.013	0.013	0.054	-0.006	0.025	-0.003	0.033	0.058	0.019	0.021
-1 ~ -2 m	0.018	0.008	0.075	-0.017	0.007	0.037	0.046	0.053	0.019	0.009
-2 ~ -3 m	0.007	0.010	0.064	-0.016	0.004	0.030	0.041	0.054	0.013	-0.003
-3 ~ -4 m	0.003	0.013	0.038	-0.008	0.002	0.031	0.039	0.013	0.015	0.015
-4 ~ -5 m	-0.001	0.012	0.016	0.003	0.000	0.032	0.027	-0.054	0.024	0.002
-5 ~ -6 m	0.002	0.008	0.001	0.005	0.000	0.044	-0.002	-0.088	0.013	-0.002
-6 ~ -7 m	0.000	0.006	0.001	0.004	0.001	0.035	-0.024	-0.066	0.020	-0.014
-7 ~ -8 m	-0.003	0.005	0.002	0.002	0.001	0.021	-0.018	-0.059	0.016	-0.006
below -8 m	-0.009	0.014	0.005			0.011	-0.004	-0.059	0.008	

Table SIII. Original data for Figure 8.

Region between adjacent isobaths (1 m interval)	Channel volume change rate in upper sub-reach (10^8 m^3 yr^{-1})		Channel volume change rate in lower sub-reach (10^8 m^3 yr^{-1})	
	1997-2002	2002-2007	1997-2002	2002-2007
0 ~ -1 m	0.014	0.019		
-1 ~ -2 m	-0.002	0.027	-0.070	-0.007
-2 ~ -3 m	-0.011	0.032	0.012	-0.008
-3 ~ -4 m	-0.015	0.025	0.001	0.037
-4 ~ -5 m	-0.019	0.015	-0.005	0.065
-5 ~ -6 m	-0.025	-0.003	-0.011	0.092
-6 ~ -7 m	-0.039	-0.012	-0.024	0.063
-7 ~ -8 m	-0.050	-0.005	-0.014	0.011
-8 ~ -9 m	-0.044	-0.008		
-9 ~ -10 m	-0.025	-0.005		
below -10 m	-0.009	-0.007		

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