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ScienceDirect
Procedia Environmental Sciences 2 (2010) 15–24
Procedia Environmental Sciences

International Society for Environmental Information Sciences 2010 Annual Conference (ISEIS)

Effects of Reservoir Impounding on Key Ecological Factors in the Three Gorges Region

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Abstract

According to the analyzing of the monitoring data of key ecological factors, such as concentration of total phosphorus (TP), concentration of total nitrogen (TN), and algae cell density during 2002-2005 in the reservoir region, we can find that the number of algae species and the cell density are significant increase, nutrient concentration in Xiangxi Bay also has marked increasing tendency after impounding. It creates a necessary condition for the outbreaking of algal blooms in the tributary bay. Hydraulic structures locates in the tributaries upstream are suggested to be used to regulate and control water quality in the bays.

Keywords: the Three Gorges Reservoir; water environment; water quality; water bloom; pollution control

1. Introduction

Large-scale reservoir construction will have diversified impacts, including both positive and negative aspects. In positive aspect, it will bring about significant benefits in electric power generation, flood control and shipping traffic; in negative one, it will produce adverse impacts on migration, environmental and cultural issues, etc. [1]. Among its adverse impacts, influence of reservoir construction on water environment has been attracting most concerns of the public. This is because that the changes of water environment within the reservoir will have direct impacts on: ① the life quality of people inhabiting in the reservoir region[2]; ② the living quality of aquatic life in the reservoir [3]; ③ the living quality of human being and other species of creatures in the lower branches within the reservoir region [4]. Therefore, it has great significance of making assessment on the impacts on the water environment in the reservoir imposed by the reservoir impoundment[5].

Generally, such environmental assessment targeted on a significantly influential reservoir has been cautiously made in details prior to its construction [6]. The assessment on what happens to environment in the future seems to be a kind of predication, whose factuality needs to be further proved by what really happens in the future. Since a

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doi:10.1016/j.proenv.2010.10.004

large-scale reservoir has possibility to produce major influences on the environment, staged impoundment method is adopted sometimes for the entire reservoir impoundment [7]. This method is also adopted for the Three Gorges Reservoir. Impoundment in the Three Gorges Reservoir is composed of 4 stages: ① to the water level 135m since the impoundment officially started on June 1, 2003 to June 10; ② to water level 139 m on November 5, 2003 for benefits in shipping traffic and electric power generation; ③ to 156 m on October 27, 2006 (since September 20, 2006 water level rise from 139 m to 156 m); ④ during the last stage, water level will reach 175 m in 2009[8]. This staged impoundment method aforesaid has provided favorable conditions for the water environmental protection within the reservoir region. During the early stage of impoundment, site inspection method can be applied to assess the impoundment impacts on the water quality within the reservoir region. Based on the observed degree of those impacts as well as their reasons, countermeasures should be timely carried out so as to prevent from the possible exaggerated adverse impacts after full impoundment of the reservoir[9].

Reservoir impoundment has significant impacts on the ecological factors. The Beijing Miyun Reservoir is a typical example. As a multi-year regulating storage reservoir, the big vertical gradient of temperature and density can inhibit transport of suspended solids, solutes, nutrients, and organisms, which in turn affects the hydrodynamic characteristics of the reservoir, as well as chemical and biological processes. During 1995-1997, based on accurate prediction of hydrology, the chlorophyll concentration in the reservoir area in 1997 is significantly reduced. Discharging water from vertical stratification and different outlet structure also had a desired effect [10].

According to the monitoring data of concentration of total phosphorus (TP), concentration of total nitrogen (TN), and algae cell density and its density during 2002-2005 in the reservoir region, especially changes of these factors before (2002-2003) and after (2003-2004) the impoundment, this paper will discuss the impacts of reservoir impoundment on key ecological factors in the Three Gorges Reservoir and propose water quality improvement measures.

2. Water body eutrophication before and after impoundment

Eutrophication issue is one of major water pollution to be confronted and solved in the Three Gorges Reservoir. As early as the argumentation phase of the Three Gorges Project, the Changjiang Water Resource Commission, the Chinese Academy of Sciences and other scientific research institutes have conducted mass researches on the eco-environmental issues of Three Gorges Project, particularly on the eutrophication issues with following understanding[11-13]: with the enclosure of impoundment and dispatching for operation, the water regime of the Yangtze River is about to be changed greatly, where the increase of staged water level and the slowing down of flow would weaken its water body's turbulent motion and diffusibility as well as extent the residence time in reservoir bays and branches[14]; large amount of nutritive substance is yielded by the submerged soil, which causes increment of nitrogen and phosphor contents in the water body [15]; due to the back water amplitude of setup, pollution in reservoir bays and branches is possibly worsened and eutrophication is possibly occurred [16-17].

Table 1 Algae species composition variation before and after impoundment in Three Gorges Reservoir

Algae category	Before impoundment		After impoundment	
	Number of species (Percentage/%)	Number of genus (percentage/%)	Number of species (percentage/%)	Number of genus (percentage/%)
Bacillariophyta	27 (34.6)	19 (28.8)	36 (23.8)	26 (25.2)
Chlorophyta	30 (38.5)	27 (40.9)	83 (55.0)	49 (47.6)
Blue algae	8 (10.3)	8 (12.1)	15 (9.9)	12 (11.7)
Cryptophyta	5 (6.4)	5 (7.6)	5 (3.3)	5 (4.8)
Euglenophyta	2 (2.5)	1 (1.5)	2 (1.3)	1 (1.0)
Pyrrophyta	4 (5.2)	4 (6.0)	5 (3.3)	5 (4.8)
Chrysophyta	2 (2.5)	2 (3.0)	3 (2.0)	3 (2.9)
Xanthophyta	0 (0.0)	0 (0.0)	2 (1.3)	2 (1.9)
Total	78 (100.0)	66 (100.0)	151 (100.0)	103 (100.0)

Synchronous monitoring of the hydrometric and water quality (aquatic life included) in key stations have been carried on for years, in which high attention has been paid to the eutrophication fluctuations, and certain quantity of data and information for eutrophication trend analysis accumulated. Paragraphs below are the analysis on eutrophication trend of the water body within the reservoir with the respect to its algae resource and nutrition level, which is stated as follows:

2.1. Investigation on algae resources

According to monitoring data (as shown in Table 1) of ChongQing Environmental Monitoring Center, Institute of hydrobiology of the Chinese academy of sciences, China Three Gorges University [18-20], algae resource is abundant within the reservoir region. Phytoplankton species have 7 categories, 66 genus and 78 kinds before the impoundment, while after the impoundment phytoplankton species increase to 8 categories, 103 genus and 151 kinds, for example, Chlorophyta increases to 83 kinds which had 30 kinds before impoundment and Blue algae increases to 15 kinds which had 8 kinds before impoundment, Xanthophyta which has not been found before the impoundment is found after the impoundment. Most of species existed in freshwater can be found in the reservoir. Among them, bacillariophyta's cyclotella, chlorophyta's dhlamydomonas chlorella, blue algae's microcystis, cryptophyta's cryptomonas, euglenophyta's euglenophyta are about to develop into dominant species under favorable conditions even cause "water blooms".

The comparison of species and density of algae in main stream and Xiangxi River Branch before and after impoundment are given in Figs. 1-2. We can see from Fig. 1, algae species change from Bacillariophyta to Chlorophyta in the main stream and its tributaries after impounding. Figure 2 indicates that in June 2003 before the impounding, algal cell density in main stream section and the Xiangxi river branch does not have big difference, while it has significant seasonal differences after impounding.

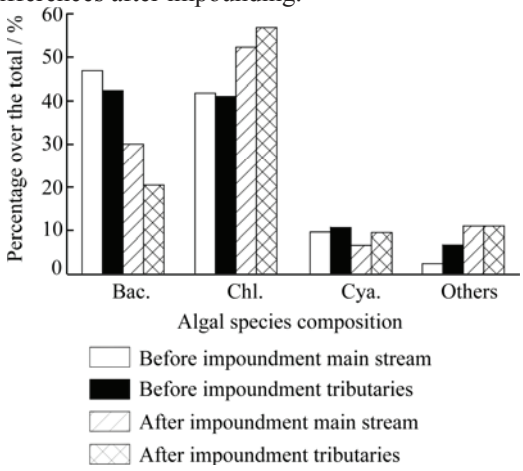

Fig. 1. Comparison of major algae species proportion before and after impoundment in Three Gorges Reservoir

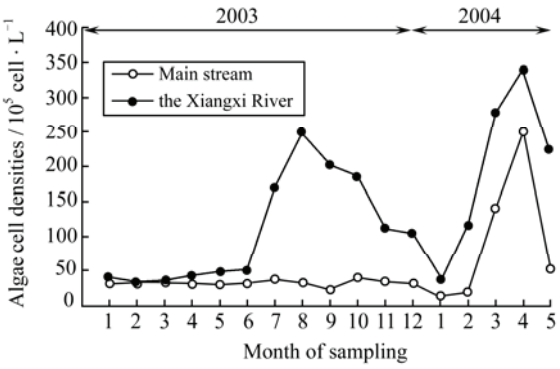

Fig. 2. Monthly variation of algae cell density during 2003-2004 in Three Gorges Reservoir and its Xiangxi River branch

The algae cell density in the Xiangxi River Branch is much higher than that in the main stream section within the reservoir, indicating that the water environment of branches is more propitious to algae growth and metabolism than the main stream water environment.

2.2. Nutritive salt in the key points of reservoir

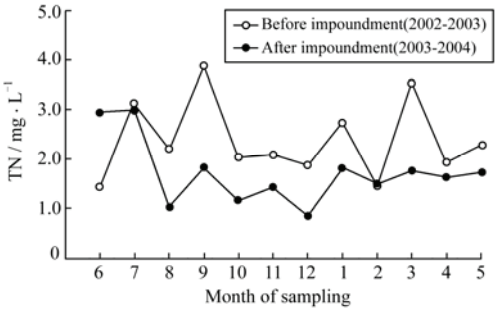

Fig. 3. Nitrogen dynamics before and after impoundment in Three Gorges Reservoir

Figures 3-4 are the statistics of major nutritive salts in the Three Gorges Reservoir. It shows that TN and TP are all dropped outstandingly after impoundment in the reservoir, revealed that possibility of algal blooms out-breaking is decreased in the reservoir area.

According to the monitoring data given in Table 2 by China Three Gorges University, the average amplitude of variation of total nitrogen for years in each fracture plane ranges from 1.37 to 2.22 mg/L, amplitude of variation of measured value ranges from 0.80 to 4.54 mg/L; the average amplitude of variation of total phosphor for years in each fracture plane ranges from 0.13 to 0.30 mg/L, amplitude of variation of measured value is 0.02-2.99 mg/L.

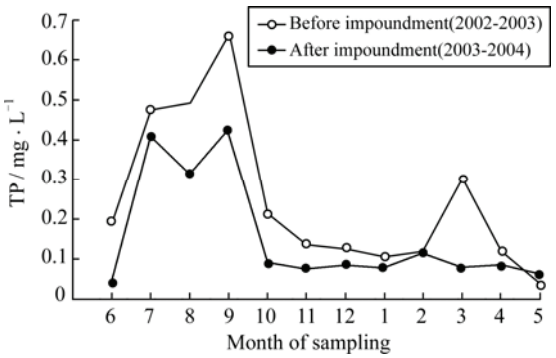

Fig. 4. Phosphor dynamics before and after impoundment in Three Gorges Reservoir

Table 2. Statistics of nitrogen and phosphor content in the Three Gorges Reservoir after impoundment mg/L

Monitoring station		Mean value		Minimal value		25%-position value		Mid-position value		75%-position value		Maximum value	
		TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP
Reservoir mainstream	Cuntan	1.61	0.27	0.80	0.02	1.32	0.10	1.50	0.18	1.80	0.32	3.85	1.12
	Qingxichang	1.69	0.28	0.87	0.02	1.37	0.11	1.56	0.16	1.90	0.36	4.37	1.24
	Tuokou	1.76	0.30	0.90	0.02	1.40	0.10	1.59	0.16	1.92	0.44	4.06	1.24
	Guandukou	1.37	0.17	0.80	0.06	1.16	0.11	1.33	0.15	1.55	0.20	2.07	0.43
	Badong	1.46	0.16	0.85	0.04	1.24	0.11	1.42	0.14	1.66	0.19	2.26	0.40
Reservoir branches	Linjiangmen	2.22	0.24	1.25	0.00	1.65	0.09	1.97	0.12	2.77	0.20	4.54	2.99
	Wulong	1.95	0.13	0.96	0.00	1.64	0.06	1.90	0.10	2.12	0.15	3.80	0.80

According to nutritive categorizing standard based on total phosphor and total nitrogen, nitrogen and phosphor contained in mainstream and branches within the Three Gorges Reservoir have reached or even exceeded the limit standard of eutrophication, indicating that the water body has nutritive conditions for eutrophication occurrence.

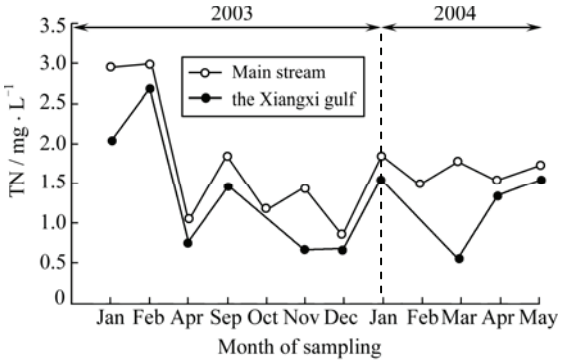

Fig. 5 Monthly comparison of TN during 2003-2004 between main stream and the Xiangxi bay

The dynamics of nutritive salt during 2003-2004 are shown in Figure 5-6. There is no significant difference in TN in both main stream and the Xiangxi bay; while the concentration of orthophosphate in main stream is lower than that of the Xiangxi bay. It also reveals that the Xiangxi bay has been severely polluted by inorganic phosphate in the upper reaches, which indicates that the bay has great contribution to orthophosphate in the main stream.

2.3. The discipline of Water bloom occurrence

According to the continuous observation and monitoring since 135 m water level in the Three Gorges Reservoir [18-19], frequency of the occurrence of water bloom in the reservoir bay is increasing and expanding. Water bloom occurred 6 times in 2004, increased to 19 times in 2005, and 10 times already in the reservoir bay only during February-March in 2006. Among 10 branches under investigation, water blooms have been occurred in 7 rivers (Xiaojiang, Tangxi, Modaoxi, Changtan, Meixi, Daning and Xiangxi) induced by backwater amplitude of setup; on the contrary, no water bloom is found in Yulin, Longxi and Long due to no/small backwater amplitude of setup.

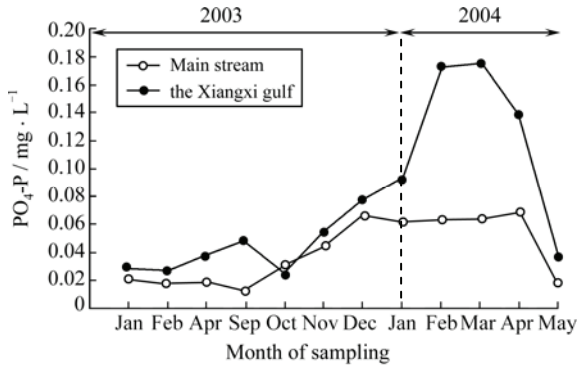

Fig. 6. Monthly dynamic comparison of PO_4-P during 2003-2004 between main stream and the Xiangxi bay

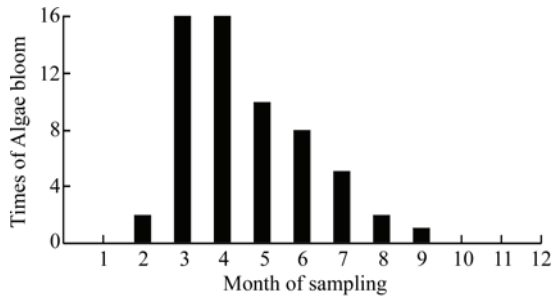

Fig. 7. Temporal distribution of water bloom in branches of the Three Gorges Reservoir in 2005

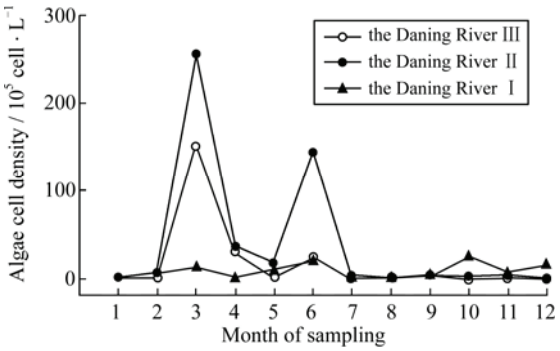

Fig. 8. Algae cell density variation in the Daning River in 2005 Ⅰ, Ⅱ, and Ⅲ mean three different observing station on the Daning River

According to the statistics of the times of water bloom occurrence shown in Fig. 7, water bloom is at its peak during spring and summer, seldom in autumn and none in winter. Water bloom is concentrated during March-July each year. In addition, different rivers varied in terms of time and scale of water bloom occurrence, for instance, severe and larger area water bloom occurred during March-June 2005 in the Daning River, while the Xiangxi River suffered the yearly largest area water bloom in July with algae density as high as 108 cell/L, as shown in Fig. 8 and Fig. 9.

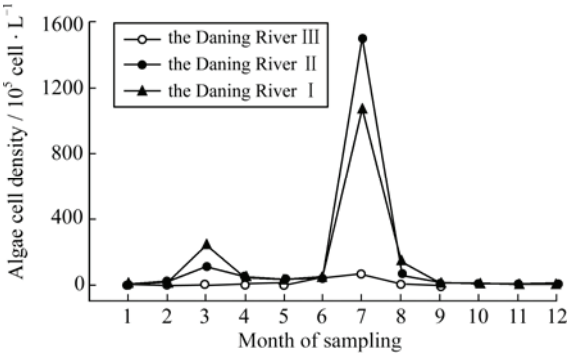

Fig. 9. Algae cell density variation in the Xiangxi River in 2005

Table 3. Water bloom predominant species distribution and development in the Xiangxi River and the Daning River

Time interval	The Daning River	The Xiangxi River
Before impoundment (Before June 2003)	—	—
Impoundment time (Jun. 2003)	Cryptophyta	Cryptophyta
Half year after impoundment (July~December 2003)	Diatom	Diatom
One year after impoundment (January~June 2004)	Green algae, diatom, inoflagellate	Diatom, Inoflagellate
One year and a half after impoundment (July~December 2004)	Inoflagellate, green algae, Diatom	Inoflagellate, diatom, Cryptophyta
Two years after impoundment (January~June 2005)	Inoflagellate, green algae, Cryptophyta	Inoflagellate, diatom, Cryptophyta
Two years and a half afterimpoundment (July~December 2005)	diatom, Inoflagellate, green algae	Inoflagellate, blue algae, green algae

As of today, the Three Gorges Reservoir has monitored 5 kinds of water blooms characterized by its dominant species of cryptophyta, diatom, inoflagellate, blue algae and green algae respectively,listed in Table 3.Generally, it reveals a developing trend from “river diatomeae to lake blue and green algae. With further slowing down of water

flow, the predominant water bloom species in the same river are gradually changing. Taking Xiangxi River as an example, the cryptophyta water bloom in June 2003, changed to diatom in March 2004, and further changed to blue algae in July 2005.

Furthermore, due to variation of water flow conditions, predominant species of water bloom in different river sections of the same river are different. Taking the water bloom occurred in May 2005 in the Daning River for example, inoflagellate water bloom was found in its river mouth section and green algae in its middle section, showing sharp difference.

The monitoring data and analyzing results indicate that Eutrophication problem in reservoir branches is the most important water environmental problem.

3. Discussion

Normally the amplitude fluctuation of average water temperature in each fracture plane of mainstream and branches within the Three Gorges Reservoir is 17.7-19.0 ^{o}C featured with outstanding seasonal change, and their measured amplitude fluctuation is 8.0-29.0 ^{o}C. Based on the statistical results (25%-position value and 75%-position value), water temperature of the reservoir and its medium and lower branches is normally ranging from 13.0-24.0 ^{o}C, which is quite suitable for the growth and development of phytoplankton, as well as diatom and cyptophyta which can be grown and developed to be predominant species under such water temperature condition, even causing the break-out of "water bloom".

Before impoundment, the Three Gorges Reservoir maintained a natural current state of river course. It had a significant water level variation up to 30-50 m during a year. Flood peak in the river usually had sudden rise and sharp fall. Daily rise rate of water level during flood season could be as high as 10 m, while daily fall rate up to 5-7 m. The reservoir river course had bigger water surface slope and rapid current with average water surface slope of 2‰ and water surface slope of over 1% at rapid current. Surface velocity in canyon section during flood period could be 4-5 m/s and max up to 6-7 m/s, while 3-4 m/s during low flow period. This condition is not suitable for growth of majority algae species, hence diatom adaptable to running water became the predominant species among floating algae species in the reservoir. However, thanks to high content of earthy material in water body, it was restricted from large amount growth and development, which was hard to be developed into water body eutrophication.

With the rise of water level after impoundment, water height of water body in the reservoir drops which results in slowing down of the current of mainstream and branches nearby the dam, and the drop of earthy material content in water body and the increase of water body transparency is in favor of photosynthesis of floating algae species. Accordingly, water flow condition will diminish its influence and restriction to the growth of algae species to some extent, and even such water flow condition can be developed to be the water environment quite suitable for the growth of some slow flow or dead water favored algae species such as bacillariophyta's cyclotella and Pyrrophyta's Peridiniaceae, where water body eutrophication is likely to be formed and even cause "water bloom" when other conditions (such as water temperature and nutrition, etc.) are available.

Table 4. Statistics of water temperature distribution in the Three Gorges Reservoir ^{o}C

monitoring station		Mean value	Minimal value	25%-position value	Mid-position value	75%-position value	Maximum value
Reservoir main stream	Cuntan	18.6	10.0	14.2	19.6	23.0	27.0
	Qingxichang	18.3	7.8	13.2	19.0	23.0	27.0
	Tuokou	18.4	10.0	13.4	19.0	22.4	27.0
	Guangdukou	19.0	9.5	14.5	20.0	23.0	28.5
	Badong	18.9	9.5	13.9	20.0	23.0	28.5
Reservoir branch	Linjiangmen	18.7	8.0	13.0	18.8	24.1	29.0
	Wulong	17.7	10.0	13.4	18.4	21.6	25.6

Branches of TGP reservoir are most important area of water environment governing. Hydrodynamic conditions and algal chlorophyll A concentration were simulated in Xiangxi Bay, a typical branch of TGP reservoir in Ref. [21-22]. The results indicate that chlorophyll A concentration in the Bay is affected obviously by the upper discharge, while the effect of water level amplitude on water velocity and chlorophyll A concentration is not very distinct.

At present, the operation of the Three Gorges Reservoir mainly meets the requirements of flood control, power generation and shipping etc, so the water level amplitude is just 10-20 cm/d. The water level amplitude is limited because of restricting of flood control, power generation efficiency and demands of industrial, agricultural production as well as the living requirements, so the possibility of increasing water level amplitude to improve ecological condition is very slim. On the other hand, the Xiangxi River is the first branch of the upper reaches of the Three Gorges Dam, also the nearest tributary to the dam, therefore it can be inferred that, the effect of water level amplitude of other branches on the upper reaches of the reservoir will be weak.

As we all know, water bloom can be inhibited if water hydrodynamic conditions is strong enough. Theoretically, the strength of hydrodynamic condition can be measured by flow velocity, but also the turbulent kinetic energy or vertical diffusion coefficient. From this point of view, the local oscillation of water body in the vertical plane is also a kind of token of hydrodynamic strength.

The methods using the small-scale hydraulic projects located in the upper reaches of Xiangxi branch to strengthen the control ability of the discharge are expected to play an important role on inhibiting the eutrophication and controlling the algal growth.

4. Conclusion

A large number of water quality monitoring results in the Three Gorges Reservoir, before and after impounding, indicate that the quantities of algae species and the cell density increase significantly in the reservoir area. Nutrient concentrations in the bay of branches have also been uplifted than the former. With the slow flow velocity, the appropriate water temperature and light conditions, the out-breaking of algal-bloom in the bay has upward trend. By correlation analyzing between chlorophyll and flow velocity, the conclusion of making full use of small scale hydraulic structures in upper reaches to regulate and improve water environment is given in the paper.

Acknowledgements

Financial supports from the National Natural Science Foundation of China (Grant No. 50779028) and National Science Foundation for Distinguished Young Scholars of China (Grant No. 50925932) are highly appreciated. The helpful comments from anonymous reviewers are also gratefully acknowledged.

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