Drought and flood monitoring and connection to climate variability in Pearl River Basin, Southern China using GRACE data

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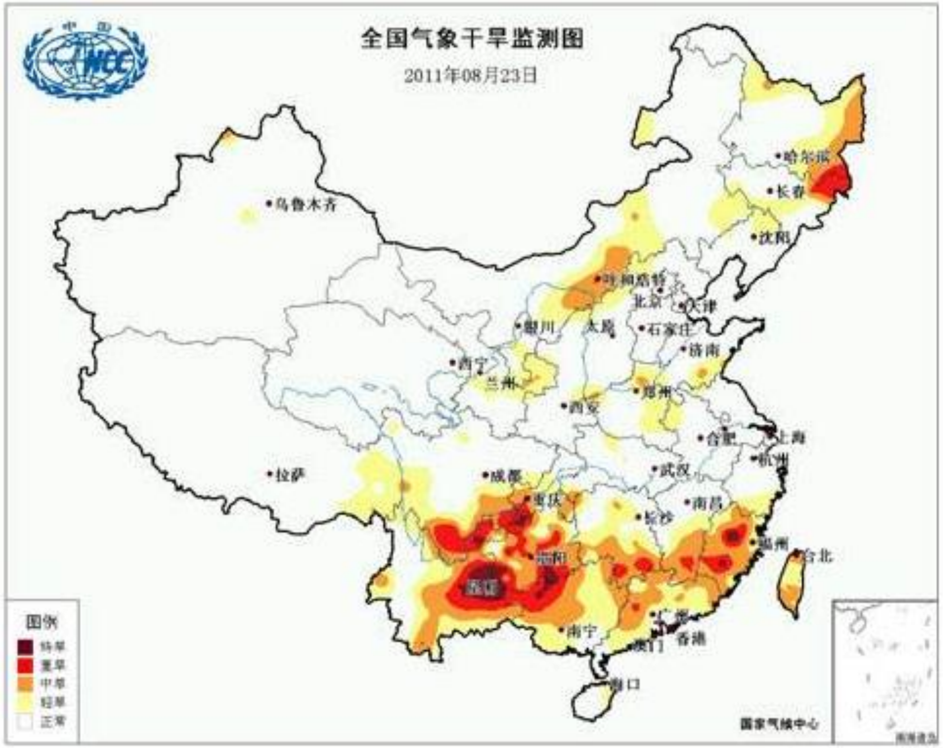
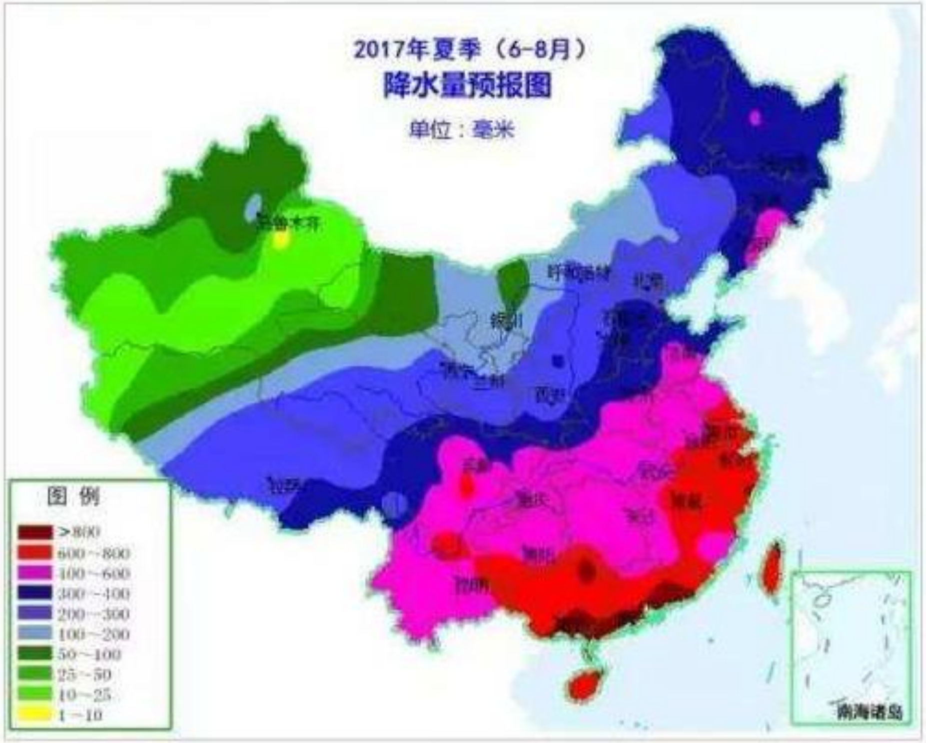
1. Introduction

China meteorological drought monitoring
Aug. 23, 2011



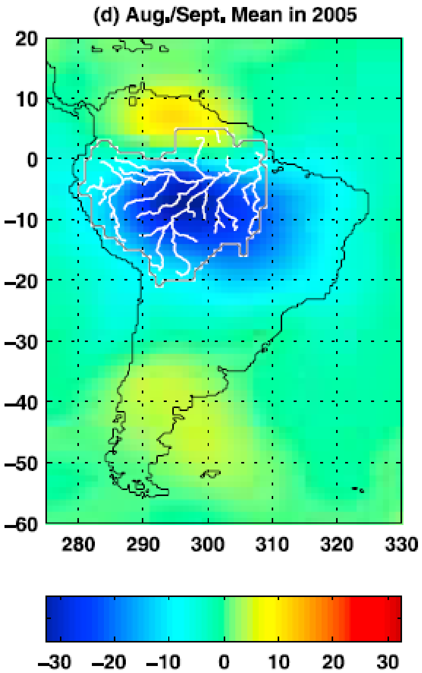
Rainfall forecasting map
Summer (Jun.-Aug., 2017)



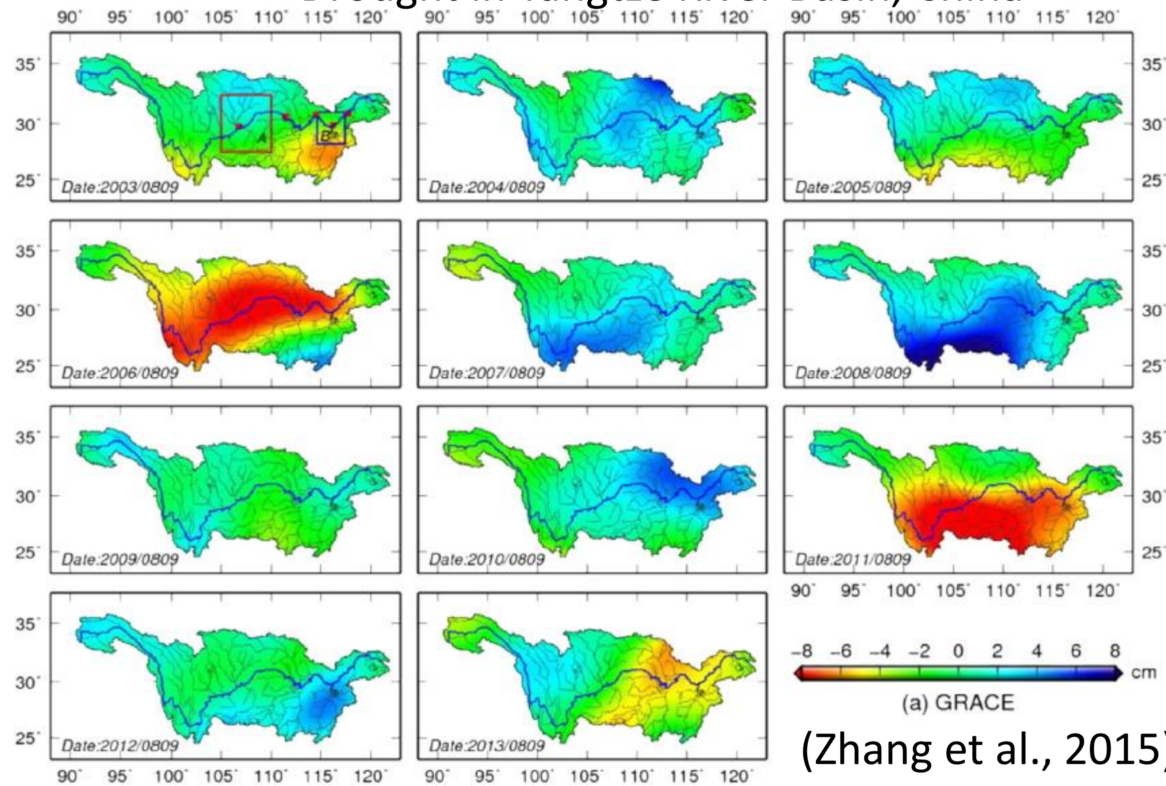
Southern China is prone to drought and flood disaster

1. Introduction (Drought and flood monitoring using GRACE)

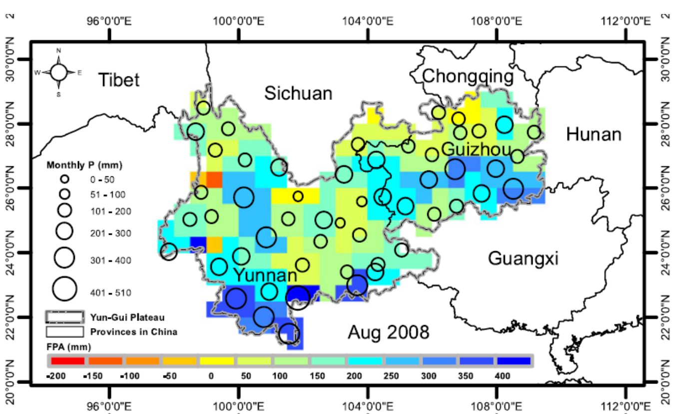
2005 drought in Amazon
(Chen et al., 2009)



Drought in Yangtze River Basin, China



(Zhang et al., 2015)



2008 flood in Yun-Gui Plateau in Southwest China
(Long et al., 2014)

Drought and flood in Pearl River Basin

1. Introduction (Literature review on drought and flood indices)

To date, more than 100 drought indices have been proposed (Zargar et al., 2011). Among the extensive list of drought indices reported, the palmer drought severity index (PDSI, Palmer, 1965), the standardized runoff index (SRI, Shukla and Wood, 2008), and the standardized precipitation index (SPI, McKee, 1993) are the most widely used indices. Yirdaw et al. (2008) initially introduced the total storage deficit index (TSDI) which has been used by Cao et al. (2015), Nie et al. (2018) and Chen et al. (2018) for drought characterization.

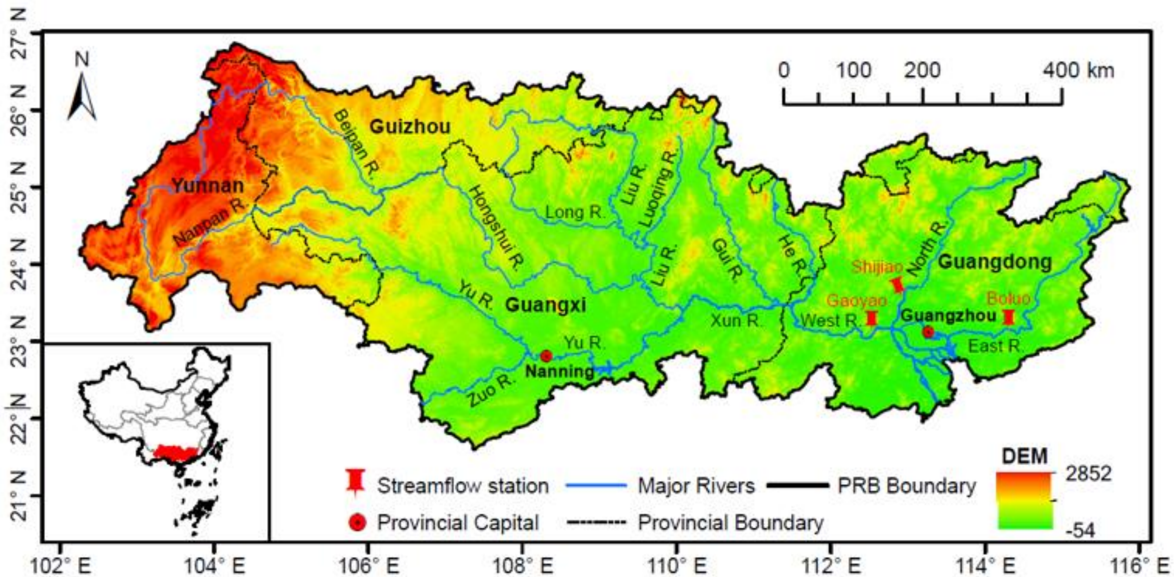
Thomas et al. (2014) presented a GRACE-based water storage deficit (WSD) approach;
Sinha et al. (2017) developed Thomas's method into water storage deficit index (WSDI);
Yi and Wen (2016) established a GRACE-based hydrological drought index (GHDI) ;
Zhao et al. (2017) designed a novel satellite-based drought severity index (DSI);
Hosseini-Moghari et al. (2019) introduced a modified total storage deficit index (MTSDI);
Sinha et al. (2019) proposed a novel combined climatologic deviation index (CCDI);

Reager and Famiglietti (2009) designed a monthly global flood index, namely Reager's flood potential index (FPI). Long et al. (2014) examined the severe flood in 2008 in Yun-Gui Plateau, Southwest China using Reager's FPI. Molodtsova et al. (2016) evaluated the efficacy of the Reager's FPI for flood risk assessment over the continental USA. Sun et al. (2017) examined large floods in the Yangtze River Basin. Idowu and Zhou (2019) assessed the flood potential in Lower Niger River Basin in Nigeria.

1. Introduction (literature review on teleconnection)

Phillips et al. (2012) and Ni et al. (2018) investigated the connection between TWS and ENSO at global scale. Forootan et al. (2019) explored the global hydrological drought and connection to ENSO, IOD and North Atlantic Oscillation (NAO). Awange et al. (2014) analyzed TWSA and assessed the influence of anthropogenic activities as well as climate variability (ENSO and IOD) in the Nile Basin. Zhang et al. (2015) used GRACE-based TWSA to study the 2006 summer drought and 2011 spring drought in the Yangtze River Basin of China and find the connection between drought and ENSO. Ndehedehe et al. (2017) examined the association of three global climate teleconnections—ENSO, IOD, and Atlantic Multi-decadal Oscillation (AMO) with TWS over West Africa.

1. Introduction (Motivation and research objectives)



The Pearl River basin (PRB) in South China is the second largest river in terms of average annual runoff among the seven major rivers in China.

Motivation:

Droughts and floods occur frequently in PRB because of the high spatio-temporal variation of precipitation/runoff (Cui et al., 2007; Niu, 2010). Previous study (e.g. Luo et al., 2016) has analyzed the TWS changes (TWSC) in PRB. However, no study focused on the drought and flood in this basin based on GRACE data.

Research Objectives:

Monitoring and characterization of drought and flood using WSDI and FPI based on GRACE data in PRB.

The teleconnection between water storage anomalies and climate indices will be investigated.

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2. Data and Methods

Data used in this study

Variable	Data name	Spatial resolution	Temporal resolution	Time span	Source
TWSA	CSR mascon, JPL mascon, GSFC mascon	0.5 degree, 0.5 degree, ~12 390km^2	monthly	Jan. 2003-Dec. 2014	http://www2.csr.utexas.edu/grace/; https://grace.jpl.nasa.gov/data/get-data/; https://earth.gsfc.nasa.gov/geo/
P	In situ observations	0.5 degree	monthly	Jan. 2003-Dec. 2014	http://www.nmic.cn/
ET	MODIS, GLEAM	0.5 degree, 0.25 degree	monthly	Jan. 2003-Dec. 2014	http://files.ntsg.umt.edu/data/MOD16_TP/; https://www.gleam.eu/
R	Streamflow gauge (Gaoyao and Shijiao stations)	Point	monthly	Jan. 2003-Dec. 2014	19870056@hhu.edu.cn (Yuanfang Chen)
ScPDSI	ScPDSI	0.5 degree	monthly	Jan. 2003-Dec. 2014	https://crudata.uea.ac.uk/cru/data/drought/
Climate indices	ENSO, IOD, NAO, PDO	-	monthly	Jan. 2003-Dec. 2014	https://www.cpc.ncep.noaa.gov/; https://www.esrl.noaa.gov/

2. Data and Methods

2.1 Validation of GRACE-derived total water storage change (TWSC)

（1） Water balance-based TWSC

$dS/dt = P + R_{in} - R_{out} - ET$

（2） GRACE-derived TWSC

$$\frac{\mathrm{dS}}{\mathrm{dt}} = \frac{TWSA(t) - TWSA(t-1)}{t}$$

2.2 GRACE-based water storage deficit index (WSDI)

$$WSD_{i,j} = TWSA_{i,j} - \overline{TWSA}_j$$

$TWSA_{i,j}$ is the GRACE-derived TWSA time series for the *j*th month in year *i*.
$\overline{TWSA}_j$ is the climatology of TWSA

$$WSDI = \frac{WSD - \mu}{\sigma}$$

μ and σ are the mean and standard deviation of the WSD time series, respectively.

$$S(t) = \bar{M}(t) \cdot D(t)$$

$\bar{M}$ is the average deficit since the onset of the deficit period; D is the duration of a drought event, and t denotes the number of drought events. *S* is total event severity. S, $\bar{M}$ and D are determined after the termination of the drought event.

2. Data and Methods

2.3 GRACE-based flood potential index

$S_{DEF}(t) = S_{MAX} – S(t-1)$

S_{MAX} is the maximum value of GRACE TWSA from 2003 to 2014, S(t-1) is the TWS of the previous month. S_{DEF} represents the highest allowable relative storage change.

$FPA(t) = P_{MON}(t) - S_{DEF}(t)$

P_{MON} is monthly precipitation, S_{DEF} is storage deficit and FPA is flood potential amount

$$\mathrm{FPI(t)} = \frac{FPA(t)}{\max[FPA(t)]}$$

The FPI value cannot be larger than 1. The closer it is toward 1, the more likely a flood is to occur.

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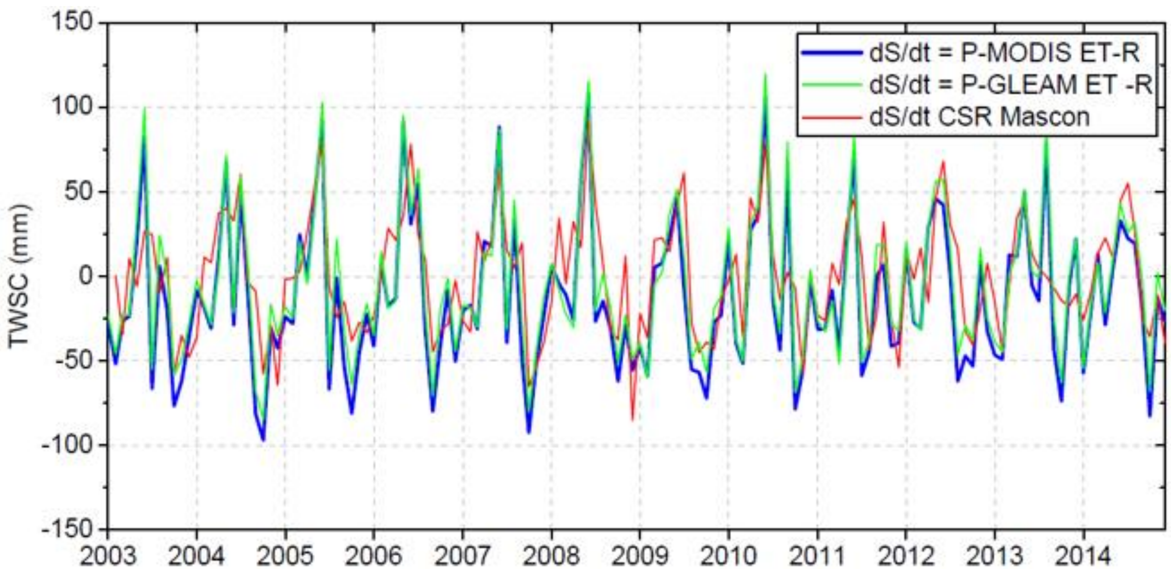
3. Results and Discussion

3.1 Validation of GRACE total water storage change

	dS/dt=P-MODIS ET-R	dS/dt=P-GLEAM ET-R
dS/dt CSR mascon	r = 0.70, RMSE = 33.6 mm	r = 0.68, RMSE = 32.1 mm
dS/dt JPL mascon	r = 0.64, RMSE = 37.9 mm	r = 0.63, RMSE = 36.3 mm
dS/dt GSFC mascon	r = 0.68, RMSE = 34.9 mm	r = 0.66, RMSE = 33.2 mm

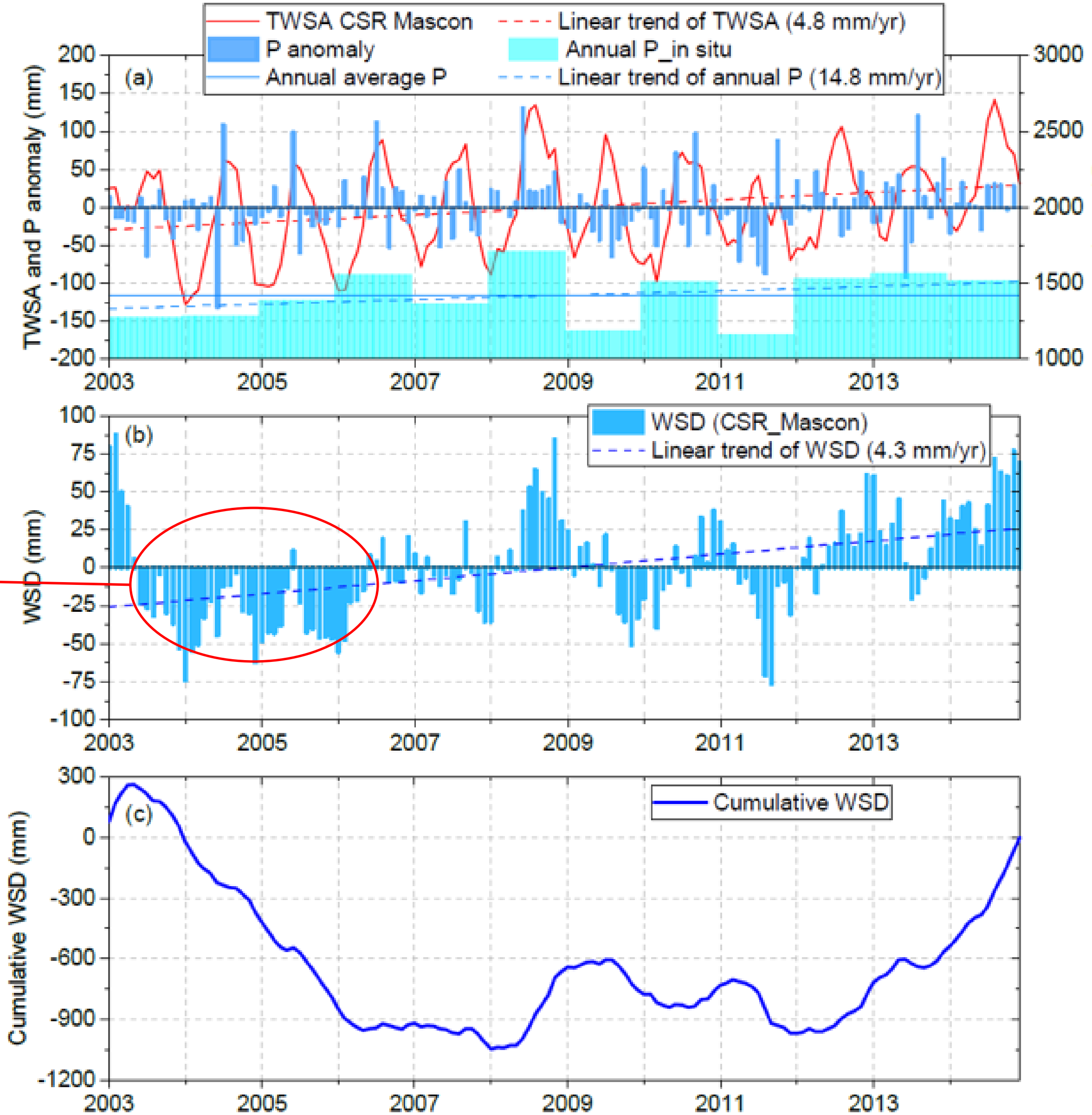


3. Results and Discussion

3.2 Characterization of drought

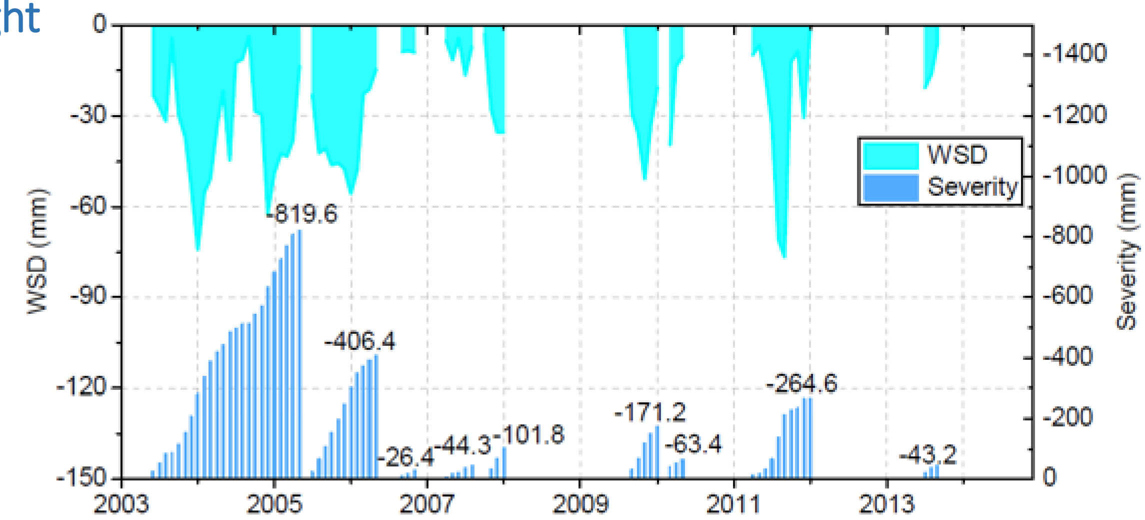
The increase trend of TWS and WSD is related to the increase trend of rainfall.

WSD during Jun. 2003-May 2006 (except Jun 2005). A total of 38 months.



3. Results and Discussion

3.2 Characterization of drought

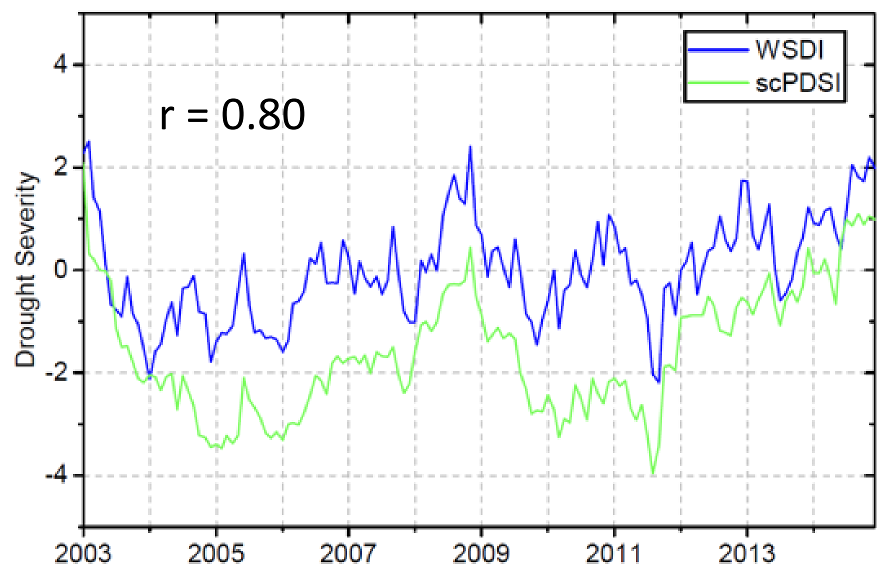


No.	Time Period	Duration (no. of months)	Average deficit (mm)	Peak deficit (mm)	Peak deficit date	Total severity (mm)
1	2003.6-2005.5	24.00	-34.15	-74.28	2004.1	-819.6
2	2005.7-2006.5	11.00	-36.95	-55.62	2006.1	-406.4
3	2006.9-2006.11	3.00	-8.79	-9.09	2006.11	-26.4
4	2007.4-2007.8	5.00	-8.85	-16.63	2007.7	-44.3
5	2007.10-2008.1	4.00	-25.44	-35.45	2007.12	-101.8
6	2009.8-2010.1	6.00	-28.54	-50.86	2009.11	-171.2
7	2010.3-2010.5	3.00	-21.14	-39.58	2010.3	-63.4
8	2011.4-2012.1	10.00	-26.46	-76.69	2011.9	-264.6
9	2013.7-2013.9	3.00	-14.39	-20.83	2013.7	-43.2

3. Results and Discussion

3.2 Characterization of drought

Good consistence in timing and obvious difference on the magnitude. WSDI value was higher than the scPDSI throughout the study period.

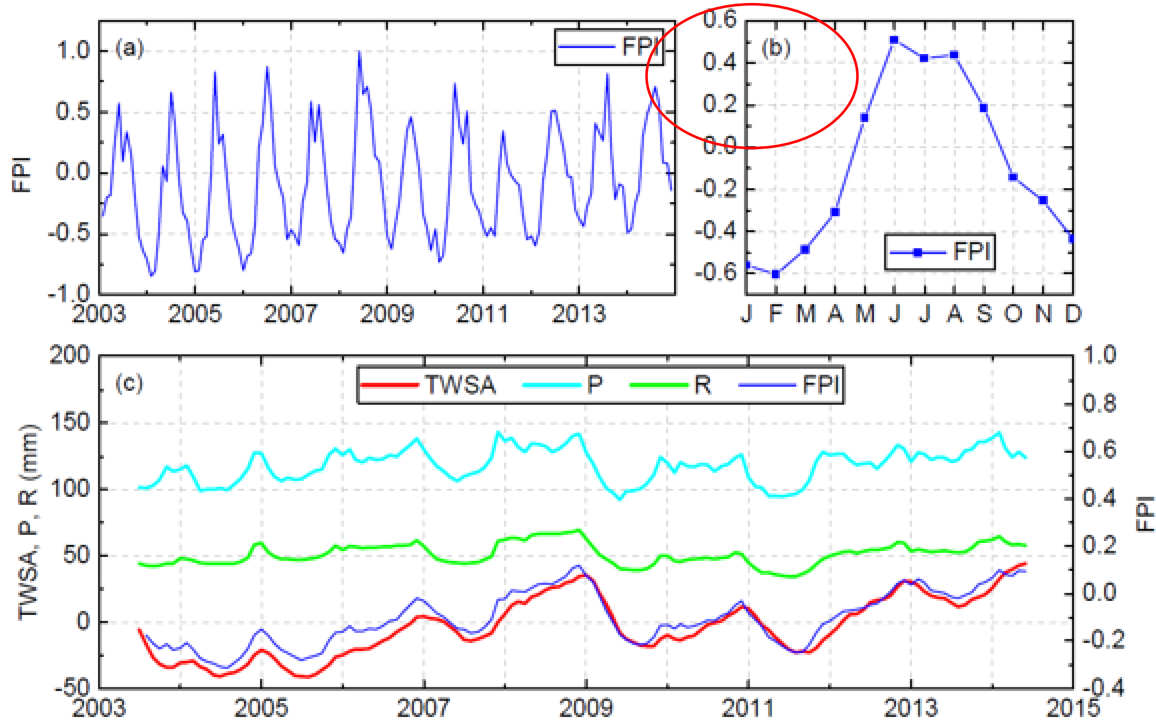


Category	Drought condition	scPDSI	WSDI
D0	No drought	-1.0 < P	0 < W
D1	Mild drought	-2.0 < P ≤ -1.0	-1.0 < W ≤ 0
D2	Moderate drought	-3.0 < P ≤ -2.0	-2.0 < W ≤ -1.0
D3	Severe drought	-4.0 < P ≤ -3.0	-3.0 < W ≤ -2.0
D4	Extreme drought	P ≤ -4.0	W ≤ -3.0

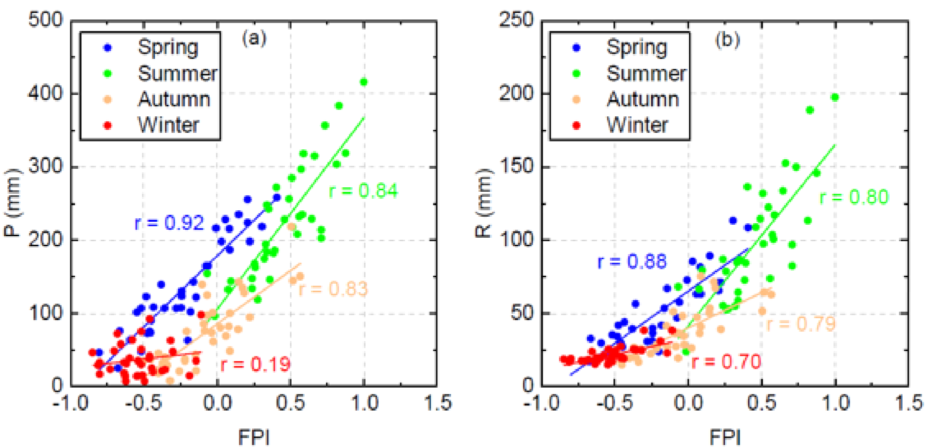
No.	Time Period	WSDI	scPDSI	Combined category
1	2003.6-2005.5	-2.13 (D3)	-3.47 (D3)	(D3)
2	2005.7-2006.5	-1.59 (D2)	-3.31 (D3)	(D2/D3)
3	2006.9-2006.11	-0.26 (D1)	-2.42 (D2)	(D1/D2)
4	2007.4-2007.8	-0.48 (D1)	-2.01 (D2)	(D1/D2)
5	2007.10-2008.1	-1.01 (D2)	-2.39 (D2)	(D2)
6	2009.8-2010.1	-1.46 (D2)	-2.80 (D2)	(D2)
7	2010.3-2010.5	-1.13 (D2)	-3.26 (D3)	(D2/D3)
8	2011.4-2012.1	-2.19 (D3)	-3.96 (D3)	(D3)
9	2013.7-2013.9	-0.60 (D1)	-1.08 (D1)	(D1)

3. Results and Discussion

3.3 Characterization of flood



FPI and GRACE TWS exhibit the same inter-annual variability and trend with the same peaks and troughs.

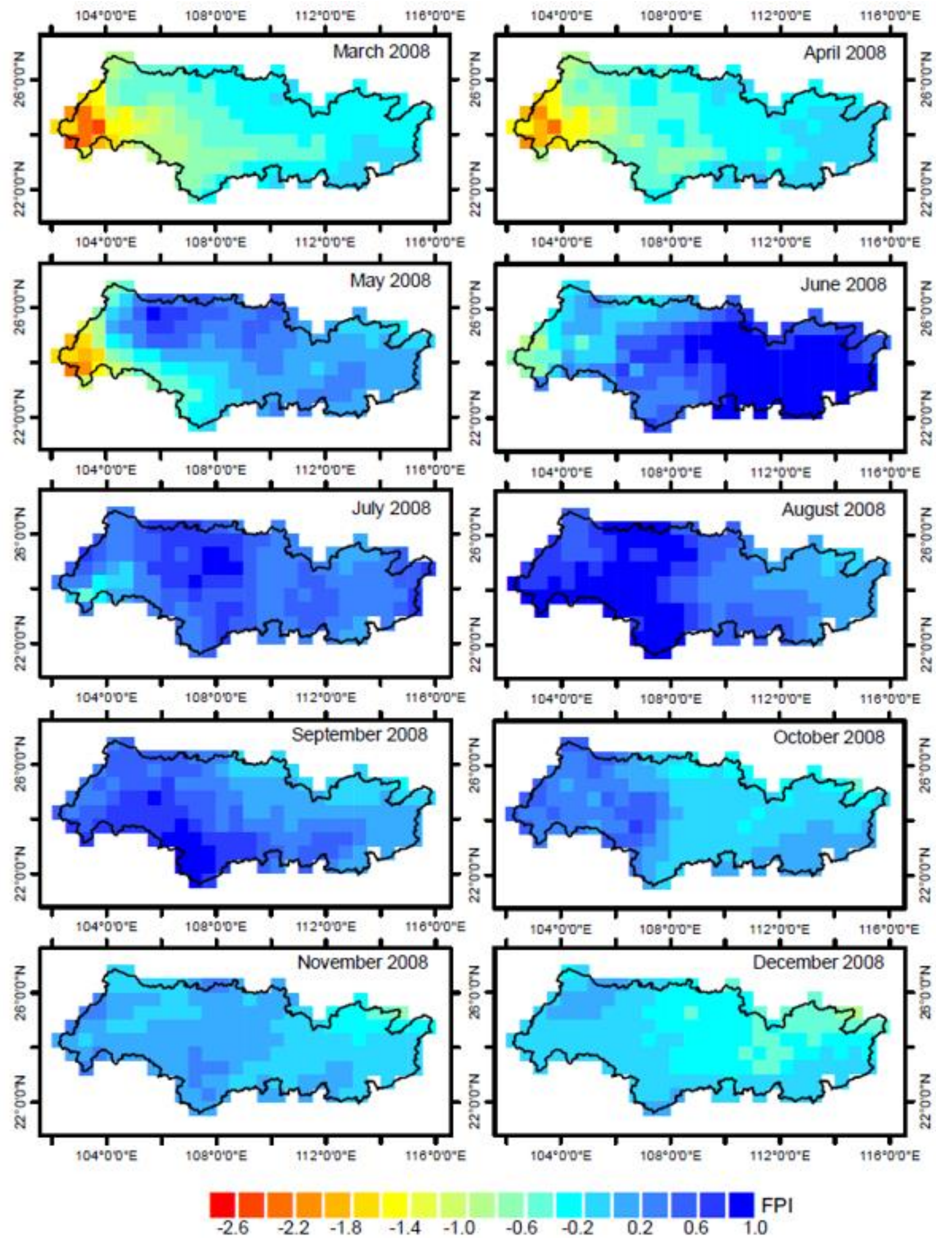


High correlation (r ≥ 0.7) between FPI and rainfall/discharge can also be found in all the four seasons except for winter rainfall. Results indicate that the flood in PRB is controlled by both rainfall and discharge.

3. Results and Discussion

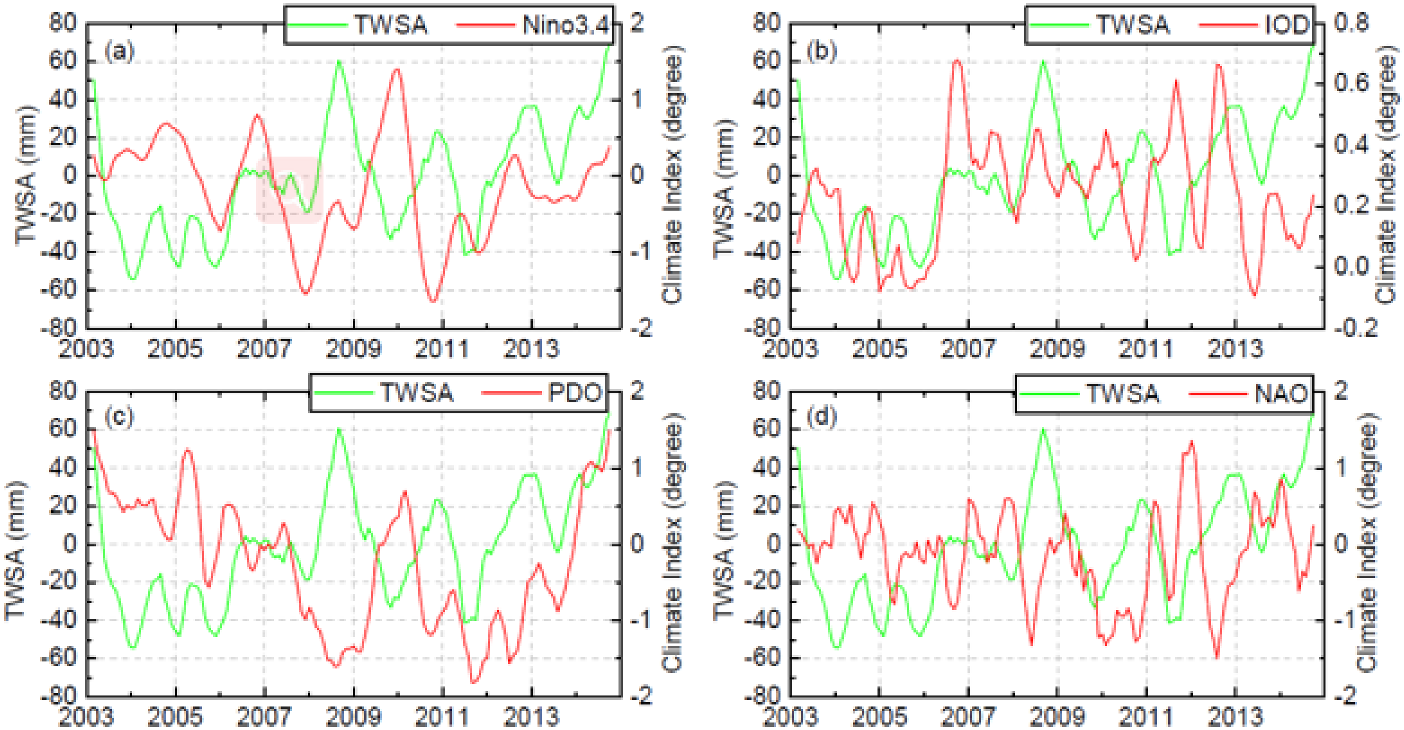
3.3 Characterization of flood

In March and April, the entire PRB was at a relatively dry status with low FPI, especially for the upper stream of the western PRB where the minimum FPI reached -2.52 in March. In May, the western PRB was still dry, but the northern PRB became wet with the highest FPI of 0.87. In June, except for the relatively drier western PRB, most of the PRB was in a flood status. In July and August, the flood spread to the entire PRB. The severity of the flood started to alleviate in the eastern PRB in September, and only the western PRB had relatively higher FPI in October. The entire PRB returned to the dry status in November and December again.



3. Results and Discussion

3.4 Drought and flood in response to climate variability



Drought 2008 flood Drought 2011 Drought

Indices	2003-2014	2003-2005	2006-2008	2009-2010	2011-2014
Nino3.4	-0.18*	-0.01	0.13	-0.87**	0.67**
IOD	0.18*	0.18	0.42**	-0.65**	-0.33*
NAO	-0.15	-0.13	-0.4*	0.26	-0.19
PDO	-0.18*	0.59**	-0.74**	-0.88**	0.76**

*denotes a two-sided 5% level significance (i.e. $p<0.05$). ** denotes a two-sided 1% level significance (i.e. $p<0.01$)

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4. Summary

1. Despite the increase of annual rainfall, a toal of nine drought events were identified in the PRB. The period June 2003-May 2006 (excluding June 2005) exprienced the most severe deficit with the drought duration of 35 months and the total water storage deficit (or severity) of over 1200 mm. In addition, a moderate drought occurred during August 2009-January 2010 (duration: 6 months, severity: -171.2 mm) and a severe drought occurred during April 2011 to January 2012 (duration: 10 months, severity: -264.6 mm).

2. WSDI is comparable to scPDSI in timing with a correlation of 0.80. Although the WSDI has higher magnitude than the scPDSI throughout the study period, for five out of nine droughts, the WSDI and scPDSI show the same drought severity, and for the other four drought events, the drought severity of scPDSI is higher than WSDI by one level.

3. The FPI in the PRB represents a seasonal cycle with flood occurs from late spring (May) to early Autumn (September). During the most severe flood event in 2008 (peak FPI with the largest rainfall and discharge), the entire basin was at a relatively dry status in March and April, but the flood spread to the entire basin in July and August. A strong correlation is found between FPI and rainfall/discharge in all four seasons (except for winter rainfall), indicating the overall control of flood by both rainfall and discharge.

4. The mechanism of flood and drought in the PRB from the perspective of climate varibility is complex. Different drought events were related to different climate indices in the PRB during 2003-2014. The severe drought during 2003-2005 was induced by a warm PDO phase. The 2009-2010 drought was jointly influenced by the warm phase of the three indices: ENSO (i.e. El Niño), IOD and PDO. The severe drought in 2011 was related to the cool phase of both PDO and ENSO (i.e. La Nina). The flood in 2008 was mainly induced by the cool PDO phase with the combined effect from IOD and NAO. PDO is the key index that influences drought and flood in the PRB.

Thank you!
Comments are welcome!