Seasonal water storage on the Amazon floodplain: a comparison between satellite measurement and model simulation

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Dai YAMAZAKI[1,2*], Doug ALSDORF[1], Shin-Chan HAN[3], Taikan OKI[2]

[1]Byrd Polar Research Center, the Ohio State University, USA
[2]Institute of Industrial Science, the University of Tokyo, Japan
[3]Goddard Space Flight Center, NASA, USA
(*Correspondence to Dai YAMAZAKI: yamadai@rainbow.iis.u-tokyo.ac.jp)

(1) INTRODUCTION

The amount of water exchanged between river channels and floodplains in the Amazon is not fully known, but it is important for understanding the flows of carbon, sediments, and nutrients in the Amazon River. We estimated the amount of water stored and moving through the Amazon floodplain from satellite observations [Alsdorf et al., 2010] and hydrodynamic model simulation [Yamazaki et al., 2010].

Seasonal water storage in six regions along the Amazon mainstem was analyzed. Surface water storage in each domain was divided into river channel storage and floodplain storage, and the amount of water exchanged between them was calculated.

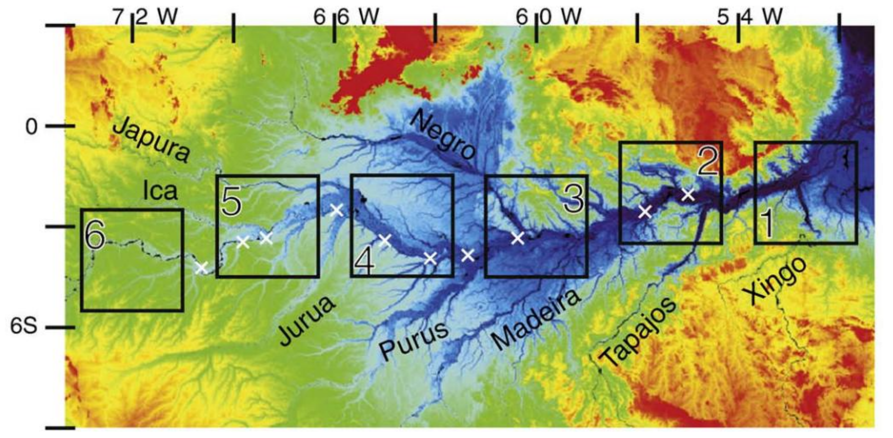


Fig. 1. Locations of six 330 km × 330 km study regions in the Amazon Basin. Colors indicate topography from the Shuttle Radar Topography Mission.

(2) SATELLITE OBSERVATION

Water storage change in floodplains ΔSf was estimated from GRACE terrestrial water storage ΔS [Han et al., 2008], ground water storage ΔSg approximated by P-ET anomaly, river channel storage ΔSr calculated from river open water area Ar [Hess et al., 2003] and water level from in-situ gauge Δh.

$$\Delta S = \Delta Sg + \Delta Sr + \Delta Sf$$

Total / Groundwater / River / Floodplain

ΔS : GRACE TWS

$$\Delta Sg = \left(P(t) - \overline{P}\right)\frac{\overline{P} - \overline{E}}{\overline{P}}$$

$$\Delta Sr = Ar \times \Delta h$$

$$\Delta Sf = \Delta S - \Delta Sg - \Delta Sr$$

The amount of water exchanged between river channels and floodplains, Qf, are estimated by the water balance in floodplain storage ΔSf. Runoff from uplands to floodplains Rup are approximated by P-ET anomaly from GPCP weighted by contribution area Af.

$$\Delta Sf = Rup + Qf$$

Floodplain storage change / Upland Runoff / Flux from river

$$Rup = Af\left(P(t) - \overline{P}\right)\frac{\overline{P} - \overline{E}}{\overline{P}}$$

$$Qf = \Delta Sf - Rup$$

Study area includes upland Aup (never inundated), floodplains Af (seasonally inundated), and river/lake Ar (always with open water). The classification from Global Rain Forest Mapping (GRFM) project using JRES-1 SAR mosaic [Hess et al., 2003] was used in this study.

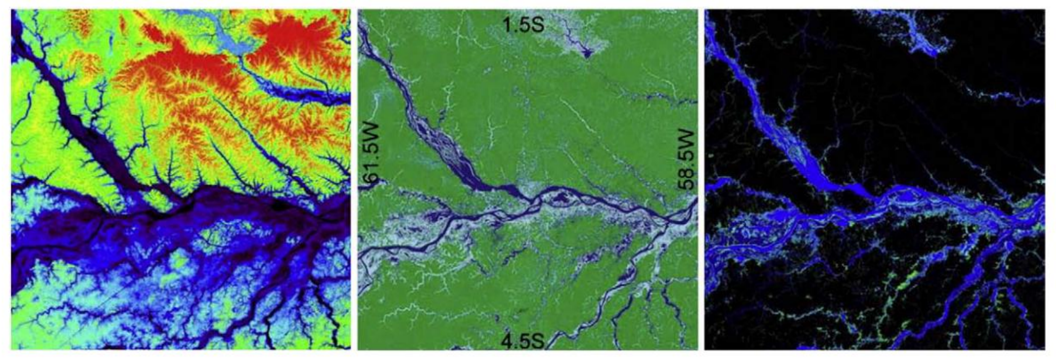


Fig. 2. The SRTM DEM (left), GRFM (middle), and classification (right) for region 3.
The GRFM image combines low and high water L-band JERS-1 SAR mosaics from GRFM to show upland areas (green), seasonally inundated areas (light blue), and continuously flooded and channels (dark blue). The classification delineates wetland areas of open water, bare soil, aquatic macrophyte, non flooded shrub, flooded shrub, flooded woodland, non flooded forest, and flooded forest [Hess et al., 2003].

(4) RESULTS

[4-1] MODEL VALIDATION Flooded area, P-ET balance, floodplain water depth, river stage range, and annual discharge are compared between satellite and model. Seasonal change in flooded area and water level is reproduced by the model. Stage range is underestimated by the model.

Table.2 Hydrologic and geomorphic statistics for each study region.

	Region 6		Region 5		Region 4		Region 3		Region 2		Region 1	
	Satellite	Model	Satellite	Model	Satellite	Model	Satellite	Model	Satellite	Model	Satellite	Model
HWA (km2)	9500	10700	25000	14100	23900	16700	21300	30200	20900	27100	30100	19700
LWA (km2)	3900	3100	6000	4300	7300	6200	7800	10500	7800	16100	16100	4900
Annual P (m/yr)	3.06	–	2.86	–	2.53	–	2.43	–	2.43	–	2.44	–
Annual ET (m/yr)	1.32	–	1.32	–	1.32	–	1.32	–	1.32	–	1.32	–
Annual R (m/yr)	1.74	2.45	1.54	1.73	1.21	1.63	0.49	1.24	0.49	1.21	0.49	1.00
HWZ (m)	3.30	3.67	2.13	3.47	3.23	3.95	3.62	5.29	2.56	6.31	1.53	3.90
LWZ (m)	0.47	1.65	0.35	1.44	0.16	1.97	0.37	1.73	0.29	2.10	0.28	0.62
StgRng (m)	11.30	11.70	10.60	10.89	10.20	12.96	9.19	11.09	6.94	6.40	4.86	0.44
AveQ (m3/s)	38000	33600	57500	55600	95000	87700	155000	179000	165000	213000	190000	236000

HWA and LWA are the high water and low water areas, these include all channels. HWZ and LWZ are the estimated high and low floodplain depths, these do not include channels. StgRng is the range in low-to-high water stage heights on the mainstem Amazon River. Avg. Q is the annually averaged mainstem discharge in the middle of each study region.

[4-2] STORAGE VARIATION Both satellite and model suggest the amplitude of channel storage variation is very small. Water storage in floodplains controls total water storage in the Amazon. The model overestimates water storage variation in Region 2-3 where flooded area is also overestimated.

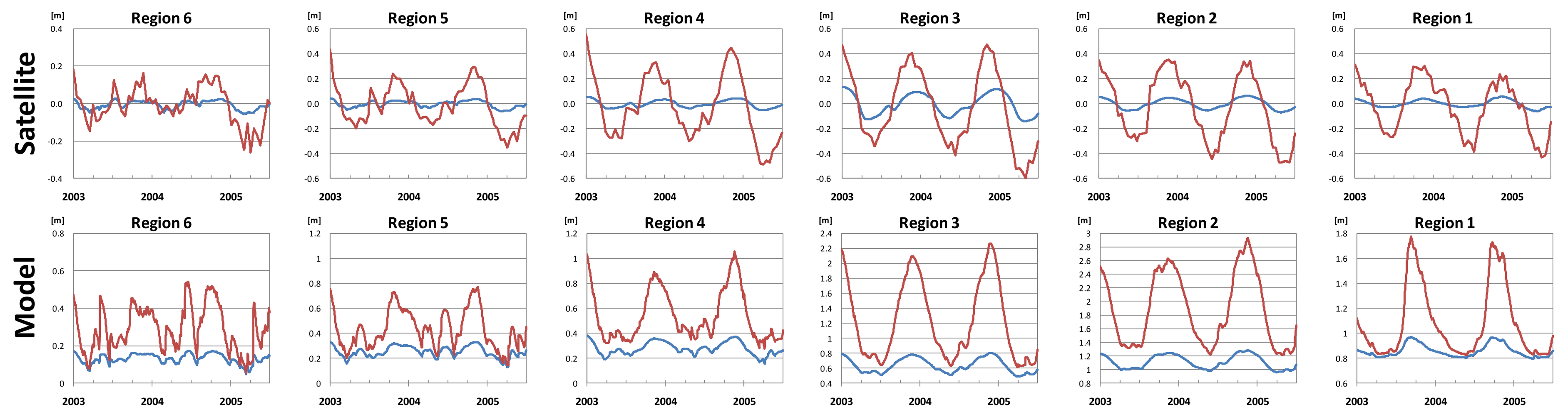


Fig.9 Total water storage variation (red) and channel storage variation (blue) for each region.
Storage anomaly is shown for satellite (top) while absolute value is shown for the model (bottom).

[4-3] FLOODPLAIN STORAGE COMPONENT In upstream regions (4-6), satellite and model shown similar trend that contribution from upland runoff is very small compared to the contribution from river channels. However in downstream regions (1-3), the model estimated that contribution from upland runoff and river channels are same, which is different from the satellite observation.

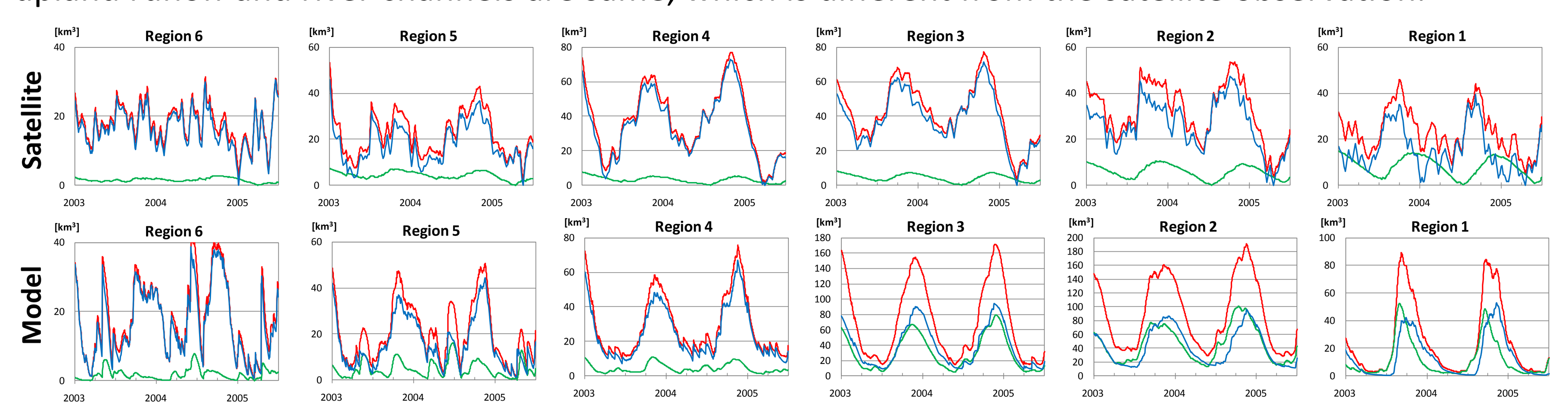


Fig.9 Floodplain storage (red) and its component: from upland runoff (green) and from river channel (blue) for each region.
Satellite observation is shifted to fit the minimum value to zero storage (top), while model estimation is the absolute value (bottom).

[4-4] WATER EXCHANGE BETWEEN CHANNELS & FLOODPLAINS Satellite and model agreed that floodplains are filled when water level in river channels is increasing, while floodplains are drained when water level is decreasing in river channels. The amount of exchanged water is estimated to be larger in the model than the satellite. Total exchanged water between river channels and floodplains (amount of water which enters to floodplains from river channels) was estimate to 285 km^3/yr (5% of annual discharge) while it was 770 km^3/yr (10% of annual discharge).

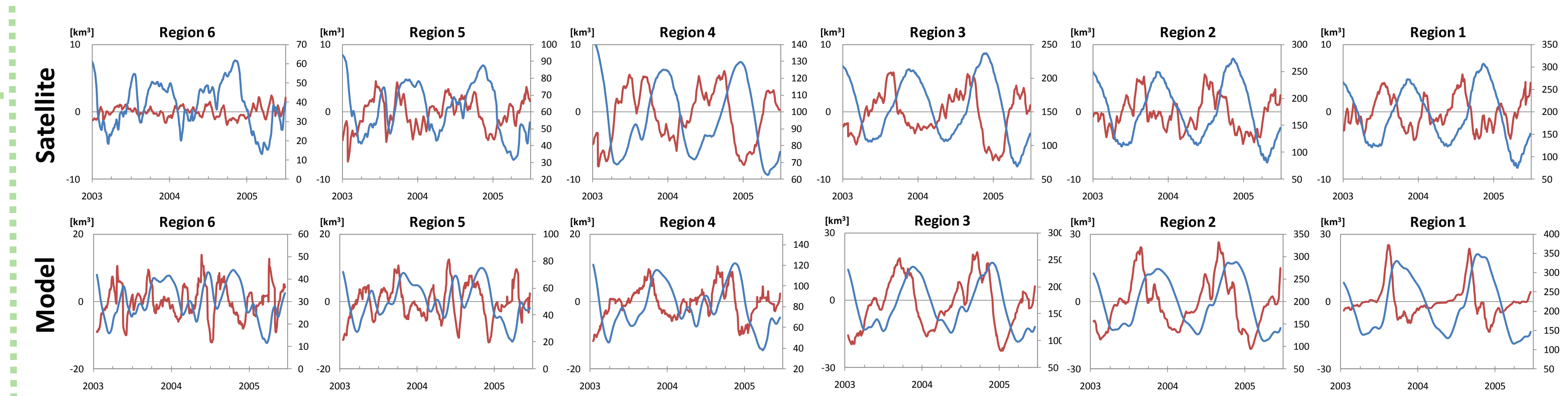


Fig.10 River discharge (blue) and water flux between channels and floodplains (red) in thousand cubic m/s.
Flux from river channels to floodplains are represented by plus flux.
Satellite observation is shifted to fit the minimum value to zero storage (top), while model estimation is the absolute value (bottom).

(3) RIVER-FLOODPLAIN MODEL

We used CaMa-Flood [Yamazaki, 2010], a distributed river routing model which is forced by LSM runoff and predicts water storage, water surface elevation, inundated area, and river discharge. Spatial resolution is set to 25 km.

Table.1 Parameters and variables

Parameter	Channel Elevation	Z
	Channel Length	L
	Channel Width	W
	Embankment Height	B
	Catchment Area	A
	Floodplain Elevation Profile	*f(Topography)*
Variables	River Storage	S_r
	Floodplain Storage	S_r
	River Water Depth	H_r
	Floodplain Depth	H_f
	Inundated Area	A_f

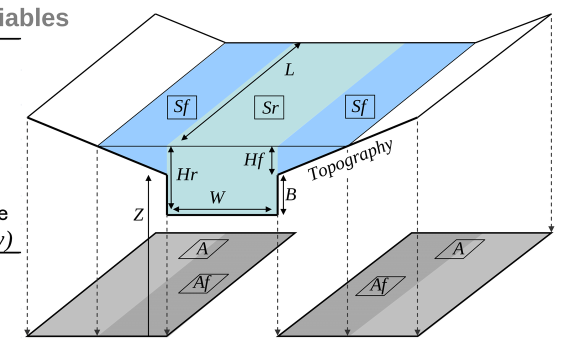


Fig.4 Reservoirs defined in each grid

[3-1] River channel and floodplain storages are defined as continuative reservoirs in each grid. Total water storage in each grid is divided into river channel and floodplain storage to balance water surface elevation of both reservoirs.

[3-2] River discharge (i.e. flux between grids) is calculated along with a prescribed river network map. Diffusive wave equation is adopted as the governing equation for representing backwater effect. Water storage in next time step is predicted by continuity equation using inflow from upstream, outflow to downstream, and forcing runoff from LSM.

$$\partial H / \partial x + i_0 - i_f = 0$$

Diffusive wave equation

$$S_i(t+\Delta t) = S_i(t) + \sum_j^{upstream} Q_j \Delta t - Q_i \Delta t + A_i R_i \Delta t$$

Continuity Equation

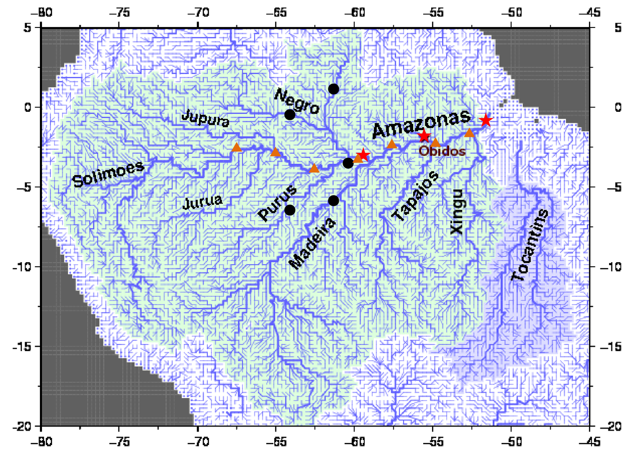
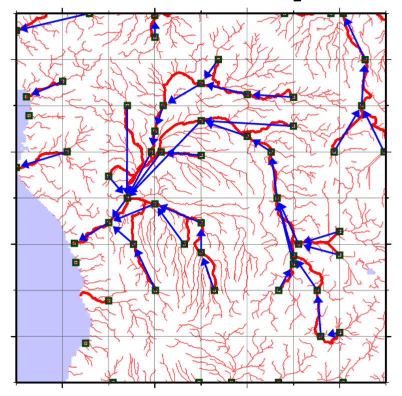
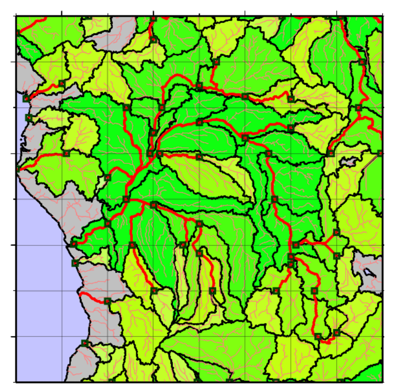


Fig.5 River Network Map for the Amazon

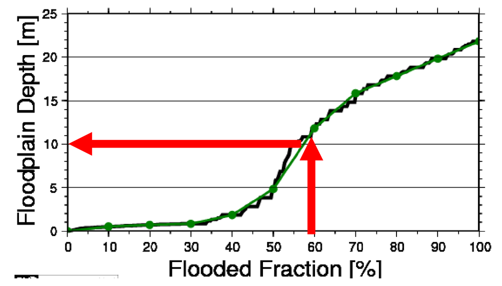
[3-3] The river network map and sub-grid topographic parameters are objectively extracted from the HydroSHEDS flow direction map and DEM at 90-m resolution using FLOW method [Yamazaki et al, 2009].



"Outlet pixel" is decided for each coarse-resolution cell. channel elevation (green), river network map (blue) are extracted from 90-m resolution flow direction map and DEM.



Channel length (red) is calculated for each cell considering meandering at 90-m scale. Unit-catchment (black tick boundaries) is decided for each coarse-resolution cell based on the flow direction map.



Elevations of the pixels within an unit-catchment is sorted to generate a floodplain elevation profile, which is used to objectively describe the relation among floodplain water storage, floodplain water depth, and inundated area.

[Ex] Water depth is 10m when 60% of the catchment area is inundated

Fig.6 Delineation of parameters from HydroSHEDS90-m flow direction map and DEM

Channel Width and Channel Embankment Height, which are not represented in 90-m fine-resolution dataset, are decided empirically.

Average Upstream Runoff $\overline{R}_{up}$

$$W = \max[10.0, 1.0 \times \overline{R}_{up}^{\,0.7}]$$

$$B = \max[1.0, 0.045 \times \overline{R}_{up}^{\,0.5}]$$

[3-4] Runoff from LSM is given to river channel storage when there is no flooding, while all of the runoff is given to floodplain storage during flooding. The amount of water moved from river channel to floodplain is defined as "flux from river to floodplain" Qf.

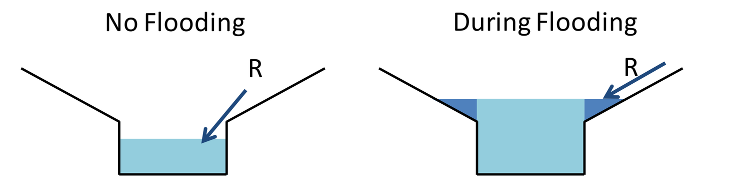


Fig.7 Input runoff from LSM

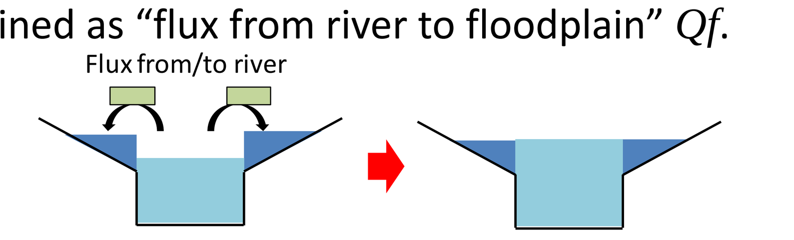


Fig.8 Definition of water flux from/to river

(5) SUMMARY

Seasonal water storage in the Amazon floodplains was estimated from satellite observations and model simulation. The satellite and model estimations agreed on seasonal variations of water storage, flooded area, and water level at a certain level, but the amount of water exchanged between channels and floodplains are estimated to be different. Further research considering detailed processes are required.

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