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Supporting Information for

**Development of Land and River Two-Way Coupling in Energy Exascale Earth System Model**

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**Test S1. Relationship between the inundation fraction and total volume**

After logarithmic transformation of the total channel volume, it exhibits linear relationship with the GIMES inundation fraction (Figure S1). This log-linear relationship can be used to represent the relationship between the total channel volume and floodplain inundation fraction at global scale, with correlation coefficients larger than 0.8 for wetter region (e.g., Amazon basin, south Asia), and correlation coefficients are around 0.5 for the North Hemisphere high latitude (Figure S2).

Chart, scatter chart

Description automatically generated

**Figure S1.** Relationship between simulated channel volume and GIEMS floodplain inundation fraction from 4 example grid cells. The blue dashed lines represent the linear regression lines.

Map

Description automatically generated

**Figure S2.** Validation of log-linear relationship between total volume and fractional inundation. The value of each grid cell shows the global distribution of correlation coefficient for the log of total volume from ELM\_MOSART\_LLR\_2way and GIEMS inundation fraction for the training period (1993 – 2002).The GIEMS inundation are zero or not available for the cells with white color during the whole training period, hence, there are no correlation coefficients.

Map

Description automatically generated

**Figure S3.** Calibrated bankful river depth with default inundation scheme in MOSART.

Chart

Description automatically generated

**Figure S4.** Seasonality of relative change of monthly streamflow ELM-MOSART-LLR-2way simulation and ELM-MOSART-LLR-1way simulation at 15 major basins. The red circles are the mean of the relative change, and the error bar represents two standard deviations. The relative change [%] are calculated as , where denotes the streamflow at the outlet of a basin.

**Chart, line chart

Description automatically generated**

**Figure S5.** Monthly spatial correlation at global scale between the two-way coupled simulated inundation and the GIEMS inundation for the validation period (2003-2007).

A map of the world

Description automatically generated with medium confidence

**Figure S6.** (a) Model biases of averaged inundation fraction from 2003 – 2004 between default inundation scheme forced by the forcing of *Qian et al.* (2006) using the calibrated geometry of *Mao et al.* (2019) and GIEMS inundation fraction. The insert shows the scatter comparison between GIEMS (X-axis) and simulation (Y-axis). Subplot (b) and (c) illustrate the comparison for the latitudinal and longitudinal averaged inundation fraction, respectively.

Map

Description automatically generated

**Figure S7.** Mean top layer soil moisture simulated from ELM-MOSART-LLR-1way.

Chart, line chart

Description automatically generated

**Figure S8.** Annual time series of total runoff, surface runoff changes, subsurface runoff changes, and total runoff changes between the ELM-MOSART-LLR-2way simulation (R2way) and the ELM-MOSART-LLR-1way simulation (R1way) averaged over the affected cells at (a) Mackenzie, (b) Mississippi, and (c) Amazon basin scale. Annual total runoff is from the ELM-MOSART-LLR-1way simulation.

Map

Description automatically generated with low confidence

**Figure S9.** Ratio between change of subsurface runoff and change of total runoff due to two-way coupling.

Diagram

Description automatically generated with low confidence

**Figure S10.** Impacts of land river two-way coupling on annual soil temperature at 10 cm. The changes are calculated as the absolute differences between 30-years mean of ELM-MOSART-LLR-2way simulation and ELM-MOSART-LLR-1way simulation.

**References**

Mao, Y., T. Zhou, L. R. Leung, T. K. Tesfa, H.-Y. Li, K. Wang, Z. Tan, and A. Getirana (2019), Flood Inundation Generation Mechanisms and Their Changes in 1953–2004 in Global Major River Basins, *Journal of Geophysical Research: Atmospheres*, *124*(22), 11672-11692.

Qian, T., A. Dai, K. E. Trenberth, and K. W. Oleson (2006), Simulation of global land surface conditions from 1948 to 2004. Part I: Forcing data and evaluations, *J Hydrometeorol*, *7*(5), 953-975.