A model tracer study tracking global riverine freshwater in the world ocean and atmosphere

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Introduction

- Although the water stored in rivers is small comparing to other global hydrologic reservoirs, river flux into the ocean plays important roles in the global hydrological cycle and ocean dynamics. The net water vapor transported in the atmosphere from ocean to land returns to the ocean as riverine freshwater (**Figure 1**).
- The main objective of the current study is to develop a water-tagging tracer module and to implement it in the ocean component of the CESM to analyze the role of rivers in the global ocean. Preliminary results of coupled tracer results between atmospheric component (CAM) and the ocean component (POP) of the CESM are discussed.

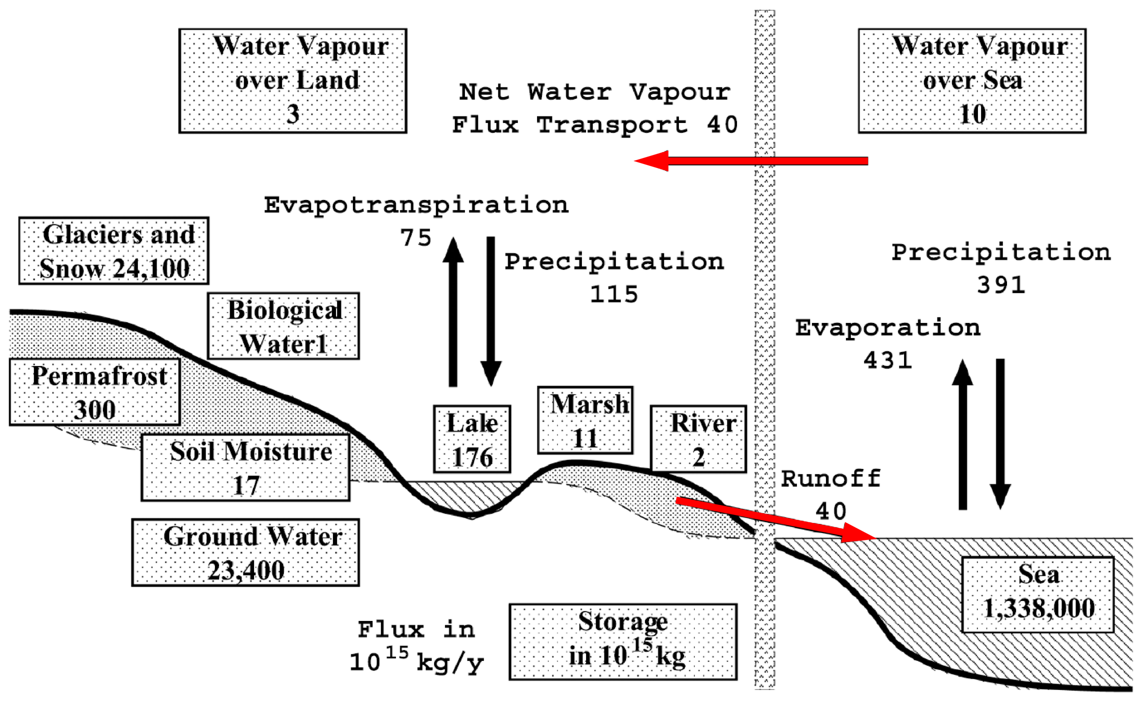

Figure 1 Schematic illustration of water cycle on the Earth for 1989-1992. The shaded boxes indicate the storage of water in different reservoirs and the arrows show the water fluxes. (Oki, Entekhabi & Harrold, 2004)

Methodology

- The tracer module in the POP applies the advection-diffusion equation (analogous to the equations for temperature and salinity) to evolving concentrations (C) of each tracer as in Eqn. 1

$$\frac{DC}{Dt} = \nabla(K\nabla C) + \frac{\partial}{\partial z}\left[\kappa\left(\frac{\partial C}{\partial z} - \gamma_C\right)\right] \quad \text{Eqn. 1}$$

- The surface boundary conditions are set by Eqn. 2

$$\kappa\frac{\partial C}{\partial z}\Big|_{z=0} = F_C \quad \text{and} \quad \kappa\gamma_C|_{z=0} = 0 \quad \text{Eqn. 2}$$

where F_C is the tracer flux forcing at the sea-surface and the surface counter gradient flux $\kappa\gamma_C$ is zero.

- Separate water tracers are evolved to tag freshwater from different sources, i.e. rivers (C^R), precipitation (C^P), sea-ice meltwater (C^M), as well as the water initially in the ocean (C^{ini}) at the start of the tracer analysis model run. The corresponding surface flux forcing for each tracer are F^R, F^P, F^M, and F^{ini}.

$$F^R = q^R C_0 + W^R(q^E + q^I) \quad \text{with} \quad W^R = C^R/C^{tot} \quad \text{Eqn. 3.1}$$
$$F^P = q^P C_0 + W^P(q^E + q^I) \quad \text{with} \quad W^P = C^P/C^{tot} \quad \text{Eqn. 3.2}$$
$$F^M = q^M C_0 + W^M(q^E + q^I) \quad \text{with} \quad W^M = C^M/C^{tot} \quad \text{Eqn. 3.3}$$
$$F^{ini} = W^{ini}(q^E + q^I) \quad \text{with} \quad W^{ini} = C^{ini}/C^{tot} \quad \text{Eqn. 3.4}$$

q^* indicates the volume fluxes from different sources (R, P and M) or sinks (E: evaporation and I: sea-ice formation), C_0 is the source tracer concentration ($C_0 = 1$), and W* is a weighting function to calculate the local ratio of the tagged water.

- C^{ini} is initialized at $C_0 = 1$ throughout the ocean. This tracer only has a surface sink (Eqn. 3.4), so its concentrations decrease over time as initial water continues to be removed by evaporation and sea-ice formation. The other tracers are initialized as uniformly zero in global ocean and have both sinks and sources (Eqn. 3.1 to Eqn. 3.3). If evolved long enough (for many thousand years), no initial ocean water tracer would remain, and the entire ocean would be composed of a mixture of water from rivers, precipitation, and sea-ice melt.
- The experiments starts from the end of a 300-year spin-up with ocean and sea-ice coupled setup (G case) and continues for another 600 years with tracer module implemented. Results averaged over the last 30 years (571 to 600 model year) are analyzed and shown in the middle section of this poster .

Results

1. Riverine water tracer distributions at the ocean surface

River tracers are divided into three subgroups: the Amazon River (**Figure 2**), the TOP 2-20 rivers ranked by the mean annual runoffs (**Figure 3**), and the remaining rivers (**Figure 4**).

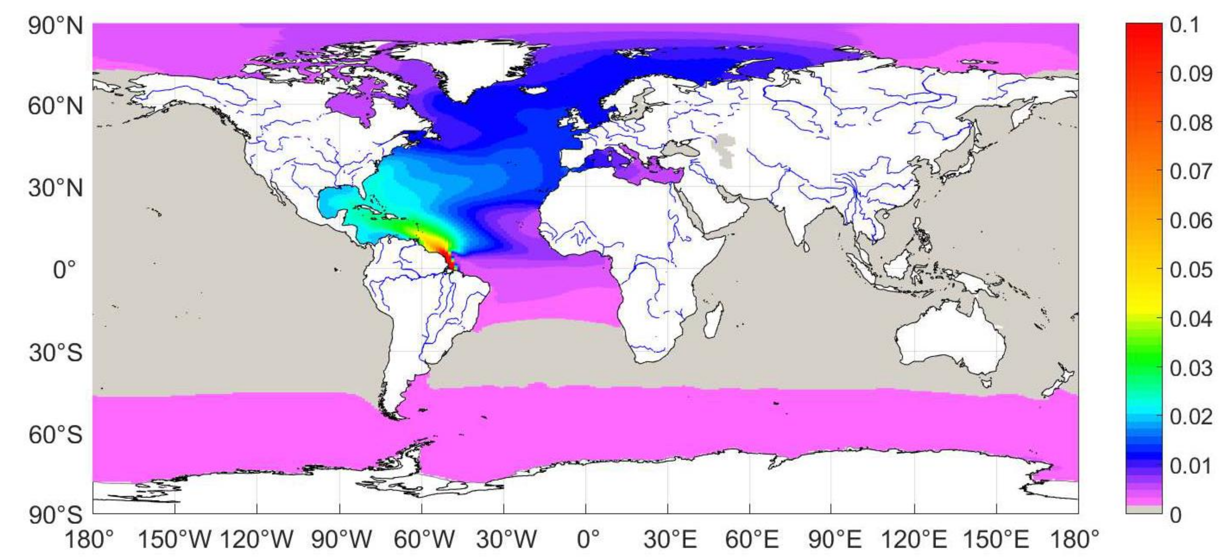

Figure 2 Amazon River water tracer concentration (kg/kg)

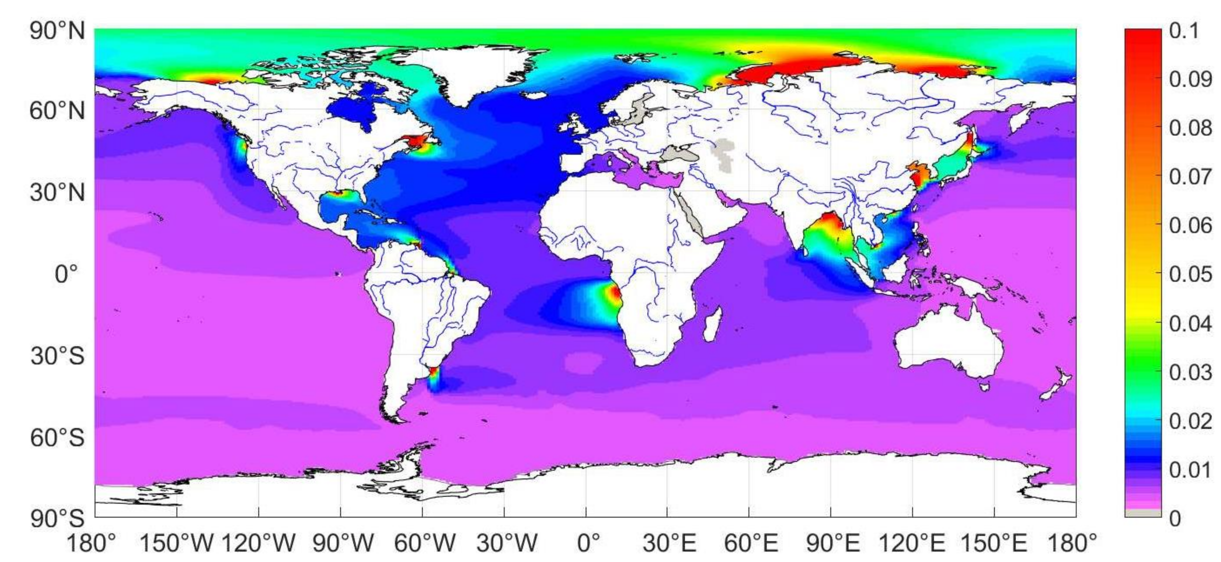

Figure 3 Top 2-20 rivers water tracer concentration (kg/kg)

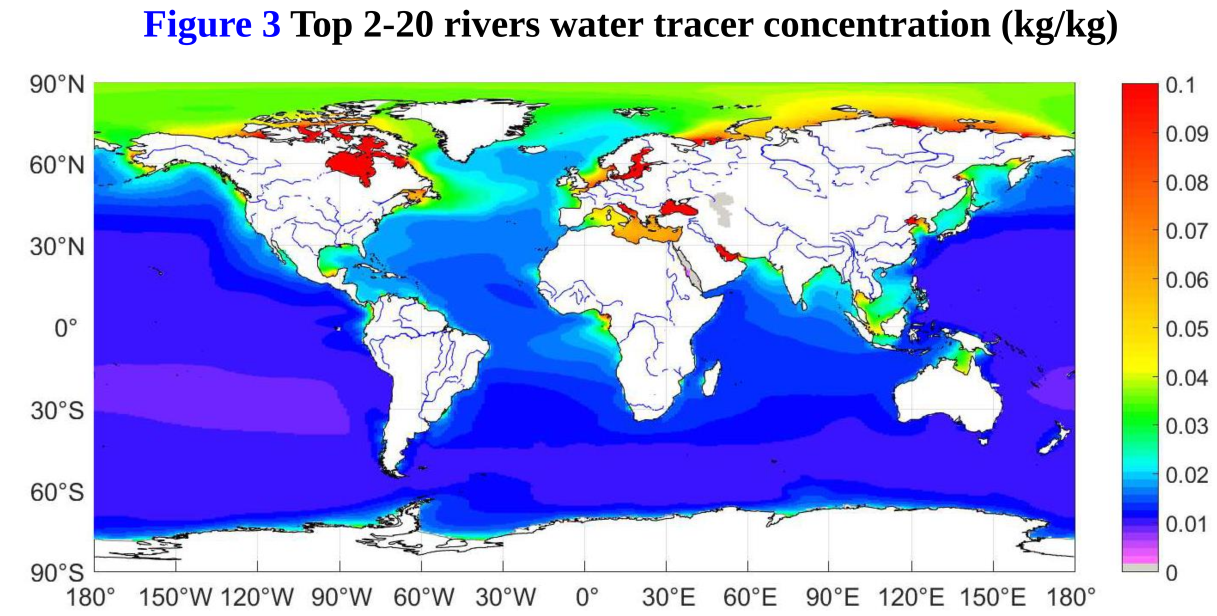

Figure 4 The rest of river water tracer concentration (kg/kg)

2. River water ratio at sea surface and in saline stratification

The contribution of all rivers in the total freshwater input at sea surface is revealed by local ratio of river trace concentration to the sum of river, precipitation and sea-ice meltwater tracer concentrations at sea surface (**Figure 5**), while the contributions of river water in saline stratifications are illustrated with vertical tracer concentration difference of rivers to that of the total freshwater in the upper ocean (**Figure 6**).

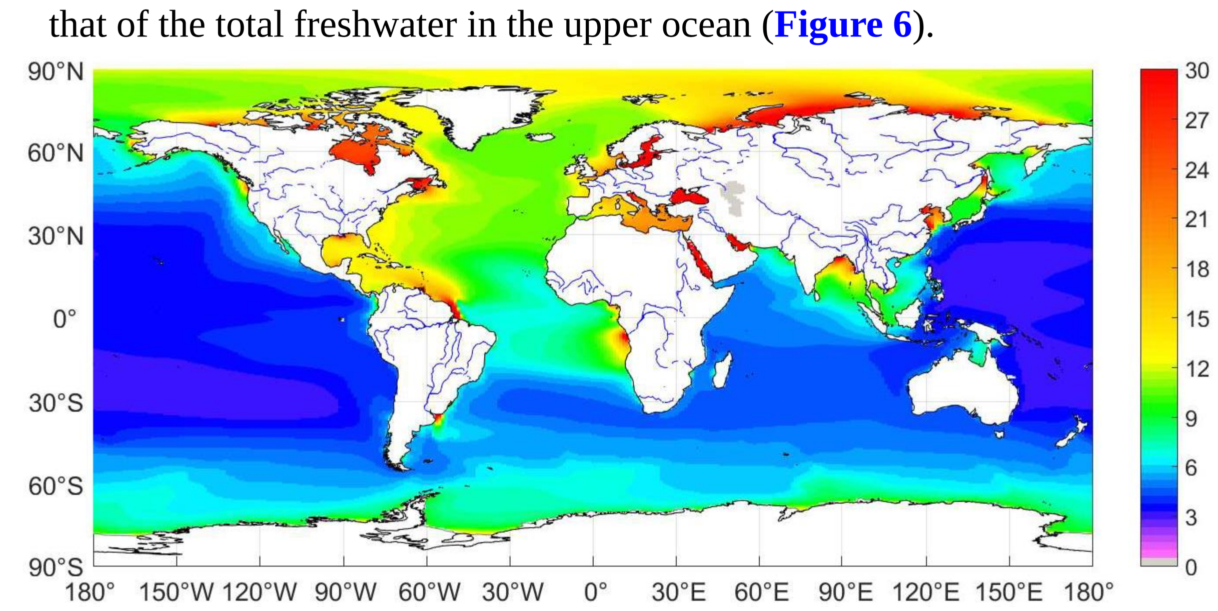

Figure 5 The river water (%) in total freshwater input into the ocean

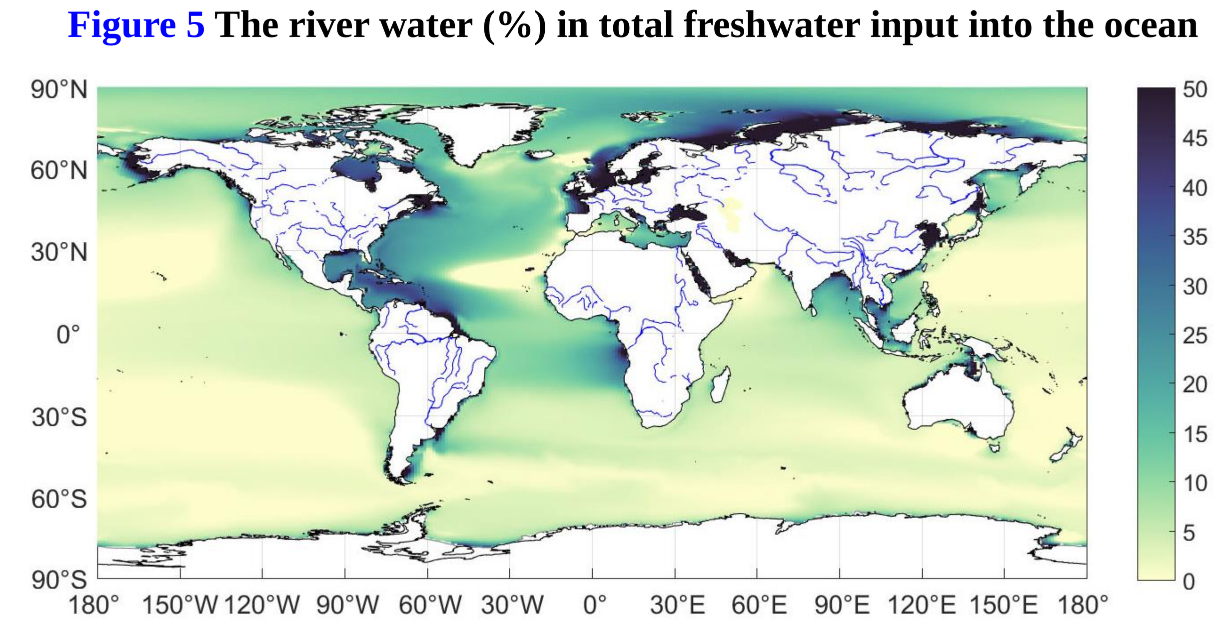

Figure 6 The percentage (%) of river water contribution in saline stratification for upper 409 m ocean

Preliminary Results

Evaporated river water in the atmosphere

- The mixing ratio (W^R in Eqn. 3.1) is passed to the coupler of the CESM, where the portion of river water in evaporation is calculated and is further tracked in the CAM. The river water is tracked in all phases (vapor, liquid and solid) in the atmosphere, and it leaves the atmosphere via precipitation.
- The experiment is conducted with fully coupled setup (B case) of the isotope-enables CESM. All water (river runoff, precipitation, glace runoff, sea-ice melt and initial water in the ocean) are tagged in the POP, while only the mixing ratio of river water is passed to the coupler and can be seen by the CAM. The experiment runs for 10 years, and annual mean fields of last model year are presented in **Figure 7**.

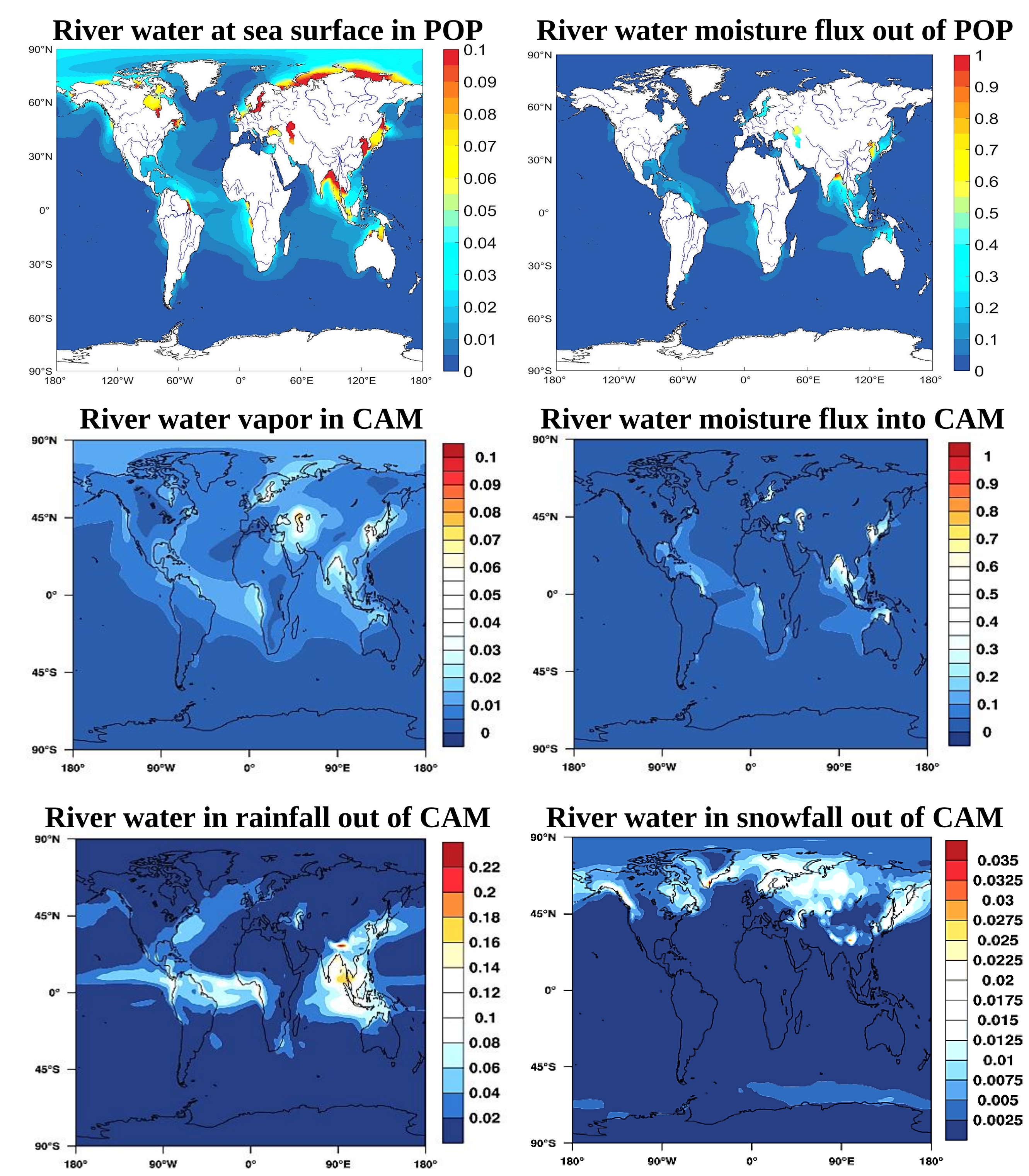

Figure 7 The water originated from land runoff is tracked in global ocean and atmosphere. The 10th model year annual mean fields are shown for river water (kg/kg) at the sea surface, moisture flux (mm/d) out of the ocean, river water vapor (kg/kg) at the bottom of atmosphere, moisture fluxes (mm/d) into the atmosphere, and river water in rainfall (mm/d) and in snowfall (mm/d) .

Conclusions

- A conservative Eulerian water-tagging tracer module is developed and implemented in the ocean component (POP) of the CESM.
- By focusing on the river water into the ocean, the Amazon River has footprint in NADW formation regions, which is then carried by AMOC in the ocean interiors and brought to sea surface again via upwelling in Southern Ocean. The Arctic and North Atlantic Oceans have overall higher river tracer concentrations than other oceans.
- The Arctic and North Atlantic Oceans are also characterized by higher ratio of river water to total freshwater input into the ocean from all sources. River waters contribute over half of the global coastal saline stratification and as much as 80% of the stratification close to river mouths and on the Eurasian Arctic continental shelf.
- The ability to track water in an atmosphere-ocean couple tracer module is demonstrated with current river water tracers.

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