Hydrologic implications of aerosol deposition on snow in High Mountain Asia rivers

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S1. Community Land Model forcing

Table S1. CLM5 Atmospheric focing

Types	Description	Units
MET	Total precipitation	mm s^{-1}
MET	incident longwave radiation	W m^{-2}
MET	incident shortwave radiation	W m^{-2}
MET	Temperature at lowest level	K
MET	Specific humidity at lowest level	kg kg^{-1}
MET	Surface pressure	Pa
MET	Wind speed at lowest level	m s^{-1}
LAP	Hydrophylic black carbon wet deposition flux	kg m^{-2} s^{-1}
LAP	Hydrophylic black carbon dry deposition flux	kg m^{-2} s^{-1}
LAP	Hydrophobic black carbon dry deposition flux	kg m^{-2} s^{-1}
LAP	Hydrophylic organic carbon wet deposition flux	kg m^{-2} s^{-1}
LAP	Hydrophylic organic carbon dry deposition flux	kg m^{-2} s^{-1}
LAP	Hydrophobic organic carbon dry deposition flux	kg m^{-2} s^{-1}
LAP	Dust dry deposition flux (size 1: 0.1-1 μm)	kg m^{-2} s^{-1}
LAP	Dust wet deposition flux (size 1: 0.1-1 μm)	kg m^{-2} s^{-1}
LAP	Dust dry deposition flux (size 2: 1-2.5 μm)	kg m^{-2} s^{-1}
LAP	Dust wet deposition flux (size 2: 1-2.5 μm)	kg m^{-2} s^{-1}
LAP	Dust dry deposition flux (size 3: 2.5-5 μm)	kg m^{-2} s^{-1}
LAP	Dust wet deposition flux (size 3: 2.5-5 μm)	kg m^{-2} s^{-1}
LAP	Dust dry deposition flux (size 4: 5-10 μm)	kg m^{-2} s^{-1}
LAP	Dust wet deposition flux (size 4: 5-10 μm)	kg m^{-2} s^{-1}

S2. LAP Radiative forcing

Figure S1 shows 2004-2018 mean seasonal LAP radiative forcing for four basins. The results show majority of LAP driven radiative forcing is BC and dust, but radiative forcing from BC is stronger than dust overall. BrC contribution is very small, therefore it is not shown. The wide-spread increased aerosol radiative forcing is seen in winter through spring. Though the radiative forcing diminishes in summer and fall due to minimal snow cover area in Ganges and Brahmaputra, the peak radiative forcing ~40 W/m2, is seen in the highest mountain areas (e.g., Karakoram ranges) in Indus River in Summer and persist in Fall.

Sarangi et al., (2020) shows BC is dominant radiative forcing below 4000m but dust becomes equal or greater radiative forcing above 4000m elevation, such as Karakoram Mountains, particularly in summer months. This similar pattern is shown in our result (Figure S1-bottom, dust radiative forcing in JJA).

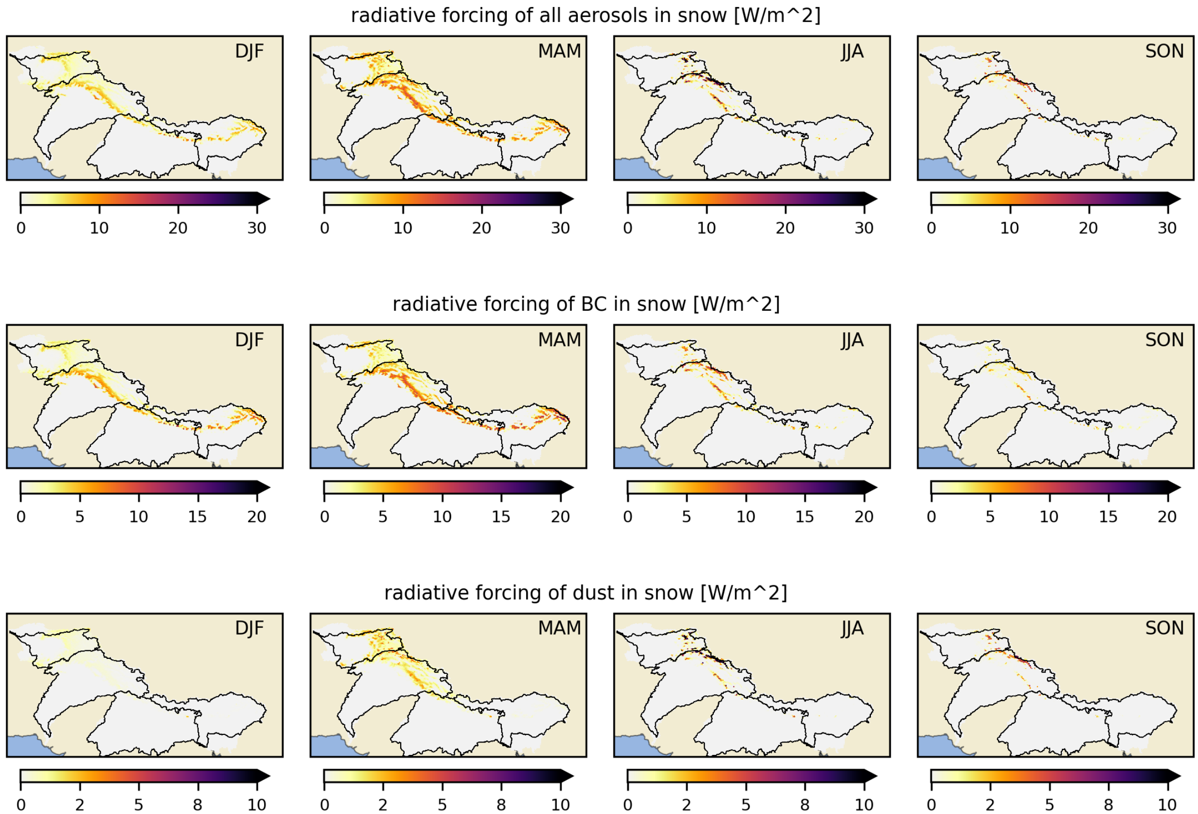
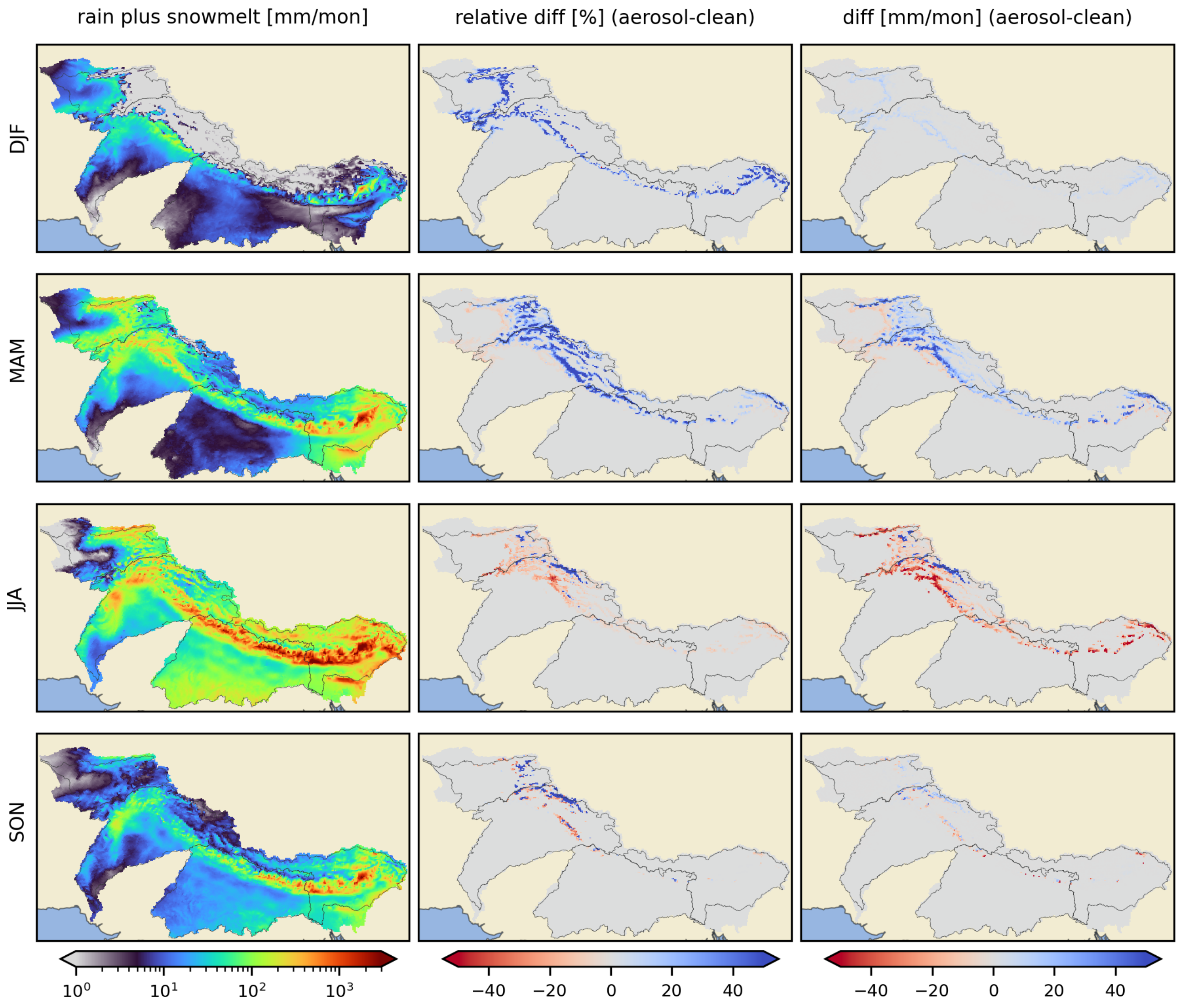


Figure S1. 2004-2018 mean seasonal LAP radiative forcing [W/m2]. Top panel: radiative forcing due to all the LAP types (top panel), BC (middle panel) and dust (bottom panel).

S3. Impacts of LAP in snowpack on seasonal water fluxes.

Figures S2 through S4 show 2004-2018 mean seasonal water fluxes, rain plus snowmelt (Fig. S2), ET (Fig. S3), and total runoff (Fig. S4), for four seasons based on CLM-LAP and differences between CLM-LAP and CLM-clean (both relative and absolute difference).



30 **Figure S2: 2004-2018 seasonal rainfall plus snowmelt [mm/month] for CLM-LAP run (left column) and relative difference [%] (middle column) and absolute difference [mm/month] between CLM-LAP and CLM-clean.**

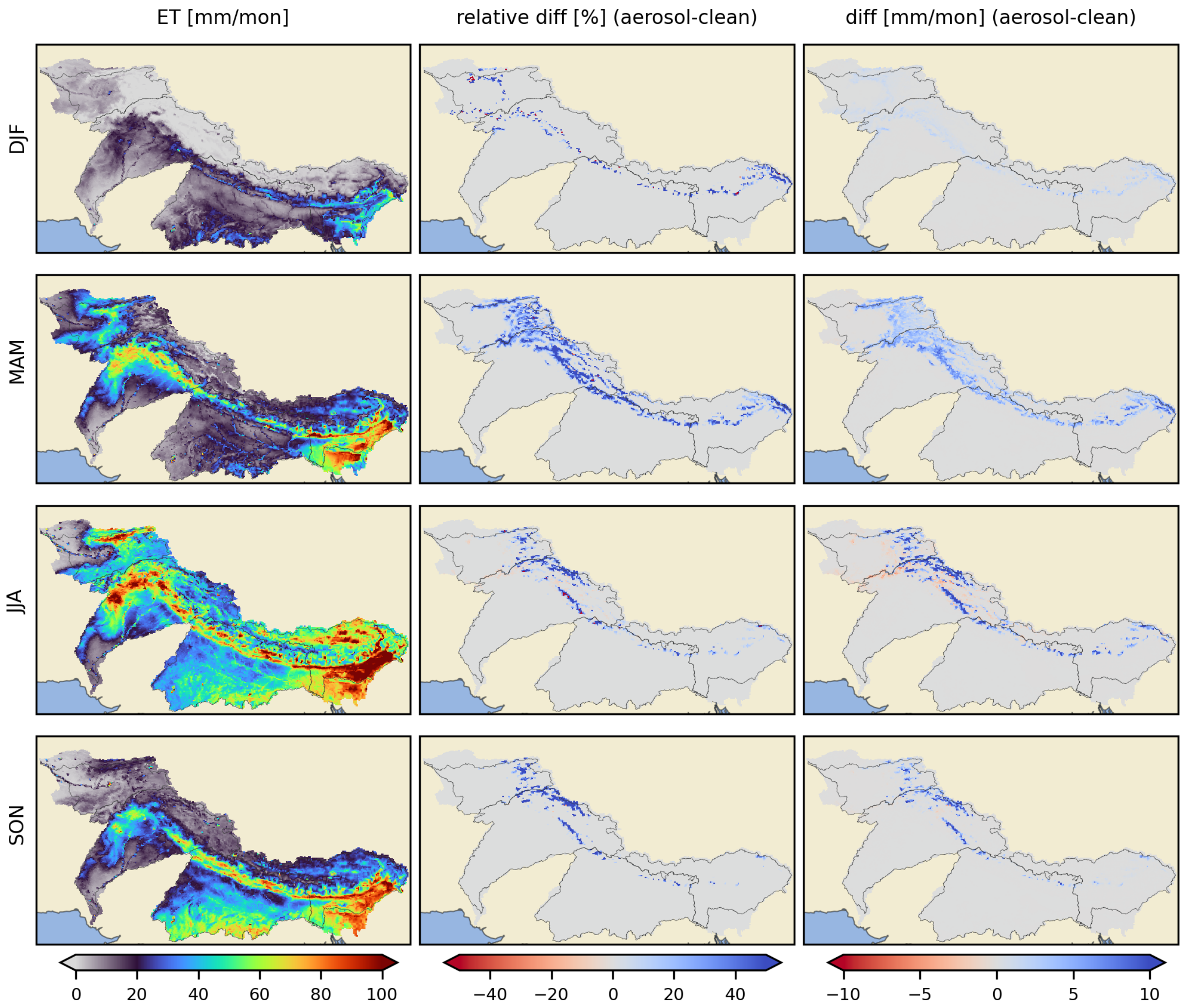


Figure S3: The same as Figure S2 except for evapotranspiration.

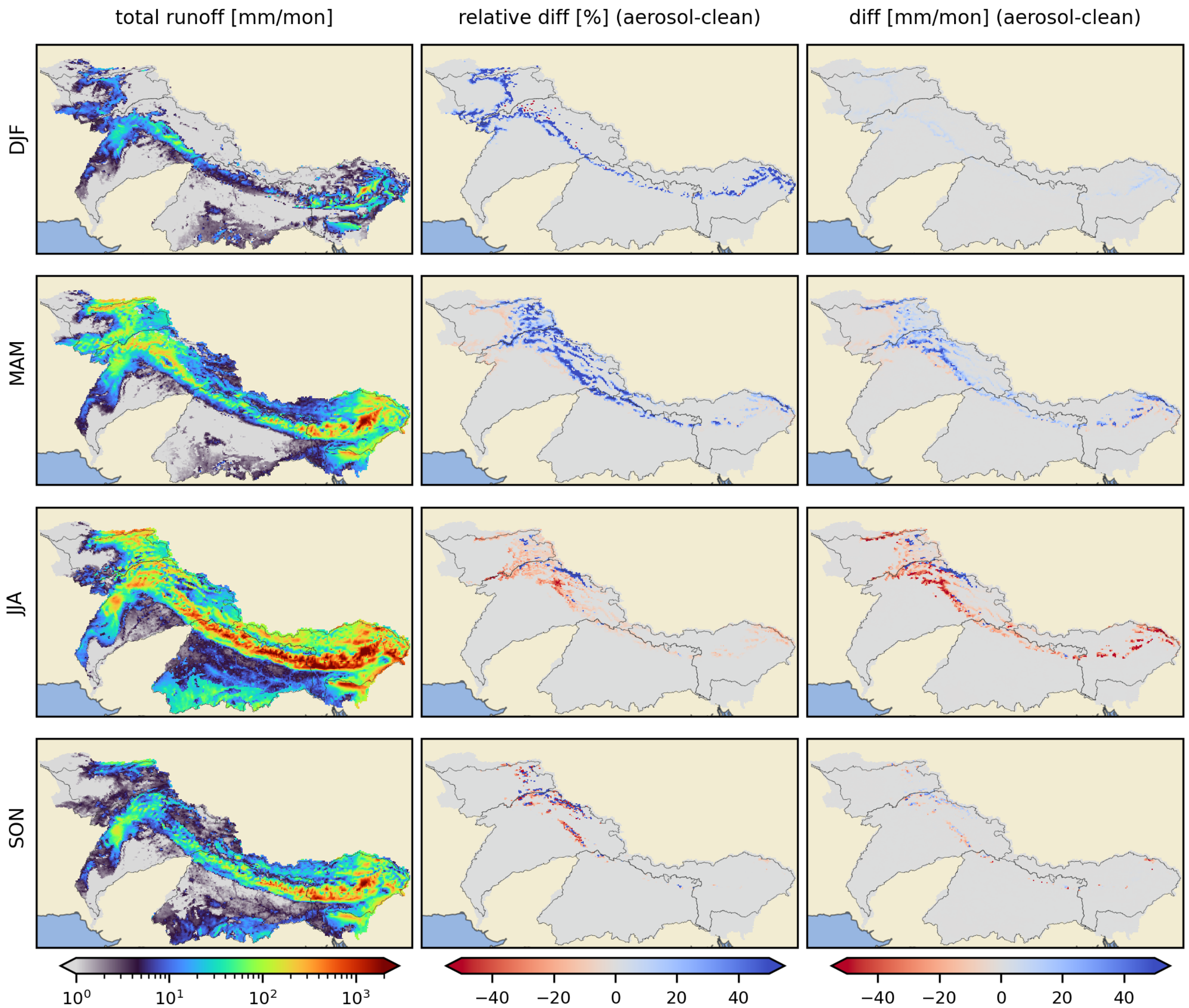


Figure S4: The same as Figure S2 except for total runoff

S4. Streamflow comparisons with observations

This study focuses on the sensitivity of LAP deposition on seasonal snowpack to simulated river discharge than extensive discharge evaluation. However, brief discharge evaluation against observed discharge is performed at gauges sites downstream of Brahmaputra and Ganges River basins available for our study (See Table S2). The results are shown in Figure S5. Note that there is no observed river discharge for the Indus River basin available for this study. In summary, simulated discharges are compared better with observed data at Brahmaputra (R=0.86, %bias=31 for monthly discharge) than at Ganges (R=0.72, %bias=42 for monthly discharge). Ganges river basin experiences a myriad of human impacts on river, including groundwater extraction and irrigation, therefore it is expected that observed flow is lower than the flow in would-be unimpaired condition, which the simulated discharge represents. On the other hand, the Brahmaputra River basin is in relatively pristine condition.

Table S2. Observed daily discharge data

River basin	Site location	Source
Brahmaputra	89.6802E, 25.1106N Bahadurabad	Bangladesh Flood Forecasting and Warning Center
Ganges	89.0255E, 24.064N Hardinge Bridge	Bangladesh Flood Forecasting and Warning Center

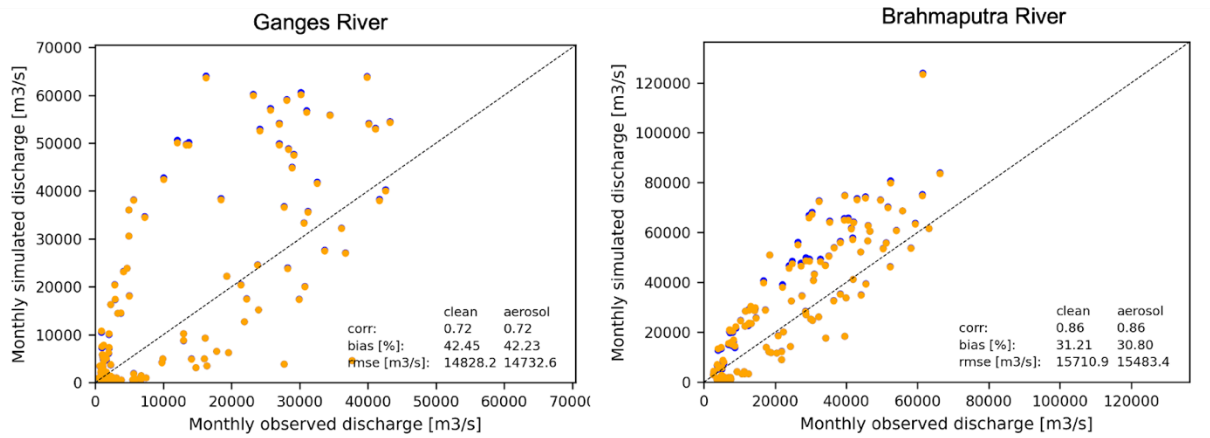


Figure S5: 2004-2018 mean peak discharge and seasonal hydrograph centroid and their changes (bottom). Negative values indicate earlier times.

References

Sarangi, C., Qian, Y., Rittger, K., Ruby Leung, L., Chand, D., Bormann, K. J., and Painter, T. H.: Dust dominates high-altitude snow darkening and melt over high-mountain Asia, Nat. Clim. Change, 10, 1045–1051, https://doi.org/10.1038/s41558-020-00909-3, 2020.