Exploring Global Hydrological Sensitivity: Assessing Noah-MP Runoff Models in Discharge Simulations

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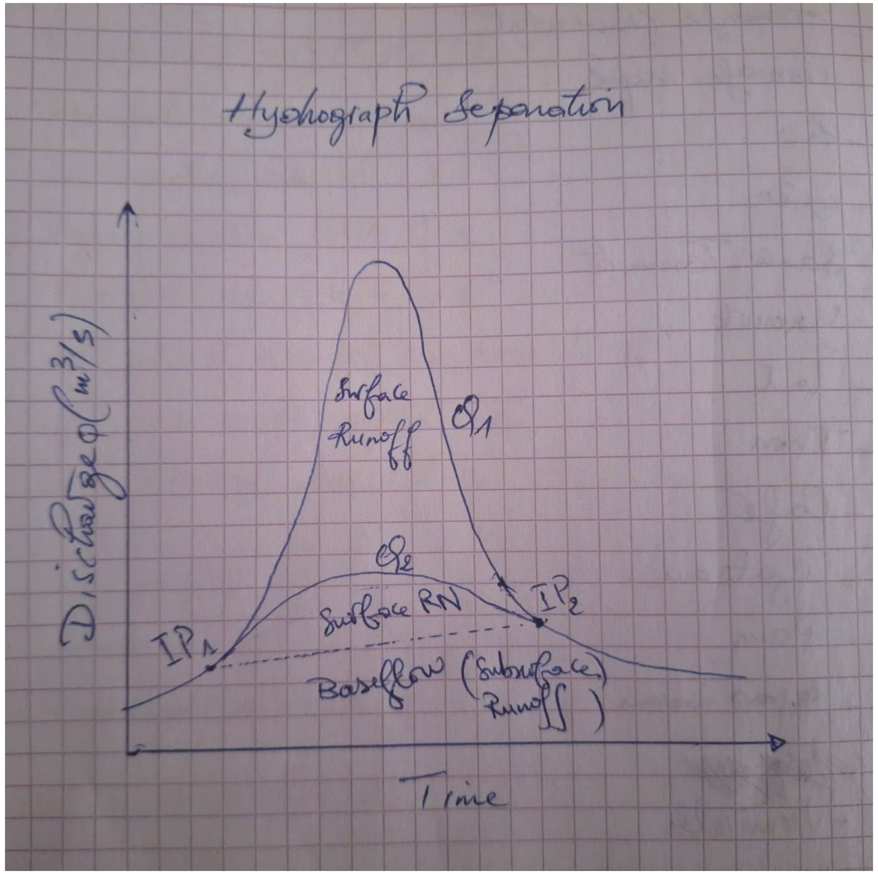
Motivation

- Runoff and groundwater dynamics are one of the most influential physical processes for land surface simulations, as demonstrated by various on site and regional simulations (Gan et al., 2019 ; Li et al., 2020)
- Past research has acknowledged the intricate interconnection between runoff and flow discharge, highlighting the propagation of uncertainty from runoff to discharge (David, C. H. et al., 2019).



Objective

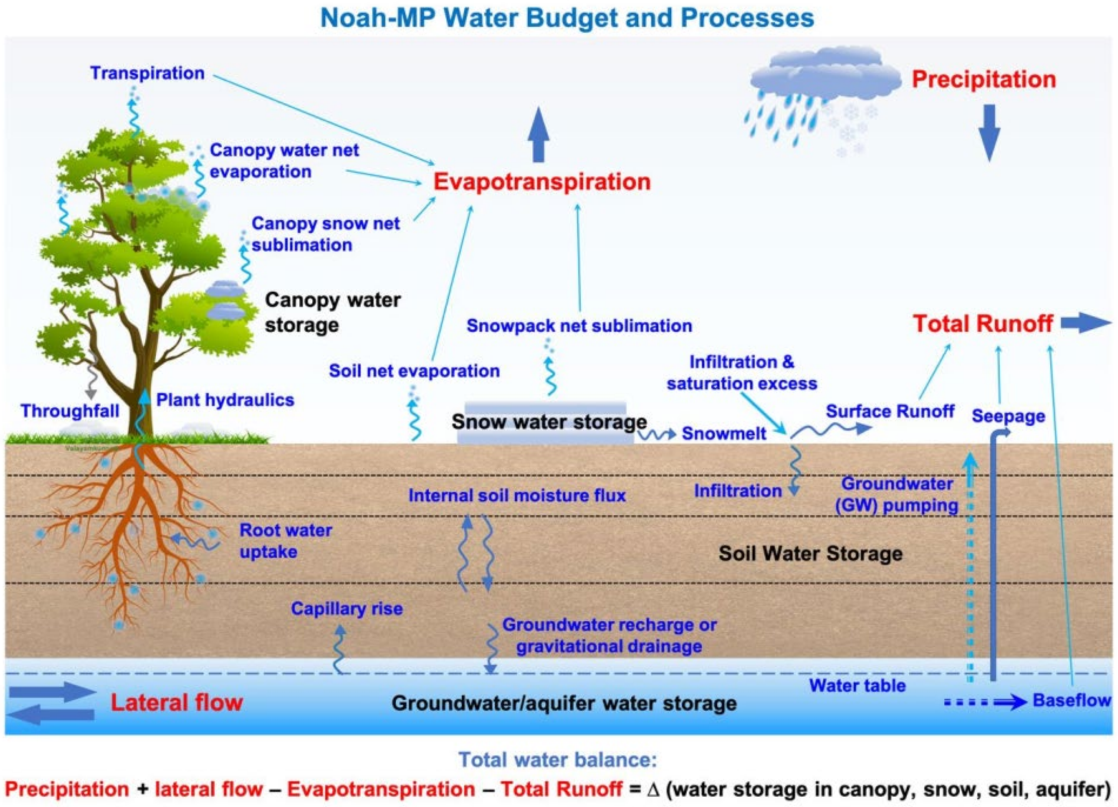
– Explore the diverse impacts that various runoff schemes can have on flow discharge, particularly at a global scale.

Noah-MP Physics options

Noah-MP Column Physics:

Contains several options for land surface processes:

1. Dynamic vegetation / vegetation coverage (9 options)
2. Rain/Snow partitioning (5 options)
3. Canopy stomatal resistance (2 options)
4. Canopy radiation transfer (3 options)
5. Soil moisture factor for stomatal resistance and ET (3 options)
6. Runoff and groundwater (8 options)
7. Surface layer exchange coefficient (2 options)
8. Supercooled soil liquid water/ice fraction (2 options)
9. Frozen soil permeability (2 options)
10. Snow surface albedo (2 options)
11. Snow/soil diffusion solution (3 options)
12. Snow thermal conductivity (5 options)
13. Ground resistance to evaporation/sublimation (4 options)
14. Lower soil temperature boundary condition (2 options)



Schematic diagram of water budget and processes represented in Noah-MP. (He et al., 2023)

Total of > 50 000 combinations can be used as multi-physics ensemble members

Noah-MP Runoff options

Noah-MP Runoff namelist options (saturation-excess; infiltration-excess; inf+sat-excess)

Noah-MP Physics	Option	Notes (* indicates the default option)
Options for surface runoff, subsurface runoff and drainage	1	TOPMODEL with groundwater (Niu et al., 2007)
	2	TOPMODEL with an equilibrium water table (Niu et al., 2005)
	3*	Schaake's surface and subsurface runoff (free drainage) (Schaake et al., 1996)
	4	BATS surface and subsurface runoff (Yang and Dickinson., 1996)
	5	Miguez-Macho&Fan groundwater scheme (Fan et al., 2007; Miguez-Macho et al. 2007)
	6	Variable Infiltration Capacity (VIC) surface runoff scheme (Liang et al., 1994)
	7	Xinanjiang Infiltration and surface runoff scheme (Jayawardena and Zhou, 2000)
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Impact of Runoff models on discharge simulations

- 7 runoff models: EXPs 1, 2, 3, 4, 6, 7 and 8 (ERA5-Land as a reference)
- CaMa-Flood routing model
- Global-Scale Study
- Different climate regions

EXP1: TOPMODEL with groundwater (Niu et al., 2007) ;
EXP2: TOPMODEL with an equilibrium water table (Niu et al., 2005) ;
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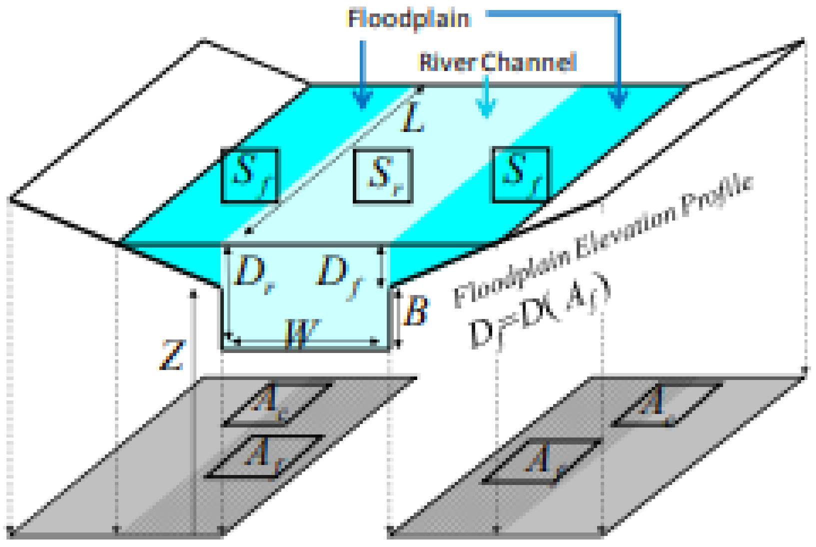
CaMa-Flood Routing model

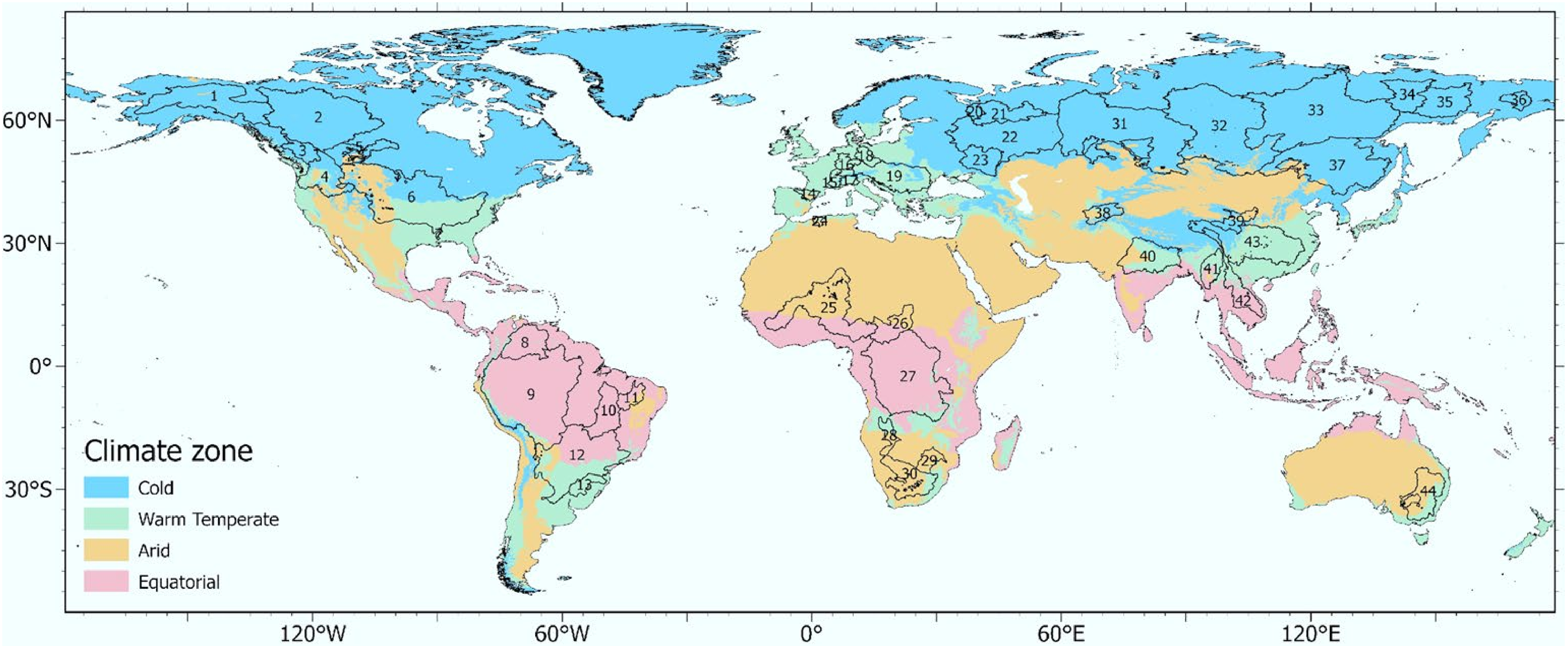
- The Catchment-based Macro-scale Floodplain model (CaMa-Flood) (https://doi.org/10.1029/2010WR009726)
- Global-scale distributed river model
- relies on runoff input from a land surface model to simulate water storage and river discharge across a predefined river network map
- available at different spatial resolutions: 15min, 6min, 5min, 3min and 1min



Experiments / Methodology

- Noah-MP :
  - ERA5-Land meteorological forcings (10m wind speed, 2m air temperature, air humidity, surface pressure, longwave and shortwave downward radiation, and total precipitation) at hourly timestep
  - Data interpolated to 0.2° spatial resolution
  - The soil water content simulations are performed over four distinct soil layers with depths corresponding to ECMWF surface model specifications: 0-7 cm, 7-28 cm, 28-100 cm, and 100-289 cm.
  - Land Cover: Modis 20-category
  - Soil types: (STATSGO)–FAO
  - 15 years of Noah-MP spinup (3 x 1980-1984)
  - Runoff simulations at daily timestep from 1985 to 2023

- CaMa-Flood:
  - CaMa-Flood model at 5min spatial resolution (simulated runoff interpolated)
  - river discharge simulations spanning from 1985 to 2023



North America
1. Yukon
2. Mackenzie
3. Fraser
4. Columbia
5. Saskatchewan
6. Mississippi
7. Pearl

South America
8. Orinoco
9. Amazon
10. Tocantins
11. Parnaiba
12. Parana
13. Uruguay

Europe
14. Ebro
15. Rhone
16. Rhine
17. Po
18. Elbe
19. Danube
20. Onega
21. Severnaya Dvina
22. Volga
23. Don

Africa
24. Chelif
25. Niger
26. Lake Chad
27. Congo
28. Okavango
29. Limpopo
30. Orange

Asia
31. Ob
32. Yenisey
33. Lena
34. Indigirka
35. Kolyma
36. Anadyr
37. Amur
38. Amu Darya
39. Yellow
40. Ganges
41. Irrawaddy
42. Mekong
43. Yangtze

Australasia
44. Murray-Darling

Results

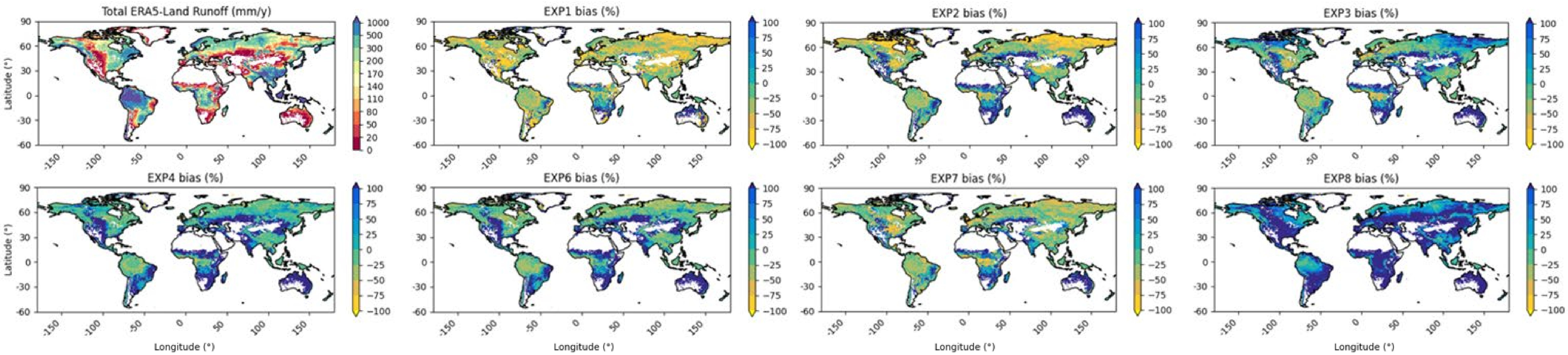


Fig. Mean (1985-2023) annual runoff bias (%) of Noah-MP runoff schemes driven by ERA5-Land climate forcing compared to ERA5-Land runoff data.

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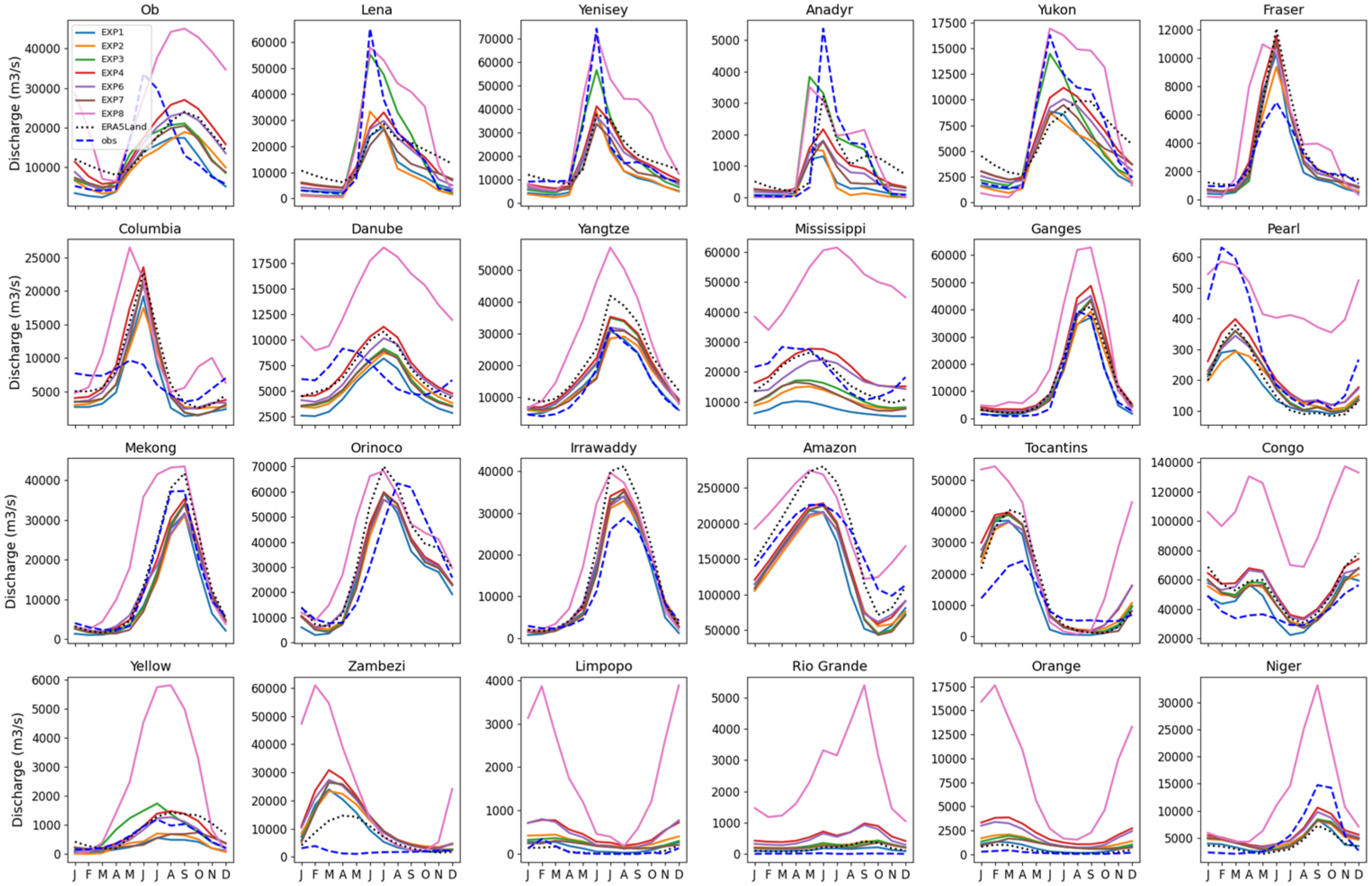

Fig. Mean seasonal cycle of river discharge (m3/s) simulated by CaMa-Flood, driven by the different Noah-MP runoff schemes, in comparison with GRDC discharge observations, over 4 climate regions: 1st row for cold regions, 2nd row for midlatitude regions, 3rd row for tropical regions, and 4th row shows arid basins. The number of years of observations contributing to the monthly mean are minimum 5 but varies depending on the available observations for the specific catchment. Observations used are within the period 1985–2023

Results

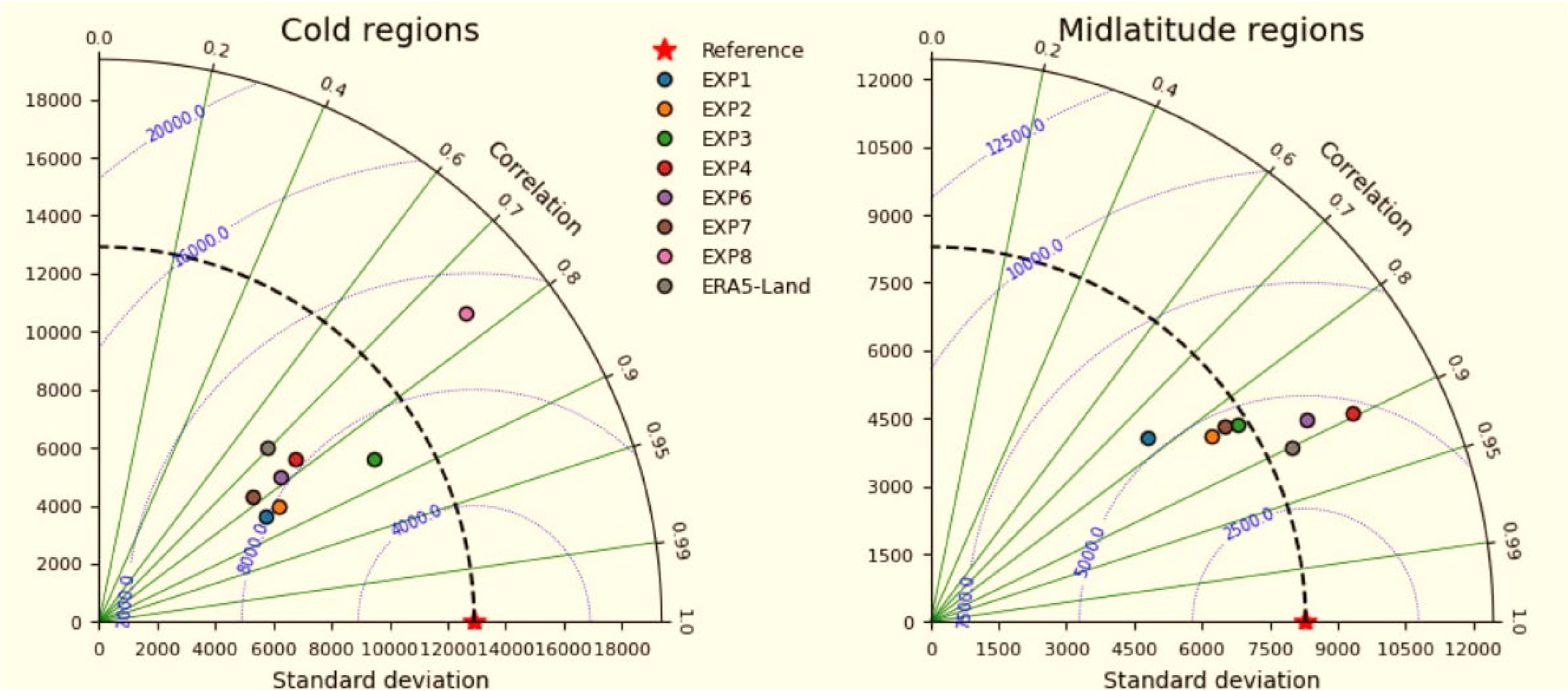

Fig. Taylor diagram showing the performances of different Noah-MP runoff models in terms of hourly discharge within cold and warm-temperate regions

EXP1: TOPMODEL with groundwater (Niu et al., 2007) ;
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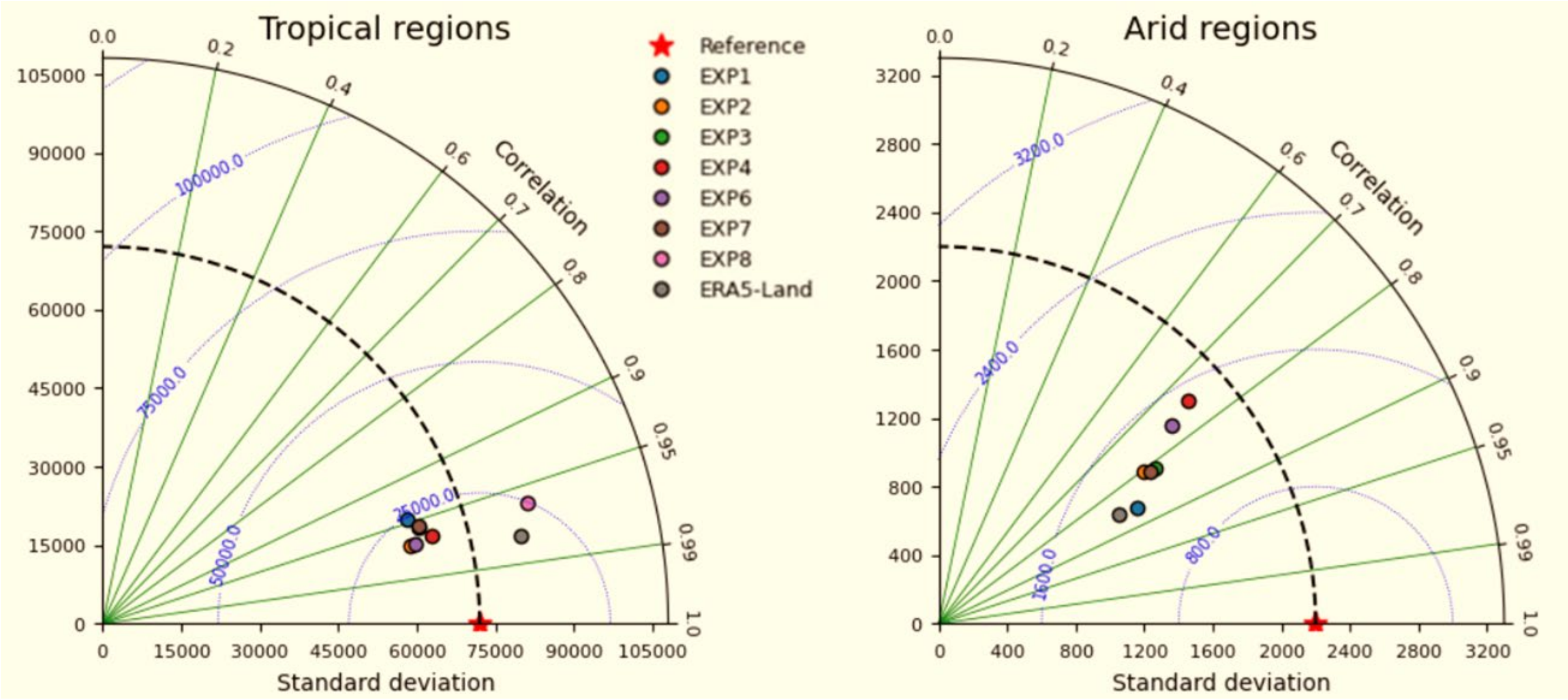

Fig. Taylor diagram showing the performances of different Noah-MP runoff models in terms of hourly discharge across tropical and arid regions

EXP1: TOPMODEL with groundwater (Niu et al., 2007) ;
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Results

EXPs	Cold Regions		Midlatitude Regions		Tropical Regions		Arid Regions	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
EXP1	7175.0	3122.4	5716.5	2856.0	26212.9	13349.6	**1241.9**	**549.2**
EXP2	6887.6	3124.6	4693.2	2315.4	21529.6	11608.6	1375.5	810.6
EXP3	**5588.7**	**2739.1**	4647.9	**2315.0**	22992.3	11982.4	1344.0	759.8
EXP4	6910.6	3045.4	4922.2	2544.7	**19576.9**	**10288.8**	1717.9	1171.4
EXP6	6866.7	2814.0	**4532.0**	2367.9	20675.1	11027.0	1564.0	1018.7
EXP7	7407.8	3041.3	4734.0	2369.2	23399.1	12171.5	1330.1	710.0
EXP8	10869.9	6715.7	15244.6	8147.3	29853.7	19879.7	6512.5	3836.1
ERA5-Land	7731.3	3606.0	**3881.9**	**2003.5**	**18892.0**	10555.2	1317.0	**514.4**

Tab. Performance metrics of Noah-MP runoff models in terms of hourly discharge across climate regions

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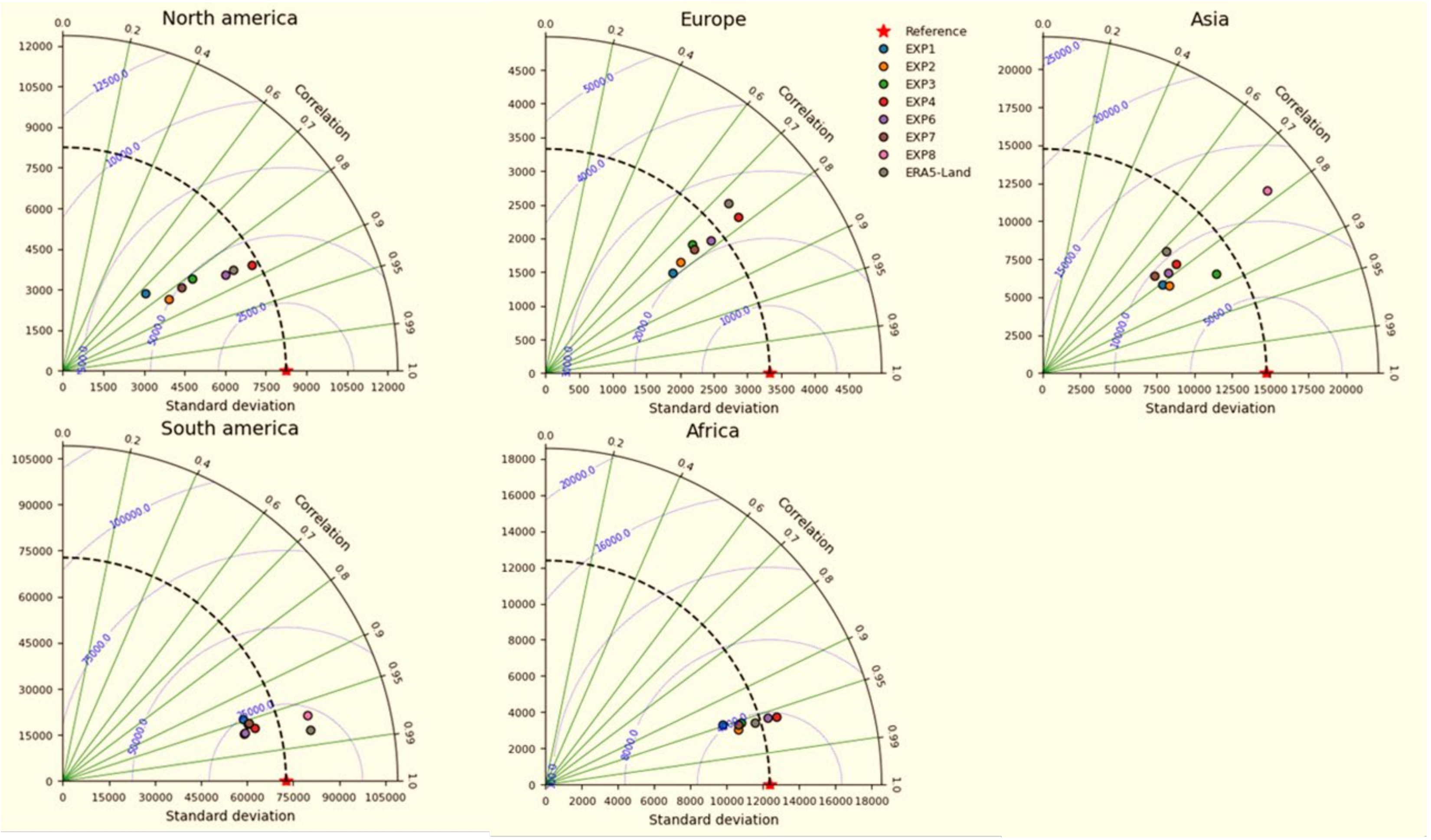

Fig. Taylor diagram showing the continental performances of different Noah-MP runoff models in terms of hourly discharge

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EXP2: TOPMODEL with an equilibrium water table (Niu et al., 2005) ;
EXP3: Schaake's surface and subsurface runoff (free drainage) (Schaake et al., 1996) ;
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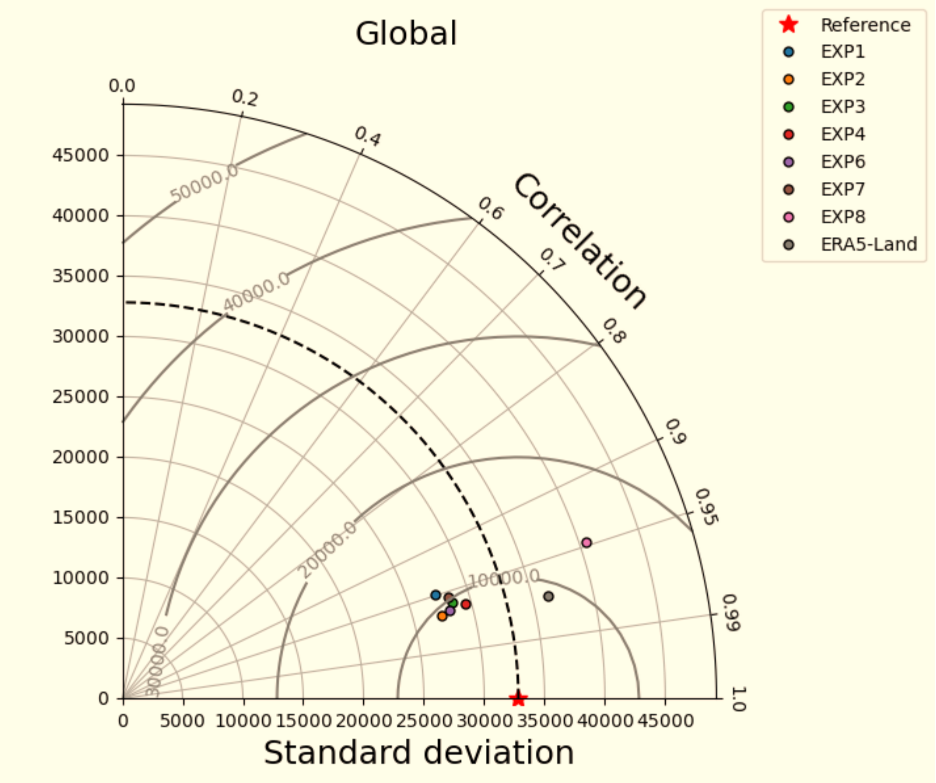

Fig. Taylor diagram showing the global performances of different Noah-MP runoff models in terms of hourly discharge

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Conclusions

- Some limitations of CaMa-Flood routing model in capturing the daily discharge (coarse spatial resolution, sub-surface routing scheme, parametrization)
- Schaake's Runoff model performs well in warm-temperate regions & in cold regions → infiltration-excess;
- At the global scale, except the Dynamic VIC, all the runoff models performs almost similarly, BATS model demonstrated slightly superior performance, followed by Schaake's, VIC, and Xinanjiang runoff models
- Possibility of an ensemble runoff model
- Calibration and extrapolation for shared sensitive parameters

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