Skill of seasonal flow forecasts at catchment-scale: an assessment across South Korea (Supplementary materials)

1. Modified Tank model

The water-balance module suggested by United States Geological Survey (USGS, 2007) is adopted in the modified Tank model. Therefore, when temperature (T) is below a specified threshold (T_{snow}), the model considers all precipitation (P) as snow. In contrast, when temperature is greater than an additional threshold (T_{rain}), then all precipitation is considered to be rain. If the temperature is between the T_{snow} and T_{rain}, the amount of snow (P_{snow}) is linearly interpolated as Eq. S1 and thus P_{rain} is computed as Eq. S2.

$$P_{snow} = P \times \left[\frac{T_{rain} - T}{T_{rain} - T_{snow}}\right] \quad \text{(S1)}$$

$$P_{rain} = P - P_{snow} \quad \text{(S2)}$$

Based on prior research, McCabe and Wolock (1999) proposed a suggested T_{rain} value of 3.3°C, while the USGS (2007) indicated that T_{snow} can vary by elevation between -10°C (below 1000 m) and -1°C (above 1000 m).

P_{snow} accumulates as snow storage (*snostor*).

The equation of snow storage that melts (snow melt fraction, SMF) can be expressed as:

$$SMF = \left[\frac{T - T_{snow}}{T_{rain} - T_{snow}}\right] \times meltmax \quad \text{(S3)}$$

Here, *meltmax* denotes a maximum melt rate and if the calculated *SMF* exceeds *meltmax*, it is capped at the value of *meltmax*.

The snowmelt (SM), measured in millimeters of snow water equivalent, is subsequently computed using this adjusted SMF.

$$SM = snostor \times SMF \quad \text{(S4)}$$

To determine the total precipitation to the soil, the snowmelt (*SM*) is added to the pre-existing precipitation that represents the difference between P_{rain} and direct runoff.

Table S1. The description of the parameters in modified Tank model.

Parameter	Description	Parameter	Description
K1	Soil moisture exchange coefficient from 2nd to 1st tank	HA2	Upper outlet height at first tank
K2	Soil moisture exchange coefficient from S1 to S2	HB	Outlet height at 2nd tank
A0	Infiltration coefficient at first tank	HC	Outlet height at 3rd tank
A1	Lower runoff coefficient at first tank (Surface flow)	U1	Ordinate of unit hydrograph at t day
A2	Upper runoff coefficient at first tank (Surface flow)	U2	Ordinate of unit hydrograph at t+1 day
B0	Infiltration coefficient at 2nd tank (Intermediate flow)	SNOSTR0	Size of snow storage
B1	Runoff coefficient at 2nd tank (Intermediate flow)	T_RAIN	Temperature that all precipitation is regarded to be rain
C0	Infiltration coefficient at 3rd tank (Supplemental baseflow)	T_SNOW	Temperature that all precipitation is regarded to be snow
C1	Runoff coefficient at 3rd tank (Supplemental baseflow)	MELTMAX	Maximum snowmelt rate
D1	Runoff coefficient at fourth tank (Primary baseflow)	ALPHA	Direct runoff fraction
HA1	Lower outlet height at first tank		

2. Supplementary results

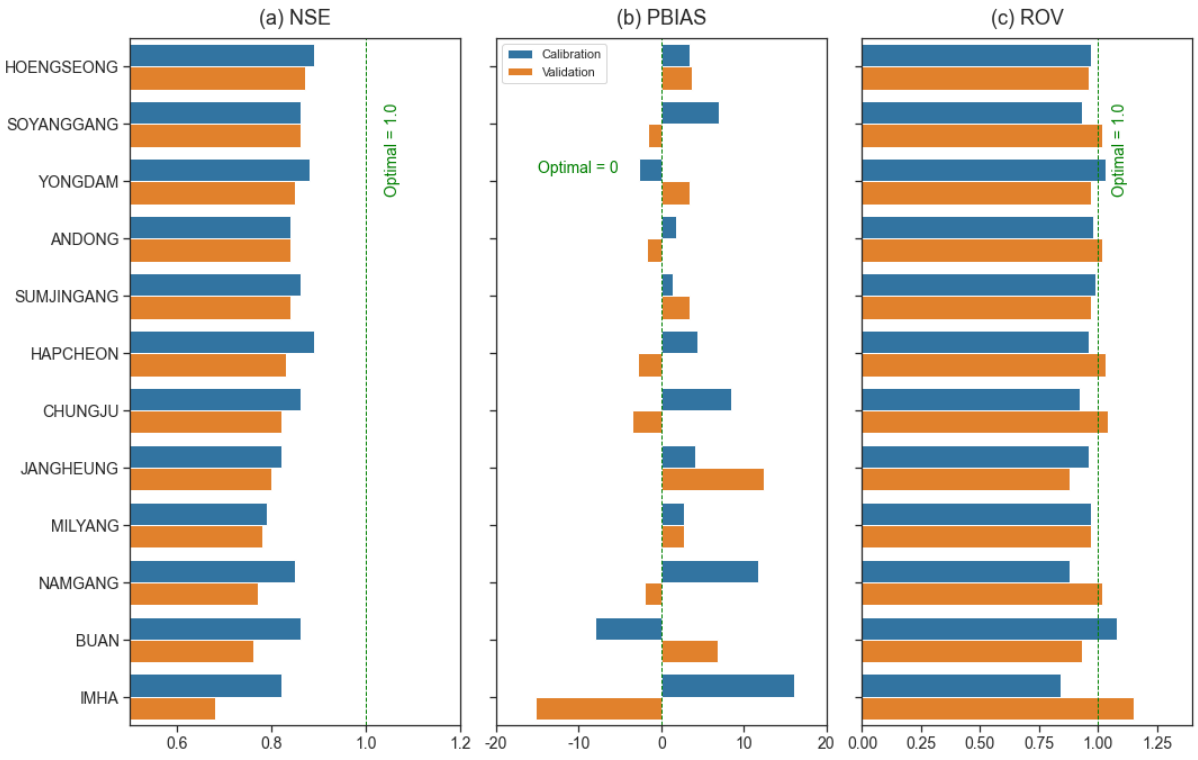

Figure S1: The performance of modified Tank model ((a) NSE, (b) PBIAS, (c) ROV) for 12 catchments (y-axis, largest to smallest catchment from the top to bottom) over the model calibration (2001-2010, blue) and validation (2011-2020, orange). period.

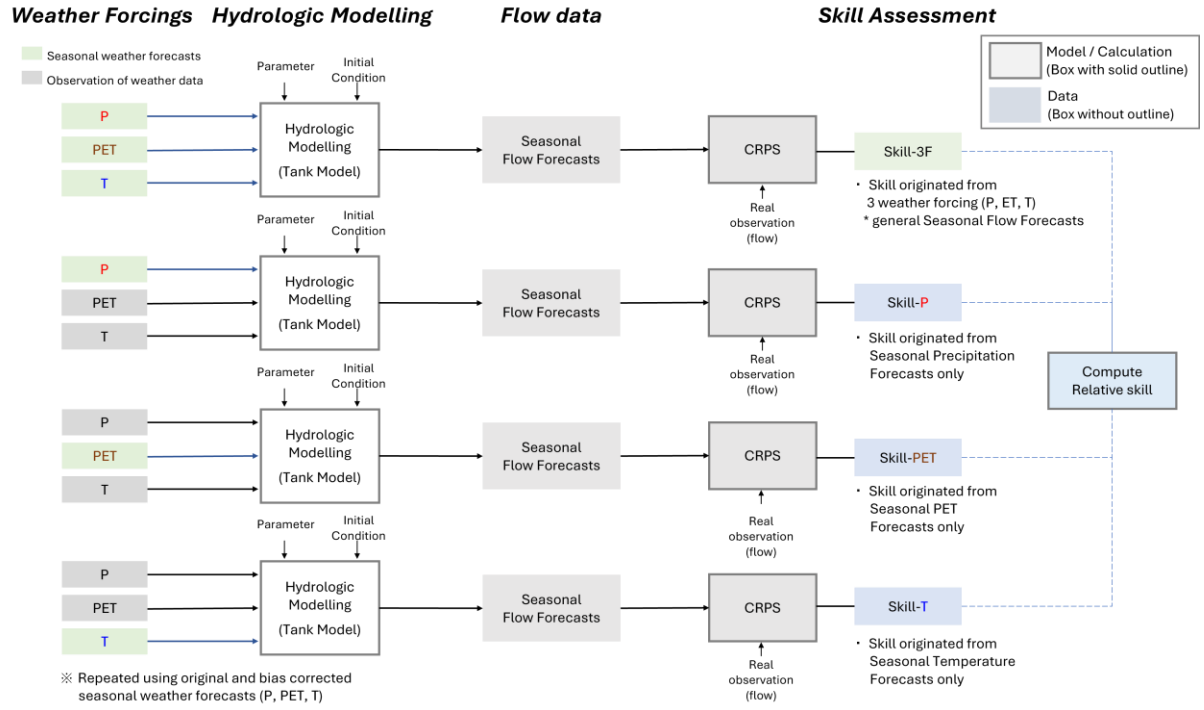

Figure S2: Schematic diagram of calculating the relative skill of each weather forcing to the skill of seasonal flow forecasts.

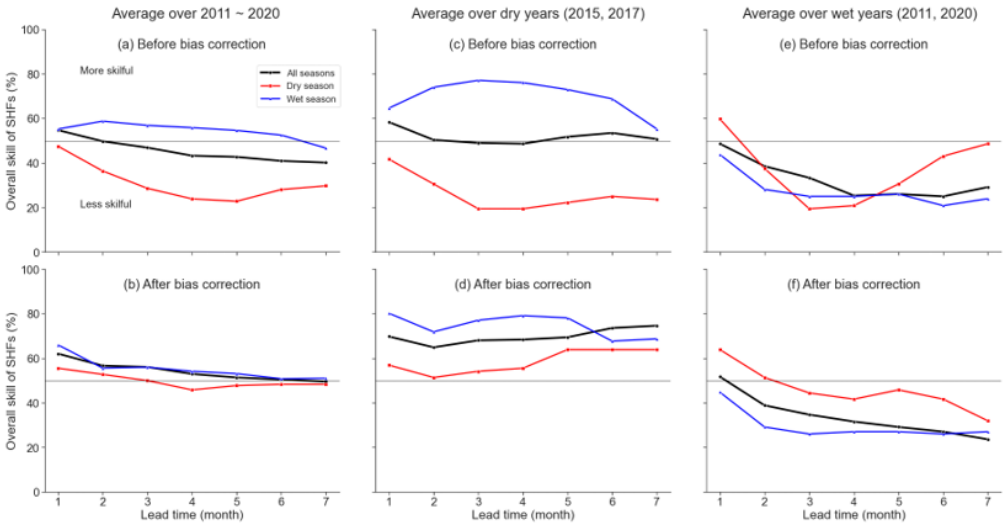

Figure S3. Averaged overall skill of SFFs over 12 catchments, before (first row) and after bias correction (second row) averaged over (a, b) entire years (2011 to 2020), (c, d) dry years (2015, 2017) and (e, f) wet years (2011, 2020) during all seasons (black lines), dry seasons (red lines) and wet seasons (blue lines).

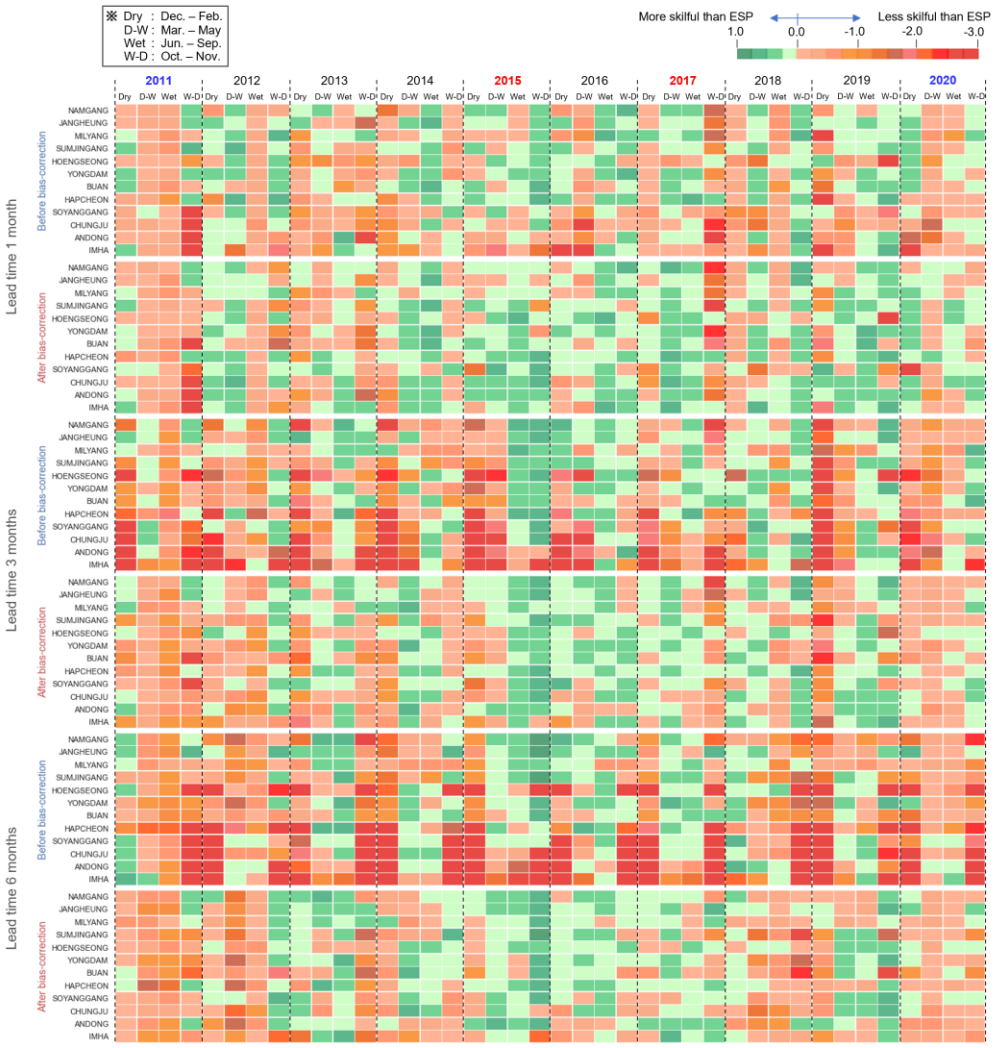

Figure S4. Seasonally averaged CRPSS of SFFs for each reservoir (y-axis, wettest to driest catchment as of annual mean precipitation) for 10 years (2011-2020, x-axis) at 1, 3, and 6 months of lead time (from the top to bottom). At each lead time, the upper and lower plot represents before and after bias-correction (for P, T and PET). 2011 and 2020 (2015 and 2017) represent wet (dry) years, respectively.

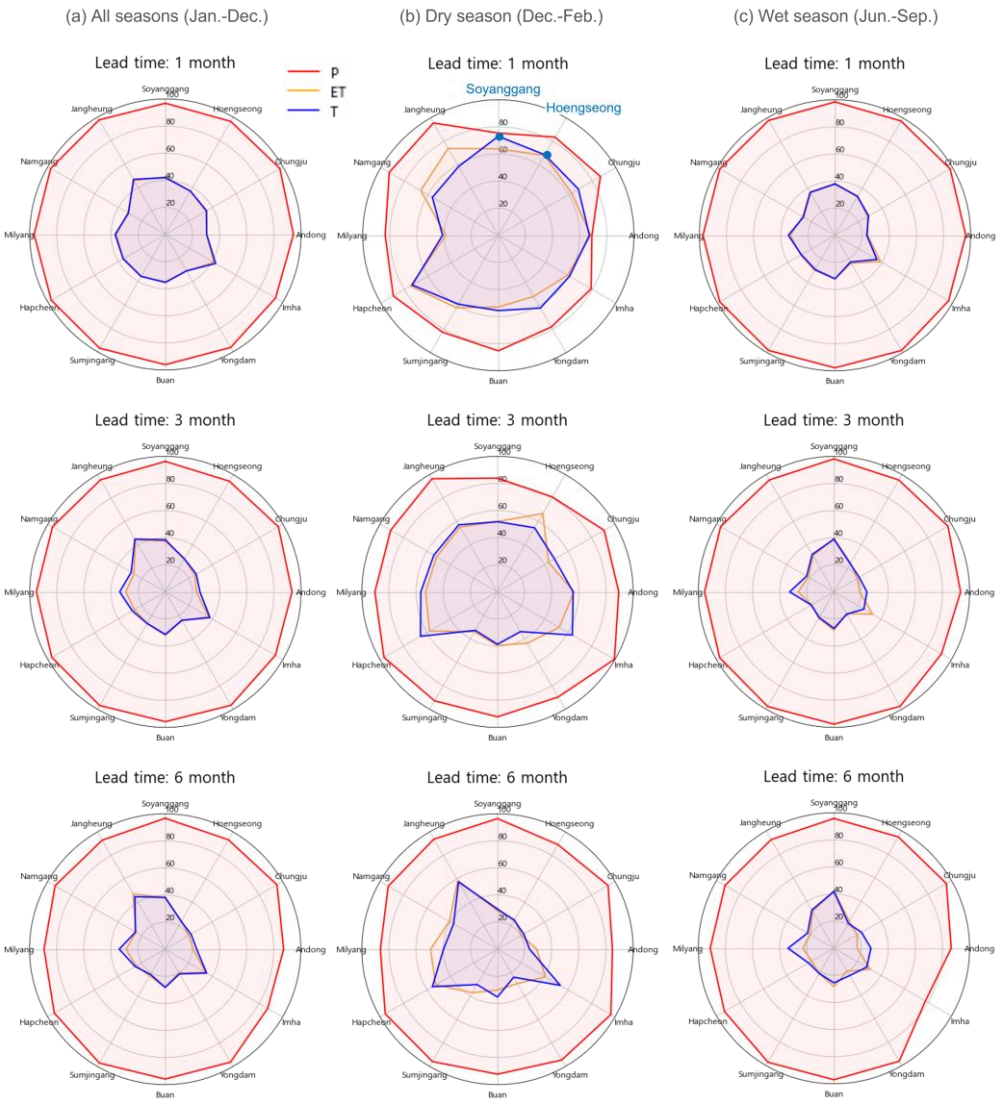

Figure S5: Contribution rate (%) of each weather forcings (Precipitation: red, PET: orange, Temperature: blue) after bias correction to the skill of SFFs averaged over 10 years (2011-2020) during (a) all seasons, (b) dry and (c) wet season at 1, 3 and 6 lead months from the top to bottom (Catchments are ordered by their location from the northernmost (Soyanggang) to the southernmost (Jangheung) in right-angle direction).

		(a) Average over 2011 – 2020							(b) Average over dry years (2015, 2017)							(c) Average over wet years (2011, 2020)						
	Lead time	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
North	Soyanggang	7	7	6	4	4	4	7	11	8	10	9	9	11	10	8	11	6	4	4	3	2
	Hoengseong	8	5	5	1	6	4	3	5	3	5	6	6	7	5	2	1	4	1	4	6	6
	Chungju	1	6	9	9	7	7	6	1	8	12	11	9	7	6	2	5	2	4	2	3	2
	Andong	6	10	8	6	8	9	9	5	6	2	2	1	3	3	11	5	1	3	7	8	10
	Imha	2	8	11	11	11	10	11	5	7	10	9	11	7	9	5	5	8	9	8	7	6
	Yongdam	4	9	6	8	9	6	8	3	8	7	8	8	6	6	10	11	8	7	10	8	10
	Buan	8	12	12	12	12	12	12	3	12	8	11	12	12	12	11	10	12	12	10	11	8
	Sumjingang	4	11	10	10	10	10	9	5	11	8	7	6	10	10	1	9	11	11	10	12	10
	Hapcheon	3	2	3	3	3	3	4	1	3	2	1	1	1	1	5	3	8	9	8	8	9
	Milyang	11	3	4	7	4	7	5	9	2	2	2	1	4	6	2	1	2	6	4	3	2
	Namgang	8	1	1	4	2	2	2	10	1	1	2	4	2	2	8	3	4	7	3	1	2
South	Jangheung	12	4	1	2	1	1	1	12	3	6	5	5	4	3	5	8	6	2	1	1	1

Figure S6. Overall skill ranks for each catchment averaged over (a) entire years (2011 to 2020), b) dry years (2015, 2017) and (c) wet years (2011, 2020) for all seasons (January to December). The catchments are arranged from the top to bottom in order of their location from the northernmost (Soyanggang) to the southernmost (Jangheung). The three most (least) skilful reservoirs are highlighted in yellow (pink) colour.

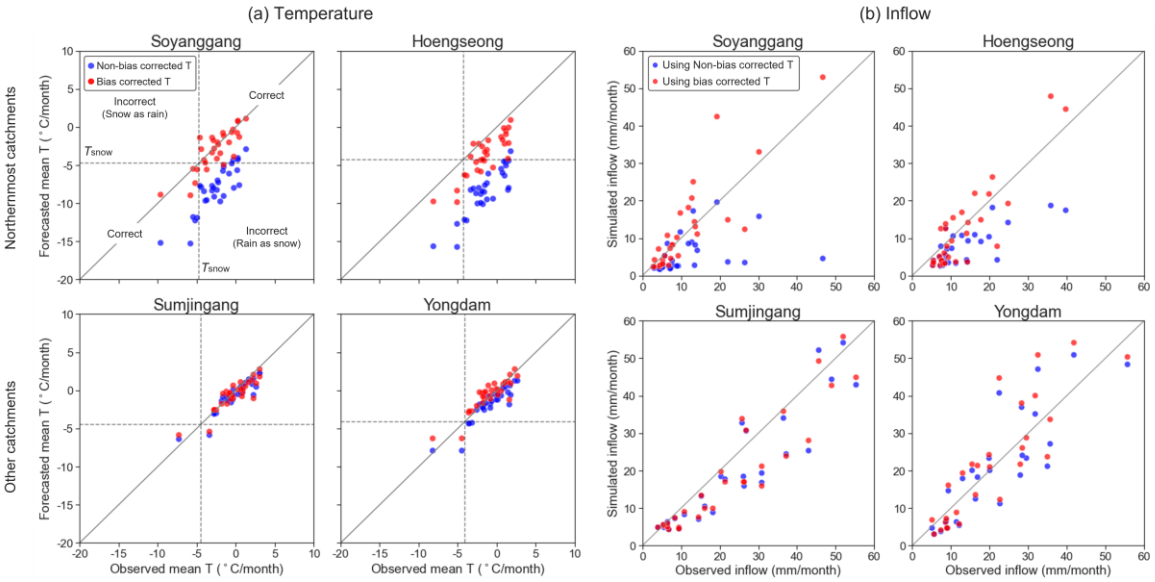

Figure S7. (a) Correlation between observed (x-axis) and forecasted (y-axis) monthly mean temperature before (blue dots) and after (red dots) bias correction during the dry season (December-February) in the two northernmost (first row) and two catchments in other regions (second row). In figure (b), the blue (red) dots represent the simulated inflow using observed precipitation, PET and forecasted temperature before bias correction (after bias correction).

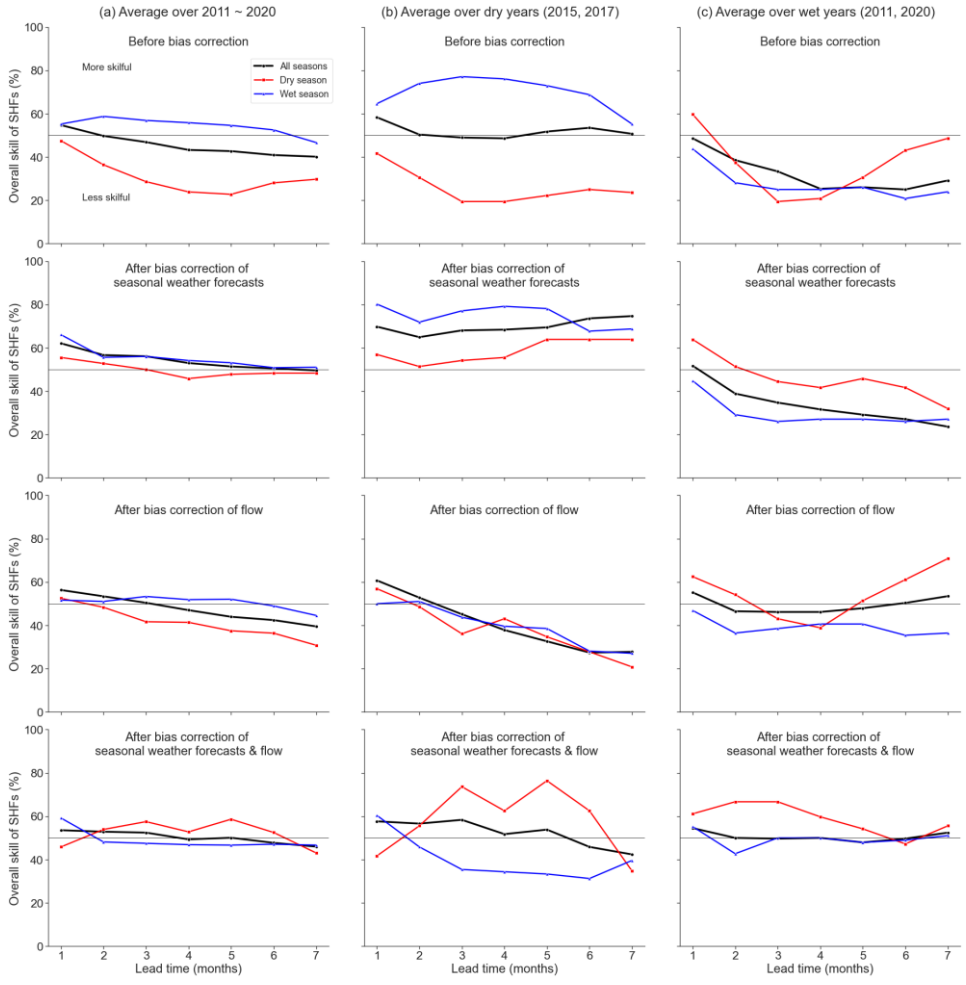

Figure S8: Overall skill of SFFs (y-axis) averaged over 12 catchments for 10 years (2011 to 2020) at lead times (x-axis) during (a) entire years, (b) dry years (2015, 2017) and (c) wet years (2011, 2020). Each row from the top to bottom represents before bias correction, after bias correction of seasonal weather forecasts, flow and both, respectively.