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Supplement of

A systematic evaluation of 15 actual evapotranspiration formulations within conceptual hydrological models

Gabrielle Burns et al.

Correspondence to: Gabrielle Burns (gabrielle.burns@unimelb.edu.au)

Supplement

S1. Site information

Table S1: Additional details on catchments and flux tower sites

Flux tower site name	Flux tower site description	Flux tower site loc.	Flux tower available data dates (and used as full-calibration)	Mean daily PET (mm/d)	Australian State or territory	Season high P / low P *
Wombat Forest	Mixed Eucalyptus regrowth forest	-37.4, 144.1	21-Jan-2010: 28-Feb-2020	2.95	Victoria	JJA / DJF
Whroo	Box woodland forest	-36.7, 145.0	02-Dec-2011: 31-Dec-2021	3.32	Victoria	JJA / DJF
Tumbar-umba	Wet sclerophyll, alpine ash forest	-35.7, 148.2	24-Jun-2015: 27-Feb-2022	3.22	New South Wales	JJA / DJF
Robson Creek	Tropical rainforest	-17.1, 145.6	01-Jan-2014: 27-Feb-2022	4.70	Queens-land	DJF / SON
Litchfield	High rainfall, frequently burnt tropical savanna	-13.2, 130.8	02-Aug-2013: 27-Feb-2022	5.54	Northern Territory	DJF / JJA
Dry River	Open forest savanna	-15.3, 132.4	21-Jan-2010: 28-May-2021	5.34	Northern Territory	DJF / JJA
Gingin	Coastal heath Banksia woodland	-31.376, 115.714	01-Jan-2008: 31-Dec-2019	4.067	Western Australia	JJA / DJF

* Southern hemisphere seasons: DJF (“summer”), MAM (“autumn”), JJA (“winter”), SON (“spring”)

S2. Model information

Table S2. Models using each AET equation. Note that some models appear under multiple equations due to different equations being used within the model for evaporating from different stores.

Equation no. (from MARRMoT)	Models featuring equation
1	Wetland model, Alpine model v1/v2, Hillslope model, New Zealand model v2, Penman, SimHyd, Large-scale catchment water and salt balance model element, Thames Catchment Model, Flex-I, Tank model, Sacramento-SMA, Flex-IS, MODHYDROLOG, Tank model – SMA, Midland Catchment Runoff Model, NAM, HYCYMODEL, ECHO, PRMS, CLASSIC, Forellenbach model
2	SimHyd, MODHYDROLOG
3	Flex-I, Flex-IS, HYCYMODEL, Collie River v2/v3, TOPMODEL, Flex-B, HBV-96
4	Plateau model
6	New Zealand model v1, New Zealand model v2, Susannah Brook v1
7	New Zealand model v2, Sacramento-SMA, NAM, PRMS, Collie River v2/v3, United States model v1, Susannah Brook v1, Collie River 1, Susannah Brook model v2, Australia model, VIC, HyMOD, MOPEX-1/-2/-3/-4/-5
8	United States model v1
11	GR4J
13	SMAR
16	Penman, Thames Catchment Model
19	Large-scale catchment water and salt balance model element (LASCAM), GSM-SOCONT
20	GSFB
21	Xinanjiang
22	ECHO
23	Forellenbach model (IHM)

S3. Timeseries figures

S3.1 Wombat Forest

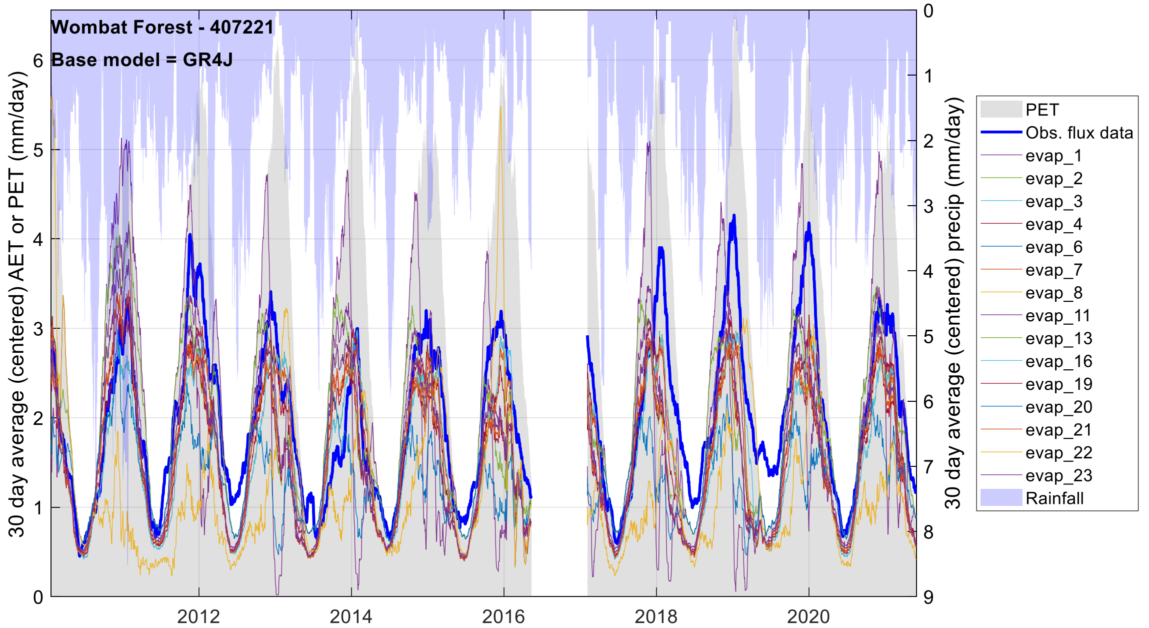


Fig. S1 Observed flux tower data, precipitation, and PET for Wombat Forest, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).

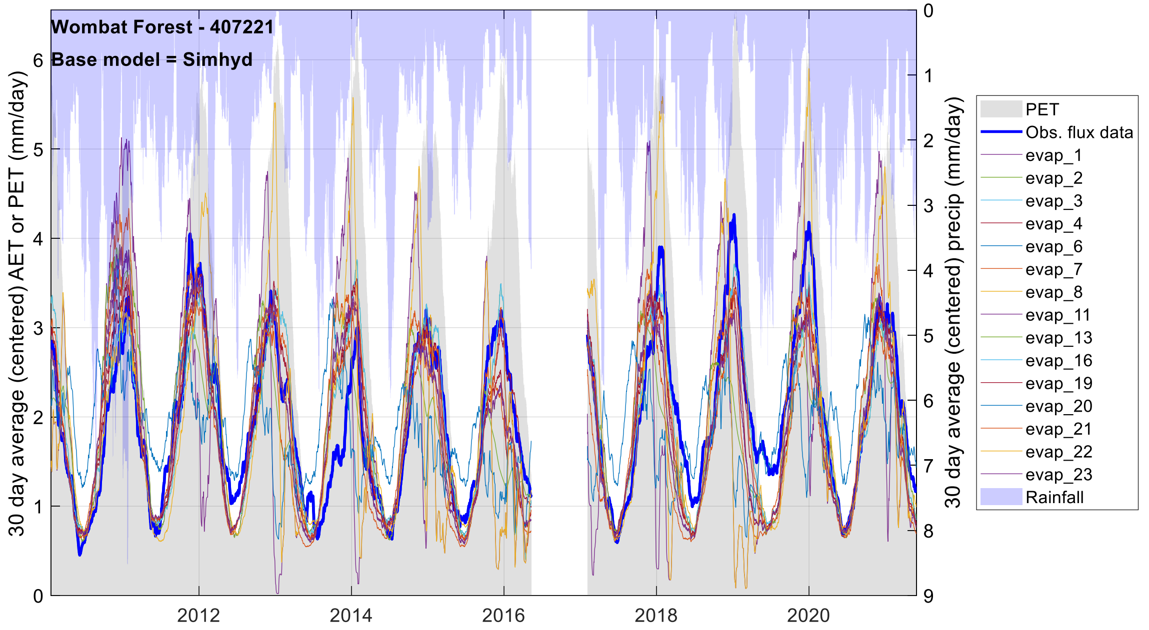


Fig. S2 Observed flux tower data, precipitation, and PET for Wombat Forest, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

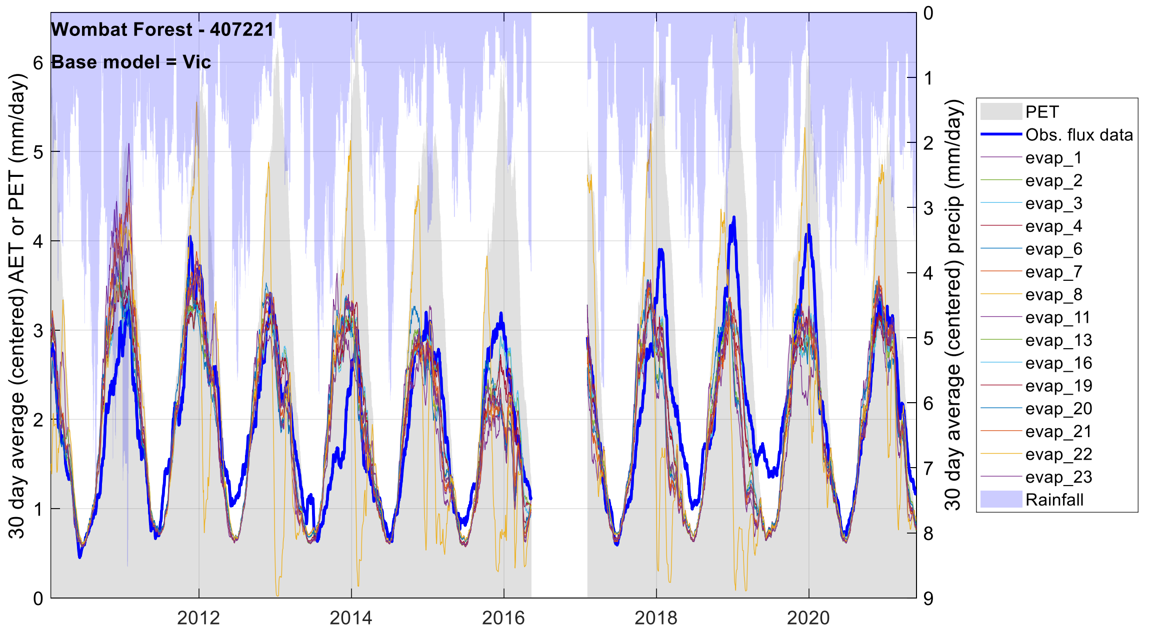


Fig. S3 Observed flux tower data, precipitation, and PET for Wombat Forest, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S3.2 Whroo

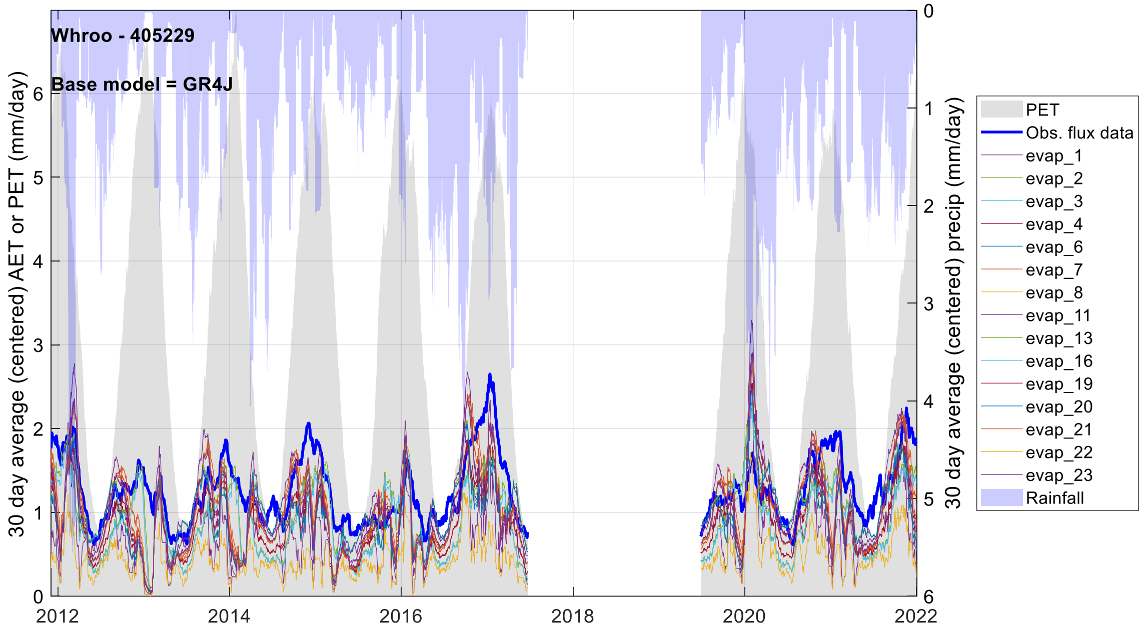


Fig. S4 Observed flux tower data, precipitation, and PET for Whroo, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).

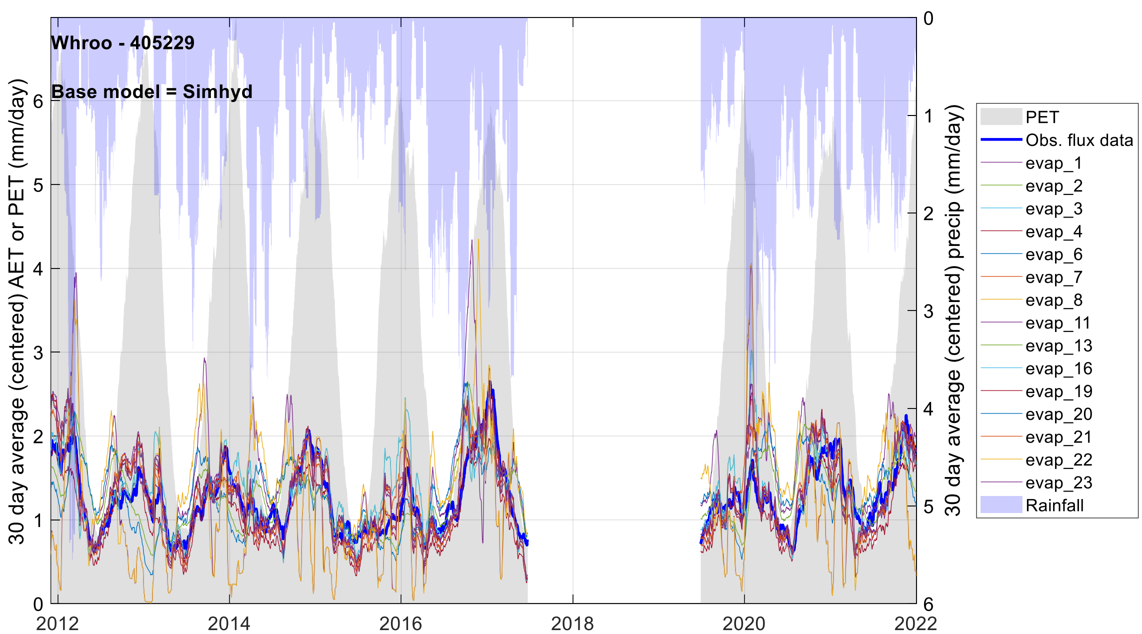


Fig. S5 Observed flux tower data, precipitation, and PET for Whroo, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

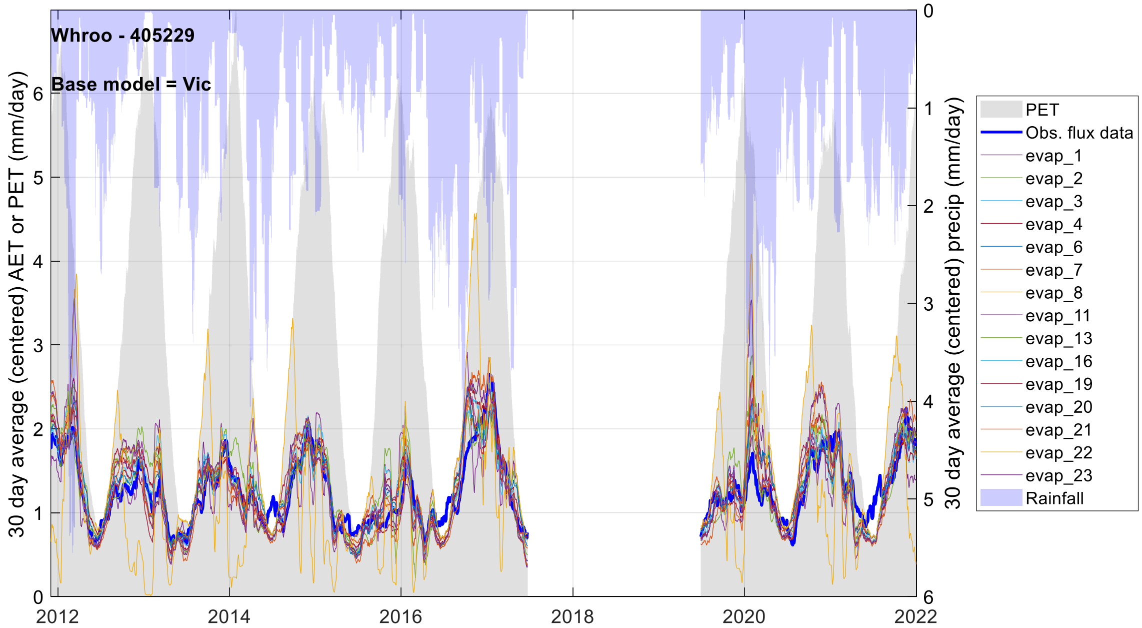


Fig. S6 Observed flux tower data, precipitation, and PET for Whroo, Victoria, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S3.3 Litchfeild

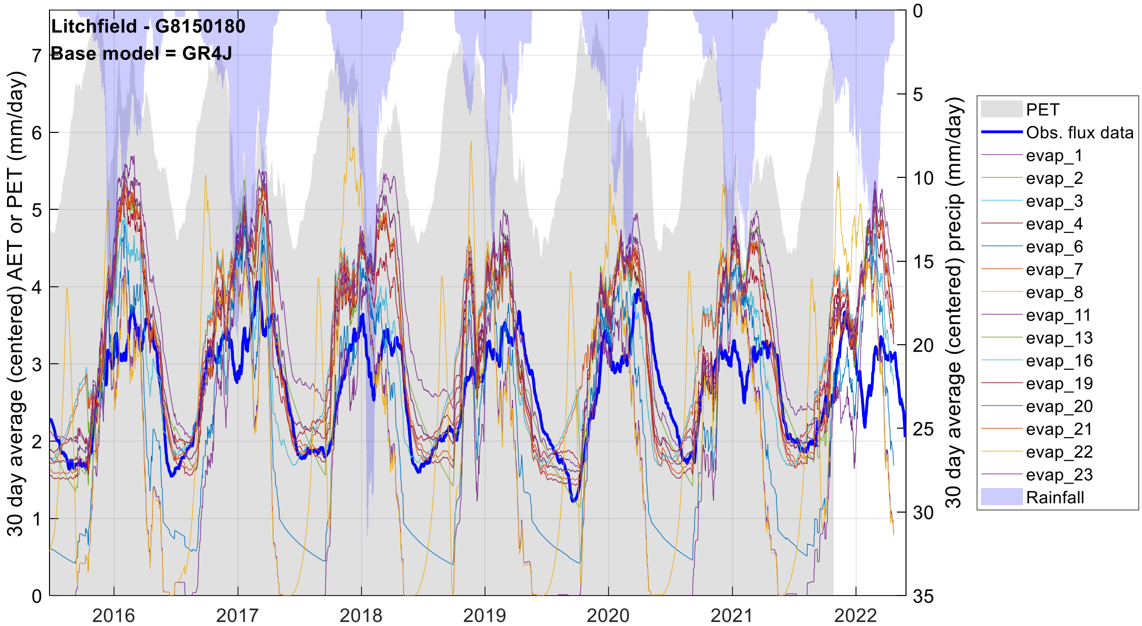


Fig. S7 Observed flux tower data, precipitation, and PET for Litchfield, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).

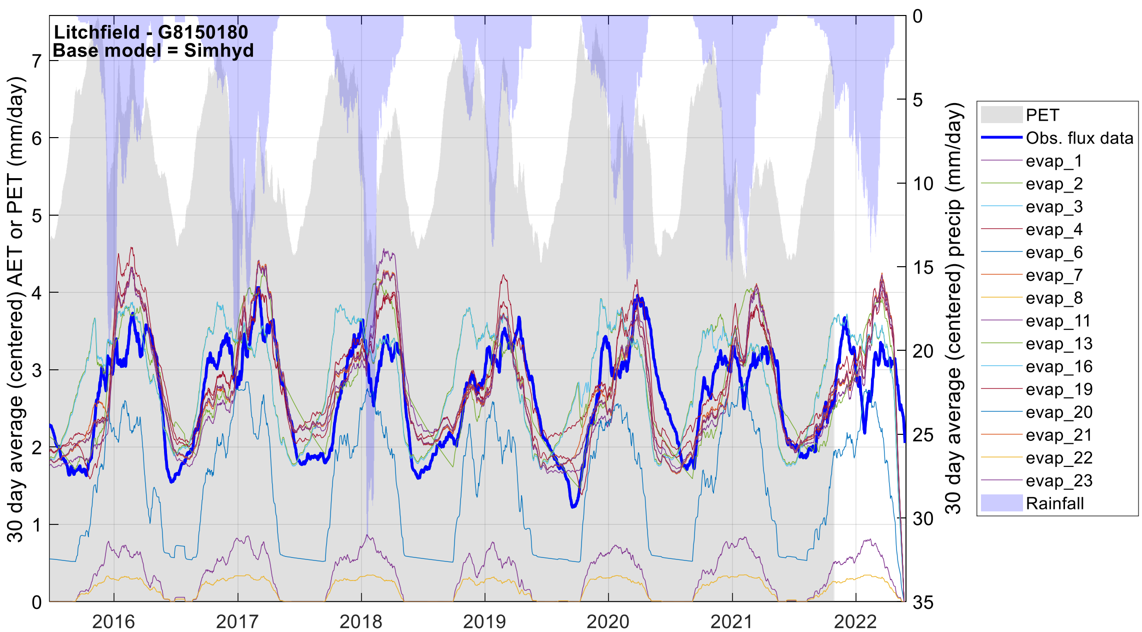
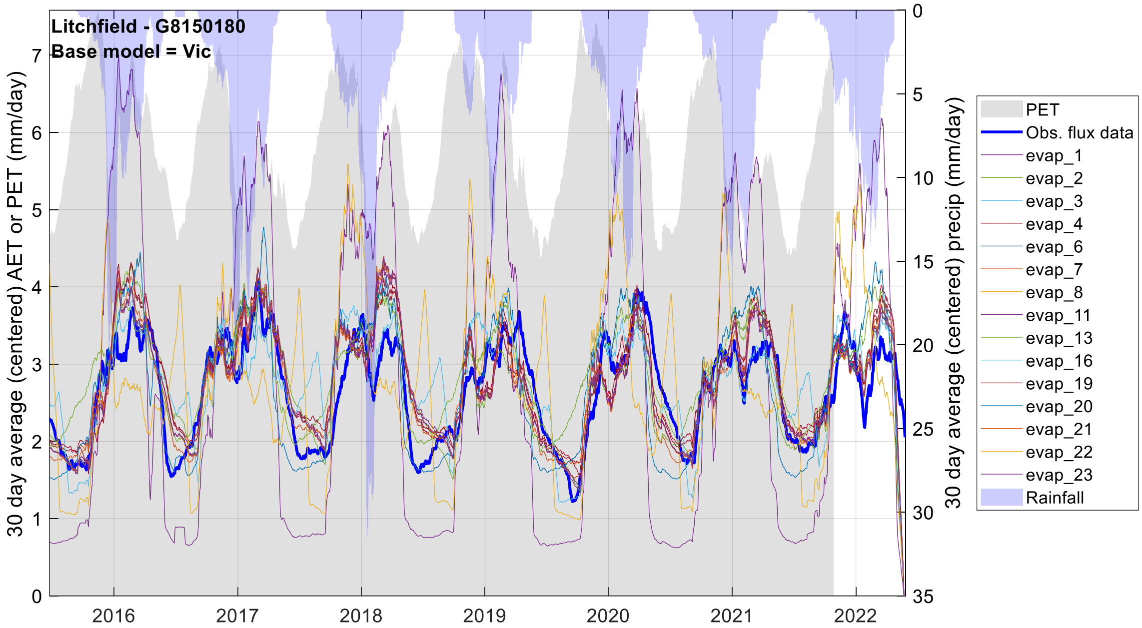
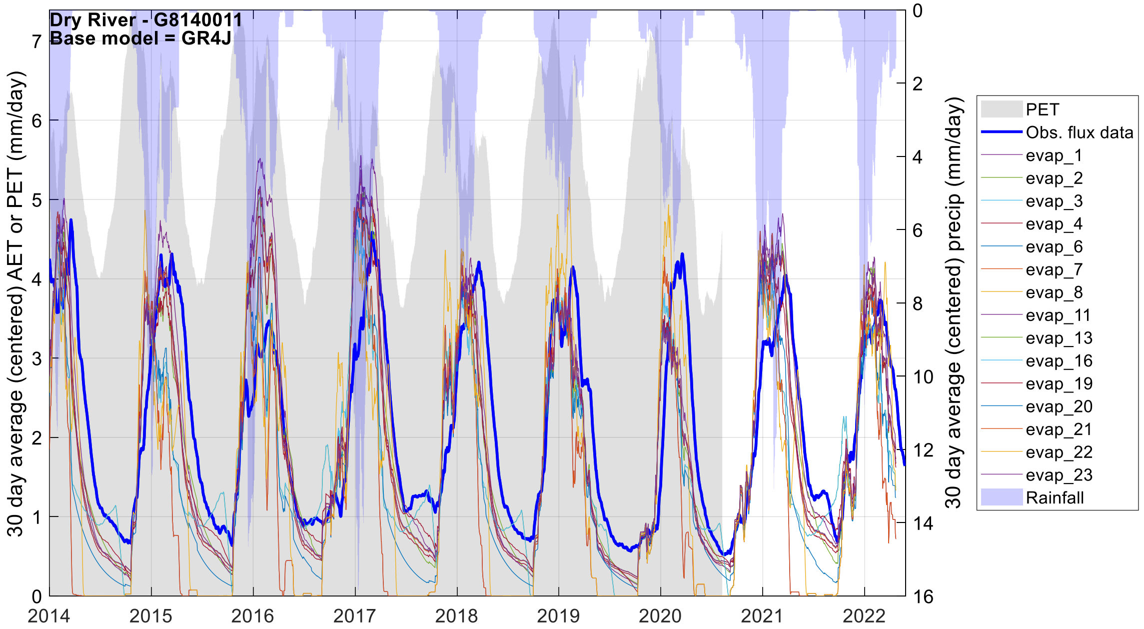


Fig. S8 Observed flux tower data, precipitation, and PET for Litchfield, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).



40 **Fig. S9 Observed flux tower data, precipitation, and PET for Litchfield, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).**

S3.4 Dry River



45 **Fig. S10 Observed flux tower data, precipitation, and PET for Dry River, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).**

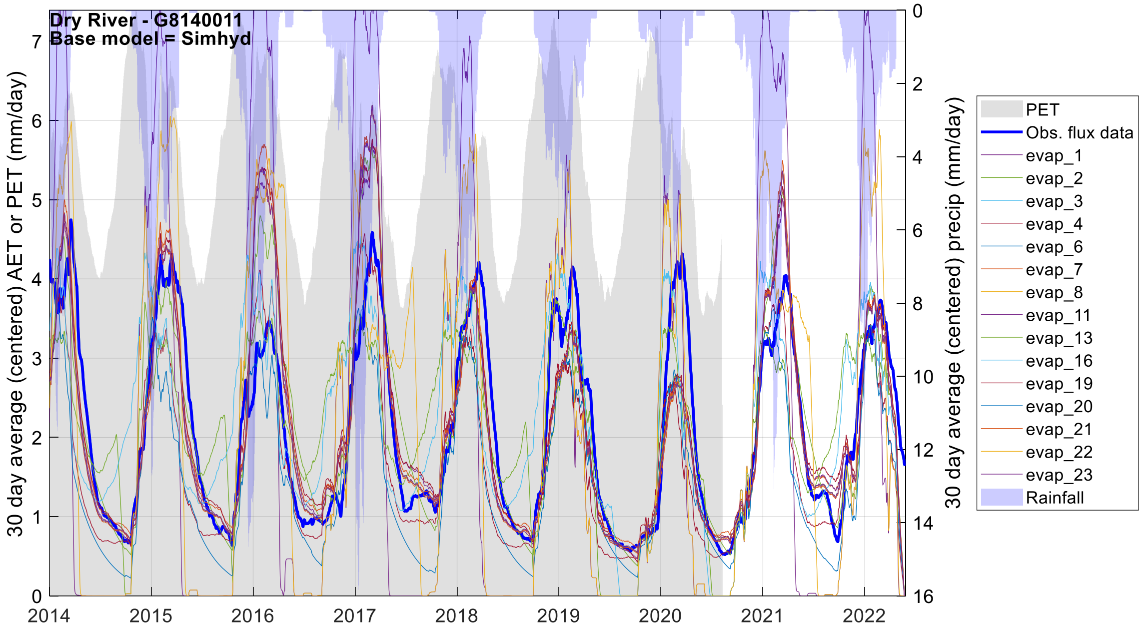


Fig. S11 Observed flux tower data, precipitation, and PET for Dry River, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

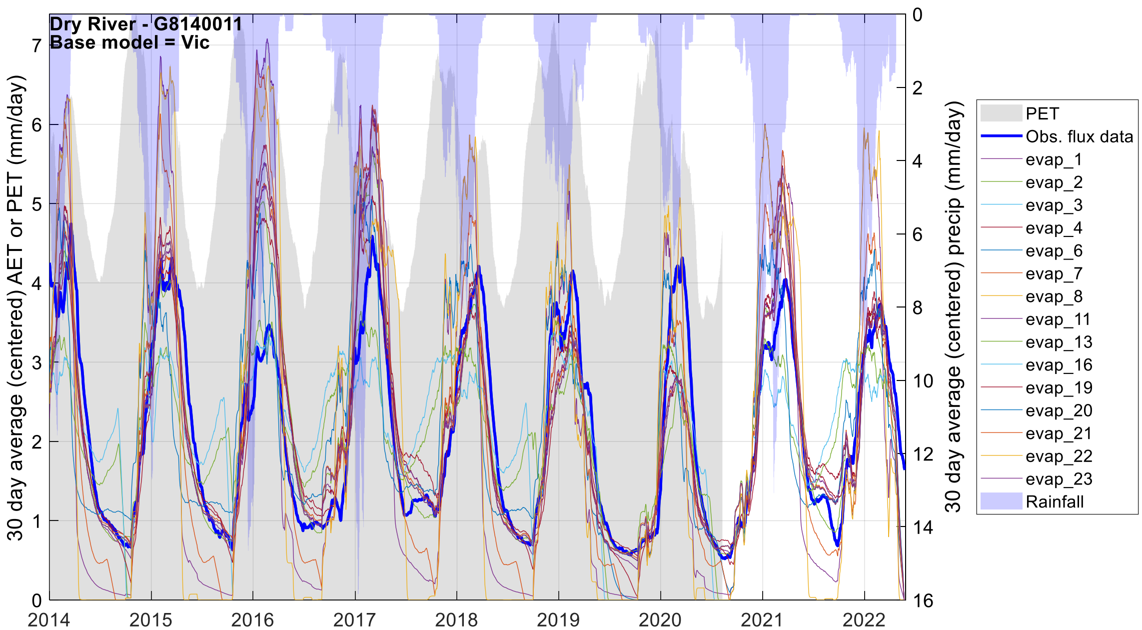


Fig. S12 Observed flux tower data, precipitation, and PET for Dry River, Northern Territory, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S3.5 Robson Creek

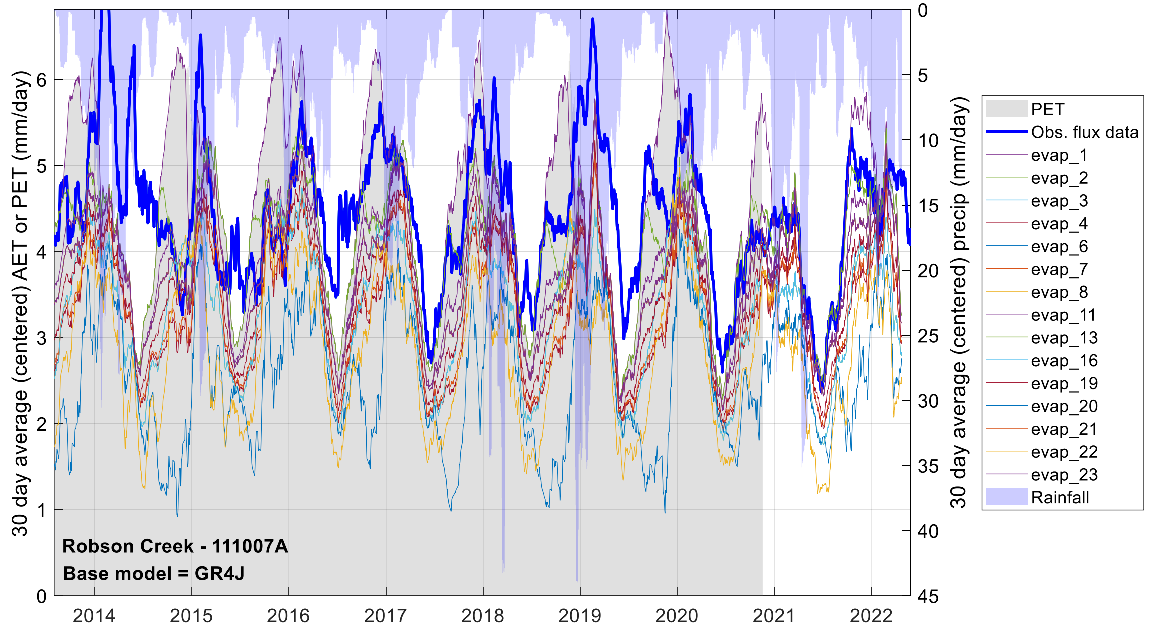


Fig. S13 Observed flux tower data, precipitation, and PET for Robson Creek, Queensland, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).

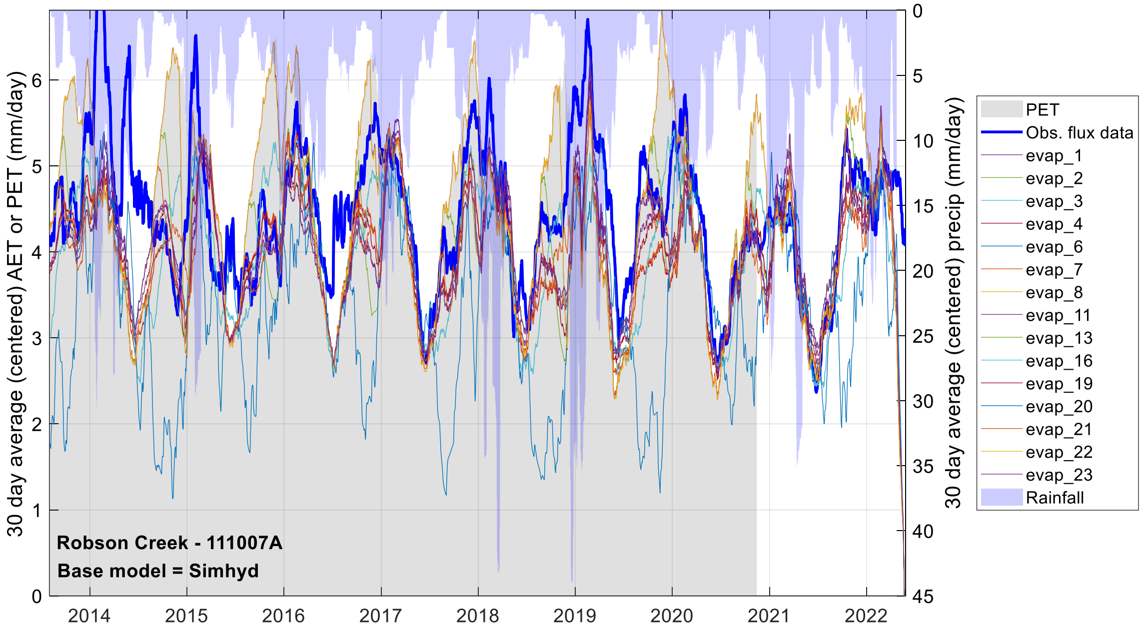


Fig. S14 Observed flux tower data, precipitation, and PET for Robson Creek, Queensland, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

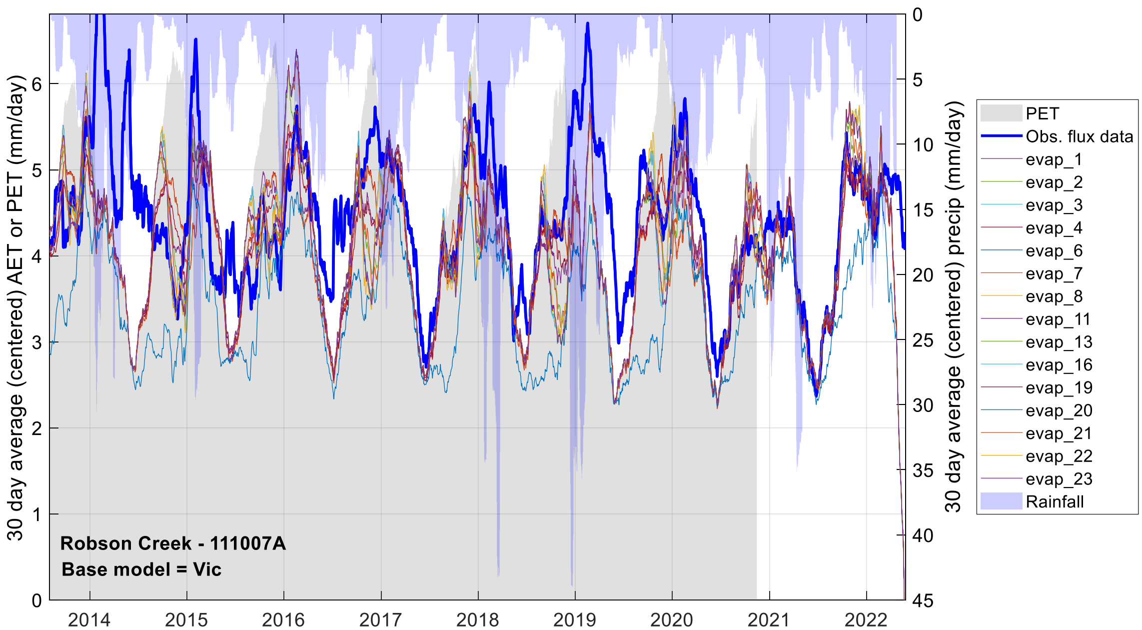


Fig. S15 Observed flux tower data, precipitation, and PET for Robson Creek, Queensland, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S3.6 Gingin

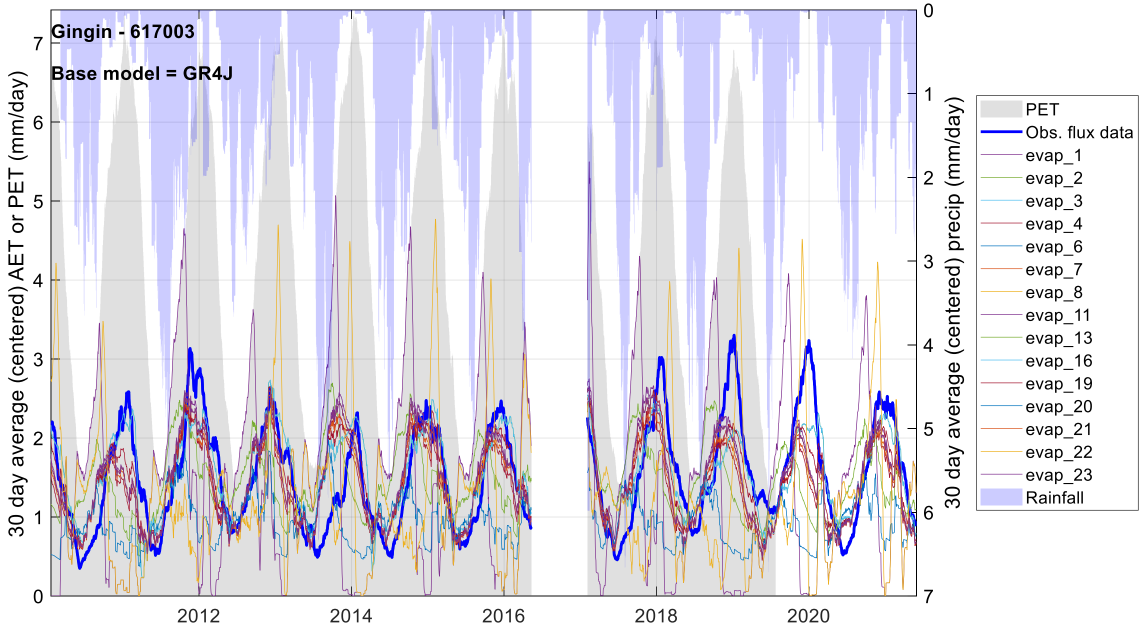


Fig. S16 Observed flux tower data, precipitation, and PET for Gingin, Western Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).

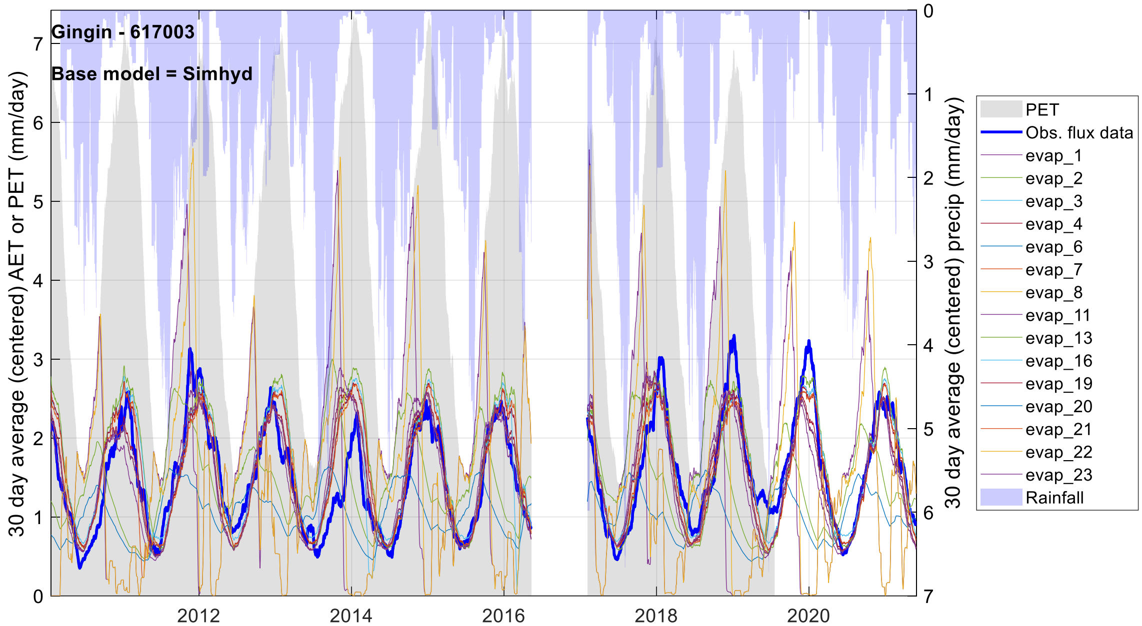


Fig. S17 Observed flux tower data, precipitation, and PET for Gingin, Western Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

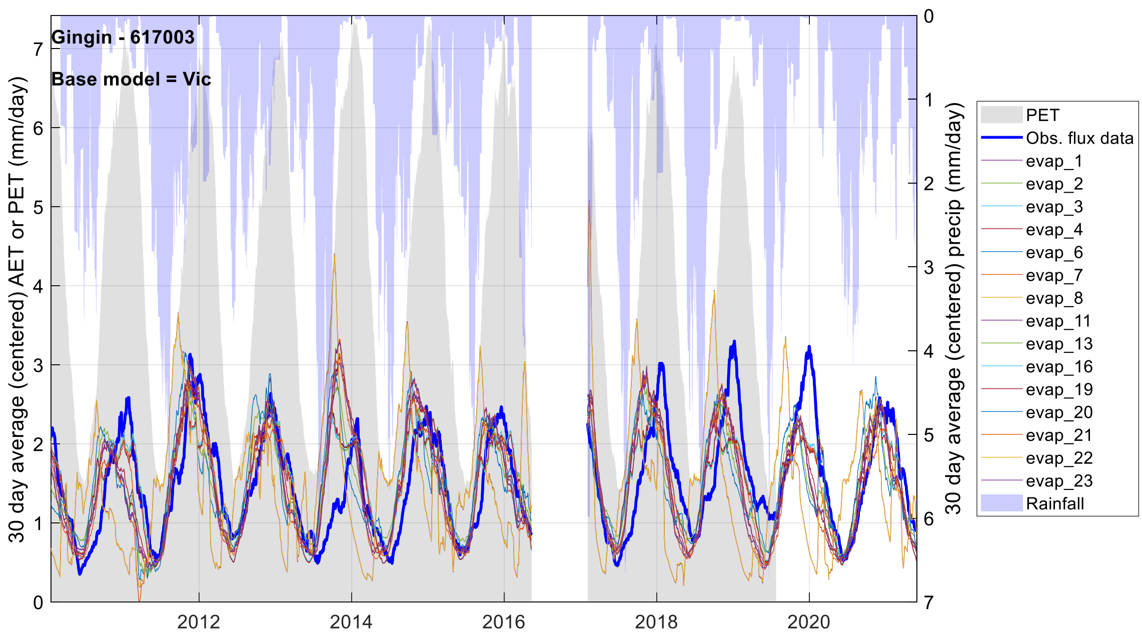
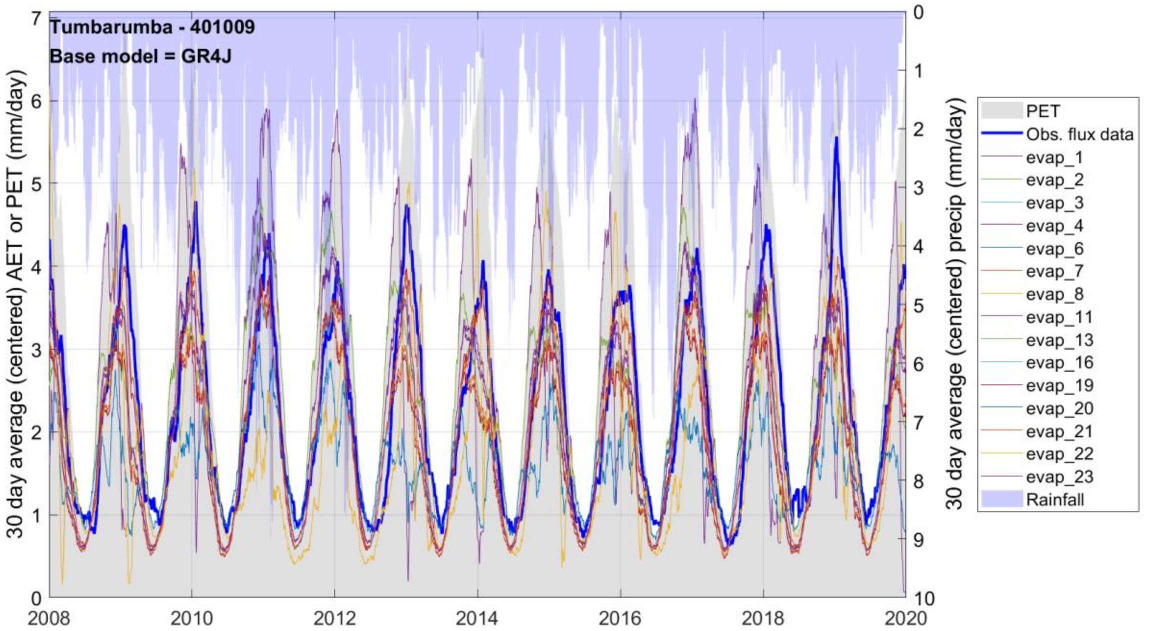


Fig. S18 Observed flux tower data, precipitation, and PET for Gingin, Western Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S3.7 Tumbarumba



80 **Fig. S19 Observed flux tower data, precipitation, and PET for Tumbarumba, New South Wales, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (GR4J).**

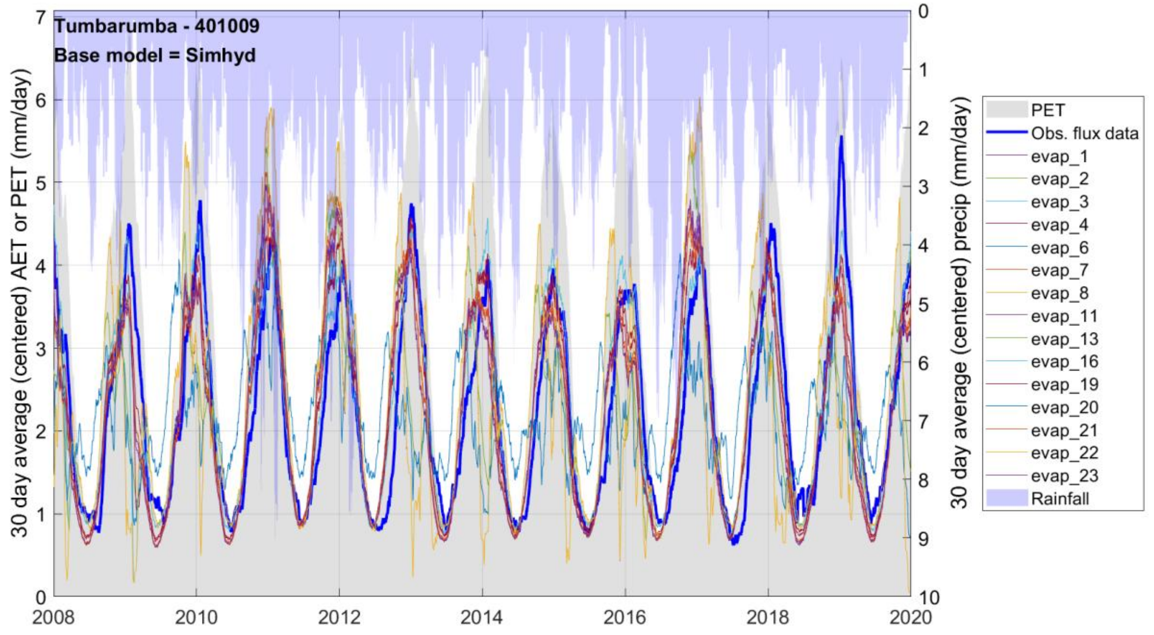


Fig. S20 Observed flux tower data, precipitation, and PET for Tumbarumba, New South Wales, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Simhyd).

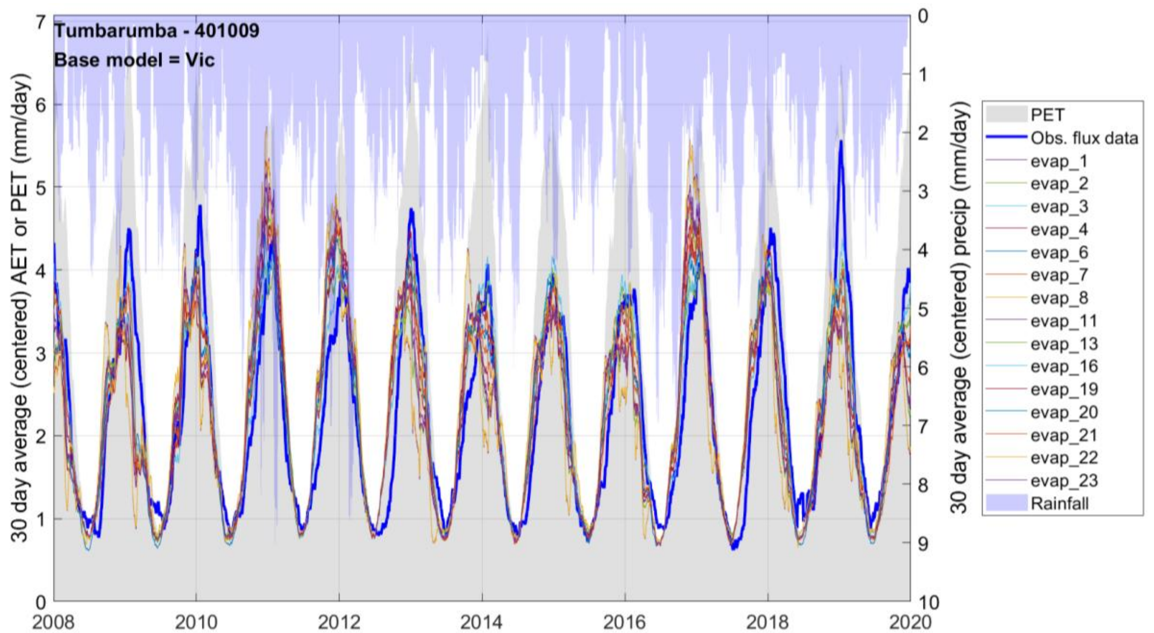


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Fig. S21 Observed flux tower data, precipitation, and PET for Tumbarumba, New South Wales, Australia. 15 calibrations showing simulated AET at the site (evap_1, evap_2, etc.) for the base model (Vic).

S4. Objective function value tables

Table S3-S6: Summary of AET equation objective function values (OFVs) and rankings (1 = best; 15 = worst) based on combined streamflow and actual evapotranspiration (AET) OFVs. Tables are GR4J, Simhyd and Vic respectively, showing all OFVs and rankings for each AET equation combination at each site.

Table S3: GR4J

	Wombat		Whroo		Litchfield		DryRiver		RobsonCreek		Gingin		Tumbarumba	
Evap eqn	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank
1	0.49	14	-0.02	13	-0.48	15	0.13	15	0.61	13	-0.03	15	0.51	15
2	0.72	12	0.14	8	0.51	12	0.49	7	0.68	10	0.45	12	0.76	12
3	0.76	9	0.14	5	0.54	8	0.50	4	0.70	3	0.70	7	0.83	8
4	0.74	11	0.15	2	0.52	11	0.46	9	0.69	9	0.68	11	0.79	11
6	0.76	7	0.14	7	0.54	8	0.50	4	0.70	3	0.70	7	0.83	8
7	0.75	10	-0.14	14	0.54	5	0.50	6	0.69	8	0.69	10	0.80	10
8	0.76	9	0.14	5	0.54	8	0.50	4	0.70	3	0.70	7	0.83	8
11	0.76	5	0.08	12	0.52	10	0.46	8	0.69	7	0.70	9	0.84	5
13	0.79	3	0.10	11	0.58	2	0.42	12	0.66	12	0.71	1	0.87	3
16	0.79	4	0.10	10	0.58	3	0.42	11	0.66	11	0.71	2	0.87	2
19	0.80	1	0.17	1	0.63	1	0.53	1	0.69	6	0.71	3	0.87	4
20	0.54	13	0.14	9	0.26	13	0.42	10	0.52	15	0.28	13	0.52	14
21	0.79	2	0.15	3	0.58	4	0.13	14	0.70	5	0.70	4	0.87	1
22	0.26	15	-0.33	15	-0.32	14	0.22	13	0.59	14	0.21	14	0.69	13
23	0.76	7	0.14	7	0.54	8	0.50	4	0.70	3	0.70	7	0.83	8

Table S4: Simhyd

	Wombat		Whroo		Litchfield		DryRiver		RobsonCreek		Gingin		Tumbarumba	
Evap eqn	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank
1	0.73	14	0.48	13	-0.05	15	0.18	14	0.60	10	0.24	14	0.68	14
2	0.79	6	0.61	2	0.66	3	0.65	5	0.60	7	0.57	12	0.76	11
3	0.76	12	0.52	11	0.66	6	0.66	4	0.60	3	0.65	7	0.77	4
4	0.80	4	0.62	1	0.67	2	0.57	9	0.58	14	0.67	4	0.75	12
6	0.76	11	0.52	11	0.66	8	0.66	2	0.60	5	0.65	9	0.77	6
7	0.80	5	0.55	7	0.65	10	0.65	6	0.58	13	0.64	10	0.76	9
8	0.76	9	0.52	11	0.66	5	0.66	4	0.60	6	0.65	7	0.77	3
11	0.75	13	0.56	6	0.65	9	0.63	7	0.60	1	0.63	11	0.77	7
13	0.81	2	0.53	8	0.61	12	0.50	10	0.60	8	0.72	1	0.76	10
16	0.81	3	0.57	5	0.62	11	0.46	11	0.60	9	0.72	2	0.76	8
19	0.82	1	0.59	4	0.68	1	0.63	8	0.59	12	0.72	3	0.78	2
20	0.77	7	0.60	3	0.46	13	0.40	12	0.39	15	0.56	13	0.52	15
21	0.77	8	0.46	14	0.66	4	0.26	13	0.60	2	0.67	5	0.80	1
22	0.32	15	0.07	15	0.34	14	0.04	15	0.60	11	0.23	15	0.68	13
23	0.76	11	0.52	11	0.66	8	0.66	2	0.60	5	0.65	9	0.77	6

Table S5: VIC

	Wombat		Whroo		Litchfield		DryRiver		RobsonCreek		Gingin		Tumbarumba	
Evap eqn	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank	OFV	Rank
1	0.49	14	0.02	15	-0.57	15	-0.03	15	0.58	14	0.01	14	0.53	14
2	0.70	12	0.42	13	0.62	10	0.59	4	0.65	12	0.38	12	0.69	12
3	0.74	9	0.51	8	0.64	6	0.58	6	0.65	11	0.70	7	0.74	10
4	0.81	1	0.54	2	0.65	2	0.52	10	0.66	5	0.70	10	0.80	2
6	0.74	11	0.51	6	0.64	8	0.58	8	0.65	9	0.70	9	0.74	8
7	0.77	4	0.51	9	0.64	4	0.75	2	0.66	4	0.70	5	0.78	3
8	0.74	9	0.51	8	0.64	6	0.58	6	0.65	11	0.70	7	0.74	10
11	0.74	7	0.51	12	0.63	9	0.59	3	0.66	2	0.70	11	0.76	6
13	0.75	5	0.51	10	0.61	11	0.47	12	0.65	6	0.73	4	0.76	5
16	0.75	6	0.51	11	0.60	12	0.42	13	0.65	7	0.73	2	0.76	4
19	0.77	2	0.52	4	0.67	1	0.75	1	0.68	1	0.74	1	0.81	1
20	0.43	15	0.54	1	0.22	14	0.50	11	0.43	15	-0.07	15	0.37	15
21	0.77	3	0.53	3	0.64	3	0.58	9	0.66	3	0.73	3	0.74	11
22	0.56	13	0.06	14	0.27	13	0.03	14	0.58	13	0.05	13	0.53	13
23	0.74	11	0.51	6	0.64	8	0.58	8	0.65	9	0.70	9	0.74	8

S5. Litchfield calibration, GR4J cal AET only.

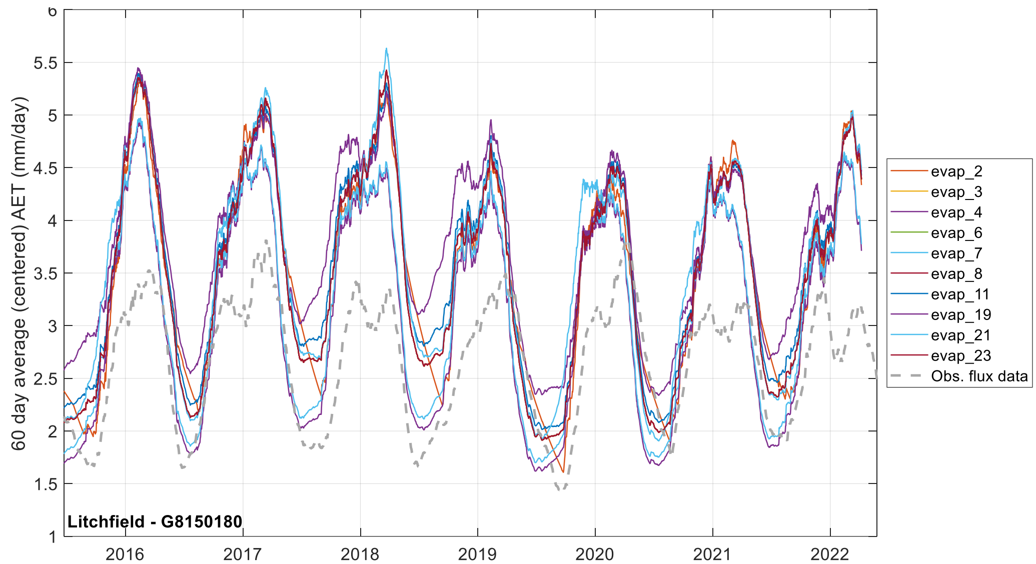

Fig. S22: Modelled AET vs. observed flux tower data for the best equations (in this specific case) at Litchfield, under AET-only calibration, for GR4J only (streamflow not considered).

S6. Signature scatterplots

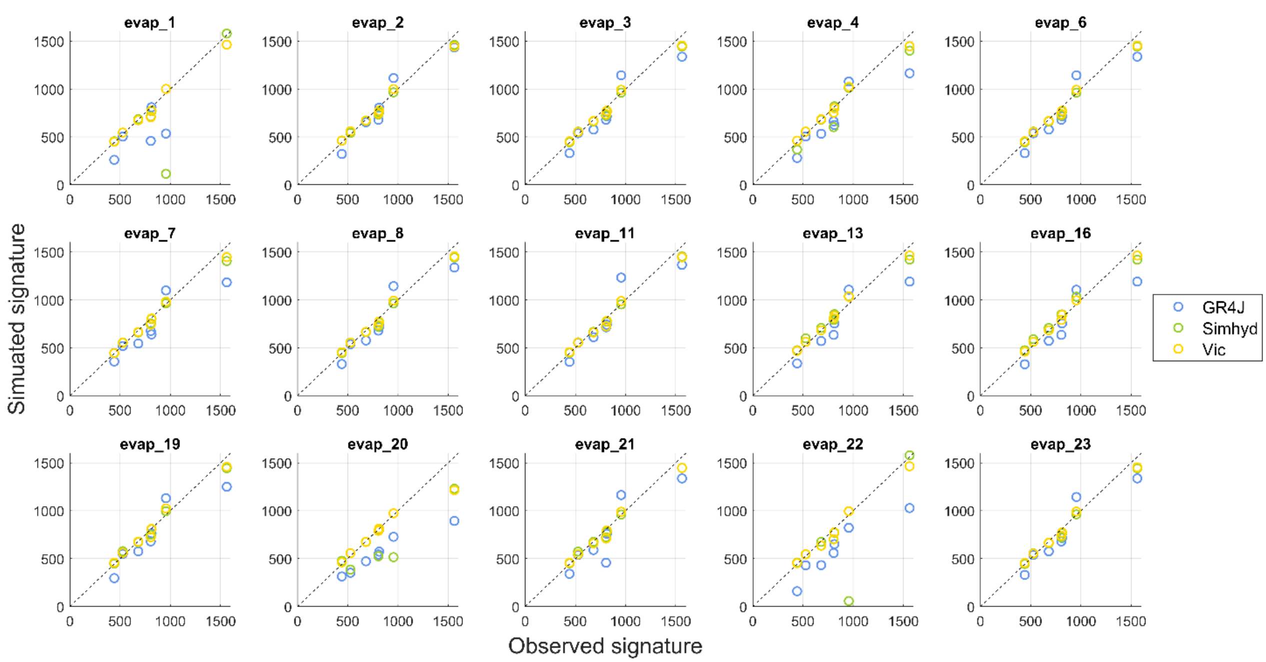

Fig. S23 Long-term median: observed vs. simulated AET across all equations and models. Annual signature.

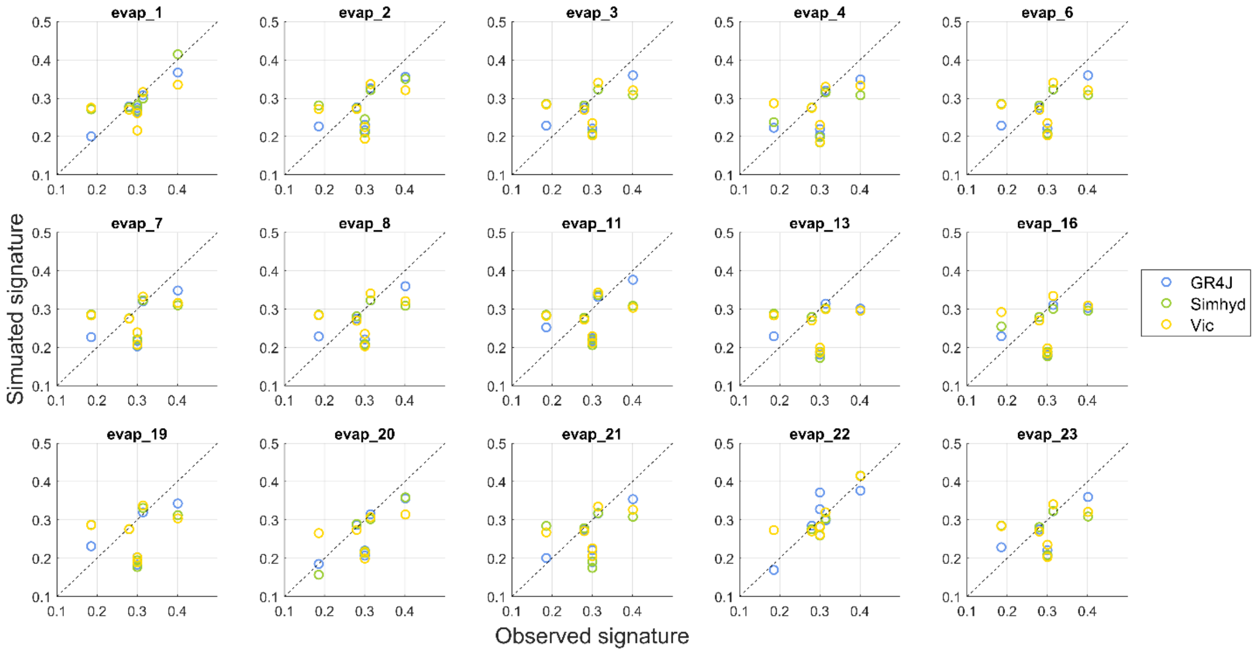

Fig. S24 Interannual variability: observed vs. simulated AET across all equations and models. Annual signature, expressed as the coefficient of variation of annual AET.

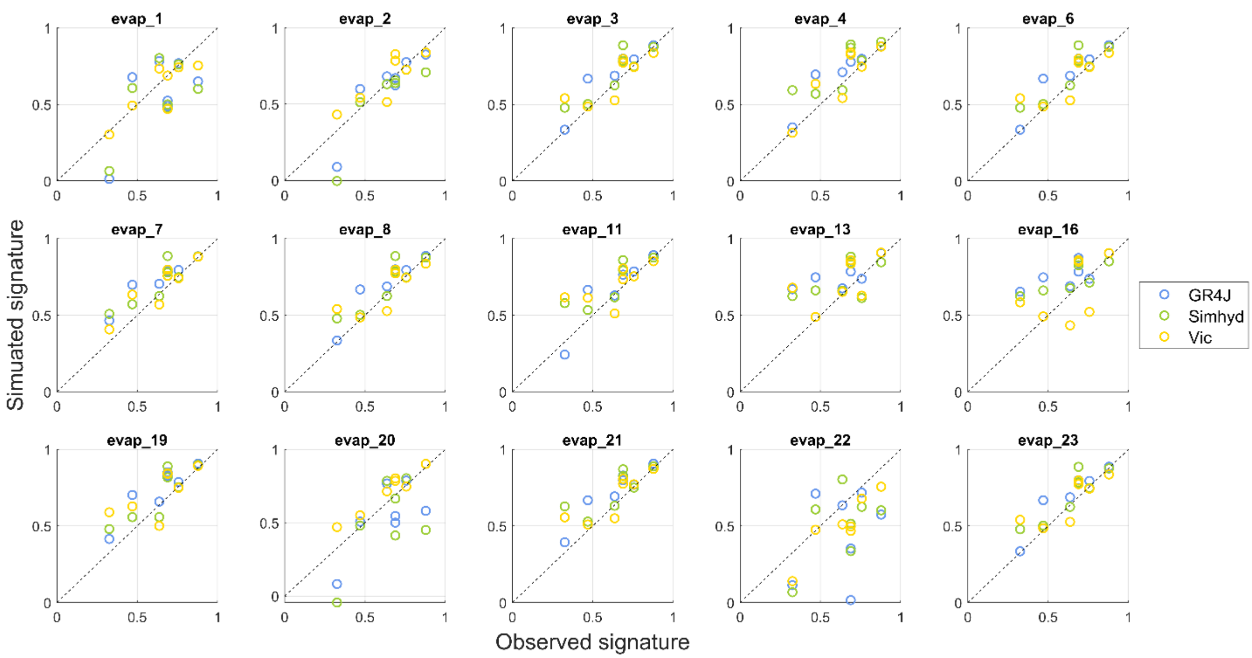

Fig. S25 Periodicity: observed vs. simulated AET across all equations and models. Seasonal signature, quantifying the tendency for AET variation to recur with the seasonal cycle (12 month period), calculated as the lag-12 autocorrelation of monthly AET.

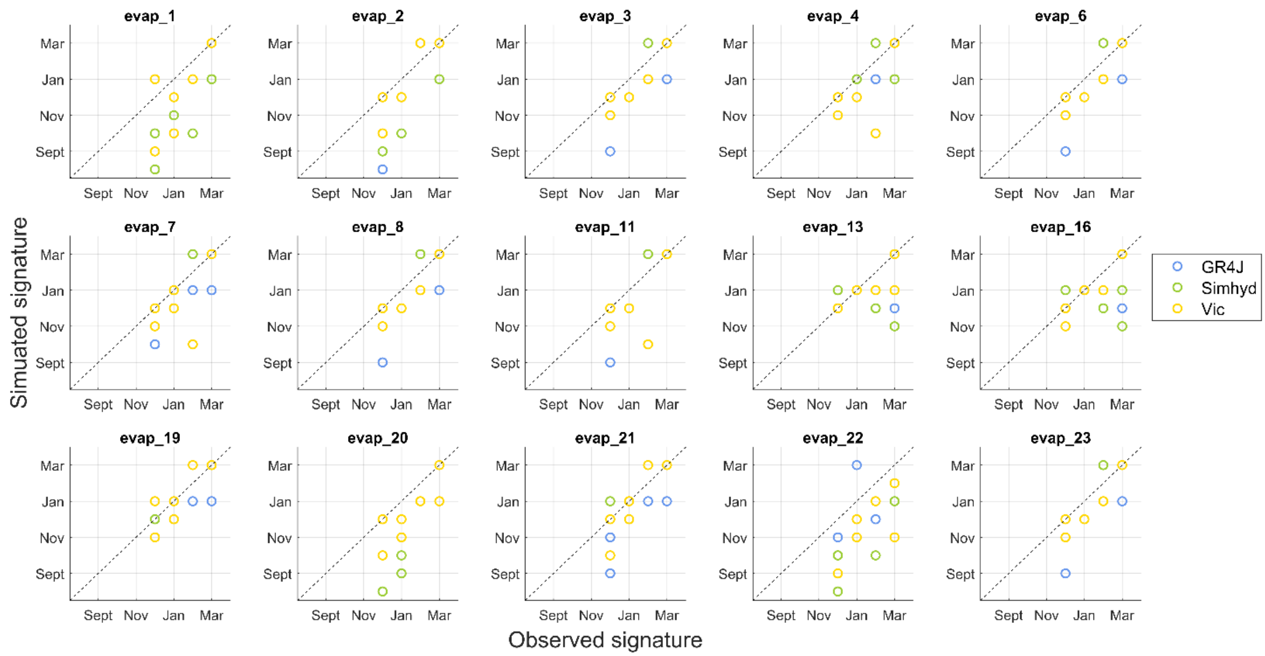

Fig. S26 Seasonal peak timing: observed vs. simulated AET across all equations and models. Seasonal signature, determined from monthly timestep data by examining the median AET for each of the 12 calendar months and identifying the month with the maximum median AET.

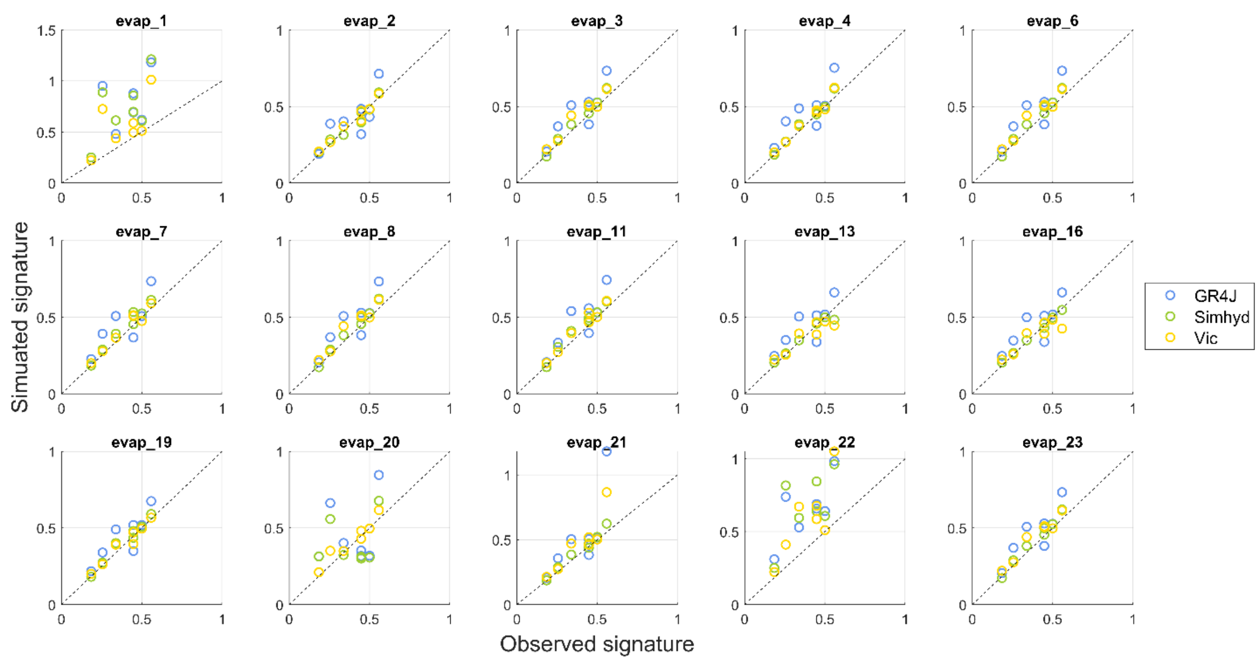

Fig. S27 Monthly variability: observed vs. simulated AET across all equations and models. Monthly signature.

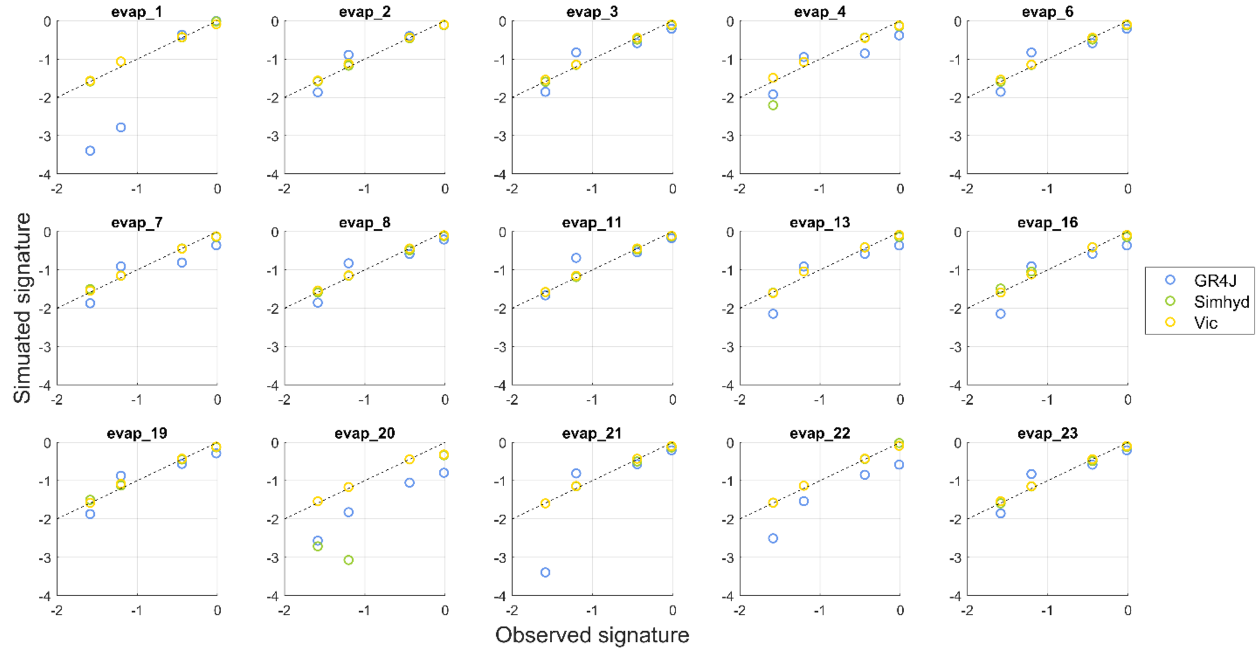

Fig. S28 Water stress: observed vs. simulated AET across all equations and models. Monthly water stress signature, defined as the difference between average monthly PET and average monthly AET, divided by the average monthly PET. Higher values of this water stress signature indicate less rainfall and/or high PET.

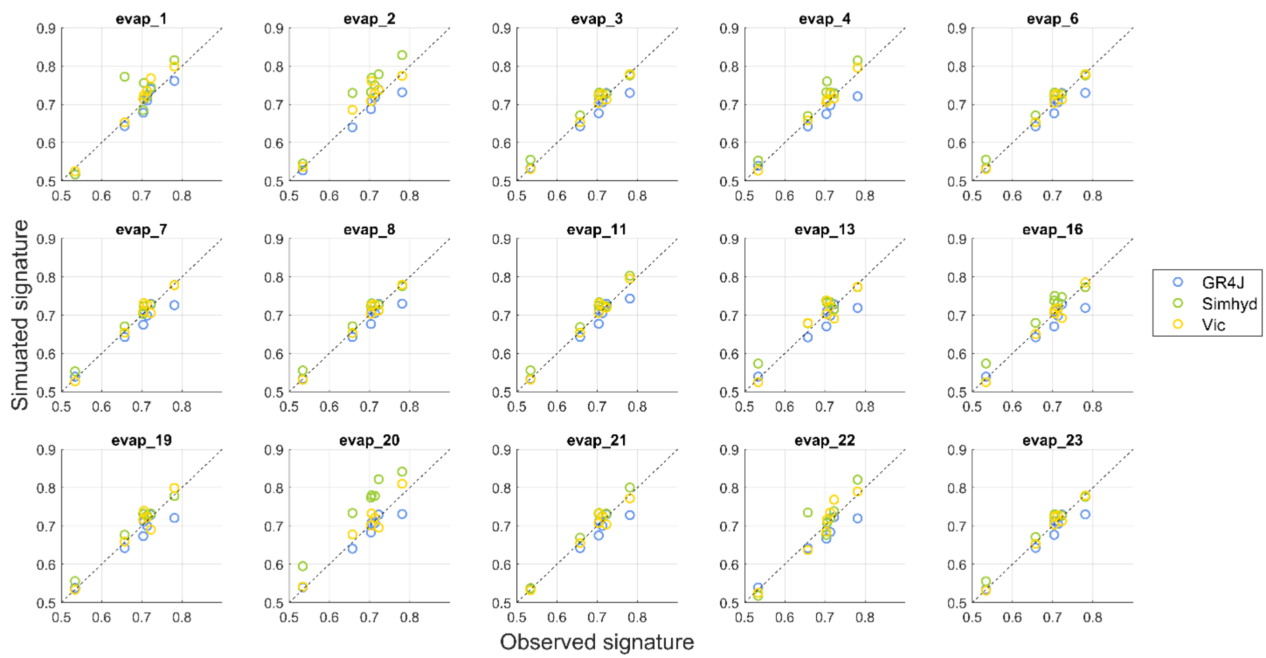

Fig. S29 Index of AET responsiveness to a rainfall event: observed vs. simulated AET across all equations and models. Event scale signature, calculated by selecting rainfall events greater than a threshold, identify the maximum daily AET value after the given

rainfall event, up to a certain window duration (in days) after that event. Then a standard linear correlation equation is applied to the anomalies of these ordered pairs of numbers.

S7. Split sample test, calibration and evaluation dates

Table S6. Dates used in calibration of split sample tests. Note the extended

Catchment / Flux tower	First calibration / second evaluation dates	Second calibration / first evaluation dates
407221 - Wombat Forest	21-Jan-2010 → 09-Feb-2015	09-Feb-2015 → 28-Feb-2020
405229 - Whroo	02-Dec-2011 → 16-Dec-2016	16-Dec-2016 → 31-Dec-2021
G8150180 - Litchfield	24-Jun-2015 → 26-Oct-2018	26-Oct-2018 → 27-Feb-2022
G8140011 - Dry River	01-Jan-2014 → 29-Jan-2018	30-Jan-2018 → 27-Feb-2022
111007A - Robson Creek	02-Aug-2013 → 14-Nov-2017	15-Nov-2017 → 27-Feb-2022
617003 - Gingin	21-Jan-2010 → 24-Sep-2015	25-Sep-2015 → 28-May-2021
401009 - Tumbarumba	01-Jan-2008 → 31-Dec-2013	31-Dec-2013 → 31-Dec-2019

S8. Additional PET analysis

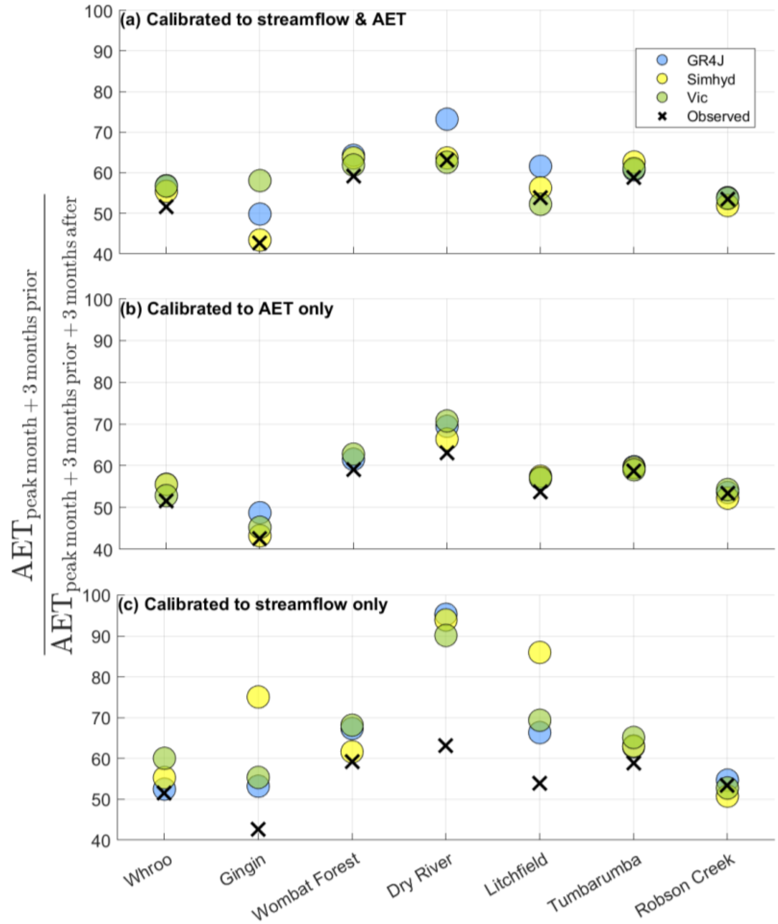

Fig. S30 Percentage of AET which occurs in the first half of the observed seasonal peak, for each catchment and model combination, utilising evapotranspiration equation evap_19. The models are calibrated to (a) streamflow and AET, (b) AET only, and (c) streamflow only. Note: The 7-month period is determined by identifying the peak month of observed AET (the most common peak month across the flux data time period—one of the AET signatures). The values shown represent the total AET accumulated in the first four months (including the peak month) as a percentage of the total AET over the full 7-month period. Catchments are ordered by increasing total AET over the 7-month period. This figure is identical to figure 8 in the report, however this figure was created using PET Morton's point potential, instead of Morton's wet environment.

S9. Evap_19 calibrated parameter values

Table S7. Calibrated additional parameter values (p1 and p2) for evapotranspiration equation Evap_19, across all seven catchments and three models.

Evap_19	GR4J		Simhyd		VIC	
	p1	p2	p1	p2	p1	p2

Wombat Forest	0.60	0.24	0.83	0.24	0.54	0.16
Whroo	0.51	0.88	0.80	0.45	0.84	1.00
Litchfield	0.57	0.29	0.61	0.30	0.58	0.37
Dry River	0.64	0.61	0.88	0.75	1.00	0.57
Robson Creek	1.00	0.76	1.00	0.25	1.00	0.34
Gingin	0.54	0.34	0.41	0.05	0.28	0.05
Tumbarumba	0.59	0.05	0.87	0.17	0.79	0.23