

1. Catchment information

Table S1. Study catchment characteristics (Australian Bureau of Meteorology; <http://www.bom.gov.au/water/hrs/>). Soil type is based on the FAO soil map of the world (FAO, 2003) and vegetation characteristics from GLCC1.2 (ECMWF, 2016) with T_L and T_H the dominant low and high vegetation types and C_L and C_H the fractional coverage of low and high vegetation.

Catchment name	Station ID	Coordinates	Climate region	Area (km ²)	Soil type	T_L	T_H	C_L (-)	C_H (-)
East Alligator River (EA)	G8210010	133.332°E, 12.717°S	Tropical	2398	coarse	Tall grass	Interrupted forest	0.68	0.32
East Baines River (EB)	G8110004	130.034°E, 15.766°S	Tropical	2443	coarse	Semidesert		1.00	0.00
Gregory River (G)	912101A	139.252°E, 18.643°S	Tropical	12652	medium fine	Short grass		1.00	0.00
Herbert River (He)	116006B	145.922°E, 18.491°S	Tropical	7487	fine	Tall grass	Evergreen broadleaf	0.01	0.99
Mitchell River (Mi)	919003A	144.290°E, 16.472°S	Tropical	7734	coarse	Tall grass	Interrupted forest	0.43	0.57
Normanby River (No)	105101A	144.839°E, 15.281°S	Tropical	2306	coarse	Tall grass		0.01	0.99
Wenlock River (W)	925001A	142.638°E, 12.454°S	Tropical	3290	medium fine	Tall grass		0.00	1.00
Abercrombie River (A)	412028	149.325°E, 33.955°S	Temperate	2631	medium	Crops, mixed farming	Interrupted forest	0.23	0.76
Dogwood Creek (D)	422202B	150.179°E, 26.709°S	Temperate	2882	medium fine	Tall grass	Evergreen broadleaf	0.14	0.86
Murrumbidgee River (Mu)	410761	149.101°E, 35.540°S	Temperate	5158	medium fine	Tall grass	Interrupted forest	0.16	0.84
Namoi River (Na)	419005	150.778°E, 30.678°S	Temperate	2532	medium	Crops, mixed farming	Interrupted forest	0.33	0.67
Paroo River (P)	424201A	144.786°E, 28.689°S	Temperate	22885	medium	Semidesert		1.00	0.00
Avoca River (Av)	408200	143.299°E, 36.438°S	Mediterranean	2677	medium	Crops, mixed farming	Interrupted forest	0.79	0.21
Kent River (K)	604053	117.087°E, 34.888°S	Mediterranean	1786	coarse	Crops, mixed farming	Interrupted forest	0.65	0.35
Reedy Creek (R)	403209A	146.345°E, 36.332°S	Mediterranean	5506	medium fine	Crops, mixed farming		0.02	0.98

Table S2. Hydrological characteristics of the study catchments with long-term (1973–2010) annual mean values for precipitation (\bar{P}), discharge (\bar{Q}) and potential evaporation (\bar{E}_p), aridity index (I_A), seasonality index (I_S), time-lag between maximum monthly mean precipitation and potential evaporation (φ) and root zone storage capacity estimates from the memory method ($S_{r,MM}$) and in the HTESSEL CTR model ($S_{r,CTR}$).

Catchment	\bar{P} (mm year $^{-1}$)	\bar{Q} (mm year $^{-1}$)	\bar{E}_p (mm year $^{-1}$)	I_A (-)	I_S (-)	φ (months)	$S_{r,MM}$ (mm)	$S_{r,CTR}$ (mm)
EA	1539	586	953	1.31	0.97	3	389	535
EB	879	134	745	2.53	0.99	3	300	535
G	509	55	453	3.96	0.95	1	194	513
He	1140	326	814	1.46	0.70	2	409	491
Mi	854	251	603	2.05	0.89	2	410	535
No	1207	288	920	1.40	0.85	2	722	535
W	1577	472	1105	1.10	0.95	3	633	725
A	787	94	693	1.55	0.07	0	208	566
D	661	24	637	2.69	0.38	0	266	725
Mu	588	59	530	2.04	0.08	2	205	725
Na	802	84	718	1.76	0.26	0	165	566
P	417	26	392	4.38	0.37	1	125	566
Av	505	8	497	2.69	0.25	5	160	566
K	889	41	848	1.36	0.50	6	315	535
R	1243	109	1133	1.02	0.26	6	487	725

2. Reference and modeled long-term annual mean fluxes

Table S3. Long-term (1975–2010) annual mean reference and modeled (HTESSEL CTR and MD models) precipitation (\bar{P}), discharge (\bar{Q}) and evaporation (\bar{E}) fluxes in the study catchments.

	\bar{P} (mm year $^{-1}$)	\bar{Q} (mm year $^{-1}$)			\bar{E} (mm year $^{-1}$)			
Catchment	GSPW-3	Station observations	CTR	MD	Water balance	FLUXCOM	CTR	MD
EA	1429	590	423	436	839	753	1002	989
EB	788	132	176	167	656	587	612	621
G	514	50	19	42	464	434	498	471
He	1051	309	198	202	742	694	847	843
Mi	1155	231	256	264	923	622	891	883
No	1405	270	570	597	1135	765	827	801
W	1538	455	675	675	1082	900	856	857
A	769	87	69	85	682	634	702	682
D	674	25	34	36	648	586	638	635
Mu	686	60	77	96	626	464	615	590
Na	889	84	96	110	805	658	790	778
P	394	24	18	22	370	333	372	371
Av	531	7	6	20	524	449	529	511
K	1066	41	200	200	1024	730	867	866
R	1056	98	305	312	958	709	755	749

Table S4. Percent biases of modeled (HTESSEL CTR and MD models) long-term (1975–2010) annual mean discharge (\bar{Q}) and evaporation (\bar{E}) with for \bar{Q} station observations as reference data and for \bar{E} water balance and FLUXCOM as reference data.

	\bar{Q} (mm year $^{-1}$)		\bar{E} (mm year $^{-1}$)			
	Station observations		Water balance		FLUXCOM	
Catchment	CTR	MD	CTR	MD	CTR	MD
EA	-28%	-26%	19.4%	17.9%	32.9%	31.3%
EB	33%	26%	-6.7%	-5.3%	4.3%	5.7%
G	-63%	-14%	7.3%	1.5%	14.8%	8.6%
He	-36%	-35%	14.2%	13.6%	22.0%	21.4%
Mi	11%	14%	-3.5%	-4.4%	43.2%	41.9%
No	111%	121%	-27.1%	-29.4%	8.0%	4.6%
W	48%	48%	-20.9%	-20.8%	-4.9%	-4.8%
A	-20%	-2%	3.0%	0.0%	10.7%	7.6%
D	34%	41%	-1.6%	-2.0%	8.8%	8.4%
Mu	28%	60%	-1.7%	-5.7%	32.7%	27.3%
Na	14%	31%	-1.8%	-3.4%	20.1%	18.2%
P	-25%	-6%	0.6%	0.2%	11.8%	11.4%
Av	-9%	196%	0.9%	-2.4%	17.6%	13.8%
K	386%	385%	-15.4%	-15.4%	18.7%	18.6%
R	211%	217%	-21.2%	-21.8%	6.5%	5.6%

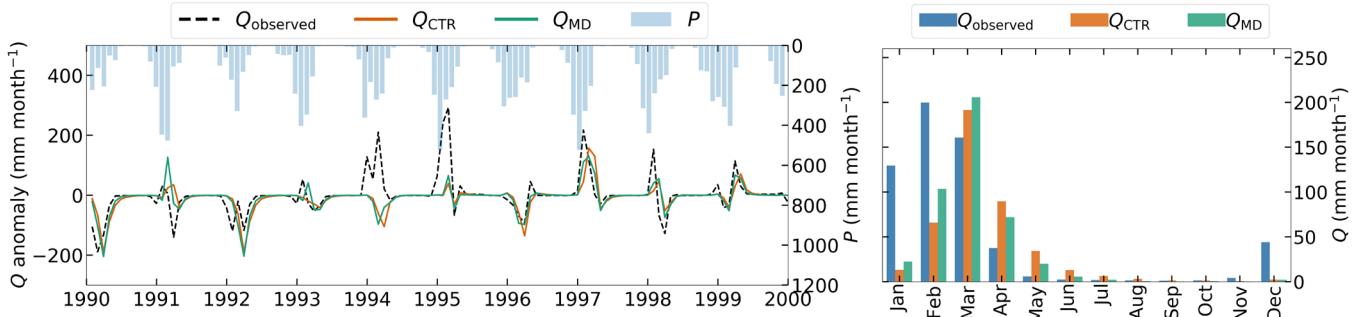
3. Model results monthly discharge

Table S5. Model performance based on monthly modeled (HTESSEL CTR and MD models) discharge fluxes compared to station observations with Pearson correlation (r) and variability ($\alpha = \sigma_{\text{mod}} / \sigma_{\text{obs}}$) for inter-annual anomalies of monthly discharge fluxes and of monthly seasonal climatology of discharge fluxes for the time series 1975–2010 in the study catchments. For both r and α a value of 1 corresponds to a perfect model fit. The significance test of the MD improvements compared to CTR is represented by ** (passing 5% level) and * (passing 10% level) and additionally P-values are provided for the cases that MD improves compared to CTR.

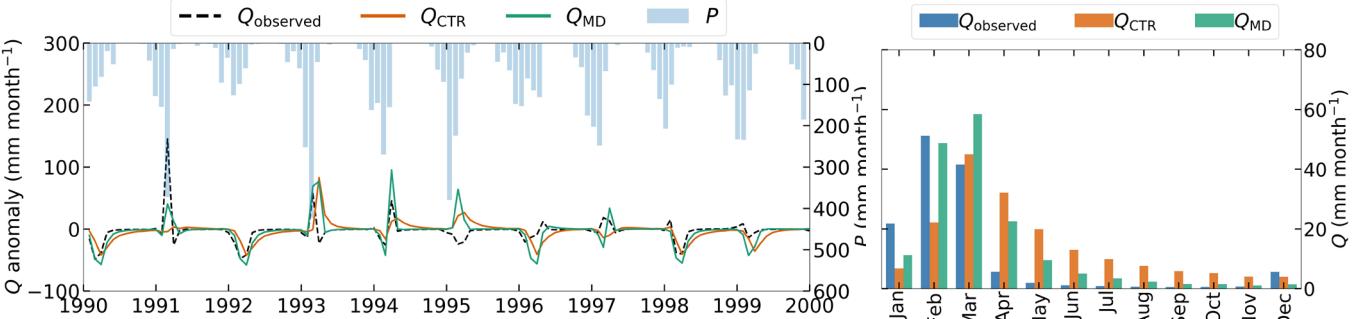
	Monthly seasonal climatology						Inter-annual anomalies					
	r (-)			α (-)			r (-)			α (-)		
Catchment	CTR	MD	P-value	CTR	MD	P-value	CTR	MD	P-value	CTR	MD	P-value
EA	0.63	0.77**	0.001	0.79	0.87**	0.045	0.61	0.65**	0.002	1.02	1.07	-
EB	0.60	0.92**	<0.001	0.73	1.11*	0.069	0.52	0.71**	<0.001	0.79	1.06**	<0.001
G	0.96	0.98	0.337	0.46	1.14**	0.05	0.85	0.86	0.39	0.47	1.65	-
He	0.98	0.99**	0.003	0.58	0.61**	0.002	0.86	0.87	0.321	0.68	0.72**	0.001
Mi	0.83	0.87	0.178	0.84	1.00**	0.003	0.64	0.71**	<0.001	0.93	1.09	
No	0.91	0.82	-	1.71	1.55**	0.022	0.86	0.80	-	1.52	1.39**	<0.001
W	0.99	0.99	-	1.31	1.37	-	0.85	0.85	-	1.35	1.39	-
A	0.94	0.99	0.206	0.39	0.84**	<0.001	0.83	0.90**	0.03	0.50	0.85**	<0.001
D	0.74	0.73	-	1.47	1.39**	0.001	0.77	0.78**	<0.001	0.91	0.93**	0.006
Mu	0.90	0.97	0.074	0.63	1.49	-	0.88	0.94**	0.007	0.84	1.45	-
Na	0.21	0.62**	0.022	0.76	0.72	-	0.72	0.84**	<0.001	0.65	0.84**	<0.001
P	0.92	0.98**	0.002	0.77	1.03**	0.023	0.78	0.79	0.421	0.81	1.23	-
Av	0.88	0.95	0.319	0.55	3.64	-	0.67	0.71	0.255	0.81	3.39	-
K	0.75	0.95**	<0.001	3.77	5.22	-	0.62	0.76**	0.002	2.55	3.47	-
R	0.96	0.98**	0.018	1.72	2.20	-	0.83	0.89**	<0.001	1.72	1.99	-

Figure S1: Monthly anomalies (left) and monthly seasonal climatology (right) of modeled discharge with the HTESSEL CTR and MD models compared to discharge from station observations in the study catchments (Table S1). Monthly anomaly discharge is presented for the time series 1990–2010 and monthly seasonal climatology is based on the time series of 1975–2010.

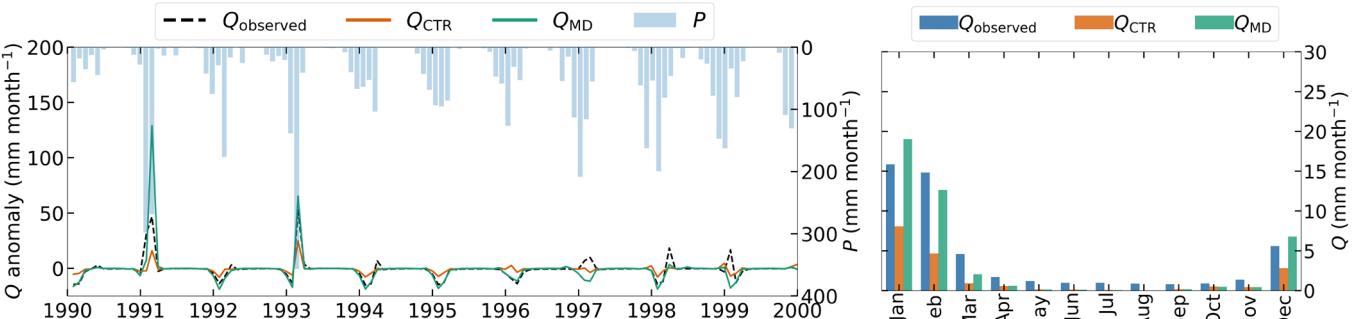
(a) EA



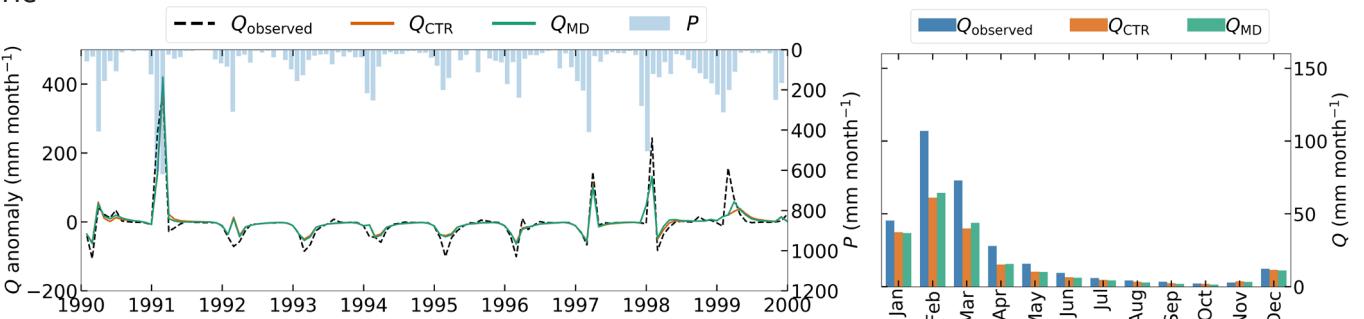
(b) EB



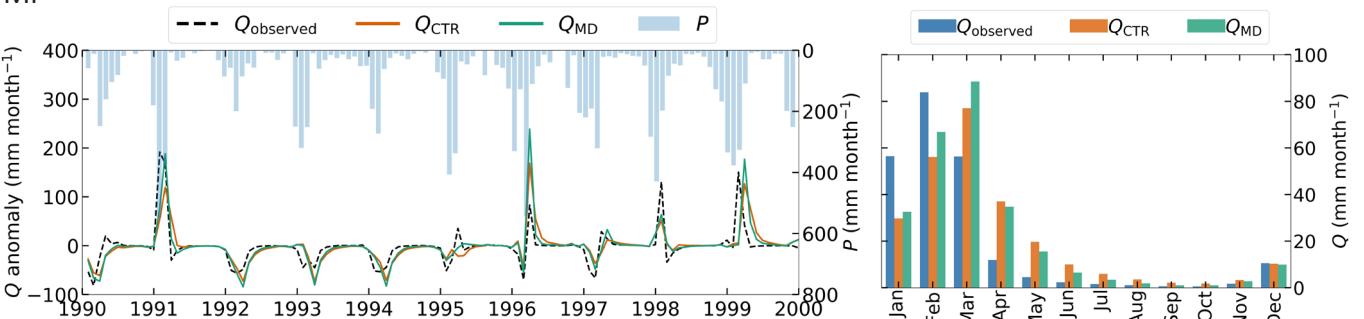
(c) G



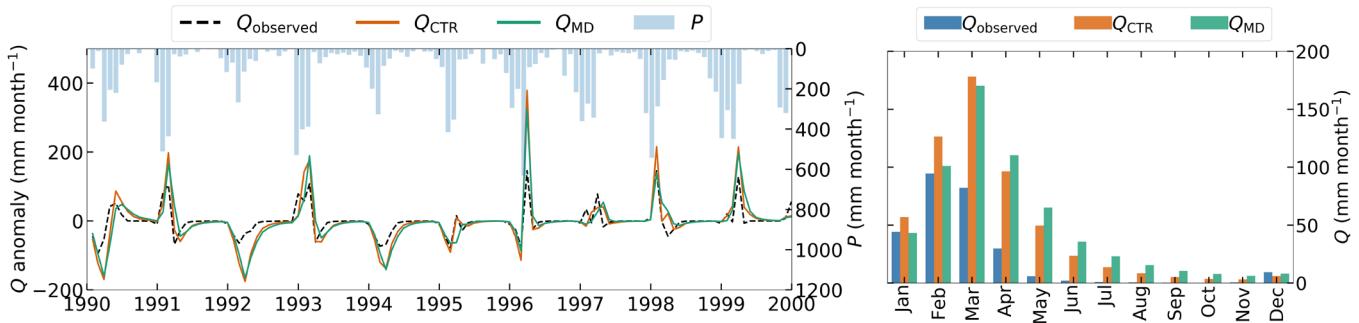
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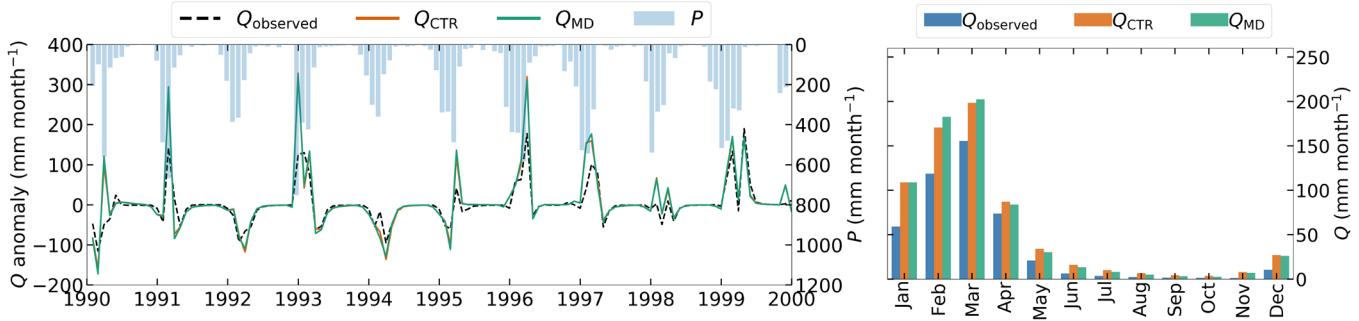
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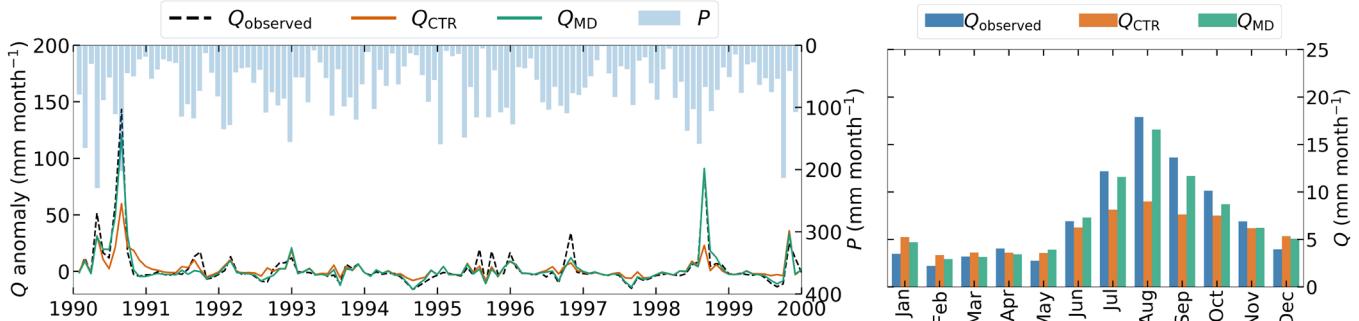
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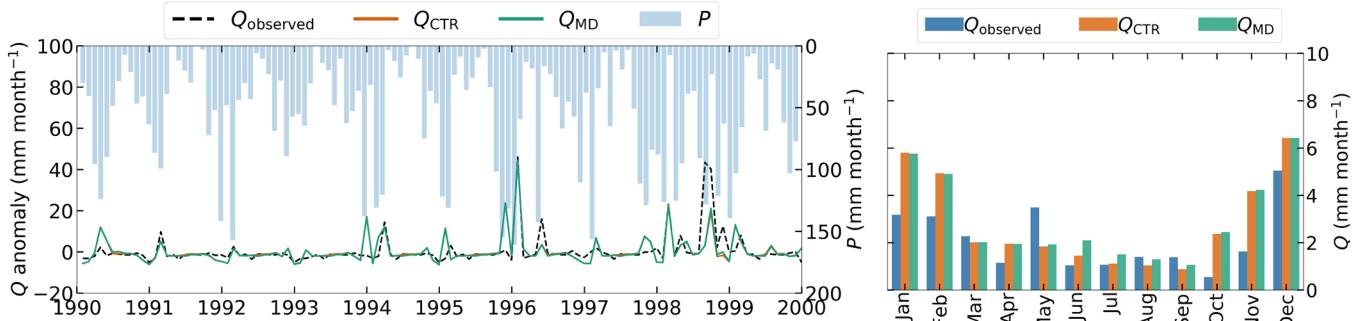
(g) W



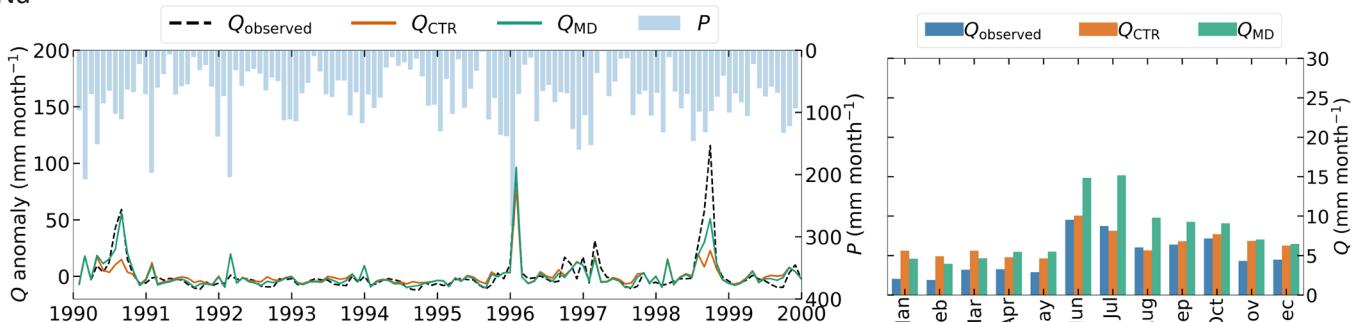
(h) A



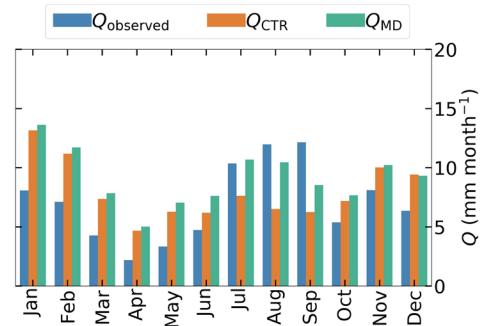
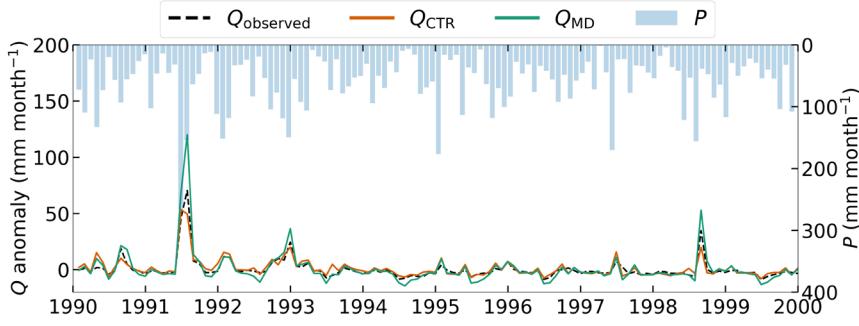
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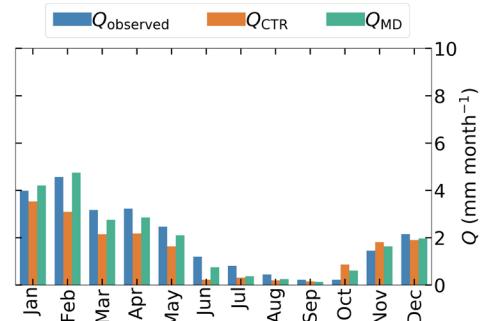
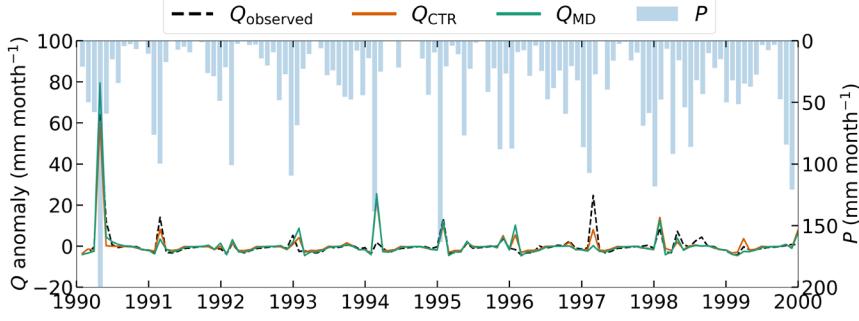
(j) Na



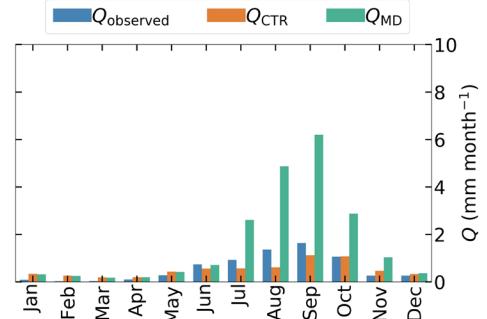
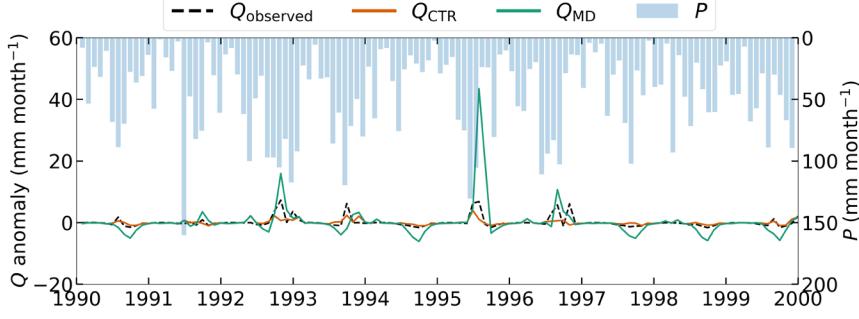
(k) Mu



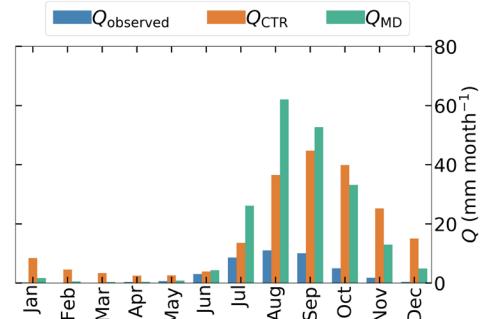
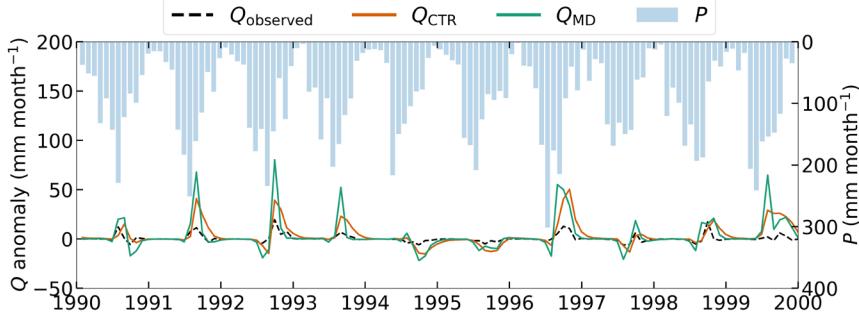
(l) P



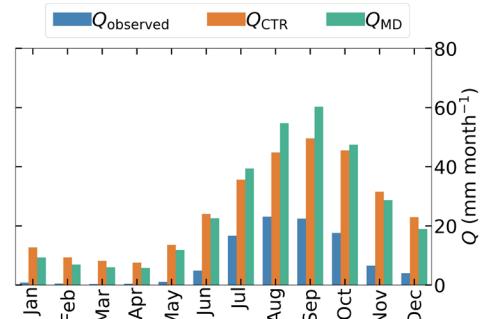
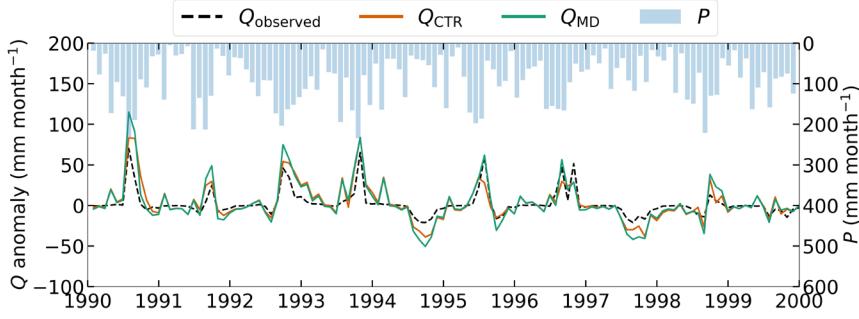
(m) Av



(n) K



(o) R



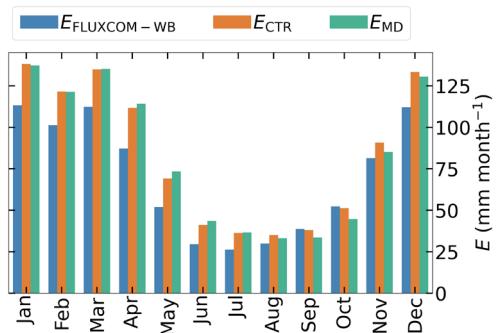
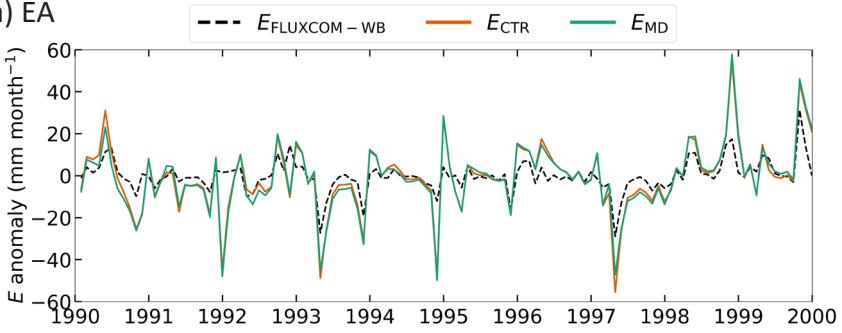
4. Model results monthly evaporation

Table S6. Model performance based on monthly modeled (HTESSEL CTR and MD models) evaporation fluxes compared to FLUXCOM-WB with Pearson correlation (r) and variability ($\alpha = \sigma_{\text{mod}}/\sigma_{\text{obs}}$) for inter-annual anomalies of monthly evaporation fluxes and of monthly seasonal climatology evaporation for the time series 1975–2010 in the study catchments. For both r and α a value of 1 corresponds to a perfect model fit. The significance test of the MD improvements compared to CTR is represented by ** (passing 5% level) and * (passing 10% level) and additionally P-values are provided for the cases that MD improves compared to CTR.

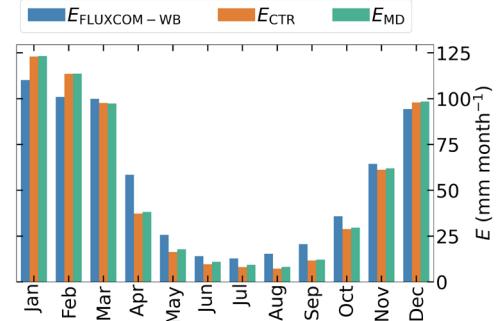
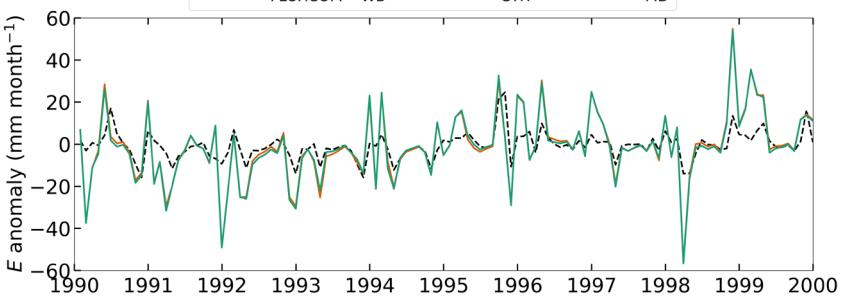
	Monthly seasonal climatology						Inter-annual anomalies					
	r (-)			α (-)			r (-)			α (-)		
Catchment	CTR	MD	P-value	CTR	MD	P-value	CTR	MD	P-value	CTR	MD	P-value
EA	0.99	0.98	-	1.22	1.23	-	0.81	0.81	-	2.12	2.16	-
EB	0.99	0.99	-	1.18	1.17**	0.004	0.70	0.70	-	2.57	2.57*	0.072
G	0.99	0.99	-	1.40	1.45	-	0.82	0.83**	0.001	3.30	3.40	-
He	0.99	0.98	-	0.88	0.88	-	0.71	0.70	-	1.72	1.74	-
Mi	0.98	0.97	-	0.69	0.69	-	0.83	0.83	-	1.36	1.38	-
No	0.98	0.99	0.154	0.65	0.68**	0.002	0.85	0.83	-	1.19	1.23	-
W	0.98	0.97	-	0.86	0.86	-	0.84	0.84	-	1.20	1.21	-
A	0.99	0.98	-	0.96	0.94	-	0.86	0.86*	0.064	1.88	2.05	-
D	0.99	0.99	-	0.73	0.72	-	0.84	0.84	-	1.52	1.64	-
Mu	0.99	0.98	-	0.87	0.82	-	0.82	0.85**	<0.001	1.32	1.50	-
Na	1.00	1.00	-	0.79	0.75	-	0.79	0.80**	0.05	1.88	2.17	-
P	0.98	0.97	-	0.77	0.76	-	0.73	0.73	0.281	2.92	3.05	-
Av	0.94	0.89	-	1.07	1.14	-	0.82	0.82	0.222	2.28	2.40	-
K	0.51	0.53**	0.031	0.60	0.64**	<0.001	0.66	0.67	0.149	2.29	2.31	-
R	0.99	0.99	-	0.74	0.74	0.486	0.86	0.85	-	1.46	1.51	-

Figure S2: Monthly anomalies (left) and monthly seasonal climatology (right) of modeled evaporation with the HTESSEL CTR and MD models compared to FLUXCOM-WB evaporation in the study catchments (Table S1). Monthly anomaly evaporation is presented for the time series 1990–2010 and monthly seasonal climatology is based on the time series of 1975–2010.

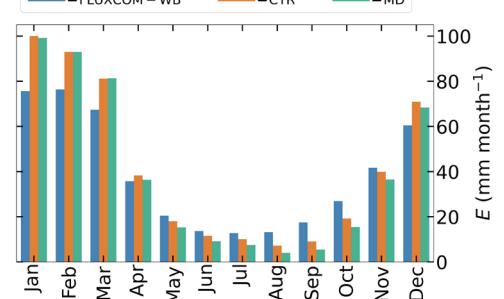
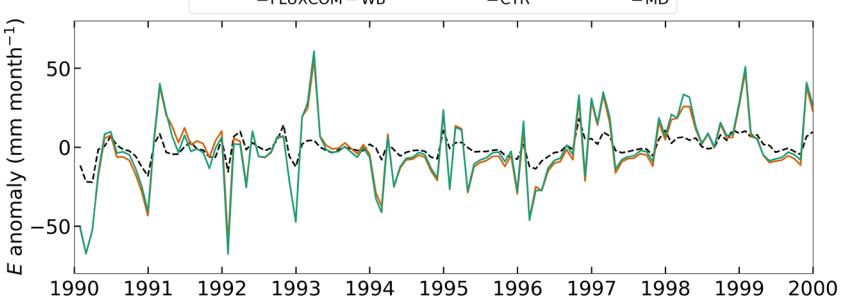
(a) EA



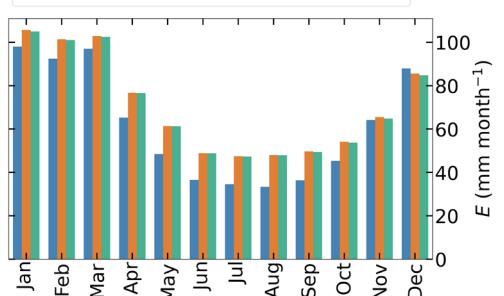
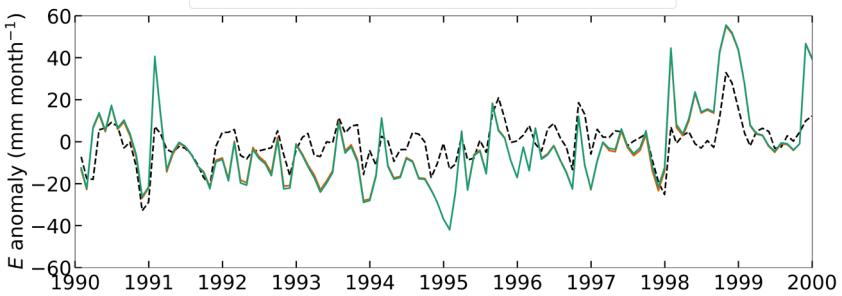
(b) EB



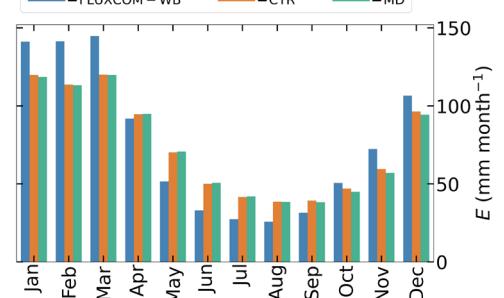
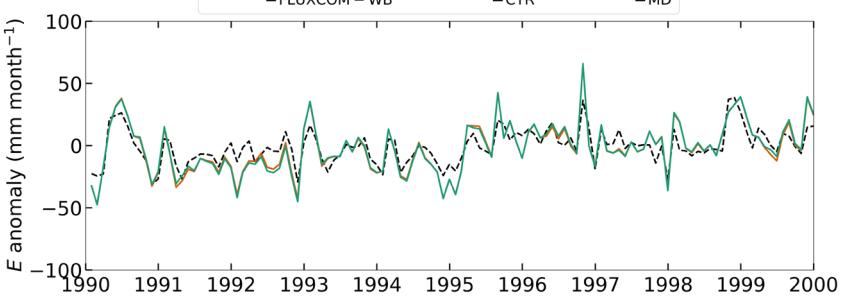
(c) G



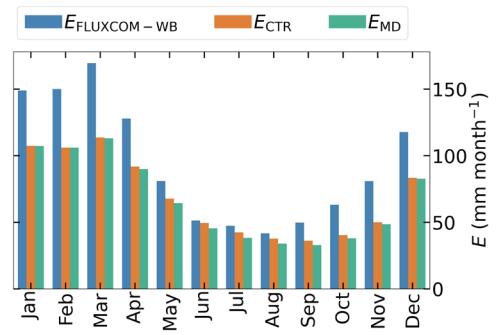
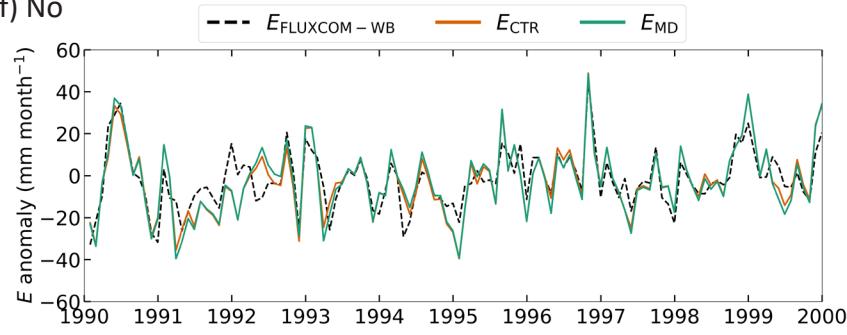
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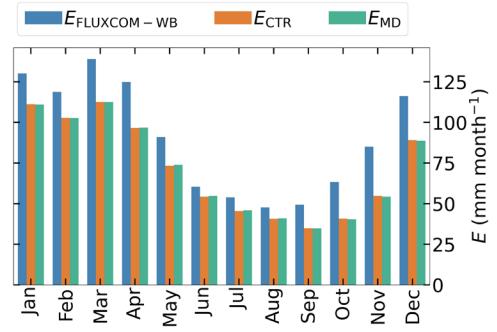
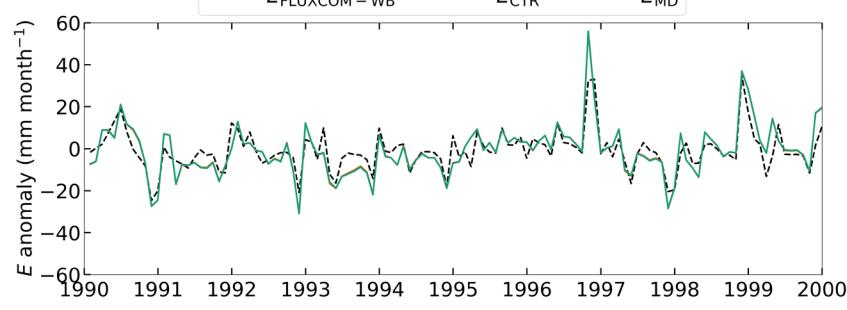
(e) Mi



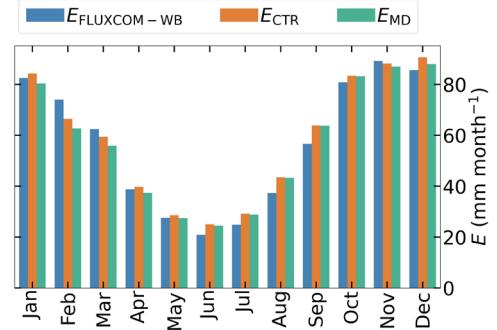
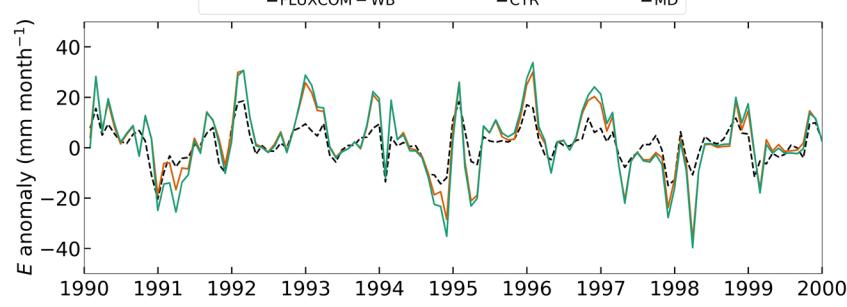
(f) No



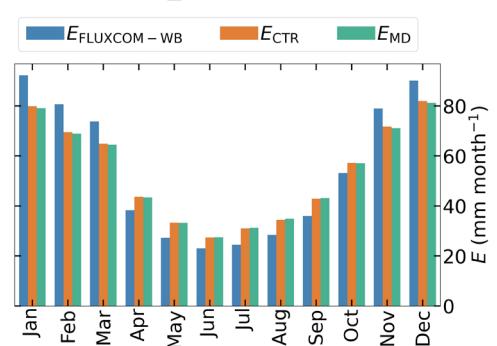
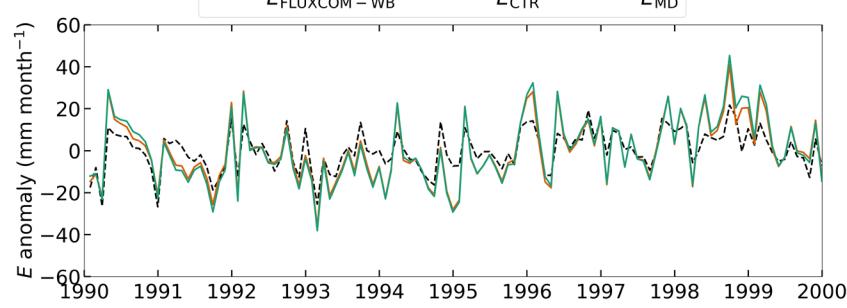
(g) W



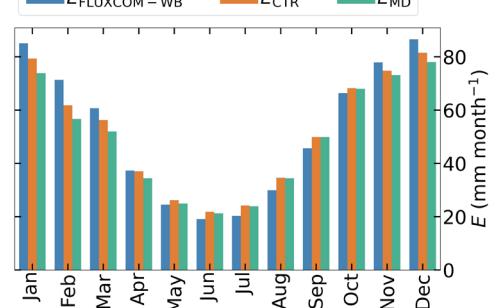
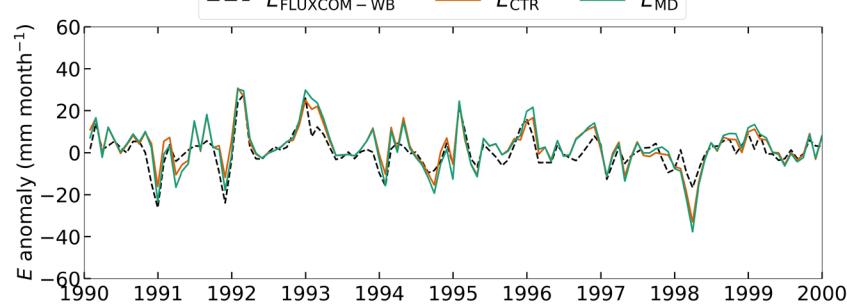
(h) A



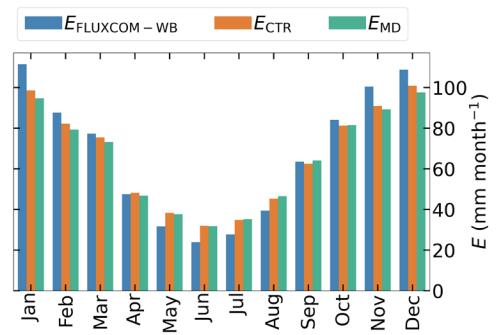
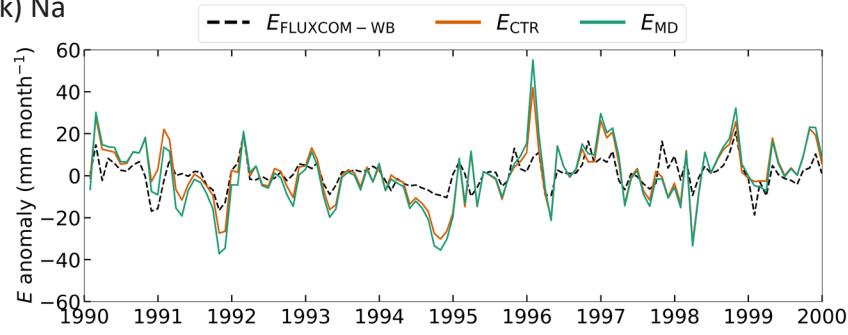
(i) D



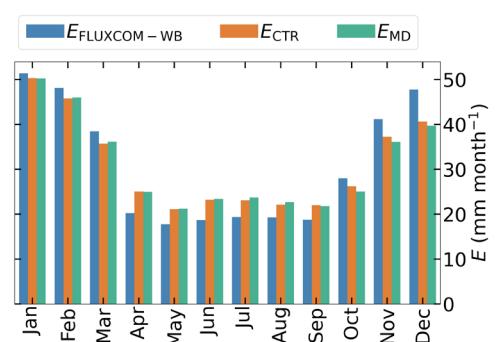
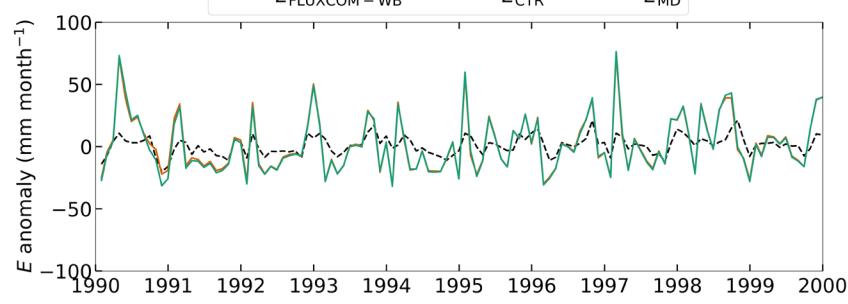
(j) Mu



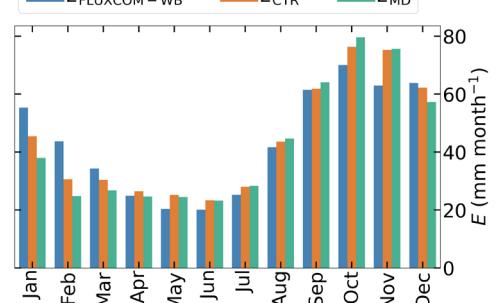
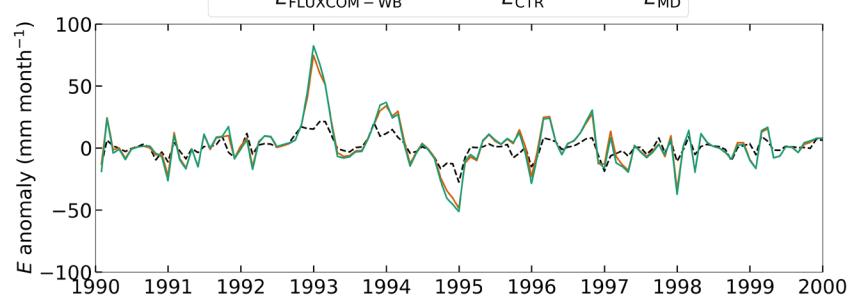
(k) Na



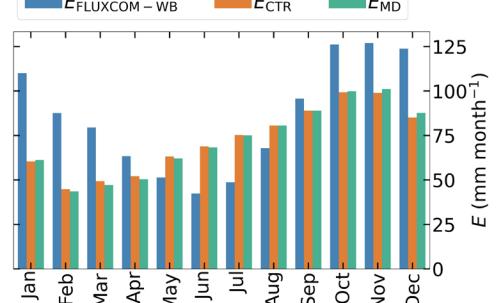
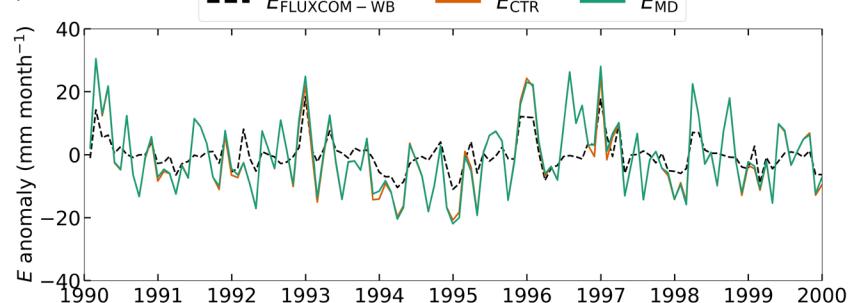
(l) P



(m) Av



(n) K



(o) R

