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On the importance of plant phenology in the evaporative process of a semi-arid woodland: could it be why satellite-based evaporation estimates in the miombo differ?

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Supplement S

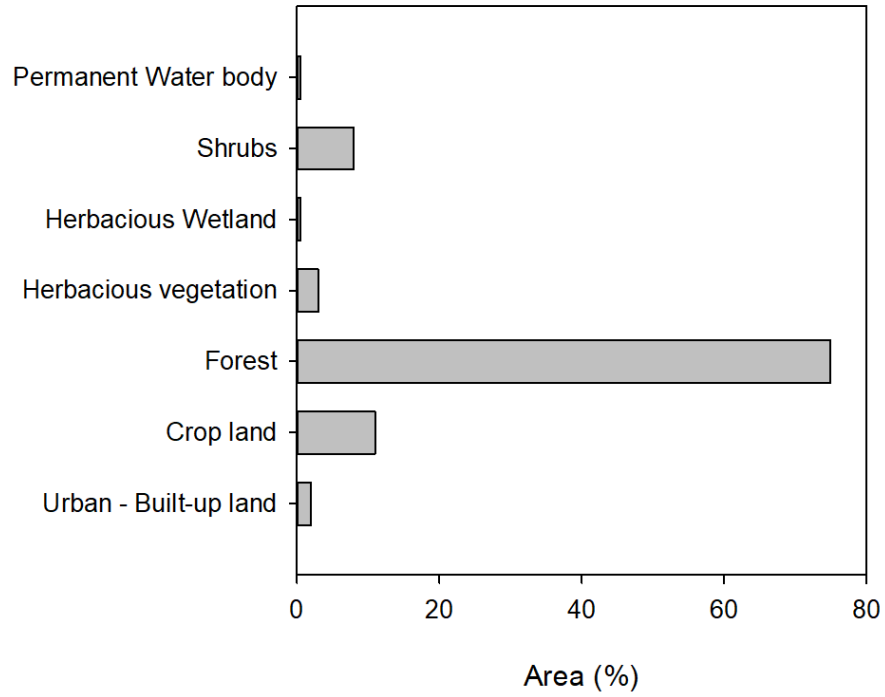

Figure S1. Landcover composition of the Luangwa Basin. About 75 % of the forest classification of the Luangwa Basin is miombo woodland.

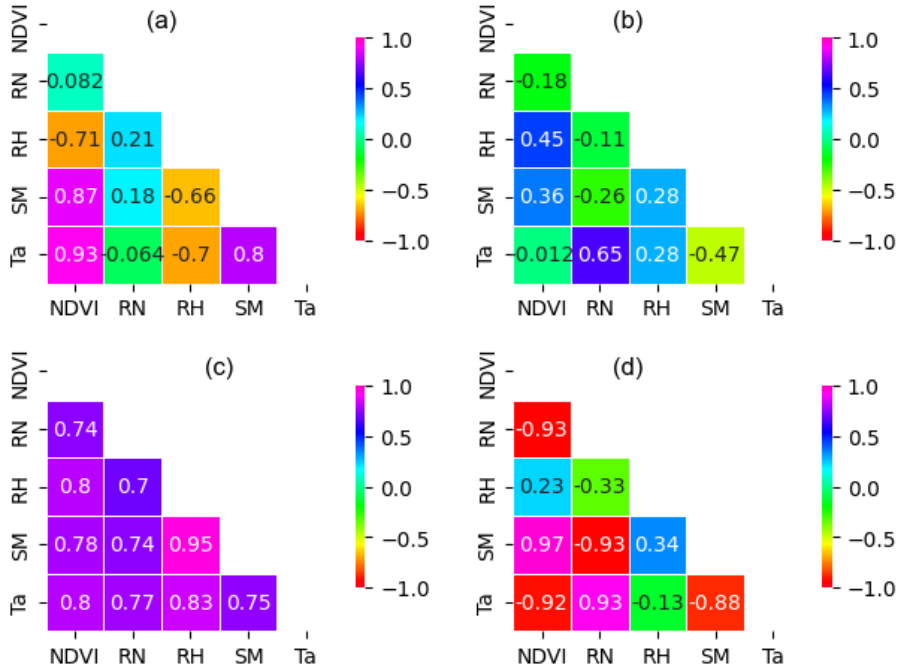

Figure S2. Phenophase-based temporal correlation of climate variables (RN, RH, SM, Ta) and phenology proxy (NDVI) of the miombo woodland in the Luangwa Basin. Phenophases for the period 2009 to 2020: (a) green-up/mid-green-up, (b) maturity/peak, (c) senescence/mid-green-down and (d) dormant RN = net radiation, SM = soil moisture, RH = relative humidity.

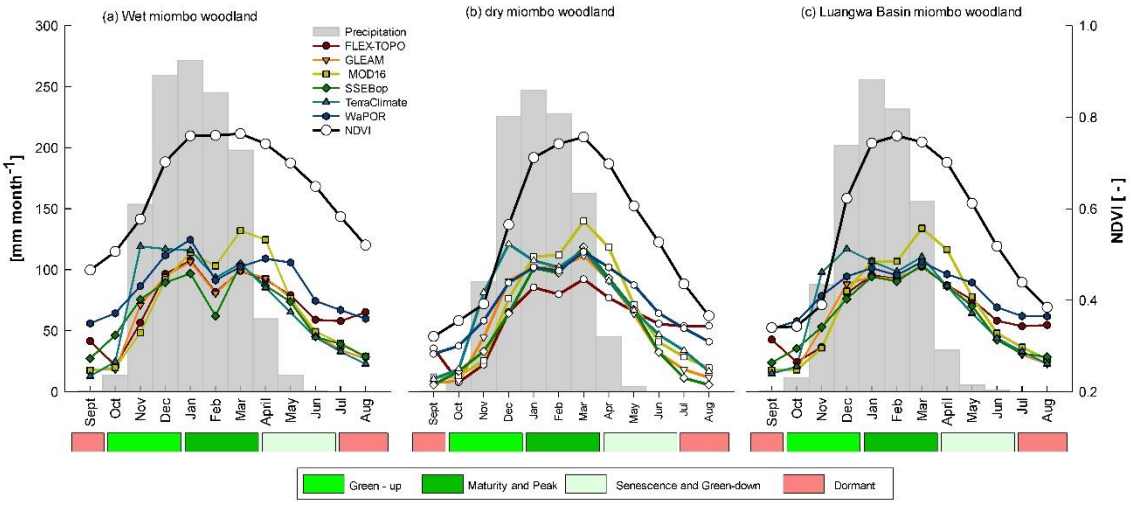

Figure S3: Comparison of aggregated 2009-2020 satellite-based evaporation estimates in relation to the NDVI (a) at wet miombo woodland, (b) dry miombo woodland, (c) delineated Luangwa Basin miombo woodland across hydrological year (September – August) in the Luangwa Basin and (d) Correlation of aggregated monthly satellite-based evaporation estimates and NDVI at pixel level (D = dry miombo woodland pixel, W = wet miombo woodland pixel) and Luangwa Basin scale (L = Luangwa Basin miombo woodland).

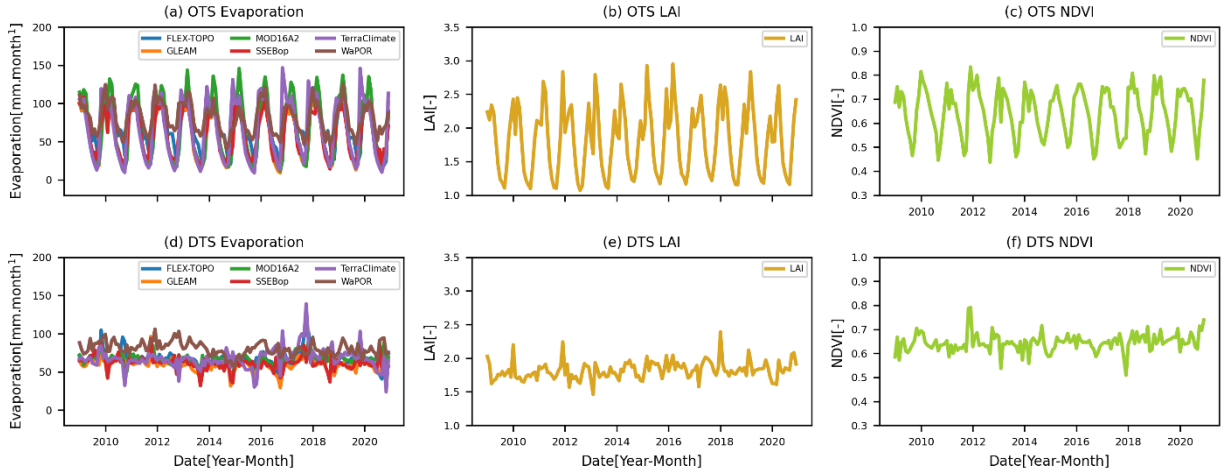

Figure S4: Evaporation, NDVI and LAI original time series (OTS) (a, b, c) and deseasonalised time series (DTS) (d, e, f) of evaporation, NDVI and LAI respectively, for the period 2009 to 2020.

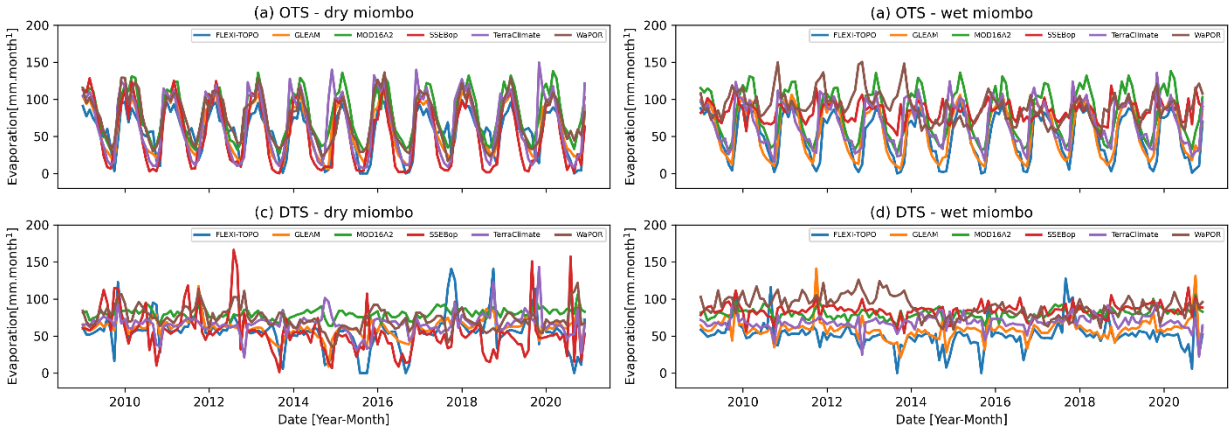

Fig. S5. Original time series (OTS) and deseasonalised time series (DTS) of satellite-based evaporation estimates for the dry miombo woodland (a, c) and the wet miombo woodland (b, d) for the period 2009 to 2020. There are visible differences in the mean estimates of evaporation in the deseasonalised time series indicative of the differences in the capacity of each satellite-based evaporation estimate.

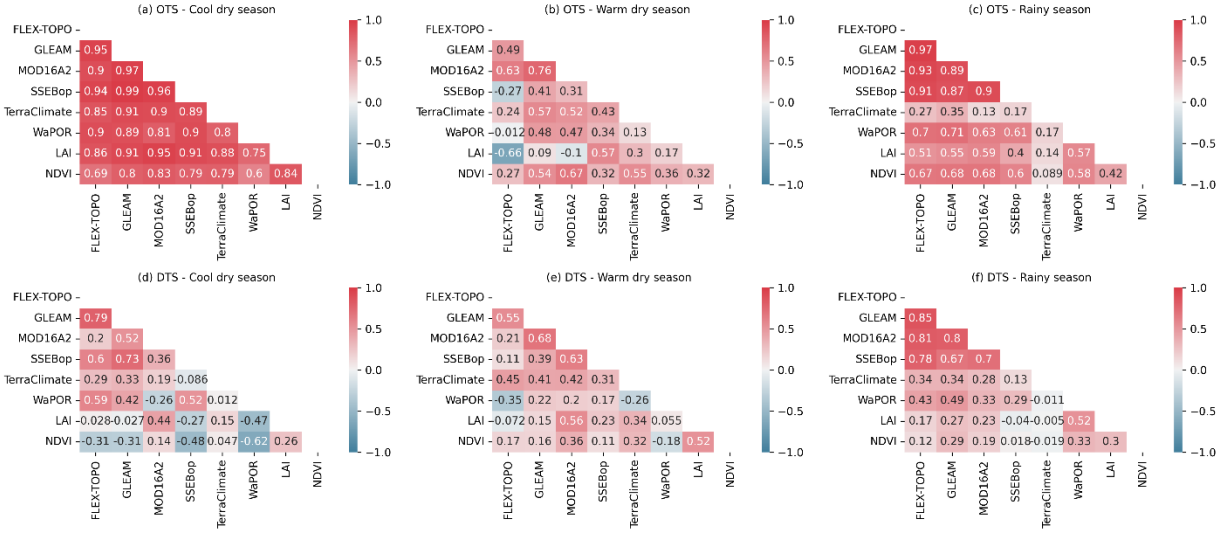

Figure S6. Climate-based phenophases correlation of satellite-based evaporation estimates for the dry miombo woodland for the period 2009 to 2020; (a-c) original time series (OTS) and (d-f) deseasonalised time series (DTS).

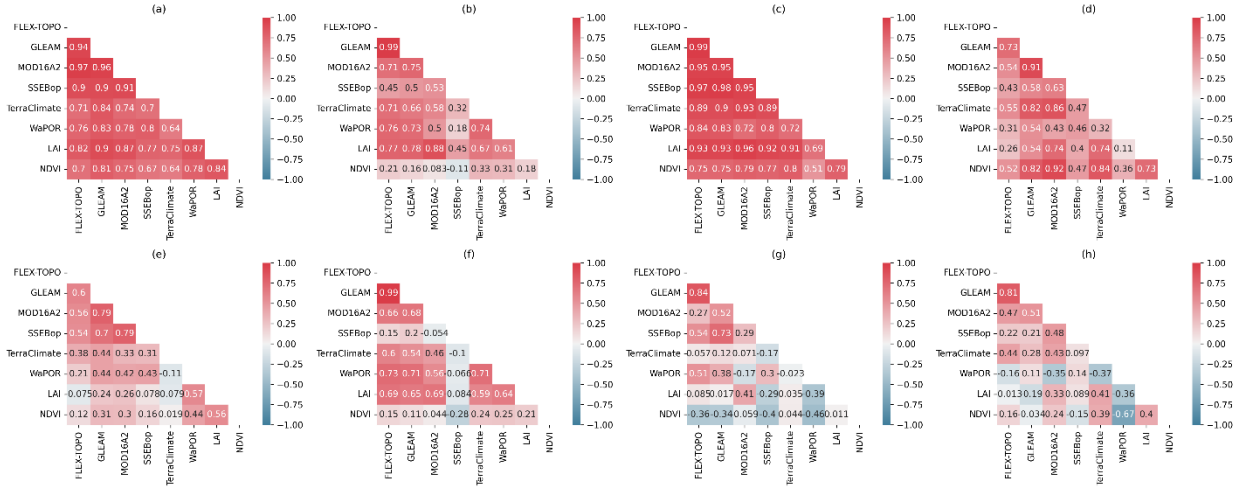

Figure S7. Satellite-based phenophases temporal correlation of satellite-based evaporation estimates for the dry miombo woodland; (a-d) original time series (OTS) and (e-h) deseasonalised time series (DTS) for the period 2009 to 2020.

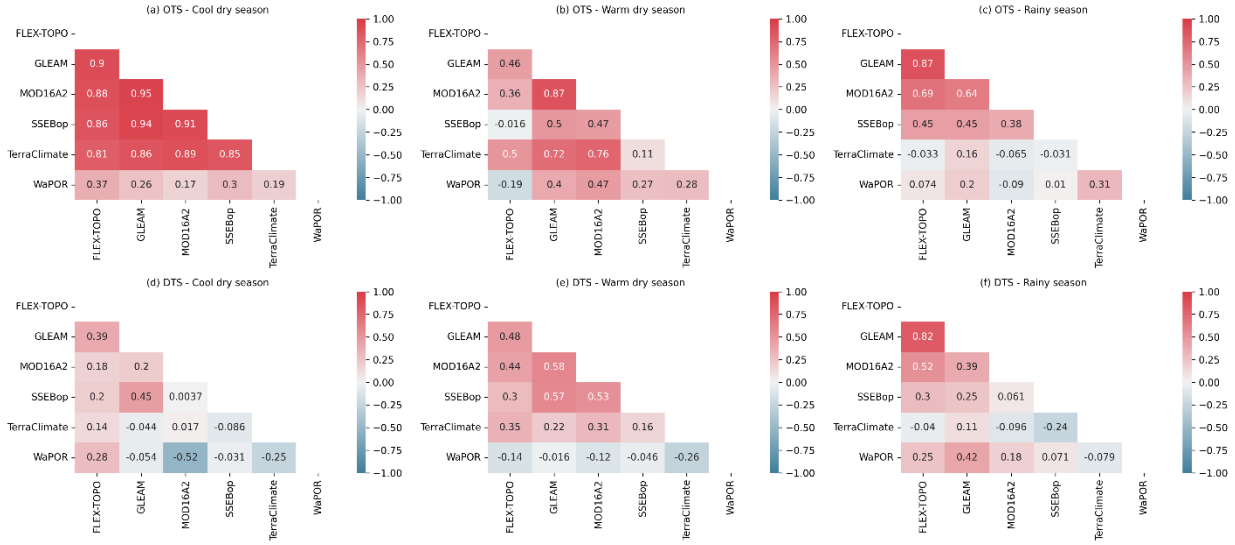

Figure S8. Climate phenophase-based correlation of satellite-based evaporation estimates for the wet miombo woodland for the period 2009 to 2020; (a-c) original time series (OTS) and (d-f) deseasonalised time series (DTS).

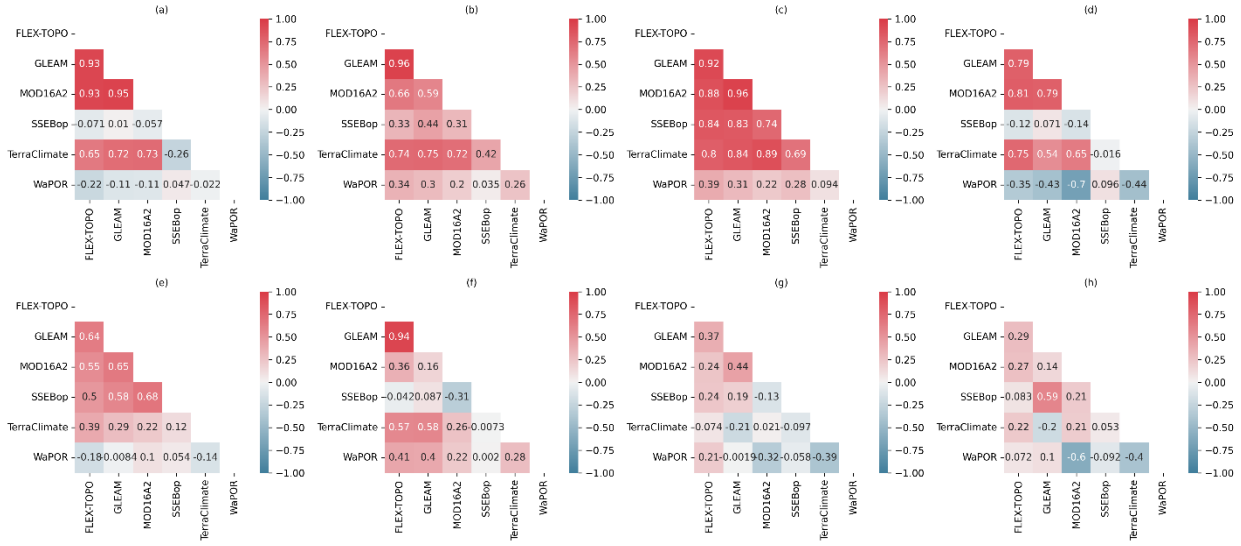

Figure S9. Satellite-based phenophase-based correlation of satellite-based evaporation estimates for the wet miombo woodland; (a-d) original time series (OTS) and (e-h) deseasonalised time series (DTS).

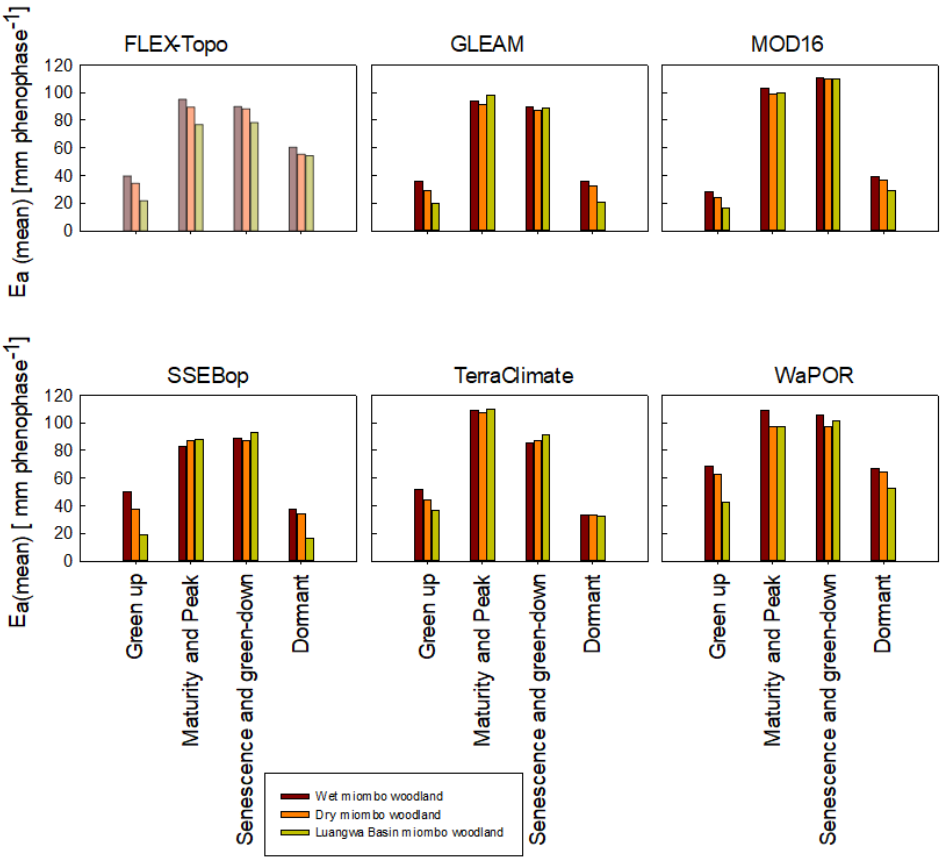

Figure S10. Temporal comparison of original time series of aggregated averages of satellite-based evaporation estimates for the wet miombo woodland, dry miombo woodland and Luangwa Basin miombo woodland for the period 2009 to 2020.

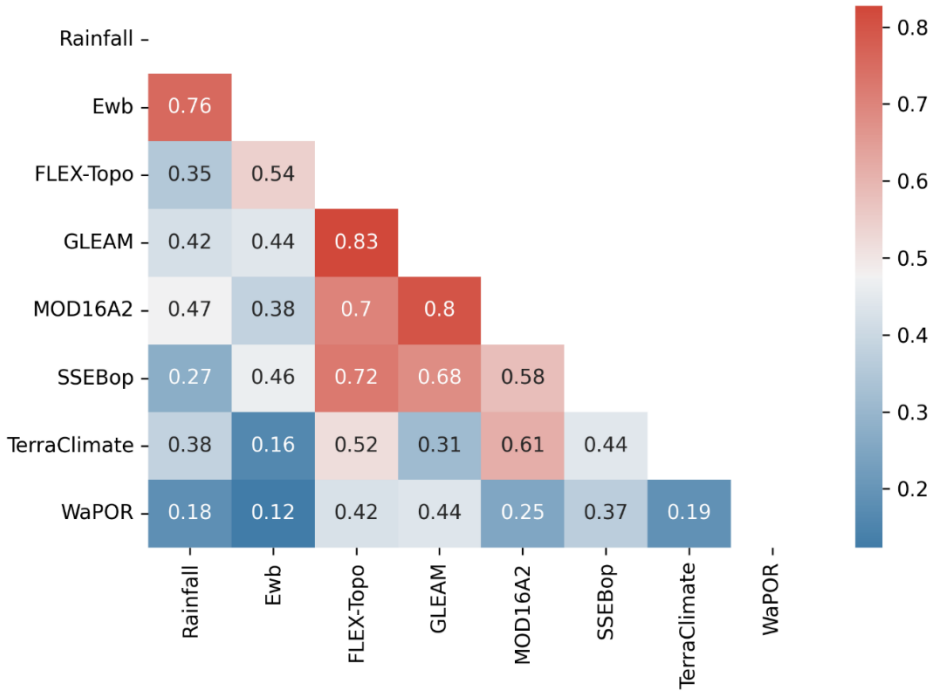

Figure S11. Pearson correlation coefficients of temporal average annual values of rainfall and evaporation time series for the period 2009 to 2020 in the Luangwa Basin, Zambia, southern Africa.

Table S1. Comparison of satellite precipitation products to field observations for selected weather stations in Zambia. Satellite precipitation average (mm year^{-1}) for the years 2014, 2015 and 2016 at each station except for Mpika whose data is for the year 2021 only and GART Chisamba for 2020 - 2022. Performance of satellite precipitation differed geographically and annually.

	YEAR AND NAME OF WEATHER STATION					
	2020	**2014**	**2014**	**2014**	**2014**	**2021**
Precipitation product	GART-Chisamba	Kabwe	KKIA	Mwinilunga	Serenje	Mpika
TerraClimate	798.00	924.00	661.00	1697.00	1416.00	1081.00
CHIRPS	918.47	819.11	892.75	1683.62	812.32	1225.91
ERA5	791.50	901.58	801.69	1690.80	1006.03	992.89
CFSR	984.01	1660.00	1510.40	1665.10	1911.51	1109.98
Average of satellite-products (ASP)	873.00	1076.17	966.46	1684.13	1286.47	1102.45
Field observations (FO)	906.20	1076.90	931.10	1721.30	1283.40	1305.63
Difference (ASP -FO)	**-33.20**	**-0.73**	**35.36**	**-37.17**	**3.07**	**-203.18**
	2021	**2015**	**2015**	**2015**	**2015**	
Precipitation product	GART-Chisamba	Kabwe	KKIA	Mwinilunga	Serenje	
TerraClimate	813.00	698.00	292.00	1633.00	1361.00	
CHIRPS	772.54	892.18	754.11	1229.23	949.14	
ERA5	828.34	929.34	794.56	1713.43	1028.21	
CFSR	996.30	1459.14	1423.96	1691.93	1466.68	
Average of satellite-products (ASP)	852.54	994.66	816.16	1566.90	1201.26	
Field observations (FO)	818.20	933.40	875.20	1309.20	1223.20	
Difference (ASP -FO)	**34.34**	**61.26**	**-59.04**	**257.70**	**-21.94**	
	2022	**2016**	**2016**	**2016**	**2016**	
Precipitation product	GART-Chisamba	Kabwe	KKIA	Mwinilunga	Serenje	
TerraClimate	1062.00	1593.00	1454.00	1640.00	1641.00	
CHIRPS	916.46	1053.56	911.35	1133.92	928.65	
ERA5	1038.22	948.21	803.85	1364.78	1119.54	
CFSR	1106.78	1994.70	1212.78	1805.85	1730.83	
Average of satellite-products (ASP)	1030.86	1397.37	1095.49	1486.14	1355.00	
Field observations (FO)	950.20	1343.60	743.00	1177.20	798.60	
Difference (ASP - FO)	**80.66**	**53.77**	**352.49**	**308.94**	**556.40**	

	LOCATION	
Weather station	Latitude	Longitude
Serenje	13.2267° S	30.21508° E
Kabwe	14.29257 ° S	28.56632° E
Lusaka International Airport	15.31929 ° S	28.4405° E
Mwinilunga	11.73998 ° S	24.431° E
Gart Chisamba	14.94656 ° S	28.08952° E
Mpika	12.3869 ° S	31.172° E

Note: Negative (-) value shows underestimation while positive value indicates overestimation by satellite precipitation products

Table S2. Summary of the results of the ANOVA of the satellite-based evaporation estimates for the dry miombo woodland and wet miombo woodland in the Luangwa Basin

Estimate	Normality test (Kolmogorov-Smirnov) (p-value)	Differences in the means (P-value)
FLEX-Topo	0.44	0.674
GLEAM	0.059	0.772
MOD16	0.56	0.851
SSEBop	0.108	0.774
TerraClimate	0.178	0.912
WaPOR	0.099	0.401

Note: For normality test, P-value > 0.05 indicates data is normally distributed. For ascertaining differences in means, P-value> 0.05 indicates no statistically significant differences in the means.

Table S3. Mann-Kendall trends analysis results for satellite-based evaporation estimates of the miombo woodland in the Luangwa Basin, Zambia, southern Africa.

	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Trend
FLEX-Topo	-0.130	-1336	335192.000	**0.021**	0.05	Yes
GLEAM	-0.133	-1374	335192.000	**0.018**	0.05	Yes
MOD16A2	0.010	108	335192.000	0.853	0.05	No
SSEBop	-0.219	-2250	335192.000	**0.000**	0.05	Yes
TerraClimate	0.108	1108	335192.000	0.056	0.05	No
WaPOR	-0.208	-2144	335192.000	**0.000**	0.05	Yes

Table S4. Statistics of satellite-based evaporation estimates in the miombo woodland of the Luangwa Basin across different phenophases

Product	Green up			Maturity and Peak			Senescence and green-down			Dormant		
	$\bar{s}$	$\bar{x}$	C_V	$\bar{s}$	$\bar{x}$	C_V	$\bar{s}$	$\bar{x}$	C_V	$\bar{s}$	$\bar{x}$	C_V
FLEX-TOPO	47.18	26.52	55.36	96.76	7.61	7.75	73.65	12.59	16.84	50.34	10.04	19.64
GLEAM	53.18	30.34	56.19	96.39	7.74	7.91	67.33	18.99	27.78	23.12	6.72	28.64
MOD16	45.37	28.97	62.87	115.93	14.55	12.36	80.84	29.00	35.32	26.81	8.24	30.28
SSEBop	54.89	20.61	36.97	96.14	8.50	8.70	66.40	18.72	27.77	27.92	5.72	20.18
TerraClimate	78.57	46.81	58.67	105.36	7.86	7.34	64.91	18.74	28.43	23.53	8.99	37.62
WaPOR	77.02	19.12	24.45	101.10	11.91	11.60	85.00	14.34	16.61	58.49	7.58	12.77

$\bar{x}$ = standard deviation (mm/phenophase), C_V = coefficient of variation (%), $\bar{s}$ = mean of observations

Table S5. Results of the ANOVA and pairwise comparison with the Tukey Test of satellite-based evaporation estimates (original time series)

(a) Note: Normality test (Kolmogorov-Smirnov) failed (P-value < 0.05). The ANOVA is run on ranks. The differences in the median values among the satellite-based evaporation estimates are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Green-up			
Comparison	Diff of Ranks	q	P<0.05
WaPOR vs FLEX-Topo	2192	5.846	Yes
WaPOR vs SSEBop	1646	4.389	Yes
WaPOR vs MOD16	1615	4.307	Yes
WaPOR vs GLEAM	1188	3.168	No
WaPOR vs TerraClimate	7	0.0187	No
TerraClimate vs FLEX-Topo	2185	5.827	Yes
TerraClimate vs SSEBop	1639	4.371	Yes
TerraClimate vs MOD16	1608	4.288	Yes
TerraClimate vs GLEAM	1181	3.149	Yes
GLEAM vs FLEX-Topo	1004	2.677	Yes
GLEAM vs SSEBop	458	1.221	No
GLEAM vs MOD16	427	1.139	No
MOD16 vs FLEX-Topo	577	1.539	No
MOD16 vs SSEBop	31	0.0827	Yes
SSEBop vs FLEX-Topo	546	1.456	Yes

(b) Note: Normality Test (Kolmogorov-Smirnov) passed (p-value > 0.098). ANOVA run on means. The differences in the mean values among the satellite-based evaporation estimates are greater than would be expected by chance; there is a statistically significant difference (P-value = <0.001).

Maturity and Peak					
Comparison	Diff of Means	p	q	P	P<0.050
MOD16 vs. FLEX-Topo	35.075	6	16.183	<0.001	Yes
MOD16 vs. GLEAM	15.934	6	7.351	<0.001	Yes
MOD16 vs. WaPOR	15.631	6	7.211	<0.001	Yes
MOD16 vs. SSEBop	15.111	6	6.972	<0.001	Yes
MOD16 vs. TerraClimate	12.478	6	5.757	<0.001	Yes
TerraClimate vs. FLEX-Topo	22.598	6	10.426	<0.001	Yes
TerraClimate vs. GLEAM	3.456	6	1.595	0.87	No
TerraClimate vs. WaPOR	3.153	6	1.455	0.908	No
TerraClimate vs. SSEBop	2.633	6	1.215	0.956	No
SSEBop vs. FLEX-Topo	19.964	6	9.211	<0.001	Yes
SSEBop vs. GLEAM	0.823	6	0.38	1	No
SSEBop vs. WaPOR	0.52	6	0.24	1	No
WaPOR vs. FLEX-Topo	19.445	6	8.971	<0.001	Yes
WaPOR vs. GLEAM	0.303	6	0.14	1	No
GLEAM vs. FLEX-Topo	19.141	6	8.831	<0.001	Yes

(c) Note: Normality Test (Kolmogorov-Smirnov) passed (p-value = 0.0514). ANOVA run on means. The differences in the mean values among the satellite-based evaporation estimates are greater than would be expected by chance; there is a statistically significant difference (P-value = <0.001).

Senescence and green-down					
Comparison	Diff of Means	p	q	P	P<0.050
WaPOR vs. GLEAM	22.387	6	5.705	<0.001	Yes
WaPOR vs. SSEBop	20.286	6	5.17	0.004	Yes
WaPOR vs. FLEX-Topo	18.447	6	4.701	0.011	Yes
WaPOR vs. TerraClimate	16.612	6	4.234	0.033	Yes
WaPOR vs. MOD16	7.892	6	2.011	0.714	No
MOD16 vs. GLEAM	14.496	6	3.694	0.094	No
MOD16 vs. SSEBop	12.394	6	3.159	0.222	No
MOD16 vs. FLEX-Topo	10.555	6	2.69	0.401	No
MOD16 vs. TerraClimate	8.72	6	2.222	0.618	No
TerraClimate vs. GLEAM	5.775	6	1.472	0.904	No
TerraClimate vs. SSEBop	3.674	6	0.936	0.986	No
TerraClimate vs. FLEX-Topo	1.835	6	0.468	0.999	No
FLEX-Topo vs. GLEAM	3.941	6	1.004	0.981	No
FLEX-Topo vs. SSEBop	1.839	6	0.469	0.999	No
SSEBop vs. GLEAM	2.101	6	0.536	0.999	No

(d) Note: Normality test (Kolmogorov-Smirnov) failed (P-value < 0.05). The ANOVA run on ranks. The differences in the median values among the satellite-based evaporation estimates are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Dormant			
Comparison	Diff of Ranks	q	P<0.05
FLEX-Topo vs SSEBop	5214	13.904	Yes
FLEX-Topo vs GLEAM	4214	11.238	Yes
FLEX-Topo vs TerraClimate	3005	8.014	Yes
FLEX-Topo vs MOD16	2808	7.488	Yes
FLEX-Topo vs WaPOR	479	1.277	No
WaPOR vs SSEBop	4735	12.627	Yes
WaPOR vs GLEAM	3735	9.96	Yes
WaPOR vs TerraClimate	2526	6.736	Yes
WaPOR vs MOD16	2329	6.211	Yes
MOD16 vs SSEBop	2406	6.416	Yes
MOD16 vs GLEAM	1406	3.749	No
MOD16 vs TerraClimate	197	0.525	No
TerraClimate vs SSEBop	2209	5.891	Yes
TerraClimate vs GLEAM	1209	3.224	No
GLEAM vs SSEBop	1000	2.667	No

Table S6. Results of the ANOVA and pairwise comparison with the Tukey Test of satellite-based evaporation estimates (time series adjusted for seasonality)

(a)Green-up/Mid green-up Deseasonalised time series Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
FLEX-Topo	36	0	65.300	59.087	74.775
GLEAM	36	0	62.265	54.292	68.846
MOD16A2	36	0	67.522	55.198	79.387
SSEBop	36	0	61.129	50.721	69.937
TerraClimate	36	0	67.701	59.323	72.489
WaPOR	36	0	81.189	73.079	88.760

H = 42.505 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
WaPOR vs GLEAM	3013.000	8.035	Yes
WaPOR vs SSEBop	2953.000	7.875	Yes
WaPOR vs FLEX-Topo	2214.000	5.904	Yes
WaPOR vs TerraClimate	2033.000	5.422	Yes
WaPOR vs MOD16A2	1967.000	5.246	Yes
MOD16A2 vs GLEAM	1046.000	2.789	No
MOD16A2 vs SSEBop	986.000	2.629	Do Not Test
MOD16A2 vs FLEX-Topo	247.000	0.659	Do Not Test
MOD16A2 vs TerraClimate	66.000	0.176	Do Not Test
TerraClimate vs GLEAM	980.000	2.613	Do Not Test
TerraClimate vs SSEBop	920.000	2.453	Do Not Test
TerraClimate vs FLEX-Topo	181.000	0.483	Do Not Test
FLEX-Topo vs GLEAM	799.000	2.131	Do Not Test
FLEX-Topo vs SSEBop	739.000	1.971	Do Not Test
SSEBop vs GLEAM	60.000	0.160	Do Not Test

(b) Maturity/peak Deseasonalised time series: Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
FLEX-Topo	36	0	66.138	64.848	69.393
GLEAM	36	0	59.421	57.828	61.999
MOD16A2	36	0	67.549	64.025	69.318
SSEBop	36	0	62.577	60.981	63.466
TerraClimate	36	0	67.183	64.811	70.329
WaPOR	36	0	79.526	76.178	86.103

H = 132.934 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
WaPOR vs GLEAM	5357.000	14.286	Yes
WaPOR vs SSEBop	4802.000	12.806	Yes
WaPOR vs FLEX-Topo	2638.000	7.035	Yes
WaPOR vs MOD16A2	2546.000	6.790	Yes
WaPOR vs TerraClimate	2237.000	5.966	Yes
TerraClimate vs GLEAM	3120.000	8.320	Yes
TerraClimate vs SSEBop	2565.000	6.840	Yes
TerraClimate vs FLEX-Topo	401.000	1.069	No
TerraClimate vs MOD16A2	309.000	0.824	Do Not Test
MOD16A2 vs GLEAM	2811.000	7.496	Yes
MOD16A2 vs SSEBop	2256.000	6.016	Yes
MOD16A2 vs FLEX-Topo	92.000	0.245	Do Not Test
FLEX-Topo vs GLEAM	2719.000	7.251	Yes
FLEX-Topo vs SSEBop	2164.000	5.771	Yes
SSEBop vs GLEAM	555.000	1.480	No

(c) Senescence/green-down phenophase – Deseasonalised time series: Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
FLEX-Topo	36	0	67.040	64.465	68.800
GLEAM	36	0	60.688	56.498	63.518
MOD16A2	36	0	66.169	65.125	68.714
SSEBop	36	0	61.539	59.068	64.144
TerraClimate	36	0	66.696	63.171	73.837
WaPOR	36	0	78.087	75.177	86.048

H = 122.053 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
WaPOR vs GLEAM	5106.000	13.616	Yes
WaPOR vs SSEBop	4833.000	12.888	Yes
WaPOR vs TerraClimate	2655.000	7.080	Yes
WaPOR vs FLEX-Topo	2651.000	7.070	Yes
WaPOR vs MOD16A2	2641.000	7.043	Yes
MOD16A2 vs GLEAM	2465.000	6.574	Yes
MOD16A2 vs SSEBop	2192.000	5.846	Yes
MOD16A2 vs TerraClimate	14.000	0.0373	No
MOD16A2 vs FLEX-Topo	10.000	0.0267	Do Not Test
FLEX-Topo vs GLEAM	2455.000	6.547	Yes
FLEX-Topo vs SSEBop	2182.000	5.819	Yes
FLEX-Topo vs TerraClimate	4.000	0.0107	Do Not Test
TerraClimate vs GLEAM	2451.000	6.536	Yes
TerraClimate vs SSEBop	2178.000	5.808	Yes
SSEBop vs GLEAM	273.000	0.728	No

(d) Dormant phenophase – Deseasonalised : Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
FLEX-Topo	36	0	65.616	59.997	71.778
GLEAM	36	0	59.736	51.455	67.664
MOD16A2	36	0	67.602	62.737	71.397
SSEBop	36	0	63.150	56.043	69.583
TerraClimate	36	0	62.659	56.768	75.396
WaPOR	36	0	81.323	75.629	86.876

H = 66.606 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	Diff of Ranks	q	P<0.05
WaPOR vs GLEAM	3960.000	10.560	Yes
WaPOR vs SSEBop	3403.000	9.075	Yes
WaPOR vs FLEX-Topo	2789.000	7.438	Yes
WaPOR vs TerraClimate	2780.000	7.414	Yes
WaPOR vs MOD16A2	2356.000	6.283	Yes
MOD16A2 vs GLEAM	1604.000	4.277	Yes
MOD16A2 vs SSEBop	1047.000	2.792	No
MOD16A2 vs FLEX-Topo	433.000	1.155	Do Not Test
MOD16A2 vs TerraClimate	424.000	1.131	Do Not Test
TerraClimate vs GLEAM	1180.000	3.147	No
TerraClimate vs SSEBop	623.000	1.661	Do Not Test
TerraClimate vs FLEX-Topo	9.000	0.0240	Do Not Test
FLEX-Topo vs GLEAM	1171.000	3.123	Do Not Test
FLEX-Topo vs SSEBop	614.000	1.637	Do Not Test
SSEBop vs GLEAM	557.000	1.485	Do Not Test

Table S7. Kendall correlation coefficients of rainfall and evaporation for the period 2009 to 2020 in the Luangwa Basin, Zambia, southern Africa. The values in **bold** are significant at alpha level 0.05.

Variable	Rainfall	E_{wb}	FLEX-Topo	MOD16A2	GLEAM	SSEBop	TerraClimate	WaPOR
Rainfall	1.000	**0.485**	0.303	0.303	0.333	0.212	0.273	0.121
E_{wb}	**0.485**	1.000	**0.515**	0.333	0.242	0.364	0.121	0.273
FLEX-Topo	0.303	**0.515**	1.000	**0.515**	**0.485**	**0.606**	0.364	0.394
MOD16A2	0.303	0.333	**0.515**	1.000	**0.667**	**0.606**	0.182	0.394
GLEAM	0.333	0.242	**0.485**	**0.667**	1.000	**0.455**	**0.455**	0.121
SSEBop	0.212	0.364	**0.606**	**0.606**	**0.455**	1.000	0.212	0.364
TerraClimate	0.273	0.121	0.364	0.182	**0.455**	0.212	1.000	0.121
WaPOR	0.121	0.273	0.394	0.394	0.121	0.364	0.121	1.000