Supplementary Information for "Evapotranspiration in the Amazon: spatial patterns, seasonality and recent trends in observations, reanalysis and CMIP models"

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Table S1 – River-gauge station data. Data for the eleven river-gauge stations used in the study.

River catchment	Part of Amazon drained	Area (km^2)	Station name	Station code	Degrees E (°)	Degrees N (°)	Years of data
Amazon	77% of basin	4,694,100	Óbidos	17050001	–55.51	–1.91	1968–2019
Aripuanã	S	134,100	Prainha Velha	15830000	–60.66	–7.17	2002–2016
Branco	N	130,800	Caracaraí	14710000	–61.13	1.81	1967–2018
Japura	NW	207,100	Villa Bittencourt	12845000	–69.42	–1.49	1980–2020
Jari	NE	48,900	São Francisco	19150000	–52.56	–0.57	1968–2014
Madeira	S/SW	1,006,200	Porto Velho	15400000	–63.92	–8.76	1967–2020
Negro	N	290,400	Serrinha	14420000	–64.80	–0.43	1977–2018
Purus	S	227,600	Lábrea	13870000	–64.79	–7.23	1931–2017
Solimões	W	1,192,200	São Paulo de Olivença	11400000	–68.79	–3.46	1973–2020
Tapajós	SE	462,700	Buburé	17710000	–56.32	–4.59	2004–2019
			Itaituba	17730000			
Xingu	SE	463,200	Altamira	18850000	–52.21	–3.20	1968–2014

Table S2 – Seasonal variation in catchment-balance error estimates. σ_P, σ_R and $\sigma_{\frac{dS}{dt}}$ respectively represent the absolute uncertainties in P, R and $\frac{dS}{dt}$, σ_{ET} represents absolute uncertainty in ET and υ_{ET} is the relative uncertainty.

	σ_P,	σ_R	$\sigma_{\frac{dS}{dt}}$	σ_{ET}	υ_{ET}
Jan	8.98	3.91	8.72	13.15	14.82
Feb	8.70	4.59	8.72	13.17	20.83
Mar	9.84	5.54	8.72	14.30	16.78
Apr	8.43	6.19	8.72	13.64	23.03
May	7.21	6.66	8.72	13.14	20.78
Jun	4.91	6.57	8.72	11.99	25.05
Jul	4.08	6.23	8.72	11.48	18.08
Aug	3.67	5.41	8.72	10.92	11.32
Sep	4.25	4.13	8.72	10.58	8.79
Oct	5.74	3.11	8.72	10.91	8.85
Nov	6.98	2.81	8.72	11.50	10.67
Dec	8.35	3.23	8.72	12.43	13.53
Mean	6.76	4.87	8.72	12.27	16.04

Table S3 – Details of the 13 CMIP5 models analysed in this study. Models that provided historical simulations of evapotranspiration, precipitation, surface radiation and leaf area index over the historical period were selected.

	Modelling centre	Model
1	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	ACCESS1-3
2	Beijing Climate Centre, China Meteorological Administration	bcc-csm1-1
3	College of Global Change and Earth System Science, Beijing Normal University	BNU-ESM
4	Canadian Centre for Climate Modelling and Analysis	CanESM2
5	National Centre for Atmospheric Research	CCSM4
6	Community Earth System Model Contributors	CESM1-BGC
7	The First Institute of Oceanography, SOA, China	FIO-ESM
8	Met Office Hadley Centre	HadGEM2-CC
9		HadGEM2-ES
10	Institute for Numerical Mathematics	inmcm4
11	Institut Pierre-Simon Laplace	IPSL-CM5A-LR
12	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)	MPI-ESM-LR
13	Norwegian Climate Centre	NorESM1-M

Table S4 – Details of the 10 CMIP6 models analysed in this study. Models that provided historical simulations of evapotranspiration, precipitation, surface radiation and leaf area index were selected.

	Modelling centre	Model
1	Commonwealth Scientific and Industrial Research Organization (CSIRO)	ACCESS-ESM1-5
2	Beijing Climate Centre, China Meteorological Administration	BCC-CSM2-MR
3		BCC-ESM1
4	Community Earth System Model Contributors	CESM2
5		CESM2-WACCM
6	NASA Goddard Institute for Space Studies	GISS-E2-1-G
7	Met Office Hadley Centre	HadGEM3-GC31-LL
8		HadGEM3-GC31-MM
9	Seoul National University, Seoul, South Korea	SAM0-UNICON
10	Met Office Hadley Centre	UKESM1-0-LL

Table S5 – Data for the six LBA flux tower sites used in the study.

Site code	Site name	Latitude	Longitude	Land cover type	Years of data
BAN	Bananal, Tocantins State	-9.82	-50.15	Seasonally flooded ecotone	2003–2006
K34	km 34, Manaus	-2.61	-60.21	Forest	1999–2017
K67	km 67, Santarém	-2.85	-54.97	Primary forest	2002–2006
K83	km 83, Santarém	-3.05	-54.93	Selectively logged forest	2000–2004
RJA	Reserva Jaru Tower A, Rondônia State	-10.08	-61.93	Tropical dry forest	1999–2002
PDG	Reserva Pé-de-Gigante, São Paulo State	-21.62	-47.63	Cerrado/ savanna	2002–2003

Table S6 – Sensitivity of K34 seasonal correlations to changing data-inclusion thresholds. Testing the sensitivity of seasonal correlations between K34 and gridded ET datasets to changing the data-inclusion thresholds for the K34 dataset. The left-hand column indicates the minimum number of hours of flux-tower measurements required in each day, and the minimum number of days required in each month, to compute monthly-mean ET values.

	Dataset	MODIS	Zhang	GLEAM	ERA5	CMIP5	CMIP6
0hrs_0days	**r**	**0.77**	**0.67**	0.16	0.55	-0.31	-0.06
	p	0.00	0.02	0.62	0.07	0.32	0.84
0hrs_10days	**r**	**0.78**	**0.67**	0.31	0.54	-0.28	-0.1
	p	0.00	0.02	0.33	0.07	0.37	0.75
0hrs_21days	**r**	**0.77**	**0.61**	0.23	0.47	-0.21	0
	p	0.00	0.04	0.46	0.12	0.52	0.99
18hrs_0days	**r**	**0.8**	**0.71**	0.1	**0.59**	-0.43	-0.09
	p	0.00	0.01	0.75	0.04	0.16	0.79
18hrs_10days	**r**	**0.77**	**0.72**	0.34	**0.61**	-0.36	-0.16
	p	0.00	0.01	0.29	0.04	0.25	0.62
18hrs_21days	**r**	**0.67**	0.51	0.12	0.43	-0.32	0.03
	p	0.02	0.09	0.7	0.17	0.31	0.93
21hrs_0days	**r**	**0.8**	**0.71**	0.21	**0.59**	-0.44	-0.08
	p	0.00	0.01	0.5	0.04	0.16	0.81
21hrs_10days	**r**	**0.74**	**0.72**	0.3	**0.65**	-0.4	-0.21
	p	0.01	0.01	0.35	0.02	0.19	0.52
21hrs_21days	**r**	**0.7**	0.56	0.03	0.5	-0.44	-0.04
	p	0.01	0.06	0.92	0.1	0.15	0.91

Table S7 – Table of catchment-mean ET estimates. The climatological annual and interannual standard deviation (σ) in ET over each catchment for each of the ET data sources in this study (mm year^{-1}). Correlations between catchment-balance ET and other ET estimates are shown. All data are from 2003–2013, apart from the CMIP5 data, which are from 1994–2004. These data are shown in a scatter plot in Figure S5.

	Catchment-balance	**MODIS**	**P-LSH**	**GLEAM**	**ERA5**	**CMIP5**	**CMIP6**
Catchment	**Mean ± σ**	**Mean ± σ**	**Mean ± σ**	**Mean ± σ**	**Mean ± σ**	**Mean ± σ**	**Mean ± σ**
Amazon	1083.1±36.5	1298.7±27.2	1266.8±16.5	1480.8±16.4	1279.7±8.0	1244.0±16.8	1298.7±15.9
Aripuanã	1403.3±81.0	1409.1±32.4	1348.4±29.0	1500.4±36.8	1239.1±33.6	1236.2±33.8	1293.7±31.5
Branco	1087.2±117.0	1187.2±24.1	1247.5±14.7	1472.0±61.9	1213.5±39.7	1049.2±45.8	1066.3±47.9
Japura	1217.0±158.4	1339.4±51.4	1263.2±19.8	1632.9±24.7	1340.0±17.5	1421.9±26.8	1386.9±24.8
Jari	1487.0±107.3	1501.0±36.4	1439.9±16.2	1793.2±62.8	1074.4±68.9	1032.6±59.1	1002.8±72.4
Madeira	1011.4±43.2	1185.8±27.1	1131.1±14.1	1196.4±38.1	1198.6±18.4	1063.2±22.1	1154.9±24.9
Negro	1206.1±85.3	1338.4±51.9	1361.5±16.9	1727.7±25.1	1367.3±14.8	1429.1±31.8	1448.6±28.0
Purus	1248.0±109.1	1406.1±46.4	1336.1±30.9	1538.8±38.3	1305.6±18.8	1224.8±32.8	1340.8±26.2
Solimões	966.6±138.9	1239.6±39.7	1209.7±17.2	1436.1±15.1	1239.4±10.6	1245.1±18.6	1269.0±18.4
Tapajós	1180.7±96.7	1291.2±31.2	1265.6±38.2	1382.6±44.5	1238.8±28.5	1178.1±30.4	1256.9±33.2
Xingu	1445.0±130.9	1336.2±27.3	1306.9±40.9	1414.8±39.3	1238.0±21.2	1173.2±33.1	1226.7±32.3
Correlation with catchment-balance ET		r=0.84, p=0.00	r=0.82, p=0.00	r=0.51, p=0.11	r=-0.28, p=0.41	r=-0.06, p=0.85	r=-0.14, p=0.69

Figures

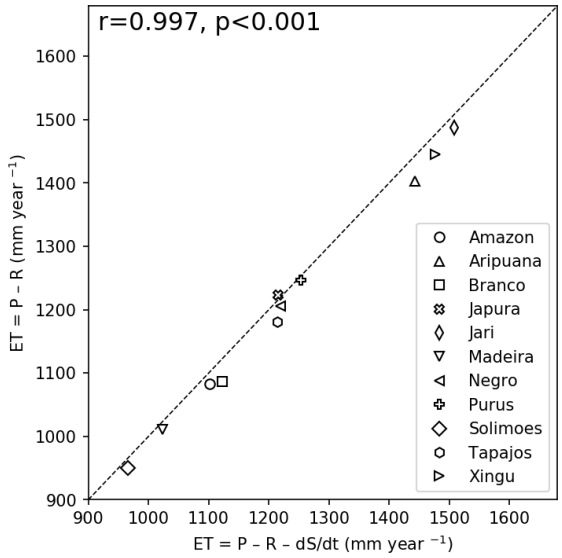

Figure S1 – Comparing ET estimates based on water-budget analysis. Relationship between climatological annual mean ET estimated from precipitation (P), runoff (R), and change in terrestrial water storage (dS/dt), and ET estimated from P and R only, over the Amazon and ten sub-catchments. Data are from 2003–2013.

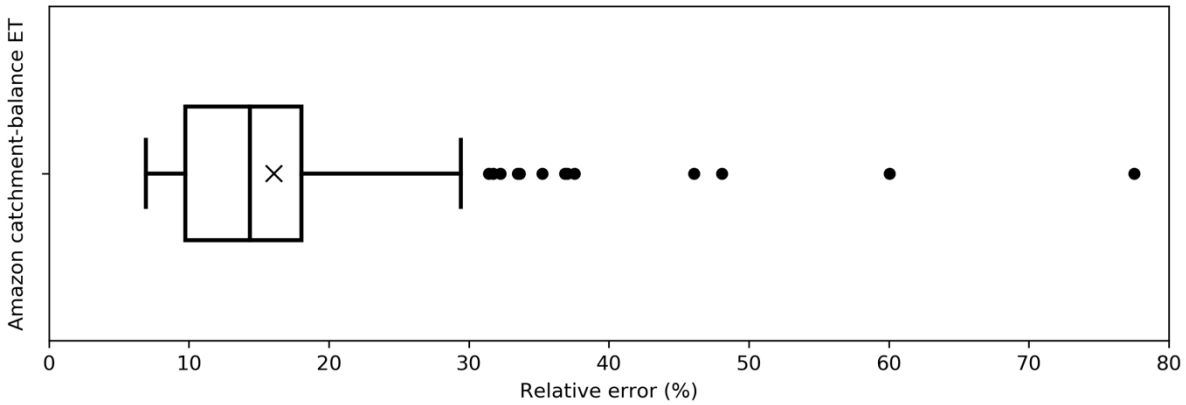

Figure S2 – Relative uncertainty in Amazon catchment-balance ET estimates. Distribution of relative errors in monthly Amazon catchment balance ET from 2003–2013.

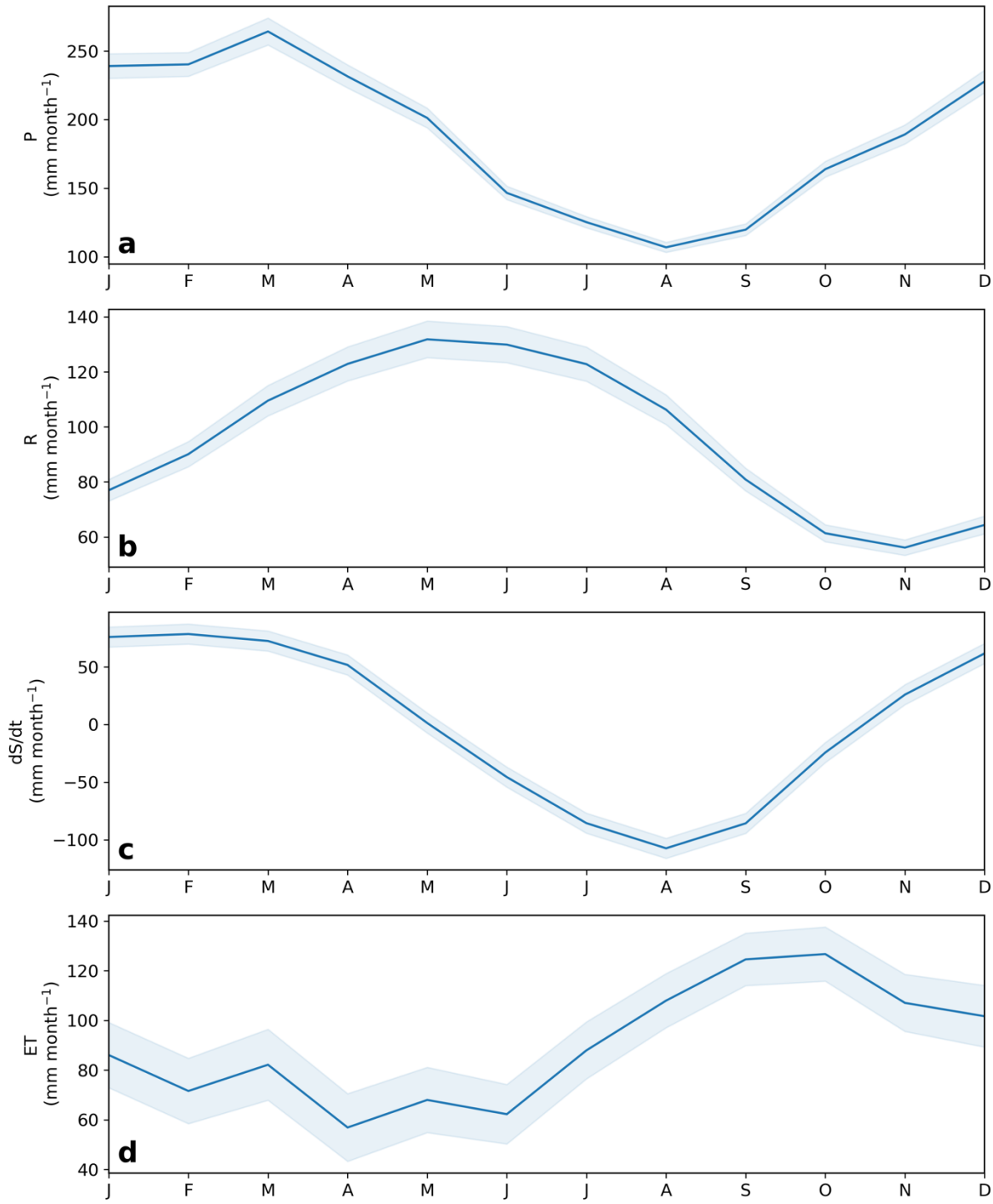

Figure S3 – Seasonal variation in components of the water-budget equation. a) Precipitation (P); b) river runoff (R); c) change in groundwater storage (dS/dt); and d) evapotranspiration (ET). Shading represents the mean absolute error in each month.

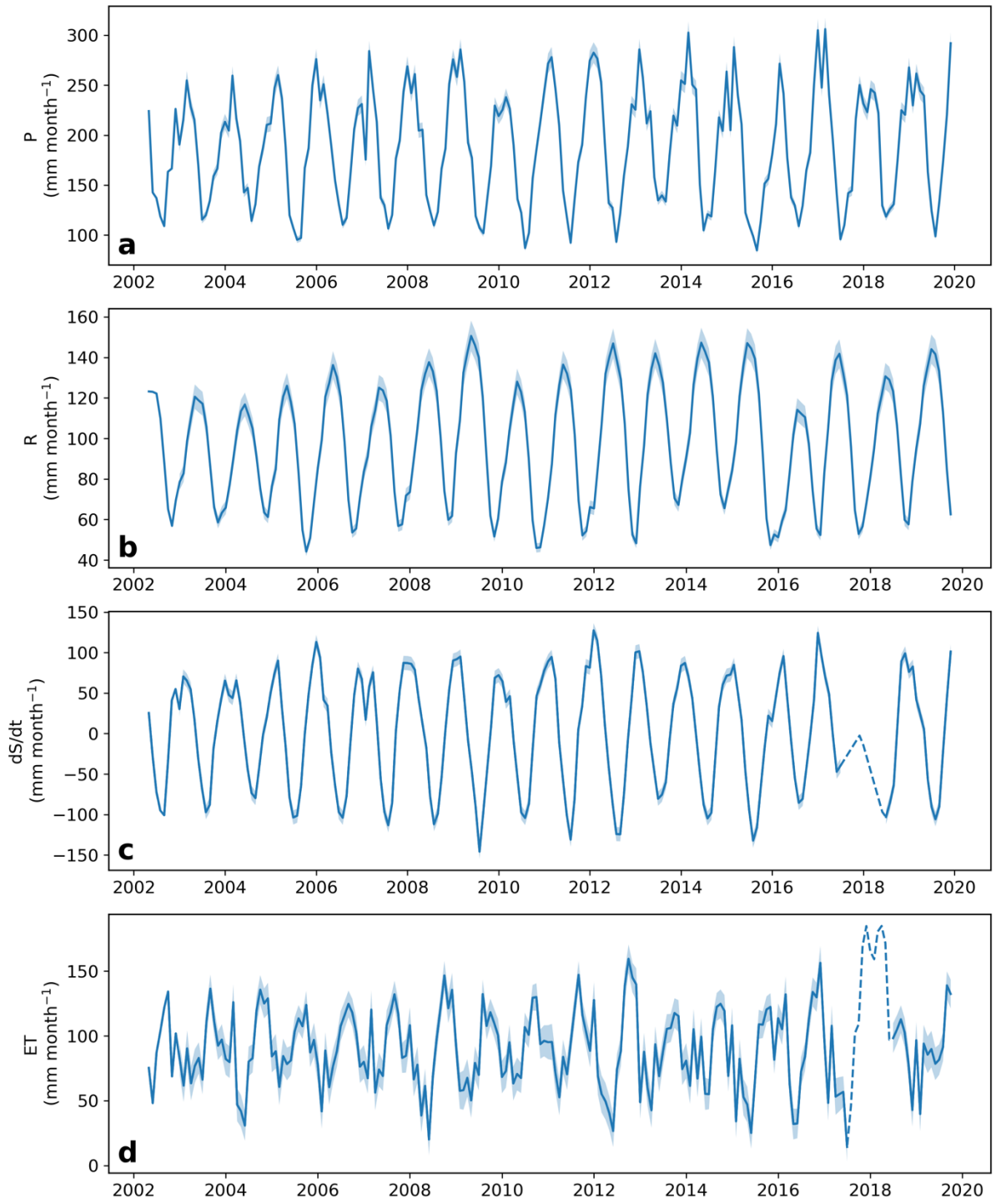

Figure S4 – Interannual variation in components of the water-budget equation. a) Precipitation (P); b) river runoff (R); c) change in groundwater storage (dS/dt); and d) evapotranspiration (ET). Shading represents the absolute error in each month. Dashed lines indicate data that was removed due to doubts over reliability.

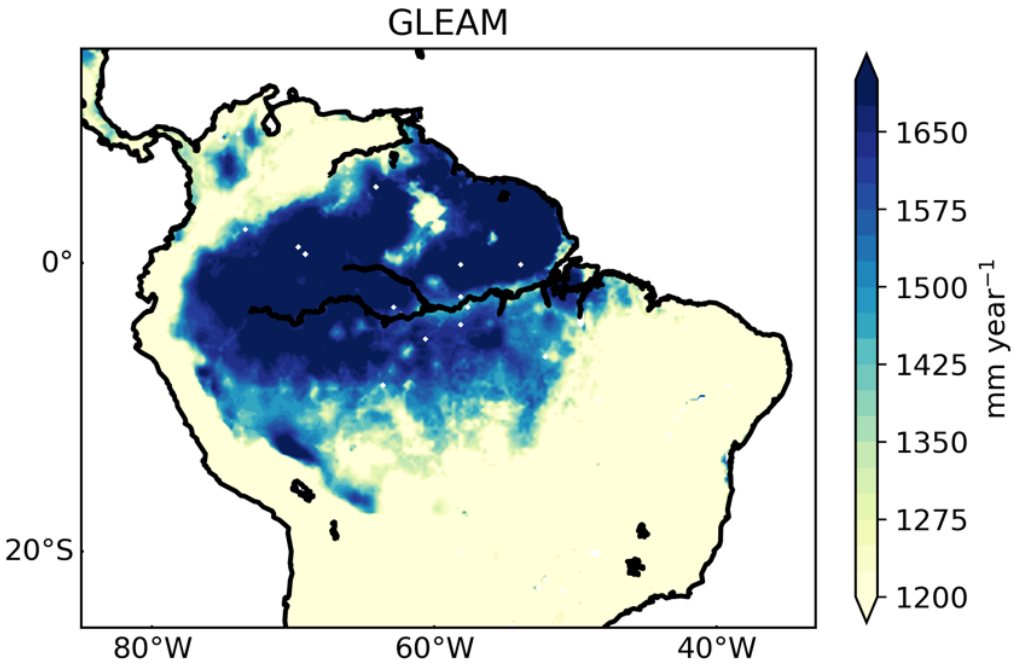

Figure S5 – Climatological mean annual ET from GLEAM (2003–2013).

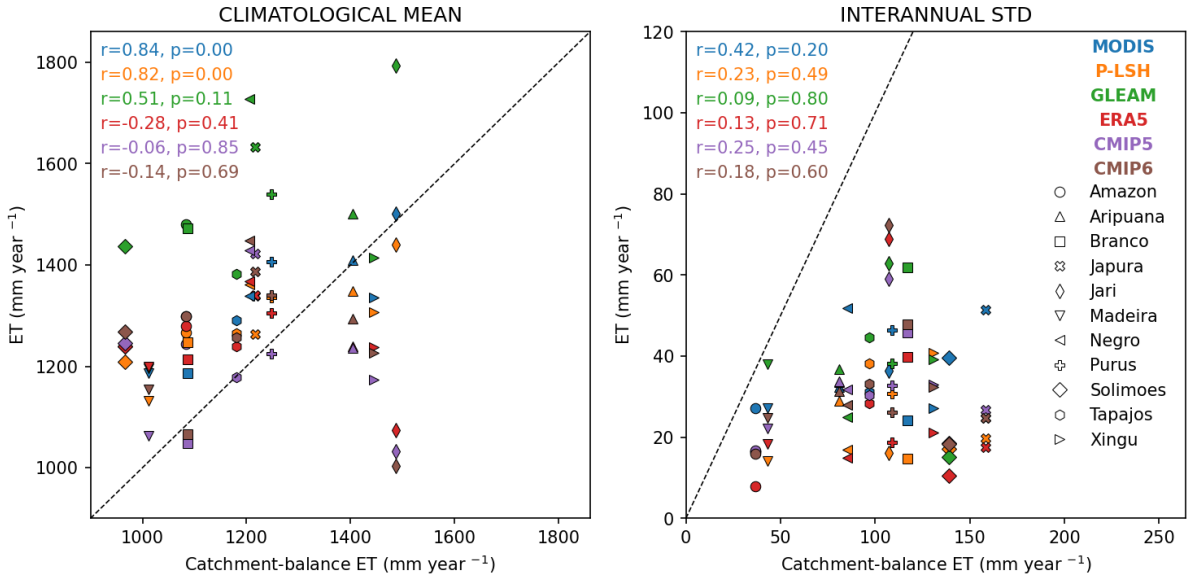

Figure S6 – Comparing catchment-mean ET estimates. The climatological annual means (left panel) and standard deviations (right panel) of catchment-balance ET estimates plotted against ET estimates from six gridded products. All data are from 2003–2013, apart from the CMIP5 data, which are from 1994–2004. Catchment locations are shown in Figure 1.

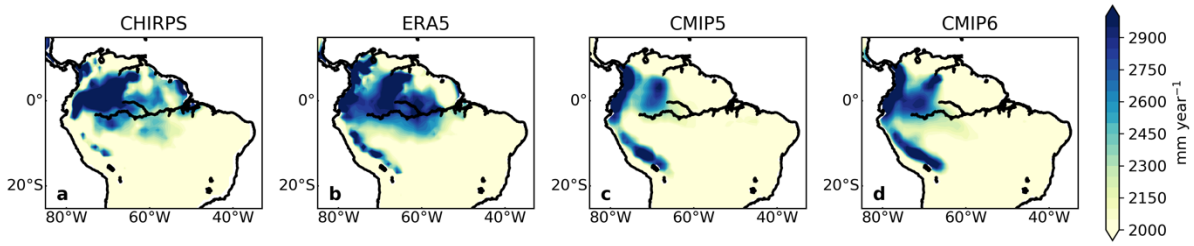

Figure S7 – Annual precipitation from satellites, reanalysis and climate models. References for each dataset are listed in Table 1.

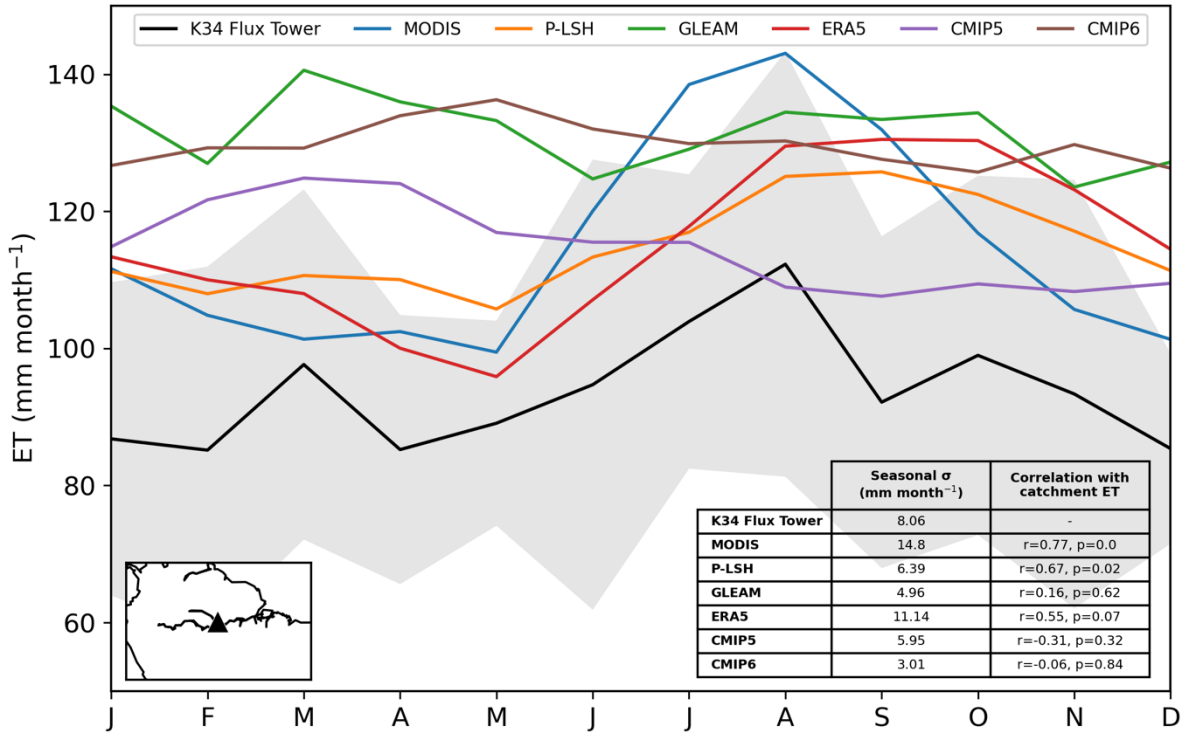

Figure S8 – Climatological seasonal cycle in ET at the K34 flux tower site. Lines indicate the seasonal time series in ET from the K34 flux tower (black), satellites (dark blue), ERA5 reanalysis (light blue) and climate models (green). The location of the K34 tower is indicated in the inset map. Data for satellite and reanalysis products were taken from a 0.25° grid cell containing the tower, and model data were from a 1° grid cell. Shading represents the interannual standard deviation in flux-tower ET (see Methods). The inset table records the seasonal variation (standard deviation, σ) in ET for each dataset, and the correlations between each dataset and flux-tower ET. ET data from the K34 tower are from 1999–2017, data for all other products are from 2003–2013. Note that the y-axis does not start at zero.

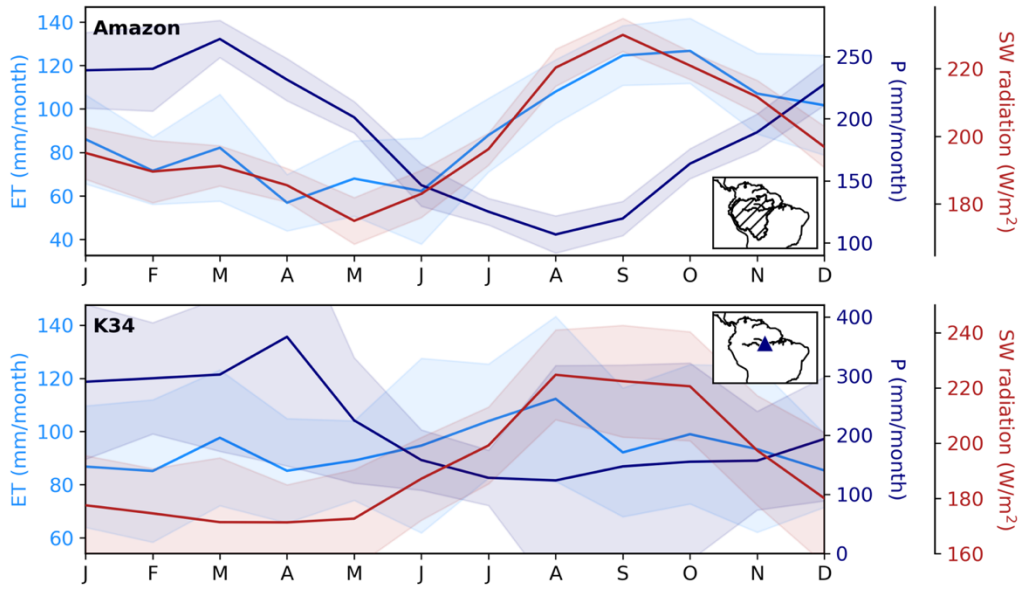

Figure S9 – Seasonal variation in controls on ET. Climatological seasonal cycles in ET (light blue), precipitation (P, dark blue) and shortwave radiation (red) averaged over the Amazon (catchment-balance data from 2003–2013, top panel) and measured at the K34 flux tower site (bottom panel, data from 1999–2017). P and radiation data for the Amazon basin are area-weighted basin-means of CHIRPS and CLARA-A1 data, respectively. Confidence intervals indicate the interannual standard deviation in each month. Note that y-axes do not all start at zero.

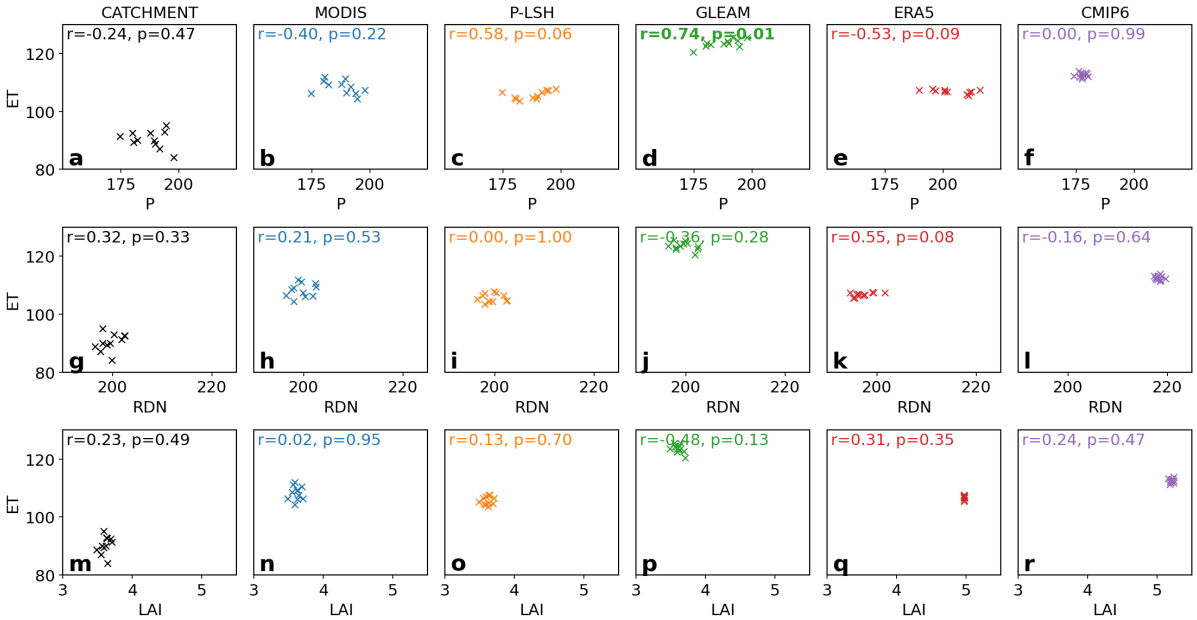

Figure S10 – Controls on interannual variation in Amazon ET. Interannual ET (in units of mm month^{-1}) for the Amazon (Fig. 1) from catchment-balance (black), satellites (dark blue), ERA5 reanalysis (light blue) and CMIP6 (green) plotted against (a–f) precipitation (P, mm month^{-1}); (g–l) surface shortwave radiation (RDN, W m^{-2}); and (m–r) leaf area index (LAI, m^2 m^{-2}). Satellite ET data are plotted against P from CHIRPS, RDN from CLARA-A1 and LAI from MODIS; ERA5 and CMIP6 ET are plotted against ERA5 and CMIP6 P, RDN and LAI, respectively. All data are from 2003 to 2013. Note that the axes do not start at zero.

Supplementary references

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